Marine Biological Invasions *of* Port Phillip Bay Victoria

CRIMP Technical Report Number 20

October 1999

Centre for Research on Introduced Marine Pests
Technical Report Number 20

Marine Biological Invasions of Port Phillip Bay, Victoria

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GPO Box 1538, Hobart, Tasmania 7001, Australia

Text layout: MBA Publishing, Hobart
Cover design: Louise Bell, CSIRO, Hobart

Citation Examples:
The Volume:
Hewitt, C. L., Campbell, M. L., Thresher, R. E., and Martin, R. B. (1999). *Marine Biological Invasions of Port Phillip Bay, Victoria.* Centre for Research on Introduced Marine Pests. Technical Report No. **20**. CSIRO Marine Research, Hobart. 344 pp.

A Chapter:
Lewis, J. A. (1999). A review of the occurrence of exotic macroalgae in southern Australia, with emphasis on Port Phillip Bay, Victoria. **pp. 61–87**. In: Hewitt, C. L., Campbell, M. L., Thresher, R. E., and Martin, R. B. (eds.). *Marine Biological Invasions of Port Phillip Bay, Victoria.* Centre for Research on Introduced Marine Pests. Technical Report No. **20**. CSIRO Marine Research, Hobart. 344 pp.

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Bibliography
Includes Index
ISBN O 643 06209 2.

1. Marine ecology - Victoria - Port Phillip Bay. 2. Marine fouling organisms - Victoria - Port Phillip Bay. 3. Nonindigenous aquatic pests - Victoria - Port Phillip Bay. I. Hewitt, Chad Le Roy, 1960- . II. Centre for Research on Introduced Marine Pests (Australia). III. Title. (Series : Technical report (Centre for Research on Introduced Marine Pests (Australia)) ; no. 20).

577.7099452

EXECUTIVE SUMMARY

Port Phillip Bay is a large, temperate embayment in southeastern Australia that borders the major metropolitan areas of Melbourne and Geelong. The bay has been a focus for shipping activity since the mid-1800's and is currently a major destination for a wide range of coastal and international shipping. Port Phillip Bay has also been the focus of a number of historical biological surveys, which makes possible an evaluation of historical patterns of invasion by exotic marine species.

A detailed analysis was undertaken of the introduced (known and cryptogenic) organisms in Port Phillip Bay. The analysis consisted of:

- reviews of the historical information, published literature, and material in private and museum collections for all groups for which local taxonomic expertise was available;
- detailed examinations, including new surveys undertaken as part of this study, of the biota in high risk areas;
- documentation and re-analysis of the possible impacts of exotic species on the ecology of Port Phillip Bay; and
- an evaluation of the broad patterns of invasion and an analysis of possible vectors for the introduction of the exotic species recorded from the bay.

Although the scope of the analysis was restricted by the taxonomic expertise available, coverage included all major benthic phyla. However, for several major groups (annelids, crustaceans, molluscs and echinoderms) the narrow focus of earlier surveys limited the analysis to the soft bottom biota.

The study identified 165 introduced and cryptogenic species (99 and 66, respectively), one species that was known to have been introduced but has subsequently become locally extinct, and another 13 species identified as 'potentially' introduced into Port Phillip Bay but whose status could not be confirmed due to the absence of voucher specimens or collections.

Depending upon the criteria used, therefore, we identified between 99 (confirmed introductions with voucher specimens) and 178 (all reports) introduced species in Port Phillip Bay. For those groups for which a comparison was possible, exotic species constitute 10–20% of the benthic biota of the bay. From a comparison of the total known biota of the bay and species numbers obtained from the more limited taxonomic and habitat coverage of this study, we estimate the actual number of exotic marine species in Port Phillip Bay at 300–400 species. We further estimate that 2–3 new exotic species are establishing in Port Phillip Bay each year.

The major source region for these species is the North East Atlantic and the historically dominant transport vector is vessel hull fouling. However, there are exotic species in Port Phillip Bay from all of the world's major bioregions (except the Antarctic) and evidence for the operation of a diverse range of introduction vectors. The rate of invasions appears to have increased over the last several decades; this increase coincides with an increasing prominence of the North West Pacific as a source region and ballast water as an introduction vector. Several of the most recent high profile introductions to the bay, however, are the result of domestic translocations of species introduced elsewhere in Australia and appear to be mediated by vessel fouling.

The number of established exotic and cryptogenic species in Port Phillip Bay is higher than reported by similar studies anywhere else in the world. This reflects at least in part the depth of the analysis we undertook, but also the current and historical role of Port Phillip Bay as a major domestic and international port, and its apparent susceptibility to biotic invasion. Recent shifts in the dominant source regions and introduction vectors suggest a renewed potential for invasions and point to the need to develop and implement effective measures to minimise this threat and protect the bay's marine communities.

ACKNOWLEDGEMENTS

A work of this magnitude and longevity could not have succeeded without the aid of numerous people. We would like to especially thank Sue Spinks and Guy Deakin for creating this visually pleasing document, and Louise Bell for the artwork which graces the cover.

Numerous people provided information and lent expertise: Jeff Cossum, Colin Gibbs, Anthony Blott, Mrs Padge Loney, and Carolyn Brinsdon. Taxonomic expertise and advice was given by Dennis Gordon, Christina Haas, Di Jones, Patt Kott, John Lewis, and Jan Watson. Fish survey and taxonomy advice was given by Tania Bardsley, Robyn Ickeringill, and Matt Lockett. Distribution and survey information was freely provided by George Branch (South Africa), Stephan Gollasch (Baltic Sea), Greg Ruiz (Chesapeake Bay), Lou Eldridge and Steve Coles (Hawaii), Andy Cohen and Jim Carlton (San Francisco Bay), Claudia Mills (Puget Sound, Washington), and Stuart Campbell and Greg Parry (Victoria).

The CRIMP survey component required numerous contributions of time and energy from Nicole Mays, Karen Gowlett-Holmes, Kathy Haskard, Alec Moore, Kirrily Moore, Charles Sutherland, Dave Evans, Sebastian Rainer, Catriona McLeod, Nick Murfet, and Ashley Coutts and his team of AMC sorters. In addition Neil Biggins (Victorian EPA) made both boat and knowledge available to the survey team.

Lastly, we would like to thank Victorian Department of Natural Resources and Environment for constructive discussions of this report as it developed.

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CONTENTS

1 INTRODUCTION

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1.1 BACKGROUND

As inhabitants of an island continent with a unique fauna and flora, Australians have long recognised the threats posed by exotic species. Australia has one of the world's most stringent biological barrier controls to minimise the risks of new introductions of macrobiota and pathogens, developed and administered by the Australian Quarantine and Inspection Service (AQIS). For those species that have breached the quarantine barrier, Australian scientists have led the world in developing and applying remedial actions including biological control. Some of these efforts have been spectacularly successful (e.g. the introduction of the moth *Cactoblastis* to control prickly pear *Opuntia*) and constitute paradigms in the field of pest management. Currently, every Australian state and territory and several Commonwealth agencies support large research initiatives aimed at minimising the impacts of exotic species.

Until recently, this effort was directed largely at terrestrial pests such as rabbits, foxes and a range of exotic plants. In the late 1980's, however, a very conspicuous exotic marine species was found in large numbers in the Derwent Estuary in southeast Australia (Buttermore *et al.* 1994). This species, the northern Pacific seastar *Asterias amurensis* (previously misidentified as a native species it superficially resembles), brought home to Australians that introduced pests also threatened the environmental integrity of Australia's marine ecosystems and the viability of marine industries that depend on them. Since the discovery of *A. amurensis*, several other high profile invaders (e.g. the Japanese kelp *Undaria pinnatifida*, the Mediterranean fanworm *Sabella spallanzanii*, and the Asian alga *Codium fragile* ssp. *tomentosoides*) have been discovered in Australia, engendering widespread concern among the public, environmental managers and marine industries about the number and impacts of such species.

In reality, scientists have been aware of exotic marine species in Australian waters since the late 1800's. The first non-native species recorded from Port Phillip Bay was *Electra pilosa*, a cosmopolitan bryozoan recorded by P H MacGillivray in 1862 (MacGillivray 1869). The first real 'pest' species was probably the European shore crab *Carcinus maenas,* which was recorded from Port Phillip Bay in the late 1890's (Fulton and Grant 1902). In the 1940's and 1950's studies of subtidal fouling communities (Allen 1950; Allen and Wood 1950; Wood 1950; Wisely 1959) led to the identification of a number of species that were translocated to Australia as fouling on ships' hulls (Allen 1953). Subsequent workers continued to document occurrences of introduced species (Hutchings 1983; Williams *et al.* 1988), and by the late 1980's Hutchings *et al.* (1987) and Pollard and Hutchings (1990a,1990b) were able to list 62 exotic marine species that were known to occur in Australian waters. One or more such introductions were found in almost all states and territories of Australia.

In 1994, the Australian federal government provided funds to the CSIRO to establish a national Centre to carry out research on the impacts and management of exotic marine species. As one of its first initiatives, the Centre for Research on Introduced Marine Pests (CRIMP) undertook to determine the scale of the introduced species problem in Australian waters. CRIMP launched two major initiatives to obtain this information. First, with the financial support and cooperation of Australian port authorities and AQIS, CRIMP surveyed representative ports around Australia, using standard survey protocols (Hewitt and Martin 1996). The data obtained provide a national assessment of the scale of the problem and document for the first time marine invasion patterns on a continental scale. To date eleven ports have been surveyed by CRIMP and a further eight by state agencies and universities.

The second major CRIMP initiative was the Port Phillip Bay survey. The aim of the Port Phillip Bay survey was to provide the most detailed analysis possible of the invasion history and introduced species status of a major Australian port. The selection of Port Phillip Bay for this survey was based on four factors:

- The bay has a history of use by shipping extending back to the early 1800's and currently contains some of the largest port complexes in Australia. Port Phillip Bay is bordered by the metropolitan areas of Melbourne and Geelong and over the years has been subject to almost all of the possible vectors thus far reported that could introduce exotic species to the area (Carlton 1992; see also Chapter 5);

- Port Phillip Bay has been extensively studied, including prior bay-wide biotic surveys in 1957–1963, 1968–1971, 1976–1977 and 1991–1996 (see Chapter 4). These surveys would provide a sound basis for the analysis of invasion patterns, and an invaluable source of information on the taxonomy and distribution of both exotic and native species;
- The various scientific institutions in the immediate vicinity of Port Phillip Bay, including the universities, the Museum of Victoria, and the Victorian Marine and Freshwater Resources Institute (MAFRI), contain marine taxonomists and ecologists who are very familiar with the bay and its biota. These could contribute the expertise required to evaluating known and possible introductions to the bay; and
- CSIRO had previously worked extensively in Port Phillip Bay, and had both experience and pre-existing data relating to the taxonomy, distribution and ecology of the biota.

1.2 APPROACH TO THE STUDY

The Port Phillip Bay introduced species study involved two parallel activities. First, CRIMP commissioned reviews of all taxa for which taxonomic expertise was locally available. The taxonomic experts (listed in Chapter 2) were asked to review all relevant literature, re-examine existing museum and private collections, and undertake field work, if necessary, to produce a comprehensive and authoritative evaluation of the native and introduced status of the Port Phillip Bay species within their areas of expertise. We made no attempt to direct them in their assignment of species to native, introduced[1] or cryptogenic[2] categories, explicitly recognising that the evidence for this assignment is often equivocal and that differences of opinion exist as to the strength of the evidence required. Using this approach, we were able to include in the reviews most of the major macrobenthic taxa, including as a group the fouling organisms, but not the plankton. The absence of coverage of this biome is a major weakness in the study. The 'cosmopolitan' nature of many plankton species dictates that a taxonomic evaluation at the level we required would entail extensive genetic work, which was beyond the scope (and resources) of the study.

Information on the physical environment of Port Phillip Bay was extracted from the recent Port Phillip Bay Environmental Study (Harris *et al.* 1996); this provides a comprehensive assessment of the oceanography and nutrient dynamics of the bay (Chapter 3). MAFRI reviewed information pertaining to the basic biology of Port Phillip Bay (Chapter 4), which provides the essential habitat understanding against which invasion patterns can be assessed.

The second activity was a field sampling program designed to fill any apparent gaps in the coverage (geographic or sampling) of previous surveys. This program was carried out by CRIMP (1995–1996). This field program was complemented by an introduced species survey of the port of Geelong, in southwest Port Phillip Bay, undertaken by MAFRI in 1997. The results of the two field programs are reported in Chapters 14 and 15.

CRIMP also commissioned reviews of the ecological impact of exotic species in Port Phillip Bay (largely reports on work in progress on community dynamics of selected species) and the nutrient dynamics of the bay. The latter arose out of concerns expressed by Harris *et al.* (1996) that introduced species could constitute a major threat to nutrient recycling in Port Phillip Bay.

The final report of the Port Phillip Bay introduced species study is a collaborative effort involving Victorian, CSIRO and New Zealand scientists and represents the most thorough evaluation to date of the introduced species status of any marine system anywhere in the world. As such, it constitutes a strong base for comparing a major Southern Hemisphere port-complex with similar Northern Hemisphere studies and provides a sound taxonomic and ecological basis for examining the long term invasion history and invasion dynamics of other temperate Australian ports.

[1] Transported to a new location outside its native range by humans.
[2] Neither native nor introduced status can be confirmed, *sensu* Carlton 1996.

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2 MATERIALS AND METHODS

2.1 INTRODUCTION

This evaluation of the introduced and cryptogenic species of Port Phillip Bay was designed to combine expert advice, literature reviews, species collection reviews (by museum and taxonomic experts) and new fieldwork to provide an overall picture of the status of introductions in the bay over time. The study is divided into five sections: introduction and background information on the bay; taxonomic reports; habitat and site surveys; impact evaluations; and a synthesis and summary.

2.2 HISTORICAL EVALUATION: CHAPTER 5 (VECTORS)

A review of the vectors for species transfer, historical trade routes and shipping patterns into Port Phillip Bay was conducted. The location or area in which a species originates is considered to be its native region (potentially spanning several bioregions or provinces). Here we use the bioregion scheme developed by the IUCN (International Union for Conservation of Nature and Natural Resources) for the establishment of a global representative system of marine protected areas (Kelleher *et al.* 1995) to denote the source regions. These bioregions are based on marine physical properties such as salinity and temperature; no consideration is given to ecological parameters such as habitat, species or communities present. A further classification, Cosmopolitan (region 19) has been added for species that are globally or widely distributed and whose origins are unknown or uncertain (potentially cryptogenic species *sensu* Carlton 1996). Brief descriptions of the regions are given below; Figure 2.1 (from Kelleher *et al.* 1995) illustrates the regions.

1. **Antarctica:** bordered by the West Africa (8), South Atlantic (9), East Africa (12), South Pacific (14), and Australia/New Zealand (18) bioregions. Includes Heard, Kerguelen, McDonald, Crozet, Marion, Prince Edward, Bouvet, South Sandwich, South Georgia, South Orkney, South Shetland, Peter and Balleny Islands.
2. **Arctic:** bordered by the North West Atlantic (4), North East Atlantic (5), Baltic (6), North East Pacific (15), and North West Pacific (16) bioregions. Includes Iceland, Greenland and the West Coast of Norway to the Bering Strait but not North America.
3. **Mediterranean:** bordered by North East Atlantic (5), West Africa (8), and the Arabian Seas (11) bioregions. Potentially broken up into east and west and the Black Sea.
4. **North West Atlantic:** bordered by Arctic (2), Wider Caribbean (7), and the North East Pacific (15) bioregions. It covers the Atlantic coasts of North America and Canada.
5. **North East Atlantic:** bordered by Arctic (2), Mediterranean (3), Baltic (6), and West Africa (8) bioregions. Includes the British Isles, the coasts of Spain, France, Belgium, Netherlands, Germany and Denmark.

Table 2.1. Taxonomic experts, their target taxa and target habitats for the taxonomic review component of the Port Phillip Bay introduced species study.

Consultants	Affiliation/Organisation	Target taxa	Target habitat
J Lewis	DSTO Aeronautical & Maritime Research Laboratory	Algae	All
J Watson	Marine Science and Ecology	Hydrozoa	All
S Boyd, R Wilson, G Poore & T O'Hara	Invertebrates, Museum of Victoria	Mollusca Polychaeta Crustacea Echinodermata	Soft substrates
M Lockett & M Gomon	Ichthyology, Museum of Victoria	Fish	All
M Keough & J Ross	Zoology Department, University of Melbourne	Fouling species	Hard substrates
P Bergquist	School of Biological Science, University of Auckland	Porifera	All

6. **Baltic:** bordered by the Arctic (2), and North East Atlantic (5) bioregions. Includes the Gulf of Bothnia, Gulf of Finland and the Gulf of Riga.
7. **Wider Caribbean:** bordered by the North West Atlantic (4), West Africa (8), South Atlantic (9) and South East Pacific (17; via the Panama Canal) bioregions. Includes the Bahamas, Cuba, Jamaica, Haiti, Dominican Republic, Puerto Rico, Virgin Islands, Guadeloupe, Antigua, Grenada, Trinidad and Tobago and ends at the southern end of French Guiana and at South Carolina in the north.
8. **West Africa:** bordered by the Mediterranean (3), North East Atlantic (5), Wider Caribbean (7), South Atlantic (9), and East Africa (12) bioregions. Runs from the Straits of Gibraltar to South Africa and includes the Canary Islands, Cape Verde, Ascension, St. Helena, Martin Vaz and Trindade Islands.
9. **South Atlantic:** bordered by Antarctic (1), Wider Caribbean (7), West Africa (8), and South East Pacific (17) bioregions. Runs from the northern end of Brazil to Ushuaia (Tip of Cape Horn) and includes the Falkland Islands.
10. **Central Indian Ocean:** bordered by Arabian Seas (11), East Africa (12), the East Asian Seas (13) and Australia/New Zealand (18) bioregions. Runs from India to Thailand and includes Sri Lanka and the Andaman and Nicobar Islands.
11. **Arabian Seas:** bordered by the Mediterranean (3; via the Suez Canal), Central Indian Ocean (10) and East Africa (12) bioregions. It includes the Red Sea, Gulf of Aden and Persian Gulf.
12. **East Africa:** bordered by Antarctic (1), West Africa (8), Central Indian Ocean (10), Arabian Seas (11), and Australia/New Zealand (18) bioregions. Runs from South Africa to the Arabian Seas off Somalia and includes Madagascar, Mauritius, Seychelles and Amsterdam and St. Paul Islands.
13. **East Asian Seas:** bordered by Central Indian Ocean (10), South Pacific (14), North West Pacific (16), and Australia/New Zealand (18) bioregions. It includes Malaysia, Cambodia, Vietnam, and Indonesia to the Philippines and Irian Jaya.
14. **South Pacific:** bordered by East Asian Seas (13), South East Pacific (14), North East Pacific (15), North West Pacific (16), and Australia/New Zealand (18) bioregions. Includes the Hawaiian Islands, Papua New Guinea, Solomon Islands, Federated States of Micronesia, Palau, Marshall Islands, Nauru, Kiribati, Tuvalu, Vanuatu, Fiji, Western Samoa, Tonga, Cook Islands, French Polynesia and Pitcairn and Easter Islands.
15. **North East Pacific:** bordered by Arctic (2), North West Atlantic (4), South Pacific (14), North West Pacific (16), and South East Pacific (17) bioregions. Runs from the Bering Strait, Alaska to the Mexican/Guatemalan border and includes the Aleutian Islands.
16. **North West Pacific:** bordered by Arctic (2), East Asian Seas (13), South Pacific (14), and North East

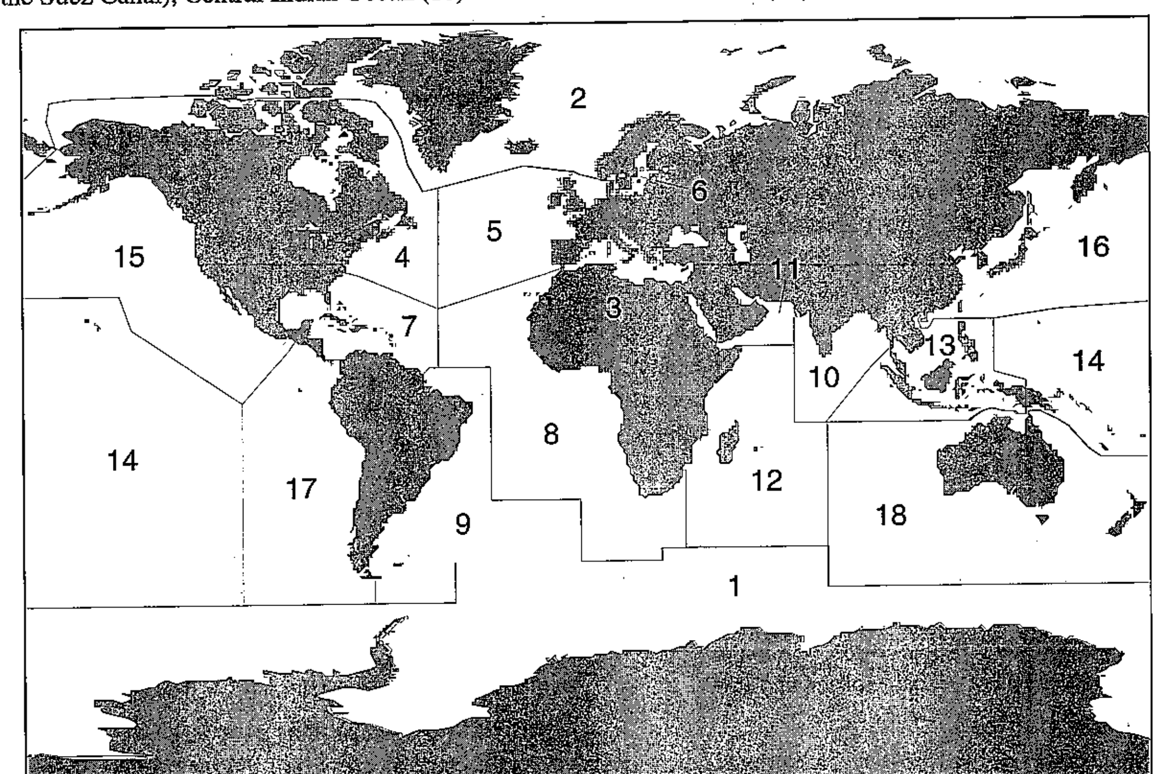

Figure 2.1. IUCN world bioregions (from Kelleher *et al.* 1995).

Pacific (15) bioregions. Runs from the Bering Strait, Russian Federation to China and includes some of the Aleutian Islands (western end), Japan and Taiwan.

17. **South East Pacific:** bordered by Antarctic (1), Wider Caribbean (7; via the Panama Canal), South Atlantic (9), South Pacific (14), and North East Pacific (15) bioregions. Runs from Guatemala (Central America) to Cape Horn and includes the Cocos and Galapagos Islands.
18. **Australia and New Zealand:** bordered by Antarctic (1), East Africa (12), East Asian Seas (13), and South Pacific (14) bioregions. Includes Ashmore, Cartier, Kermadec, Bounty, Antipodes, Campbell, Auckland and Macquarie Islands. Also included are Norfolk, Cocos and Christmas Islands though these are not explicitly incorporated into the bioregional subdivisions provided in the IUCN classification.
19. **Cosmopolitan:** Widely distributed in more than 6 bioregions typically in more than two ocean basins. May be either extremely widely distributed or have disjunct distributions.

2.3 TAXONOMIC REVIEWS

A number of taxonomic experts (Table 2.1) were consulted to develop a target list of introduced species previously recorded from Port Phillip Bay (Table 2.2). This was achieved by literature review, and evaluation of both private and museum collections in order to determine the extent of introduced marine and estuarine species in coastal areas in the state of Victoria, Australia, particularly Port Phillip Bay. Information was sought on: the biology and ecology, with respect to modes of transport from their source populations; ecological effects on native species; and potential methods of control of introduced species. Some voucher specimens and other material (slides, video footage and photographic film) of presumed and probable exotics as well as closely related species was provided by the consultants to CRIMP to enable the verification of collected specimens. The short-term research needs essential for understanding the scale of the problem of introduced species in Port Phillip Bay were also identified by some of the experts. The methods employed by each expert are further described below.

Algae (Chapter 6)

Literature and algal collection were reviewed to establish introduced and likely introduced species resident in Port Phillip Bay. Comparisons of species descriptions and materials in Port Phillip Bay, southern Australia and the world provided an analysis of probable origin and status.

Hydroids (Chapter 7)

Extensive review of the literature including publications by J F Mulder and R E Trebilcock on the hydroids from Port Phillip and the Bellarine Penninsula ocean coastline from 1909 to 1916; P M Ralph (1966) and Watson & Utinomi (1971) accounts of hydroids collected by the National Museum of Victoria Survey (1957–1963) in Port Phillip Bay; and later publications by Watson (1978, 1980, 1982, 1984, 1985, 1992a, 1992b, 1993, 1994). A review of hydroid introductions on a global scale was undertaken using information from CRIMP collections, the Museum of Victoria (Australian collection of W M Bale 1872–1929; Kirchenpauer's material collected in the 1860's; type and voucher specimens deposited by R E Trebilcock; the Mawson BANZARE Antarctic collection; and collections deposited by J E Watson), the Australian Museum and J E Watson's private collection.

Polychaeta (Chapter 8)

Literature on introductions in Australia and the world were reviewed to establish introduced and likely introduced species in Port Phillip Bay. Recent collections of polychaetes archived at the Museum of Victoria were also examined to determine the presence of introductions.

Mollusca (Chapter 9)

Recent collections of molluscs archived at the Museum of Victoria and literature on introductions in Australia and the world were reviewed to establish introduced and likely introduced species resident in Port Phillip Bay.

Crustacea (Chapter 10)

Recent collections of crustaceans archived at the Museum of Victoria and literature on introductions in Australia and the world were reviewed to establish introduced and likely introduced species resident in Port Phillip Bay.

Echinodermata (Chapter 11)

Collections of echinoderms from the Museum of Victoria were reviewed. The echinoderms of Port Phillip Bay Environmental Study phase 1 study were identified using keys in Clark (1966) and voucher specimens identified by Dr A N Baker of the Wellington Museum, New Zealand (G Poore pers. comm.). The material was lodged in the Museum of Victoria where it was re-examined as part of this study. The identifications are mostly reliable (T O'Hara pers. obs.). The few exceptions include the specimens of *Patiriella brevispina* mis-identified as *P. gunni; Plesiocolochirus ignava* misidentified as *Pentacta australis;* and several specimens of *Coscinasterias muricata* (until recently known as *C. calamaria*) misidentified as *Allostichaster polyplax*. The only additional echinoderm collected by the Port Phillip Bay Environmental Study phase 3 was an undescribed holothurian (*Taeniogyrus* sp MoV 1643).

Chordata (Pisces) (Chapter 12)

A preliminary species list of fishes present in Port Phillip Bay was prepared by extracting all records of fish sampled in the bay over a 100 year period from the Museum of Victoria ichthyological database. Dubious identifications were verified or corrected after examining relevant specimens. Additions to the list were made following a literature review and the examination of previously unpublished species lists (Coleman 1972; Hobday 1994). Species that are continuously distributed along the southern coast of Victoria and for which suitable habitats occur within the boundaries of Port Phillip Bay were also added. Special attention was paid to large families such as the Clinidae and Gobiidae that have many undescribed species and for which distributional data is often incomplete. Unidentified examples of these families in the museum's collection from Port Phillip Bay were examined and identified. Many of these species are cryptic and difficult to sample and may be misidentified when collected. The species list was refined through peer review. Species that could not be confirmed as occurring in Port Phillip Bay either from previous sampling, literature review or personal observation, were deleted. Also deleted were species erroneously reported as occurring in Port Phillip Bay because of historically inaccurate identifications.

Field sampling sites were chosen throughout Port Phillip Bay with an emphasis placed on commercial areas. Sampling was generally carried out in two broad habitat types: hard substrate and soft substrate. In the commercial areas hard substrate habitats were mostly represented by piers with vertical and horizontal piles providing an attachment for sessile organisms and thus, greater habitat complexity. Depths at these piers are maintained at approximately 10—12 m by dredging and represent disturbed habitats. Rocky reef of varying relief, characterises "non-disturbed" hard substrate sites outside the ports and harbours, with some reef areas extending into commercial sectors.

Hard substrates were sampled using the ichthyocide rotenone. This method, while effective in enclosed environments, is less effective at sites with high levels of turbidity or water movement. Fish affected by rotenone were collected using hand nets underwater by SCUBA divers and on the surface by a snorkeler. Soft substrate sites were situated off sandy beaches and had varying amounts of seagrass and algae. Sampling at these sites was carried out using a 6 m beach seine net with a mesh size of 1 cm. Generally, two shots were conducted at each site. Virtually all specimens collected were preserved, identified, registered and incorporated into the Museum of Victoria collection.

Initially, two field surveys were planned for November–December (Spring) and March–April (Autumn) periods, to identify seasonal variations in fish populations. Due to logistical constraints, however, this was not possible and the second sampling period was brought forward to February. As a result, definition of seasonal influences on compositions of fish communities not possible and sites that were sampled twice are combined for analysis and reporting.

Sampling for this project was restricted to the coastal environments for several reasons. Given the current knowledge of introduced species of fishes throughout the world and their dispersal mechanisms, coastal habitats and commercial zones are the likely sites of occurrence. In addition, because pelagic exotics are rare (Carlton 1985; Paxton and Hoese 1985) due to their biology and since most of the offshore habitats in Port Phillip Bay have been reasonably sampled over the last 20 years (Hobday 1994), further investigation of this region was considered to be less important. The rocky reefs around the entrance to Port Phillip Bay were not included because of the difficulty in sampling this area and because it was felt that there was a low probability that exotic species would occur in this region. Sampling in regions such as these which are subject to strong currents and open to diverse weather conditions require a more specialised approach that was beyond the financial limits of the present study.

2.4 HABITAT AND SITE SURVEYS

2.4.1 Port Phillip Bay Regions

For descriptive purposes, Port Phillip Bay was divided into five geographical regions; Port Melbourne; Geelong Arm; the Heads; the Eastern Shore and; the Middle Bay (Figure 2.2). These regions are subject to different shipping (type and movement), anthropogenic effects and prevailing conditions. A brief description of each region is presented below.

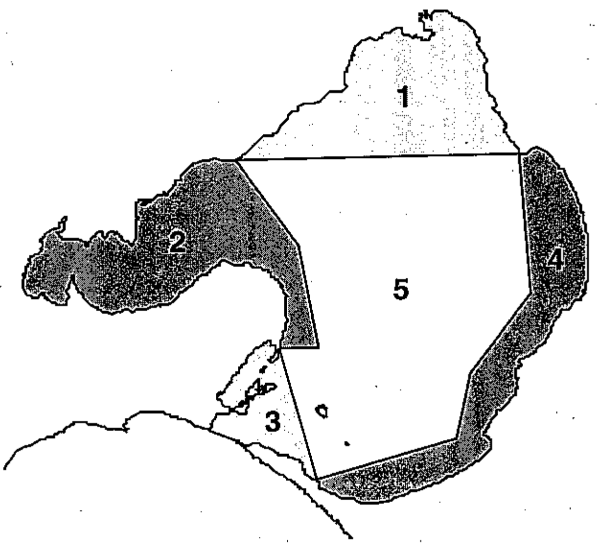

Figure 2.2. Designated Port Phillip Bay regions. 1) Port Melbourne; 2) Geelong Arm; 3) Heads; 4) Eastern Shore; 5) Middle Bay.

Region 1: Port Melbourne

This region encompasses the major industrial region of Melbourne, southwest from Port Melbourne to Werribee South and southeast from Port Melbourne to Ricketts Point. The suburbs of Sandringham, St. Kilda, Williamstown, Altona, and Werribee are all included in this region. Port facilities extend up into the Yarra River. The wharves mostly deal with container vessels, port maintenance vessels and naval vessels. Historically, most overseas passenger ships berthed at Port Melbourne on Station and Princes Piers (Priestley 1984).

Region 2: Geelong Arm

This region includes the Geelong Arm (Bellarine Peninsula), the City of Geelong and industrial port and north towards South Werribee. South of Werribee is dominated by market gardens and light industry. The port of Geelong is industrial with jetties and wharves dealing with a range of products such as wheat and other grains, refinery products, alumina, phosphate, explosives, steel, other dry bulk cargo, general cargo, roll-on roll-off and port maintenance vessels. In recent years there has been a shift in vessel types from grain cargo to petroleum cargo vessels (Walters 1996). Aquaculture and recreational uses dominate the Geelong Arm. Historically, vessels berthed at Point Henry to disembark passengers and unload cargo (Priestley 1984).

Region 3: The Heads

Encompasses both sides of the entrance to Port Phillip Bay. The area is characterised by sandy sediments, strong currents and tides, rocky shorelines, a well-mixed water column and is oceanic in extent. Queenscliff is considered a 'resort' and fishing town: historically, Sorrento was a fishing village, which became a resort town (Priestley 1984; Kerr and Kerr 1979). Some recreational fishing occurs in the area (mostly from shore) and a ferry transports passengers and cars between Sorrento and Queenscliff. A small wharf used for fishing, recreational and research needs is located at Queenscliff.

Region 4: Eastern Shore

This region is dominated by recreational (diving, boating, fishing, etc) and commercial fishing activities. Historically, suburbs like Hastings, Mordialloc, Rye, Dromana, and Frankston were fishing villages that sometimes supplied the city with firewood and burnt lime (Priestley 1984) and mostly have remained as fishing towns. This region has many rocky reefs and shallow sandy regions.

Region 5: Middle Bay

The majority of the shipping channels are located in this region. Four main navigation channels lead to Melbourne and Geelong (Kerr and Kerr 1979). Large channel markers and piles mark the channels. Recreational activities in this area include fishing and diving. The sediments are often silty, but closer to the heads the sediments become sandier, with the increased tidal movement.

2.4.2 Fouling species (Chapter 13)

Information was drawn from published accounts, collections at the Museum of Victoria, Melbourne University field collections and settlement records, largely from a few sites around Port Phillip Bay. Settlement data are drawn mainly from Breakwater Pier, Williamstown and from a series of recruitment collections over monthly and bimonthly intervals for four years at Williamstown, Mornington, Sorrento and Queenscliff, in Port Phillip Bay and more restricted series from Geelong, Point Wilson and St. Kilda. In general, systematic records of fouling species are available from only a handful of ecological studies, from a very few locations in Port Phillip Bay, with the strongest focus on Hobson's Bay.

Museum of Victoria collections vary in the extent to which the material has been sorted, and the identifications verified. There is also substantial variation in the status of taxonomic identifications between major fouling groups. Our use of these collections, therefore, varied. For ascidians, which are well catalogued and sorted, we examined all material of species considered by Kott (1985, 1990a, 1990b) as potentially introduced. In contrast, bryozoa have been collected for many years, with a substantially older literature, but many families are in dire need of taxonomic revision. We targeted specimens of known fouling species, to try and identify the oldest material collected from Port Phillip Bay from museum records and from 19th century publications. In other cases, such as the sponges, the collections are not extensive, and material is notoriously difficult to identify, so museum collections were of limited use. Additional sponge information was obtained from Bergquist's (1996) report to CRIMP.

Additional information on potential rates of spread of some bryozoan species was also obtained from the New Zealand review of Gordon and Mawatari (1992). These authors located initial records for a range of introduced bryozoans, and were fortunate to have a wealth of natural history information that allowed them to be more precise about timings of introduction and present distribution than is possible for southern Australia.

2.4.3 MAFRI Port of Geelong survey (Chapter 14)

A survey of the Port of Geelong, targeting exotic species, was conducted in August and October 1997 by MAFRI. The protocols for sampling and collection of introduced marine species followed the methods outlined by Hewitt and Martin (1996). Details of survey methods are given in Chapter 14.

2.4.4 CRIMP bay-wide survey (Chapter 15)

This survey aimed to detect the presence of introduced species within Port Phillip Bay. The effectiveness of detecting introduced species using the modified methods of Hewitt and Martin (1996) was determined by comparing the target list (Table 2.2) against the introduced species collected by CRIMP. The protocols used were those outlined in Hewitt and Martin (1996), with the following exceptions:

- Pile scrapings were performed in a destructive qualitative fashion to represent the entire fouling community across all depths, ensuring that depth stratification and total fouling/encrusting communities were adequately represented.
- Qualitative visual surveys also involved towing divers (on a manta board) along 100 m transects.
- Three large cores were collected from inner and outer regions at each wharf and along a beach transect. The beach transect cores were taken from one transect that ran perpendicular to the beach/coastline sampling at depths of 0, 1, 2, 5, and 10 m. At each of these depths, two replicate cores were taken and coring areas were photographed.
- Beam trawl tows were made at depths of 1, 2, 5, and 10 m at a towing speed of no more than 25–30 m s^{-1}. Tows were either of a known duration (5 min) or of a known length (100 m) but were reduced in areas where algae, seagrass, or other benthic material causes rapid filling of the trawl.
- A small version of a CSIRO-seamount sled was also used to sample benthic infauna and benthic epifauna. The sled was trawled at depths of 5, 10, 15, 20 and 25 m depending on the water depth at each site. Tows were made in a similar fashion to the beam trawl. In very soft or silty regions, tow duration was shortened to avoid rapid filling of the nets. A video was mounted upon the sled to film the region being sampled and the samples being collected. Samples were recorded as a qualitative measure of mobile epibenthos and benthic infauna. Samples from the beam trawl and benthic sled were randomly sub-sampled.

The field survey of Port Phillip Bay could never be a systematic survey of all available habitats because of logistical and financial constraints. Thus a number of areas were targeted for a thorough survey (Geelong and Port Melbourne), whilst a general qualitative overview of the remaining areas was performed. The sites that were sampled using each method are shown in Figure 2.3a–i. The sampling methods ensured a comprehensive coverage of both hard and soft habitats.

All samples (quantitative and qualitative) were rough sorted into sub-samples of representative fauna and flora. The sub-samples were then sorted into groups of least taxonomic unit by CRIMP and Australian Maritime College (AMC) sorters. All sorted samples, with the exception of algae and hydroids were transferred into 90% ethanol. The completed rough sorted samples were fine sorted and taxonomically identified at CSIRO.

Specimens that could not be classified were sent to appropriate taxonomic experts for identification. If a specimen remained unidentified it was categorised to least taxonomic unit (usually genus level) and given a 'type number'. A reference collection for each phylum was made and stored at CSIRO, with verification of these species being conducted by taxonomic experts. A voucher collection was established for each species at each site and stored at CSIRO.

2.4.5 Target introduced species list

From Chapters 6 to 14, a target list of 182 introduced, cryptogenic or possibly introduced species found on hard or soft substrates were identified as being present in Port Phillip Bay (Table 2.2). This target list was then used to compare against recent surveys to validate collection methods for the detection of introduced species.

2.5 IMPACTS OF INTRODUCED SPECIES IN PORT PHILLIP BAY

2.5.1 Impacts of selected species (Chapter 16)

Research students working on introduced species in Port Phillip Bay were invited to write an abstract of their work. The abstracts cover species' biology, ecology and the known and inferred impacts each species may have on the bay's ecosystem. The species examined are the echinoderm *Asterias amurensis*, the bivalve *Corbula gibba*, the algae *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides*, the crustacea *Corophium* spp., and the polychaetes *Euchone limnicola* and *Sabella spallanzanii*. Distributions of these species in the bay are also provided.

2.5.2 Impact of introduced species on nitrogen cycling (Chapter 17)

Existing models of Port Phillip Bay nutrient sinks and cycling were used to attempt to answer three questions. Firstly, what environments in Port Phillip Bay are more likely be successfully invaded? Secondly, how successful an invasion may be in the bay? Finally, what are the possible disruptions to the biogeochemical/ecological processes within the bay, if an invasion occurs? The case history of *Sabella spallanzanii* in Port Phillip Bay is used to illustrate the impact introduced species can have on an ecosystem.

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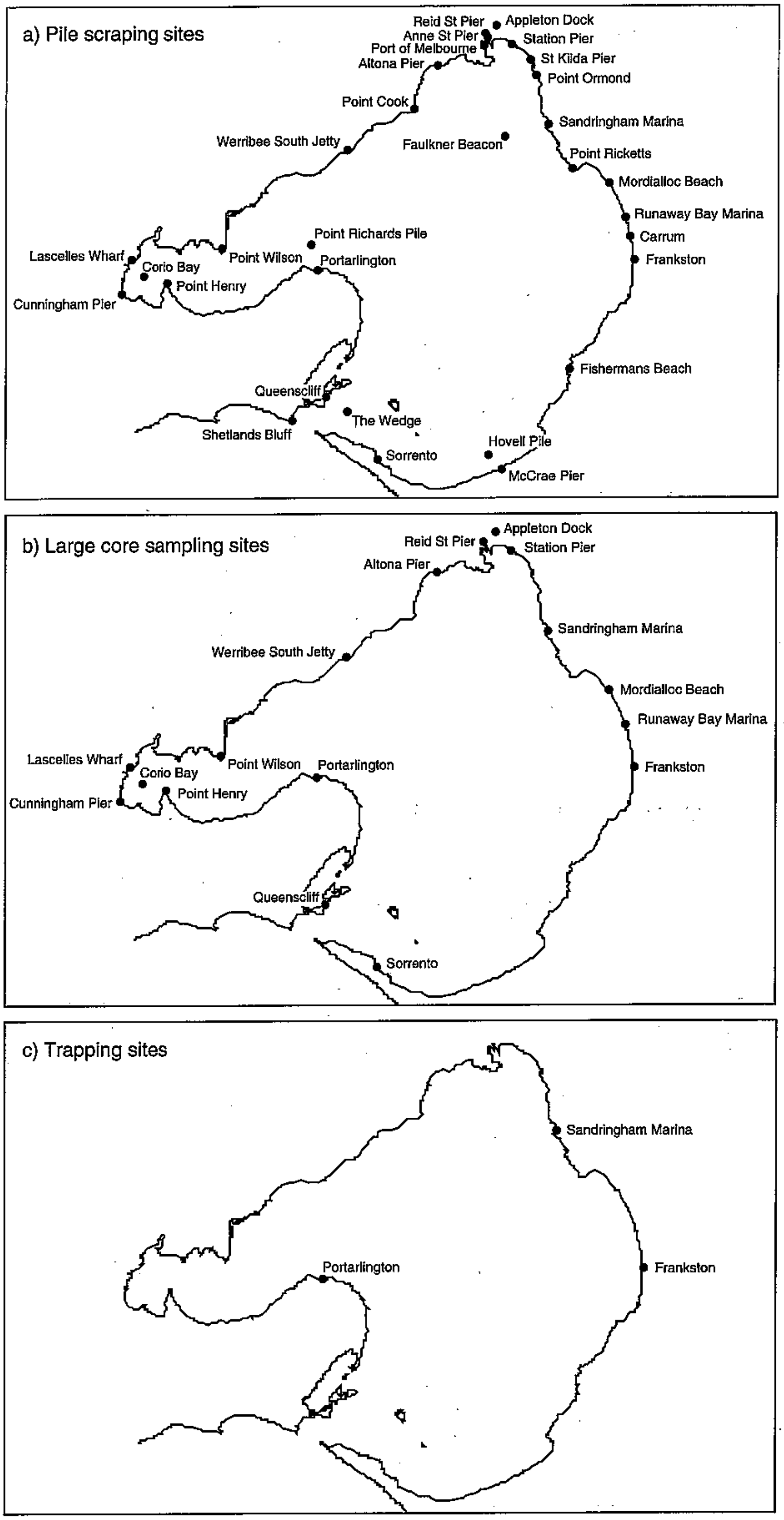
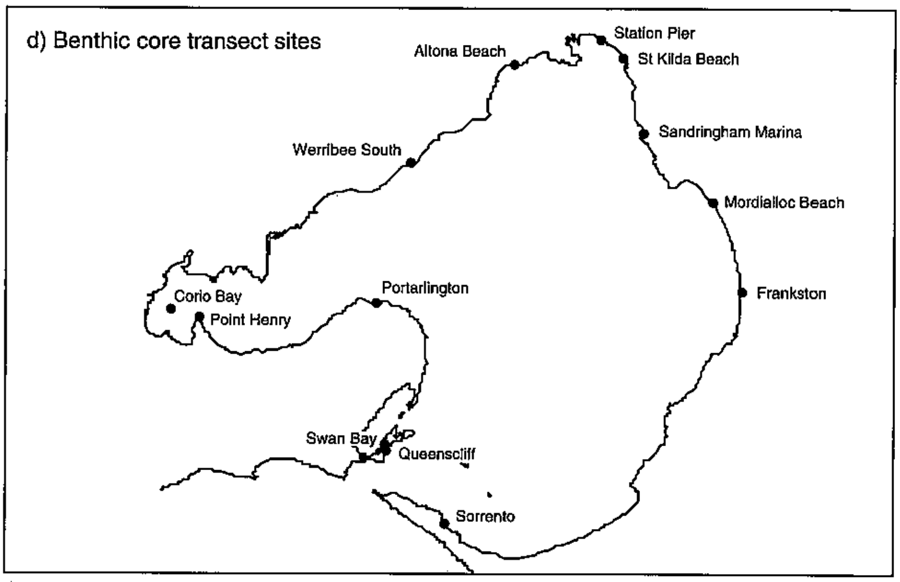
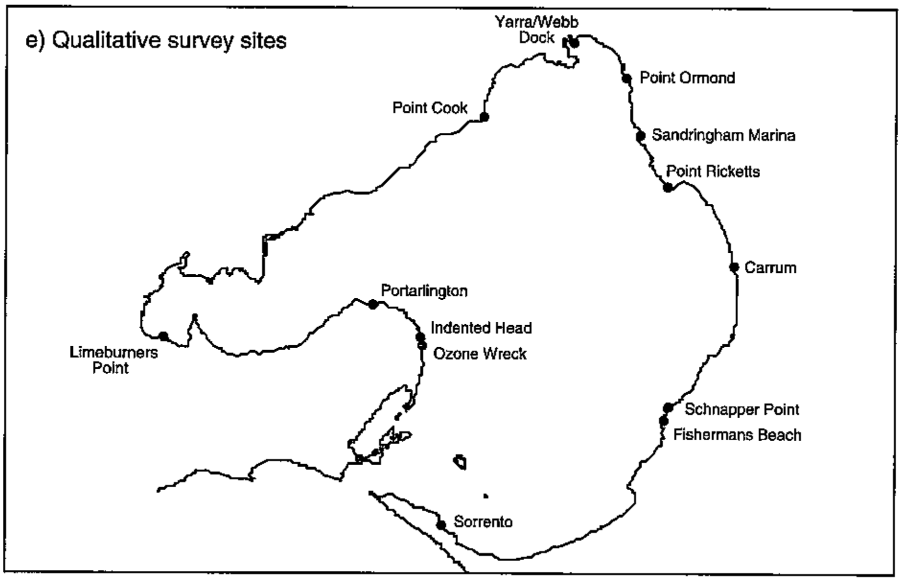


Figure 2.3a–i. CRIMP Port Phillip Bay introduced species survey; distribution of sampling sites for different sampling methods used in the bay-wide survey.





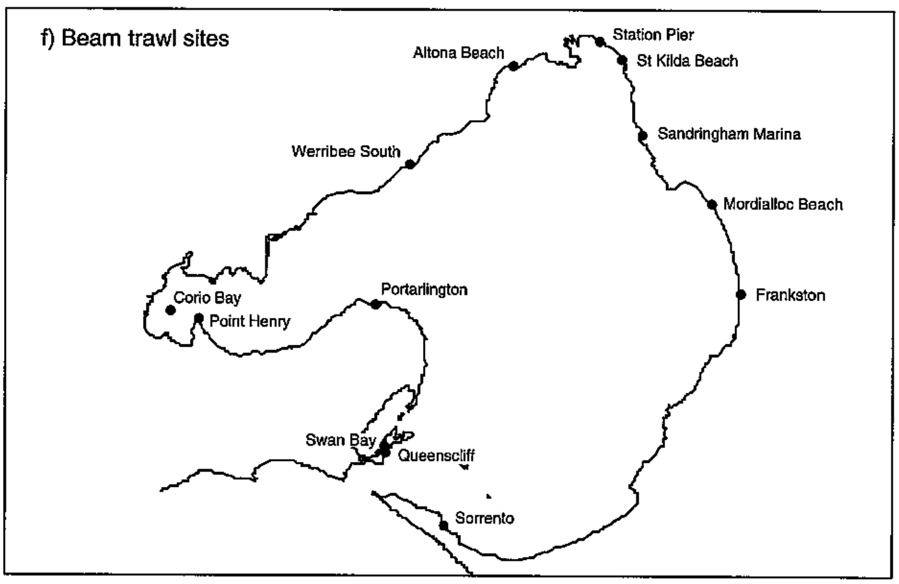


Figure 2.3a–i. continued.

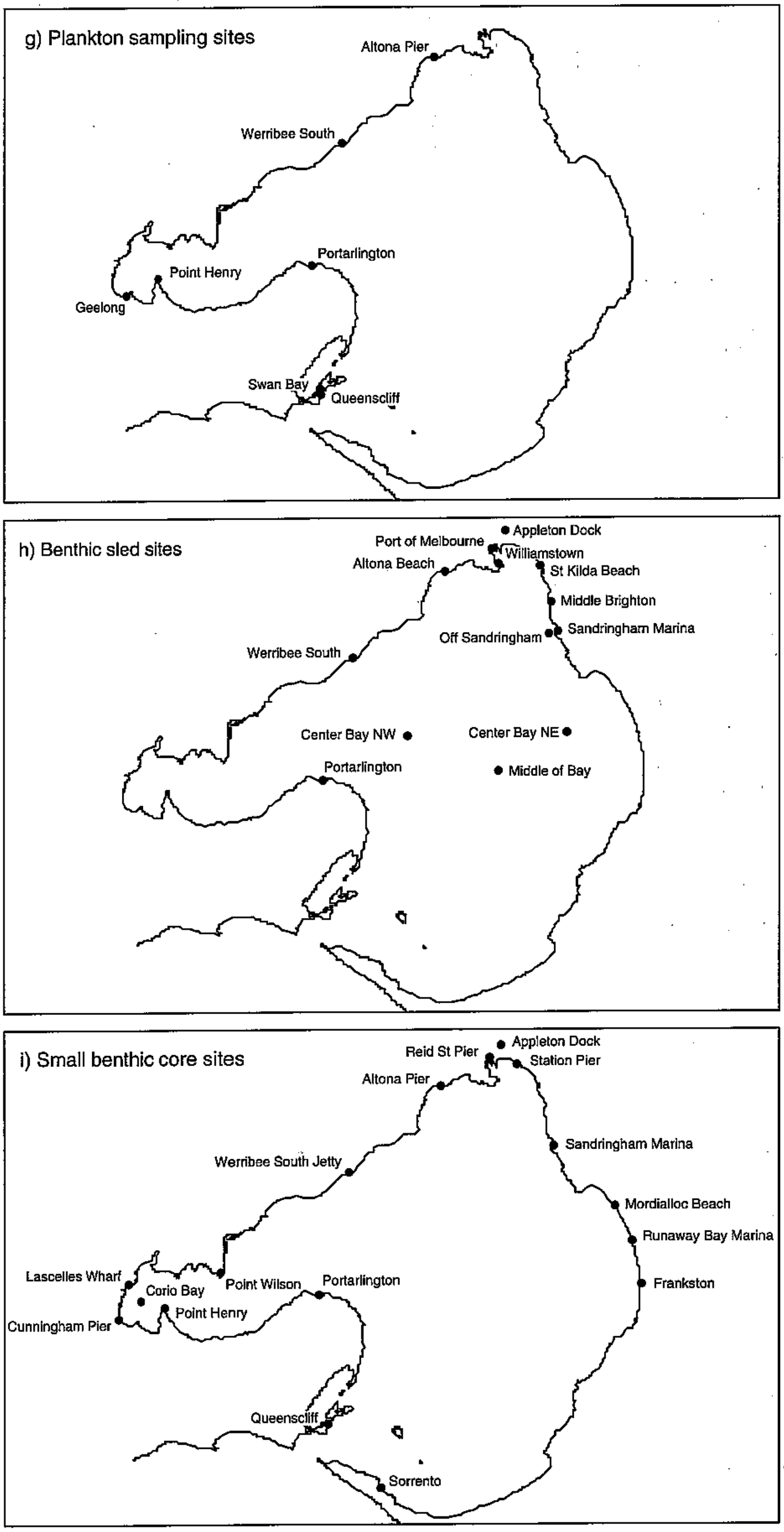


Figure 2.3a–i. continued.

Table 2.2. Target list of 182 introduced, cryptogenic and possibly introduced species identified from taxonomic reviews. Substrate type: hard (H) and/or soft (S). Taxonomic consultants: 1) Lewis (algae); 2) Lockett and Gomon (fish); 3) Keough and Ross (fouling organisms); 4) Watson (hydroids); 5) Boyd, Wilson, Poore and O'Hara (molluscs, annelids, crustaceans and echinoderms); and 6) Bergquist (sponges). [1] denotes not known from PPB.

Taxa and species	Substrate type	Taxonomic consultant 1	2	3	4	5	6
Algae – introduced							
Antithamnionella spirographidis	H	+					
Asperococcus compressus	H	+					
Chondria arcuata	H	+					
Cladophora prolifera	S	+				+	
Codium fragile ssp. *tomentosoides*	S	+					
Deucalion levringii	H	+					
Gymnogrongus crenulatus	H	+					
Medeiothamnion lyalli	H	+					
Polysiphonia brodiaei	H	+					
Polysiphonia senticulosa (pungens)	H	+					
Schottera nicaeensis	H	+					
Solieria filiformis	H	+					
Sorocarpus micromorus	H	+					
Stictyosiphon soriferus	H	+					
Ulva fasciata	H	+					
Undaria pinnatifida	H	+					
Porifera – introduced							
Aplysilla rosea	H			+			
Corticium candelabrum	H			+			
Dysidea avara	H			+			
Dysidea fragilis	H						+
Haliclona heterofibrosa	H						+
Halisarca dujardini	H						+
Cnidaria: Hydrozoa – introduced							
Amphisbetia operculata	H				+		
Antennella secundaria	H				+		
Bougainvillea muscus (ramosa)	H			+	+		
Clytia hemisphaerica	H				+		
Clytia paulensis	H				+		
Ectopleura crocea	H			+			
Filellum serpens	H				+		
Halecium delicatulum	H				+		
Monotheca obliqua	H				+		
Obelia dichotoma (australis)	H				+		
Phialella quadrata	H				+		
Plumularia setacea	H				+		
Sarsia eximia (radiata)	H				+		
Turritopsis nutricula	H				+		
Annelida: Polychaeta – introduced							
Boccardia proboscidea	S					+	
Euchone limnicola	S					+	
Hydroides norvegica	S		+				
Mercierella enigmaticus	H/S			+			
Neanthes succinea	S					+	
Pseudopolydora paucibranchiata	S					+	
Sabella spallanzanii	H/S		+			+	
Mollusca – introduced							
Aplysiopsis formosa	S					+	
Corbula gibba	S					+	
Janolus hyalinus	S					+	
Musculista senhousia	S					+	
Raeta pulchella	S					+	
Theora lubrica (fragilis)	S					+	
Arthropoda: Crustacea – introduced							
Balanus amphitrite	H			+			
Carcinus maenas	S					+	
Cirolana harfordi	H/S					+	
Corophium acherusicum	S					+	
Corophium insidiosum	S					+	
Corophium sextonae	S					+	
Jassa marmorata	S					+	
Pyromaia tuberculata	S					+	
Bryozoa – introduced							
Aetea anguina	H			+			
Amathia distans	H			+			

Table 2.2. continued.

Taxa and species	Substrate type	Taxonomic consultant 1	2	3	4	5	6
Bowerbankia spp.	H			+			
Bugula calathus	H			+			
Bugula flabellata	H			+			
Bugula neritina	H			+			
Bugula simplex	H			+			
Bugula stolonifera	H			+			
Celleporella hyalina	H			+			
Conopeum reticulum	H			+			
Cryptosula pallasiana	H			+			
Electra pilosa	H			+			
Fenestrulina malusii	H			+			
Membranipora membranacea	H			+			
Microporella ciliata	H			+			
Schizoporella unicornis	H			+			
Scruparia ambigua	H			+			
Scrupocellaria bertholetti	H			+			
Scrupocellaria scrupea	H			+			
Scrupocellaria scruposa	H			+			
Tricellaria occidentalis	H			+			
Watersipora arcuata	H			+			
Watersipora subtorquata (=subovoidea)	H			+			
Echinodermata – introduced							
Asterias amurensis	H/S					+	
Chordata: Pisces – introduced							
Acanthogobius flavimanus	H		+				
Acentrogobius pflaumi	H		+				
Forsterygion lapillum	H		+				
Tridentiger trigonocephalus	H		+				
Urochordata: Ascidiacea – introduced							
Ascidiella aspersa	H			+			
Botrylloides leachi	H			+			
Botryllus schlosseri	H			+			
Ciona intestinalis	H			+			
Molgula manhattensis	H			+			
Styela clava	H			+			
Styela plicata	H			+			
Algae – cryptogenic and possibly introduced							
Acinetospora crinita	H	+					
Antithamnion cruciatum[1]	H	+					
Antithamnionella ternifolia	H	+					
Arthrocladia villosa[1]	H	+					
Audouinella pacifica	H	+					
Audouinella simplex	H	+					
Bangia atropurpurea	H	+					
Bryopsis plumosa	H	+					
Caulerpa filiformis[1]	H	+					
Centroceras clavulatum	H	+					
Ceramium flaccidum	H	+					
Ceramium rubrum	H	+					
Chaetomorpha aerea	H	+					
Chaetomorpha capillaris	H	+					
Chaetomorpha linum	H	+					
Cladostephus spongiosus	H	+					
Colpomenia peregrina	H	+					
Colpomenia sinuosa	H	+					
Cutleria multifida	H	+					
Derbesia marina	H	+					
Dictyota dichotoma	H	+					
Discosporangium mesarthrocarpum[1]	H	+					
Ectocarpus fasciculatus	H	+					
Ectocarpus siliculosus	H	+					
Elachista orbicularis[1]	H	+					
Enteromorpha compressa	H	+					
Enteromorpha intestinalis	H	+					
Erythrotrichia carnea	H	+					
Feldmannia globifera	H	+					
Feldmannia irregularis	H	+					
Feldmannia lebelii	H	+					

Table 2.2. continued.

Taxa and species	Substrate type	Taxonomic consultant 1	2	3	4	5	6
Gelidium pusillum	H	+					
Gymnothamion elegans	H	+					
Hildenbrandia occidentalis var. *yessoensis*	H	+					
Hildenbrandia rubra	H	+					
Hincksia granulosa	H	+					
Hincksia mitchellae	H	+					
Hincksia ovata	H	+					
Hincksia sandriana	H	+					
Kuckuckia spinosa	H	+					
Leathesia difformis	H	+					
Myrionema strangulans	H	+					
Nemalion helminthoides	H	+					
Petalonia fascia	H	+					
Petrospongium rugosum	H	+					
Peyssonnelia conchicola	H	+					
Pilayella littoralis	H	+					
Polysiphonia subtilissima	H	+					
Pterocladia capillacea	H	+					
Punctaria latifolia	H	+					
Scytosiphon lomentaria	H	+					
Sphacelaria fusca	H	+					
Striaria attenuata[1]	H	+					
Stylonema alsidii	H	+					
Ulva lactuca	H	+					
Ulva rigida	H	+					
Ulva stenophylla	H	+					
Vaucheria piloboloides[1]	H	+					
Porifera – cryptogenic and possibly introduced							
Callyspongia pergamentacea	H			+			
Darwinella australianensis	H			+			
Darwinella gardineri[1]	H			+			
Lissodendoryx isodictyalis	H			+			
Phorbas cf. *tenacior*[1]	H			+			
Tedania anhelans	H			+			
Mollusca – cryptogenic and possibly introduced							
Crassostrea gigas[1]	H/S					+	
Kaloplocamus ramosus[1]	H			+			
Okenia plana[1]	H			+			
Polycera hedgpethi[1]	H			+			
Arthropoda: Crustacea – cryptogenic and possibly introduced							
Balanus variegatus	H			+			
Caprella acanthogaster	S					+	
Caprella equilibra	S					+	
Caprella penantis	S					+	
Caprella scaura	S					+	
Elminius modestus	H			+			
Bryozoa – cryptogenic and possibly introduced							
Aeverrillia armata[1]	H			+			
Anguinella palmata[1]	H			+			
Bugula avicularia[1]	H			+			
Celleporaria albirostris	H			+			
Conopeum seurati[1]	H			+			
Electra tenella[1]	H			+			
Hippothoa aporosa[1]	H			+			
Hippothoa distans[1]	H			+			
Hippothoa divaricata	H			+			
Membranipora savartii	H			+			
Membranipora tuberculata[1]	H			+			
Parasmittina trispinosa	H			+			
Zoobotryon verticellatum[1]	H			+			
Echinodermata – cryptogenic and possibly introduced							
Amphipholis squamata[1]	H/S					+	
Amphiura parviscutata[1]	H/S					+	
Taeniogyrus sp.[1]	H/S					+	

3 THE PHYSICAL ENVIRONMENT OF PORT PHILLIP BAY

Summarised from Harris *et al.* (1996). Port Phillip Bay Environmental Study Final Report, CSIRO, Canberra 2601 Australia

3.1 INTRODUCTION

Port Phillip Bay is a large (1930 km^2) sheltered, temperate bay on the southern coast of Victoria, Australia (Figure 3.1). First "discovered" by Europeans in 1802, European settlement began in 1834 and immigration in 1836. Today, the shores of Port Phillip Bay host Australia's second largest metropolitan area (Melbourne, Geelong and associated areas) with a total human population of about 3.5 million. It is therefore subject to a high level of shipping and recreational boating use, commercial and recreational fishing, mariculture, effects of urban run-off and very high levels of coastal modification. About 11% of the catchment has been urbanised.

Physically, Port Phillip Bay is a drowned river system, formed about 8,000 years BP, when the eustatic rise in sea level following the last ice age resulted in flooding of the delta formed by the Yarra, Werribee and Little Rivers, and the Kororoit Creek. Overall, the bay is relatively shallow; maximum depth is ~100 m but most is less than 8 m. The salinity over most of the Port Phillip Bay exceeds 32‰, the only real exception being near the mouth of the Yarra River. Temperatures fluctuate seasonally from about 11° to 21° C and are relatively uniform across the bay.

As a result of its large size, shallow depth, proximity to urbanised areas and at times substantial freshwater run-off, the bottom of Port Phillip Bay is predominantly silt, fine sands and clay, with coarser sediments in shallower areas and a high-organic loose floc in the deeper center of the bay. Water movement is driven by tides, winds and density differences, the latter due to sea water entry

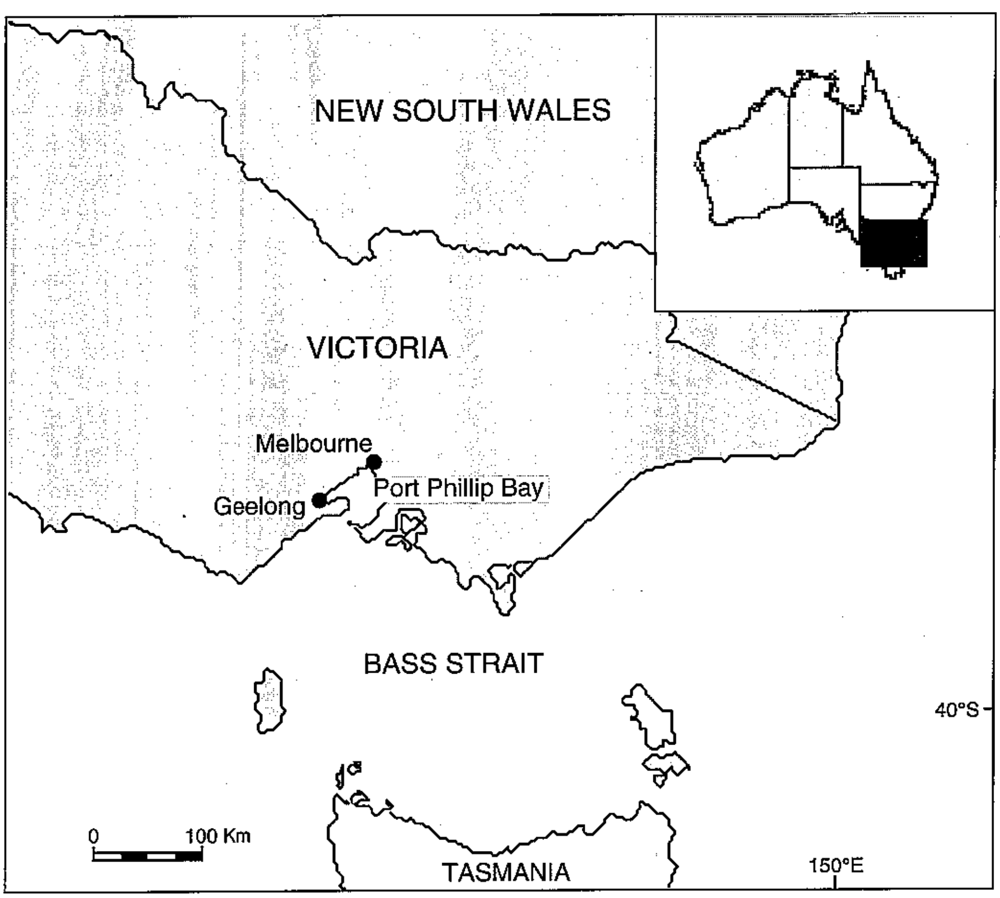


Figure 3.1. Locality map, southeast Australia.

through the heads from Bass Strait and freshwater sources from the river systems in general and the Yarra River in particular. The general circulation pattern, driven by the dominant west winds, consists of two large gyre systems – a clockwise one in the north of the bay and an anti-clockwise one in the south. Analysis of patterns of tidal mixing and water movement suggest a residence time for water in Port Phillip Bay of 10–16 months.

3.1.1 Previous surveys of Port Phillip Bay

Charles Robbins performed the first biological survey of Port Phillip Bay in 1803 (Leggett 1949; Shaw 1997). The first marine taxa to be reviewed and described were the marine algae. A committee convened by the Council of the Royal Society of Victoria then became responsible for numerous other studies. One of the later Royal Society studies, by Wilson (1894), examined flora and fauna collected from his own dredging activities, which concentrated at the Heads, but also included Corio Bay and the eastern shore.

Subsequent, comprehensive studies of the bay included the Port Phillip Study (PPS), from 1957–1963, which focused on the physical properties of the bay, and included a semi-quantitative study of the bay's macroflora, fauna, geology and geomorphology, terrestrial and marine sediments, and the coastal vegetation. Samples were collected using divers and dredges.

A more extensive survey carried out from 1968 to 1971, the Port Phillip Bay Environmental Study or 'Phase One Study' (PPBES-1), was designed to provide baseline data on the physics, chemistry, and the biology of the bay. The initial objective was to determine the effects of a proposed sewerage treatment plant at Carrum (discharging effluent at Patterson River) would have upon the flora and fauna of the bay. Ultimately, the effluent discharge was diverted to Cape Schanck and the study went ahead with a revised objective of providing baseline information on the long-term effects of urbanisation on the bay. The study concluded that there were high nutrient levels adjacent to Werribee and in Hobsons Bay, but the rest of the bay was "healthy".

In 1977, the Port Melbourne study was commissioned. The aim of this study was to assess the environmental effects associated with the planned construction of Berth No. 6 Webb Dock and at the same time, provide baseline data on the marine environment of Hobsons Bay. The study identified physical and biological patterns within Hobsons Bay and concluded that the disturbance caused by the construction of berth No. 6 Webb Dock would not be detrimental to the physical and biological environment of Hobsons Bay (Port of Melbourne Environmental Study 1979). The dominant fauna identified during the survey were polychaetes and bivalves (Port of Melbourne Environmental Study 1979). Interestingly, this study provides the first mention of introduced species in Port Phillip Bay stating that "the invertebrate fauna comprised hardy estuarine species, many of which have been introduced over the past century by shipping" (Port of Melbourne Environmental Study 1979).

Corio Bay was surveyed in 1987 by the Victorian Environmental Protection Authority using a Smith-McIntyre benthic grab to sample the macrobenthos of Corio Bay (Coleman 1993). A pattern analysis indicated three major site groups that were partly related to sediment type. Polychaetes, molluscs and crustaceans dominated the fauna and constituted 85% of all individuals sampled (Coleman 1993). Although population densities were low, the number of species collected was comparable with numbers collected from similar habitats in Victoria and there was no clear evidence that pollution within the Bay had adversely affected the fauna (Coleman 1993).

The most recent bay-wide survey occurred in 1996 and was coordinated by CSIRO Divison of Fisheries and Division of Oceanography and involved a range of participating Victorian organisations (Harris *et al.* 1996). The principal objective of this study was to assess the health of Port Phillip Bay and to determine the extent to which it could sustain the effects of continued urban development. The principal components of the work including hydrodynamic and nutrient modeling, which was based on reviews of existing information, new data on nutrient loads and processes, and the ecology of the bay.

Table 3.1. Amplitudes (metres) of the major tidal constituents for sites near and in Port Phillip Bay (reproduced from Harris *et al.* 1996, Table 2.2).

Gauge	M2	K1	O1	S2	N2
Lorne	0.615	0.209	0.145	0.193	0.117
Point Lonsdale	0.438	0.144	0.102	0.128	0.084
Queenscliff	0.259	0.111	0.085	0.073	0.051
West Channel	0.205	0.096	0.067	0.046	0.035
Hovell Pile	0.202	0.096	0.070	0.049	0.035
Geelong	0.268	0.100	0.072	0.066	0.047
Breakwater Pier	0.236	0.098	0.068	0.054	0.039

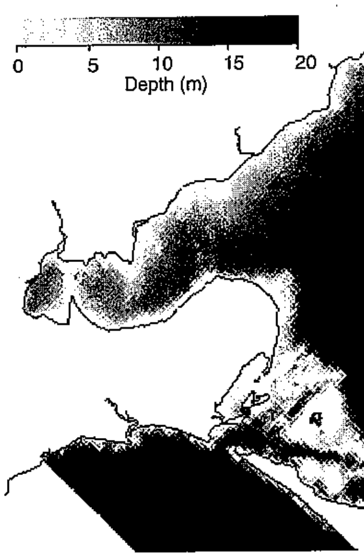


Figure 3.2. Bathymetry of Port Phillip Bay. Areas deeper than 20 m are shown in black. Coordinates on this and other figures are in metres, referenced to AMG Zone 55 (reproduced from Harris *et al.* 1996, Figure 2.2).

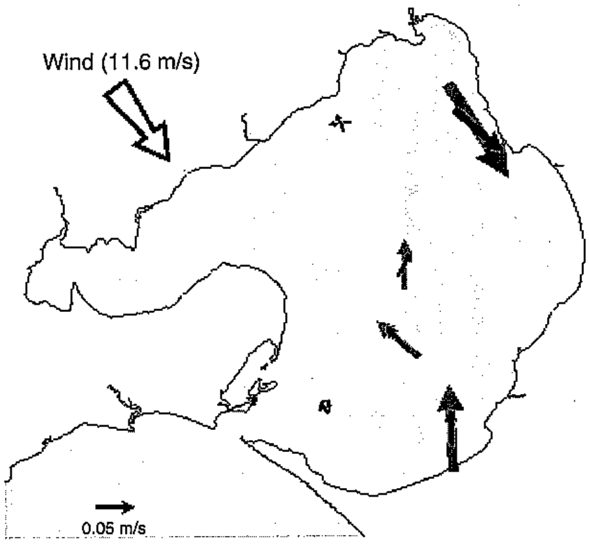


Figure 3.3. Mean currents measured for 17–18 May 1994. Data from lower metres are shown as grey arrows, upper metres are shown as black arrows. Arrow length is proportional to current speed. Mean wind velocity (measured at Hovell Pile) is also shown (reproduced from Harris *et al.* 1996, Figure 2.4).

3.2 PHYSICAL ENVIRONMENT OF PORT PHILLIP BAY

3.2.1 Bathymetry

Port Phillip Bay is a large, relatively shallow body of water that has a restricted connection to Bass Strait. The main part of the bay is almost circular, sloping gently on the western side and more steeply on the southern and eastern sides (Figure 3.2). The maximum depth in the center of the bay is around 24 m. To the south of the main body of the bay lies the Great Sands region, a flood tide delta consisting of substantial sand bars and shallows dissected by deeper channels. This region greatly restricts exchange between the Port Phillip Bay and Bass Strait. Further south again lies the entrance to the bay, which is about 3 km in width, and characterised by strong tidal currents. The deepest parts of the bay are found in this area (chart AUS158), with deep scour holes in the South Channel (36 m) and in the Rip (almost 100 m). To the west of the main bay lies the Geelong Arm and Corio Bay. Exchange between Corio Bay and the main body of the bay is restricted by a shallow bar; a channel has been dredged through the bar to allow shipping access to the Port of Geelong. The Port of Melbourne at the northern end of the bay is accessed by dredged channels that traverse Hobsons Bay.

From coastline data, the area of the bay can be calculated to be about 1930 km^2. Bathymetric data obtained from the Royal Australian Navy show that the mean depth of the bay is about 13.6 m, so that the bay has a total volume of about 26.3 billion (10^9) m^3.

The most obvious variations in water level in the bay are caused by the tides. Tidal amplitudes in the bay are less than half of those in northern Bass Strait, and there is a large phase difference between the main body of the bay and Bass Strait. Tides are semi-diurnal (two tidal cycles per day), with a large diurnal inequality. Most of the attenuation of the tides takes place near the entrance to the bay. Compared to its amplitude at Lorne, the M2 component drops to about 70% at Point Lonsdale and about 40% at Queenscliff (Table 3.1). The remaining attenuation occurs across the Sands region. North of the Sands, the tides are reasonably uniform throughout the bay, with some increases in amplitude in Corio Bay and Hobsons Bay.

Variations of water level in the bay are also caused by lower frequency motions in Bass Strait, winds, atmospheric pressure variations and horizontal density gradients. A discussion of these effects can be found in Hunter (1992), and Black and Mourtikas (1992). In general, the low-frequency (periods of several days or more) variations in water level in the bay are closely correlated with those in Bass Strait. In effect, the Rip and Sands act as a low-pass filter for sea level, so that the relatively higher frequency tides are attenuated as they enter the bay, but lower frequency variations are not. Particularly high water levels in the bay are associated with low pressure systems and winds with a strong westerly component. Low pressure systems located over Bass Strait will tend to raise sea level generally over the bay, and westerly winds tend to raise the sea-level on the northern side of Bass Strait (due to the rotation of the earth).

3.2.2 Currents

Tidal currents dominate the circulation in the southern-most parts of the bay, with speeds over 2.5 m s^{-1} during peak flood and ebb flows through the Rip, and up to 0.8 m s^{-1} in the major channels through the Sands. In the main body of the bay, currents are weaker, typically 0.05 to 0.1 m s^{-1}, and predominantly driven by the wind. These wind-driven currents tend to show the following features (Hunter 1992):

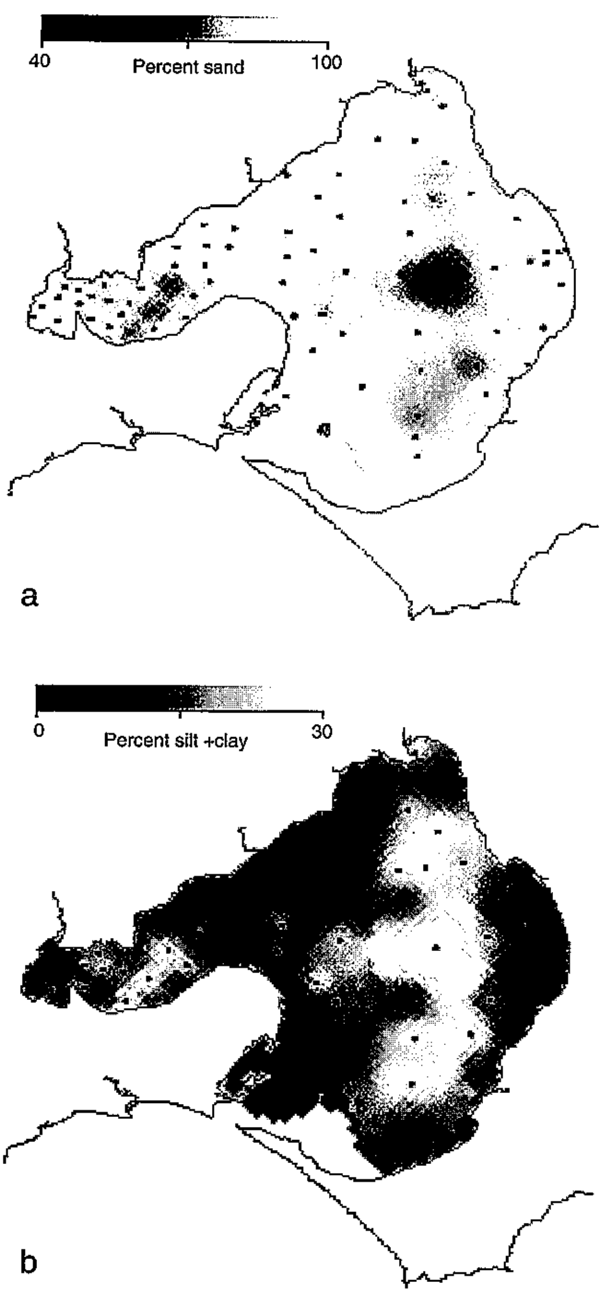


Figure 3.4. Distribution of a) sand; and b) silt/clay in sediments in Port Phillip Bay. These data were interpolated to a 1km grid from sampling sites shown as black dots. No data is present in and to the south of the Sands region (reproduced from Harris *et al.* 1996, Figure 2.10).

- horizontal gyres with the currents directed with the wind in shallow areas and against the wind in deeper areas; and
- an overturning pattern, with currents directed with the wind near the surface and against the wind near the bottom.

Density driven currents may also be important in the region affected by the Yarra River plume (Hunter 1992). In 1994, CSIRO deployed current meters at five sites in the bay for two periods, each of about six weeks, to monitor the net (non-tidal) water movements around the bay. Figure 3.3 shows mean velocity vectors at all meters over a representative two-day preiod (17-18 May 1994) when strong northwesterly winds prevailed. The plot clearly suggests a gyre type circulation in the eastern half of the bay, with currents of about 0.1 m s^{-1}, directed with the wind in the center of the bay. Somewhat surprisingly, the mean currents at the deeper meters are stronger than those nearer the surface over this period. Instantaneous speeds are similar at lower and upper metres; this effect seems primarily to be because the near surface currents are more variable in direction over this period.

3.2.3 Sediments

The sediments of Port Phillip Bay are a mixture of fine sands, silts and clays, with coarser sediments in shallow areas and the Sands region, and finer sediments towards the deeper central portion of the bay. Sediment studies carried out prior to the CSIRO study are summarised in Black and Mourtikas (1992).

Physical measurements of sediments undertaken by Harris *et al.* (1996) included the collection and analysis of cores from 80 sites in the bay. The cores were analysed for grain size, density, porosity, viscosity, permeability and consolidation characteristics. These data are presented in Greilach *et al.* (1995) and summarised in Figure 3.4.

Particulates enter the bay from a number of sources. No data is available for inputs from coastal erosion, or from Bass Strait (which might provide sand to the southern-most parts of the bay). Other inputs are dominated by the Yarra river. The CSIRO study shows a total non-filterable residue (NFR) input of about 145,000 t over the period January 1993 to October 1995 (inclusive), which corresponds to an annual average of about 51,000 t. Average figures do not give a good idea of the variations in input, however, and closer examination of the data shows that most input occurs in just a few short events. Total particulate inputs amount to about 85,000 t y^{-1}. If it is assumed that the material is deposited uniformly over the bay, then the equivalent sedimentation rate in that area is 0.04 kg m^{-2} y^{-1}. Assuming grain density of quartz (2,650 kg m^{-3}), and a deposit porosity of 0.5, this is equivalent to a build-up of sediment of 0.03 mm y^{-1}. This calculation is likely to underestimate the actual sedimentation rate.

Table 3.2. Mean flows for each year in the period 1990 to 1995. Values are in $m^3 s^{-1}$. 1995 data does not include November or December (reproduced from Harris *et al.* 1996, Table 2.6).

Input	1990	1991	1992	1993	1994	1995
Yarra River (total)	23.9	22.5	36.4	39.0	18.3	30.0
Mordialloc Creek	2.0	2.0	2.8	2.1	2.0	-
Patterson River	4.2	5.4	7.1	6.6	2.0	-

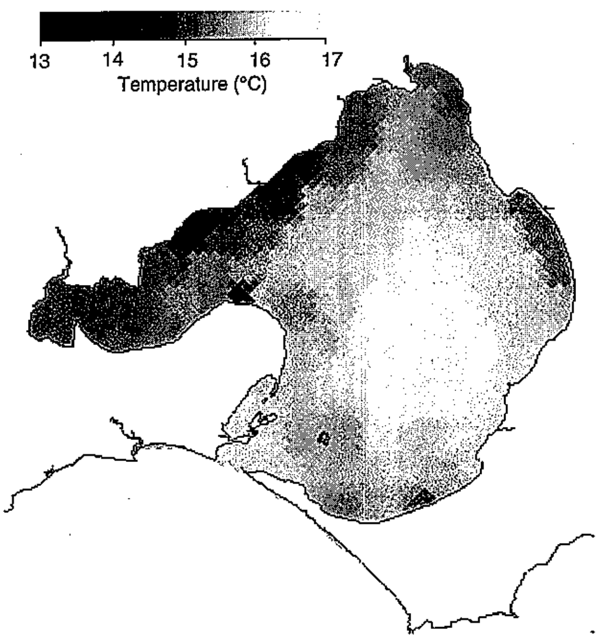


Figure 3.5. Temperature averaged between surface (0) and 1 m depth, interpolated from a CTD survey of 85 sites occupied on 3–4 May 1994 (reproduced from Harris *et al.* 1996, Figure 2.14).

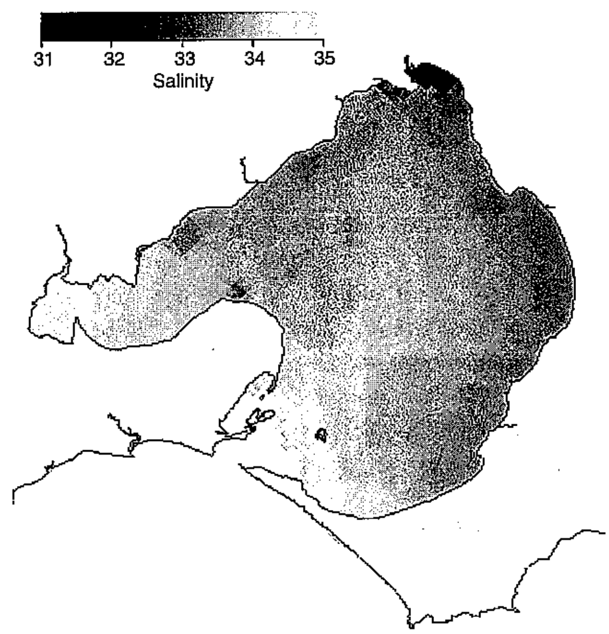


Figure 3.7. Salinity averaged between surface (0) and 1 m depth, interpolated from a CTD survey of 85 sites occupied on 3–4 May 1994 (reproduced from Harris *et al.* 1996, Figure 2.16).

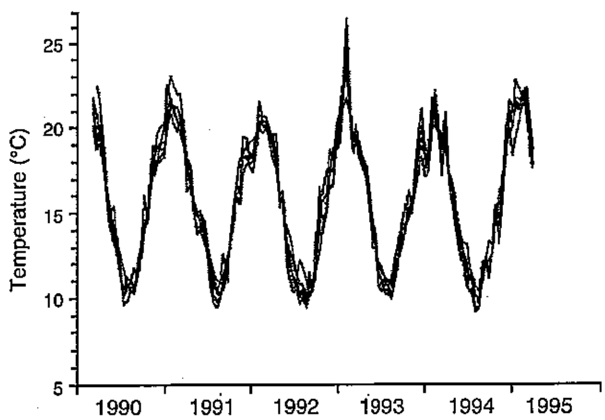


Figure 3.6. Surface temperature measured at 6 sites in Port Phillip Bay from 1990 to 1996 (reproduced from Harris *et al.* 1996, Figure 2.15).

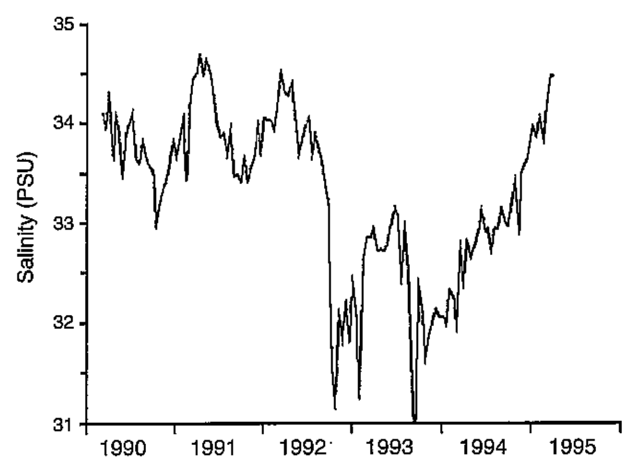


Figure 3.8. Surface salinity measured at site 11 (near the Werribee River), 1990 to 1996 (reproduced from Harris *et al.* 1996, Figure 2.15).

3.2.4 Fresh water

On average, the amount of fresh water lost by evaporation from the surface of Port Phillip Bay almost equals the inputs to the bay from rivers, creeks and direct rainfall, so that the net fresh water input to the bay is very small (Hunter 1992). The total flow rate into the bay from rivers, creeks and drains was estimated to be about 44 $m^3 s^{-1}$, most of which enters the bay at the mouth of the Yarra River. The data show that inflows vary substantially from year to year. For example, Table 3.2 shows mean flows from some of these inputs for each year in the period 1990 to 1995. Here the data for Chandler Highway, Keilor, Moonee Ponds Creek, Merri Creek and Gardiners Creek have been combined to give a single total flow for the Yarra River. The last 2 months of 1995 were not available at the time of these calculations were done, so that the 1995 figure for the Yarra River is an average over 10 months. Substantial variation is seen in all inputs, apart from Mordialloc Creek, where the flow is controlled. 1994 was a dry year compared to other years in the 1990's, but the early 1980's were much drier.

Groundwater inputs to the bay are estimated to be greater than $5.5 \times 10^7 m^3 y^{-1}$, or 1:7 $m^3 s^{-1}$ (Otto 1992).

3.2.5 Temperature and salinity

The temperature of Port Phillip Bay varies spatially and temporally as a result of a diverse mix of processes, including solar radiation, evaporative heat loss and water inputs. A typical spatial pattern is shown in Figure 3.5.

The Victorian Fisheries Research Institute (VFRI[1]) have monitored a number of sites around the bay fortnightly since 1990, conducting a range of measurements. The seasonal signal in a compilation of these data is obvious (Figure 3.6), with water temperatures ranging from 21° C in summer to 11° C in winter. Temperature differences from site to site within the bay are minor, relative to the seasonal signal.

Salinity in the bay is controlled by inputs of freshwater from rain, rivers and creeks, loss of freshwater from evaporation, and exchange with Bass Strait. Spatial analysis, carried out in the CSIRO study (see Svenson and Pattiaratchi 1994) indicate a number of relatively consistent features (e.g. Figure 3.7). These include the Yarra River plume in Hobsons Bay, and the influence of Bass Strait water to the south of the Sands region.

Salinity measurements were also carried out at the VFRI sampling sites. Observations for site 11 are shown Figure 3.8. Data from other sites show broadly similar features, but the behaviour at each site depends to some extent on the location of the site with respect to river inputs and to Bass Strait. Site 1 in the south of the bay, for example, shows less variation in salinity than the other sites due to the proximity of Bass Strait, whereas sites to the north all show sudden drops in salinity associated with the Yarra River plume and east coast inputs during floods. Baywide, the salinity dropped markedly in late 1992 and again in late 1993, due to large freshwater inputs. 1994 was relatively dry, so salinity increased steadily, due to both exchange with Bass Strait and evaporation.

3.2.6 Mixing and flushing

The freshwater from the Yarra River mixes with saline bay water in the Yarra estuary and in Hobsons Bay to form a buoyant surface plume[2]. The plume can be readily discerned by its salinity, and to a lesser extent its temperature (operation of the Newport Power Station tends to locally increase water temperature in the plume). The shape and extent of the plume depend strongly on river flow, and wind speed and direction. Higher flows increase the extent and thickness of the plume. Northerly winds moved the plume to the western side of Hobsons Bay, while during westerly winds the plume moved in a southeast direction along the coast. Southerly winds have a long fetch across the bay to this area and so have a larger capacity for wind stirring. Mixing processes observed in the area were associated with wind mixing, interfacial shear and bottom boundary shear.

The 'flushing time' of the bay depends on where it is measured. For example, a water parcel originating in the south of the bay near the Rip will exchange with Bass Strait quite quickly, a water parcel located in the center of the Bass will exchange with Bass Strait more slowly, and one in Corio Bay more slowly still. Hunter (1992) quotes several estimates of flushing time for the bay, ranging from about 10 to 16 months.

In the CSIRO study, CTD surveys gave a detailed picture of the movement of Bass Strait water and bay water through the Sands region. The two water masses were distinguished by their salinity, with Bass Strait water having a salinity greater than 35.3 PSU, and bay water having a salinity of less than 34 PSU, at the time of the surveys. Intermediate salinities were found in the Sands, representing mixtures of Bass Strait and bay water. The area is well mixed vertically, with horizontal salinity distributions determined by the state of the tide. At the end of the flood tide, Bass Strait water extends about 6 km north and east past the entrances to the channels, but with little reaching the main body of the bay. Similarly, little bay water reaches Bass Strait at the end of the ebb tide.

The flushing time of the bay was estimated over a tidal cycle (observed on 10 May 1994). The cycle

[1] VFRI, now Marine and Freshwater Resources Institute (MAFRI).

[2] Editor's Note: Note the Yarra River plume in the Landsat image (November 1993) on the cover.

begins with Bass Strait water present at the start of the ebb tide. As the ebb tide progresses, the salinity drops, indicating the presence of bay water. At the end of the ebb tide, the water is about 70% bay water. The flood tide begins, and salinity rises. By halfway through the flood tide, the water present is again Bass Strait water. By integrating such curves for all channels, the net amount of bay water lost can be calculated. The resultant average flushing time for the example given equals about 380 days (Pattiaratchi *et al.* 1995a). This figure compares well with previous estimates, though based on data from only two tidal cycles.

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4 PORT PHILLIP BAY: BIOLOGY, HABITATS AND DISTURBANCE HISTORY

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4.1 INTRODUCTION

Biologically, Port Phillip Bay is extremely diverse, with nearly 500 species of benthic macro-algae, 12 species of seagrasses, small mangrove forests, extensive hard bottom and soft sediment communities with over 700 invertebrate species, 68 species of fish, and a diverse assemblage of seabirds (including penguins) and marine mammals. The bay supports commercial fisheries worth Australian $30-40 million per year, the bulk of which historically is based on shellfish.

4.2 HABITAT TYPES AND ASSOCIATED COMMUNITIES WITHIN PORT PHILLIP BAY

Soft, subtidal sediments provide the major benthic habitat type in the bay (Figure 4.1). Sediments are sandy near the edge of the bay and become progressively muddier towards the deeper waters in the centre of the bay. Other habitat types include subtidal reefs, intertidal sandy and rocky areas and estuarine areas. While the distribution of seagrass, algae and mangroves is related to physical habitat type, these plant communities also provide a distinct habitat type for the biota, both plant and animal, that is associated with them.

Subtidal soft sediments

The soft-bottom macrobenthos of Port Phillip Bay is diverse. A total of 713 species was collected during the 1969–73 survey (Poore *et al.* 1975) although this is not considered to be exhaustive. Some groups are particularly notable for their high level of within-genus species radiation. Barnard and Drummond (1978) described Port Phillip Bay and nearby Western Port as 'species packed' because these areas contain unusually high numbers of species of phoxocephalid amphipods.

The distribution of benthic infauna, epifauna and fish communities associated with soft sediments are correlated with depth and sediment type (Figure 4.2; Poore 1992; Cohen *et al.* 1998). The centre of the bay consists of mud and infaunal species richness is low. Species richness is also low in the muddy sediments of Corio Bay. Species richness is higher in the silt- and clay-sand sediments which surround the central basin and extend into the Geelong Arm. Species richness is also high in the coastal sandy sediments around much of the bay, but low in the coarse sands near to the entrance to Bass Strait. Common species in the muddy sediments include the polychaetes *Owenia* sp., *Lumbrineris* sp., the molluscs *Theora lubrica* (an introduced species), *Notospisula trigonella* and *Chioneryx cardioides* and the crustaceans *Neochallichirus limosus* and *Dimorphostylis cottoni*; and in sandy sediments the polychaetes *Protodorvillea* sp., *Magelona* cf. *dakini*, *Lumbrineris* sp and *Phyllochaetopterus* sp., the molluscs *Chioneryx cardioides*, *Mytilus edulis planulatus*, and *Ethminolia vitiliginea* and the crustaceans *Dimorphostylis cottoni*, *Euphilomedes* sp., *Elminius modestus*, *Glyphocuma bakeri*, *Urohaustorius pulcus* and *Paradexamine moorehousei* (Wilson *et al.* 1998). Deposit feeders predominate in the muddy sediments and suspension feeders in the sandy sediments.

Data on annual and seasonal variability in community composition and structure of the benthos are available for three stations, one in Corio Bay, one in the centre of Port Phillip Bay and one off Martha Point in the southeast of the bay, that were monitored from 1973 to 1975 (Poore and Rainer 1979). Year to year variation in community structure was greater than seasonal variation. Only a few species showed seasonal changes in abundance but several were more abundant in some years than others. The population density of common species and the identity of rare species fluctuated irregularly. These fluctuations could not be correlated with physico-chemical characteristics of the overlying water, nor were there any obvious environmental perturbations during the study period.

Significant changes have occurred in the benthos of the bay over the last 25 years (Currie and Parry 1999a; Wilson *et al.* 1998). During the 1970's only one introduced species, the bivalve *Theora lubrica*, was abundant in the benthos. Since then an additional four introduced species: the polychaetes *Sabella spallanzanii* and *Euchone limnicola*, the bivalve *Corbula gibba* and the crab *Pyromaia tuberculata*, have become abundant and widespread. Other changes include a decrease in the population density of particular species, an increase in the relative abundance of polychaetes as compared with crustaceans and molluscs, an increase in the proportion of suspension feeders and a decrease in the proportion of

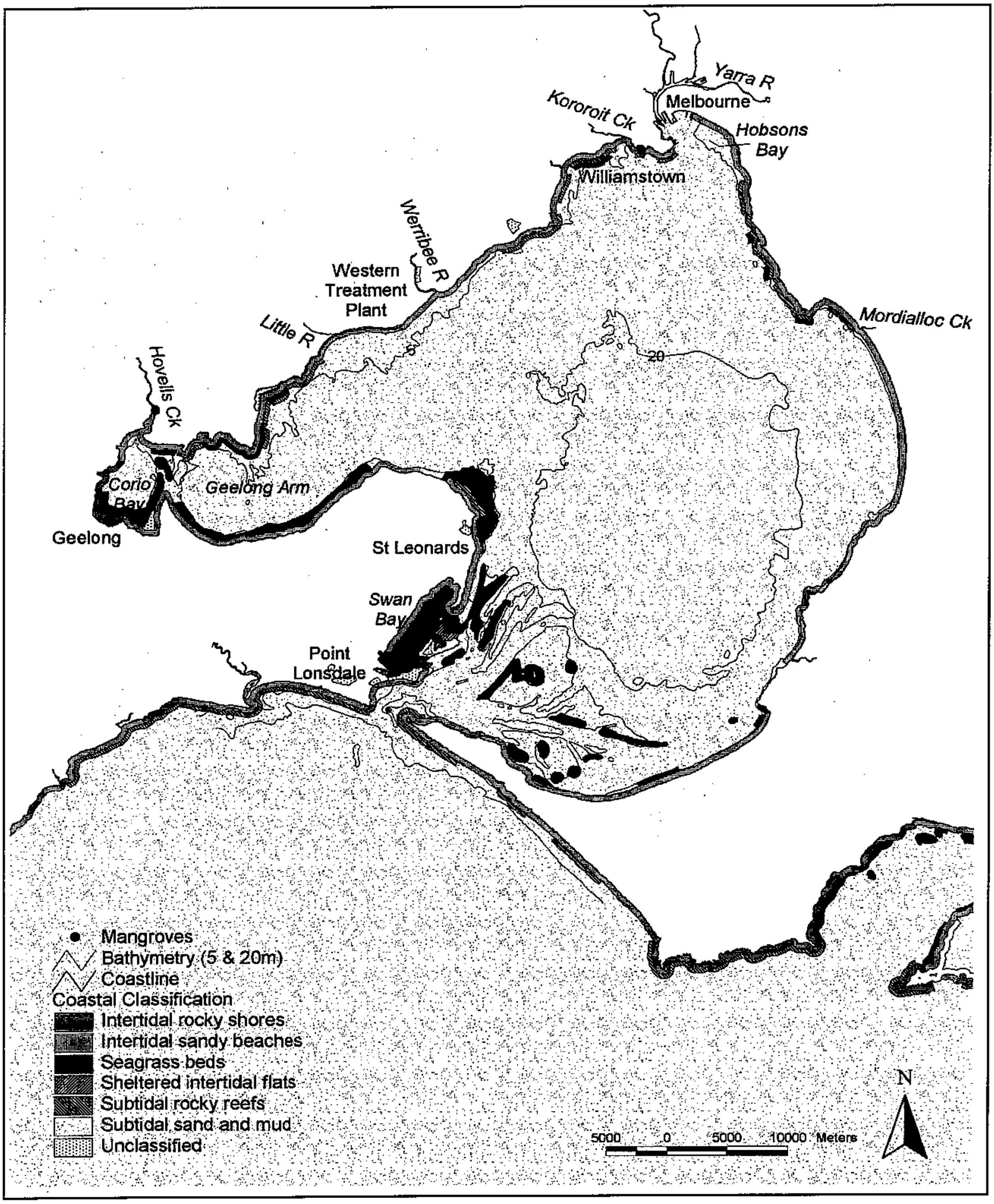

Figure 4.1. Major marine habitat types in Port Phillip Bay (based on Land and Conservation Council 1993, map 2).

deposit feeders. The total number of taxa does not appear to have decreased.

Except for those due to higher numbers of exotic species, causes of the observed changes are not understood. However, decreases in the number of individuals and in the proportion of deposit feeders are consistent with the decrease in nutrient input from the sewage treatment plant at Werribee that occurred in the mid 1970's (since which time the output has remained fairly constant). In the absence of continuous monitoring, it is not known whether changes represent long-term trends or merely reflect interannual variation, but changes over the past 25 years are within the range encountered during the 3-year monitoring study carried out during the 1970's (Wilson *et al.* 1998).

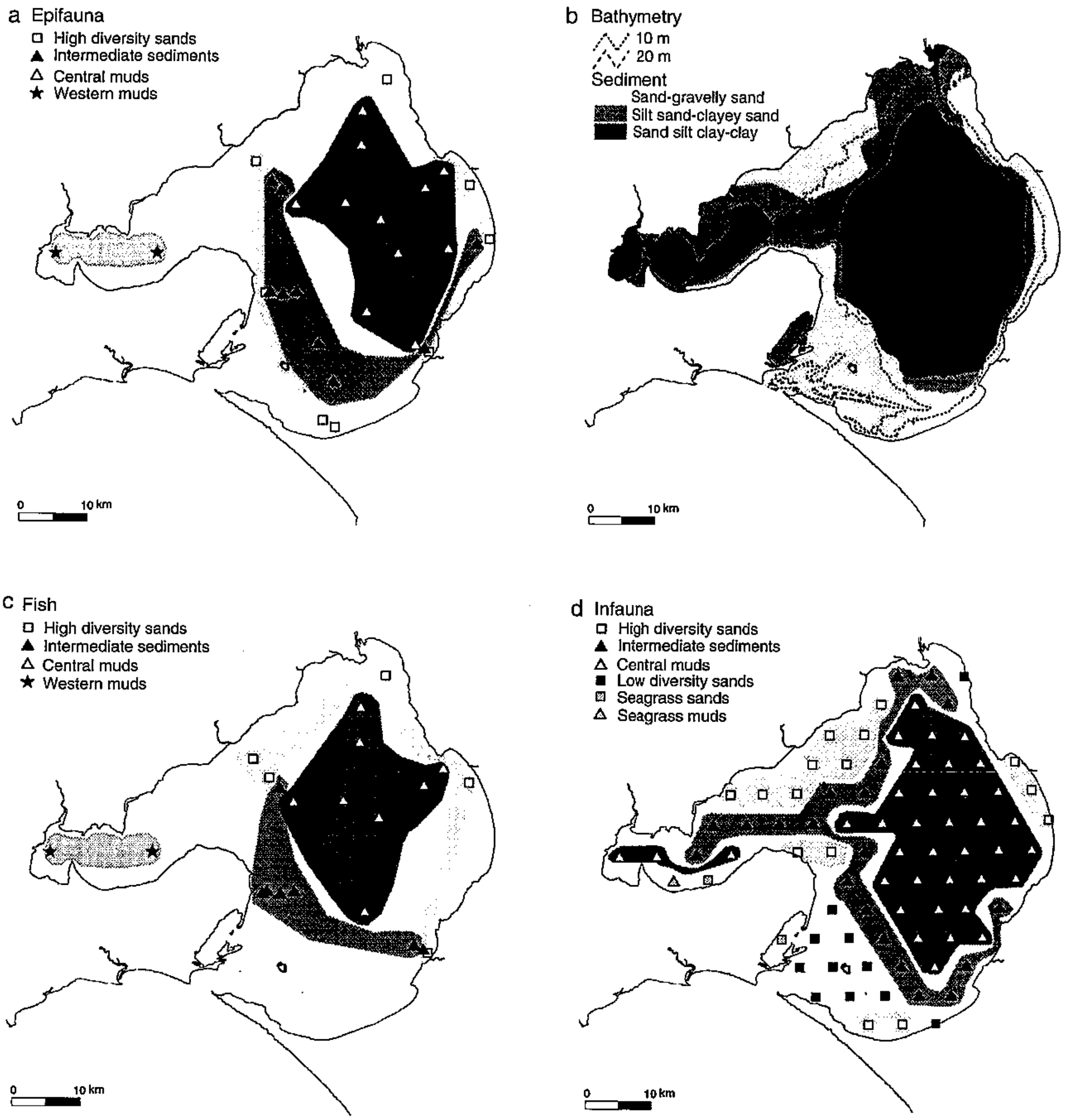

Figure 4.2. Distribution of marine communities and sediments in Port Phillip Bay. a) stations sampled for epifauna in 1998 and their classification into four regions based on multidimensional scaling ordinations (MDS); b) sediment distribution and bathymetry; c) MDS groupings of stations sampled for demersal fish in 1997; and d) MDS groupings of infaunal communities fromstations sampled in 1975 (data derived from various sources and analysed in Cohen *et al.* 1998).

Subtidal sediments also support an epibenthic community. A depth-stratified survey (Cohen *et al.* 1998) found that epifaunal abundance, biomass and species richness were generally greater at shallow (7 m) stations than at deeper (12–22 m) stations. These shallow stations are dominated by the ascidian *Pyura stolonifera* that has an average density of 648 individuals per 100 m^2, and forms small biogenic reefs, completely covering the sediment surface over several square meters. *Pyura* reefs provide a stable anchorage for the mussel *Mytilus edulis planulatus* and the anemone *Actinia tenebrosa*, a grazing surface for the echinoid *Heliocidaris erthyrogramma* and shelter and refuge for motile species such as the polychaete *Eunice laticeps* and the crab *Pilumnopeus serratifrons*. *Pyura* reefs also provide a suitable substratum for epizoic algae (Light and Woelkerling 1992).

Filter feeders dominate the epibenthos with around 95% of all individuals and biomass utilising this feeding mode. This contrasts with the infauna where deposit feeders dominate (Wilson *et al.* 1998). Ascidians accounted for 65% of all species collected. The importance of this phylum, and of *P. stolonifera* in particular, to the dynamics of the bay may have been underestimated previously because of the difficulty of accurately sampling large ascidians.

Four epibenthic communities can be recognised in Port Phillip Bay and their distribution patterns are similar to those found in demersal fish and infaunal communities, generally reflecting differences in sediment grain size and depth (Figure 4.2). The 'high diversity sands' are found around the shallow, sandy margins of the bay and are dominated by *Pyura stolonifera* and the rich fauna this ascidian supports. The 'intermediate sediments' are located in the deeper areas of the southern end of the bay. This community has the lowest epifaunal abundance and biomass of the four communities but corresponds to the area that traditionally produced the highest catches of the scallop *Pecten fumatus*. The sediments of the 'central muds', found in the central and northern body of the bay, are similar to the sediments of the 'western muds' of the Geelong Arm but the communities differ. The 'central muds' are dominated by exotic species (72% of fauna by abundance) including the ascidians *Stylea clava* and *Ascidiella aspersa* and the northern Pacific seastar, *Asterias amurensis*, which has recently appeared in the bay in considerable numbers. The 'western muds' community is characterised by the echinoderms *Echinocardium cordatum* and *Stichopus mollis* and the exotic ascidian *Styela plicata*.

4.2.1 Subtidal hard substrata

While soft sediments dominate the bay, the rocky reefs in Port Phillip Bay support an abundant and diverse fauna and flora (Black 1971). Reefs in the bay account for approximately 1% of the substrata and are generally limited to less than 12 m depth (Black 1971) but they constitute an important fisheries resource. McShane *et al.* (1986) mapped 8.4 km^2 of reef which produce about 50 t of abalone per year (mostly blacklip abalone, *Haliotis rubra*), worth a million dollars (Harris *et al.* 1996). Most of this abalone catch is from the low profile basalt reefs along the west coast of the bay. This contrasts with the reefs on the east coast of the bay, which are made of sandstone in the north and granite near Mt Martha. The extensive reefs at the entrance to Port Phillip Bay are calcarenite and support a very rich community more typical of open coast reefs (Black 1971).

Ecological research into the subtidal rocky reef habitats within Port Phillip Bay is limited. The Marine Research Group has documented intertidal invertebrates found in the bay (Marine Research Group of Victoria 1984) and many of these species are also found subtidally. The basalt reefs on the west coast have a high cover of coralline algae and mussels are occasionally found in large numbers (Dixon, MAFRI pers. comm.). The comparatively soft nature of some of these basalt reefs allows burrowing organisms, such as the mollusc *Pholas australasiae*, to establish (Black 1971). Brown *et al.* (1980) found that these basalt reefs supported more species of algae than the surrounding soft sediments. Womersley (1966) suggests that the overall poor species richness of algae in the bay, compared with the adjacent coasts, was in part attributable to the limited hard substratum available. Interestingly, the largest biomass of algae is not found attached to these rocky reefs but is drift algae, including *Botryocladia*, *Jeanerettia* and *Polysiphonia* (Chidgey and Edmunds 1997), which is healthy and capable of growth. Chidgey and Edmunds (1997) found that the distribution of these drift algae is temporally and spatially distinct. On the soft sediments, Harris *et al.* (1996) suggest that red algae dominate the north-western areas of Port Phillip Bay and green algae (*Caulerpa*) dominate the north-eastern areas. Light and Woelkerling (1992) provide a detailed review of information on the benthic flora of Port Phillip Bay.

Man-made structures such as piers and channel markers also provide important substrata for epibiota in Port Phillip Bay, especially given their proximity to national and international shipping. Mussels dominate the mature fouling community in the bay, except near the entrance where sponges and ascidians dominate (Holmes 1982; Nicholson *et al.* 1997; Currie *et al.* 1998a).

4.2.2 Seagrass, algal and mangrove communities

Seagrasses

The distribution of seagrass is related to intertidal height, depth, turbidity, water currents and sediment stability. Seagrass beds are confined mainly to the southern part of the bay, including Corio Bay, the Geelong Arm, Swan Bay and the sandbanks near Port Phillip Heads at the entrance to the bay (Bulthuis 1981; Figures 4.1 and 4.2). Smaller, isolated patches of seagrass occur along the eastern and northern shores, but these represent less than 5% of the total area of seagrass in Port Phillip Bay.

Major species of seagrass reported from the Bay are *Heterozostera tasmanica* and *Zostera muelleri*, with smaller amounts of *Amphibolis antarctica*, *Halophila ovalis*, *Ruppia tuberosa*, *Ruppia megacarpa* and *Lepilaena marina*[1] (Willis 1966; Black 1971; King *et al.*

[1]Editor's Note: *Lepilaena* is generally not recognised as a seagrass (Robertson 1984).

1971 Bulthuis 1981; Denning *et al.* 1986). *H. tasmanica* is the most abundant and widespread of these and occurs from about the intertidal to a depth of 9 m below mean water. *Zostera muelleri* generally occurs higher in the intertidal zone than *Heterozostera tasmanica* and at low tide may be exposed to air for up to 4 or 5 hours. *A. antarctica* is confined to the area around Port Phillip Heads. It is found subtidally and typically occurs in areas of strong water movement but may also be found in rock pools. *H. ovalis* is largely confined to the western side of the bay and occurs subtidally, particularly around Corio Bay and the Geelong Arm. *Ruppia tuberosa*, *R. megacarpa* and *L. marina* are recorded from Swan Bay.

Seagrass beds provide a habitat for epiphytic algae and epifaunal invertebrates, which are associated with the shoots and leaf blades, and for infaunal invertebrates and fish. Epiphytes include the brown algae *Feldmannia* and *Sphacelaria*, the red algae *Acrosorium uncinatum*, *Antithamnion*, *Callithamnion*, *Ceramium*, *Champia*, *Chondria*, *Dasya*, *Hypnea* and *Polysiphonia* and the green algae *Enteromorpha* and *Ulva lactuca*, but there are no quantitative data on epiphyte abundance and distribution (Watson 1979; Brown 1980; Brown *et al.* 1980; Light and Woelkerling 1992).

Few details of invertebrate epifauna associated with seagrass are available although Watson (1979) reports seagrass beds harbouring colonies of up to 1680 individuals m^{-2} of the byssally-attached bivalve *Electroma georgiana*, and Brown and Davies (1991) report an abundance of grazing invertebrates in seagrass beds around Werribee.

Based on studies of *Heterozostera* and *Zostera* beds in Swan Bay, Denning *et al.* (1986) found that seagrass beds contain higher numbers of individuals and species than do sparsely vegetated areas nearby. While some of the invertebrate species associated with seagrass in Swan Bay were common throughout Port Phillip Bay, overall the invertebrate community was not particularly similar to communities reported from other *Heterozostera* and *Zostera* beds in Victoria. They suggested that there is no typical and widely distributed infaunal community associated with *Heterozostera* and *Zostera* beds. Rather, each bed supports a community that is determined by a range of environmental conditions only one of which is the presence of seagrass.

The abundance and species richness of fish in intertidal and shallow subtidal areas, like that of invertebrates, is also generally greater in 'grassed' than in 'ungrassed' areas (Jenkins *et al.* 1997; Jenkins and Wheatley 1998). However, the relationships with habitat type may be complex. Several species which appear as juveniles in seagrass beds subsequently recruit to reef-algal communities. In the case of King George whiting, juveniles settle in both grassed areas and reef algal habitats but with further growth show an increasing preference for reef-algal habitats and eventually move into unvegetated areas.

Algae

The major factors influencing the distribution of algae within the bay are wave action, water depth, temperature, salinity, turbidity, nutrient availability and the availability of suitable areas for attachment. Most algae require a hard substratum for attachment although species of *Caulerpa* can grow anchored in unstable sediments and monospecific stands of these species may cover large areas (Womersley 1966; Light and Woelkerling 1992).

Species richness amongst subtidal algae is highest at the entrance where wave action is stronger, and water quality higher and more stable than within Port Phillip Bay. Womersley (1966) described three groups of species based on their distributions: those found fairly generally within the bay (*Ulva lactuca*, *Caulerpa remotifolia*, probably *Codium harveyi* and *Cutleria multifida*, *Solieria robusta*, *Griffithsia teges*, *Wrangelia protensa*, *Polysiphonia cancellata*, *Dictymenia harveyana*, and *Laurencia filiformis*); those largely restricted to Corio Bay, the calm western coast, and in some cases the northern part of the bay (*Caulerpa geminata*, *C. longifolia* f. *crispata*, *Acetabularia peniculus*, *Dictyota dichotoma*, *Caulocystis uvifera*, *Rhabdonia coccinea*, *Rhodoglossum foliiferum*, *Botrocladia obovata*, *Lophothalia verticillata*, and *Jeannerettia pedicellata*); and those found around the bay, excluding the central bay and very calm western areas (*Caulerpa brownii*, *Dictyopteris muelleri*, *Ecklonia radiata*, *Cystophora retroflexa*, *Sargassum paradoxum*, and *S. verruculosum*).

The diversity of intertidal algae is also higher at the entrance than within the bay. King *et al.* (1971) reported 171 species of intertidal algae from the bay and based on their distribution were able to distinguish two areas, the open coast area of the entrance to the bay and the bay proper. This distinction was less marked on the eastern side of the bay. The major difference between the regions was the greater number of species around the entrance with 68 species, many characteristic of rough coasts, confined to this area. While many species found at the entrance did not occur within the bay, the reverse was not true and most of the species from within the bay were also found at the entrance.

In addition to attached algae, large quantities of unattached macroalgae occur in the bay. There have been few studies of these communities and their extent, distribution, biomass, productivity and general ecological significance are largely unknown (Light and Woelkerling 1992).

Algal beds provide a habitat for a wide range of plants and animals. These include epiphytic algae, invertebrates, either free-living or attached, infaunal invertebrates and fish. Thirty eight species of plants and animals have been reported as growing on the red alga *Jeanerrettia lobata* (White 1982), and free living species, such as the grazing molluscs *Thalotia conica* and *Phasianotrochus* spp., are also found in association with macroalgae. Grazing species may feed on epiphytes attached to the weed rather than the weed itself.

Invertebrates may themselves provide a substratum for macroalgae. In areas of soft sediment that are otherwise unsuitable for algal growth, molluscs, particularly the mussel *Mytilus edulis planulatus*, and the large ascidian *Pyura stolonifera* may provide a site for attachment. *Acrosorium uncinatum*, *Phymatolithon* sp., *Tenarea* sp., *Caulerpa remotifolia*, *C. longifolia*, *C. brownii*, *Ulva lactuca*, *Rhodoglossum proliferum*, *Ceramium* spp., *Griffithsia teges*, *Dasya capillaris*, *Polysiphonia* spp. and *Pterosiphonia pennata* have all been recorded growing this way. In some areas, the amount of subtidal flora increases as the abundance of invertebrate fauna suitable for algal attachment increases.

Mangroves

One species of mangrove, *Avicennia marina*, occurs in Port Phillip Bay. Mangroves are found in Swan Bay, at the mouth of Kororoit Creek and in Hovells Creek (Light and Woelkerling 1992). They are not extensive at any of these locations. In 1980, the population at Kororoit Creek was limited to one tree 2 m tall and 6 smaller trees (Davey and Woelkerling 1980). Five species of algae have been recorded as associated with mangrove pneumatophores (Davey and Woelkerling 1980).

4.2.3 Intertidal communities

The predominant intertidal habitat type within the bay is beach although rock platforms and rubble and shelly beaches occur around the bay and areas of seagrass are found, particularly in the south west of the bay.

The distribution of common intertidal species in the bay is illustrated in Marine Research Group of Victoria (1984). Most conspicuous are epifaunal species associated with rocky areas. Communities can be divided into those of the open coast area around the entrance to the bay and those within the bay proper. More species are found near the entrance than within the bay, but the distinction between the bay and entrance communities is not clear cut on the eastern side of the bay (King *et al.* 1971). There is some ecological replacement of species within the bay. The green alga *Caulerpa scalpelliformis* occurs at the entrance and on the south-eastern coast of the bay but elsewhere is replaced by *Caulerpa remotifolia*. Similarly, the gastropod *Bembicium nanum* is found at the southern end of the bay but is replaced by *Bembicium auratum* or *B. melanostomum* in the north.

Intertidal zonation within Port Phillip Bay is not as marked as at the entrance. This is partly because tidal range within the bay (generally less than 1 m, with a mean tidal amplitude ranging from 0.4 m at Point Lonsdale to 0.2 m at Williamstown) is much less than that at the entrance (about 1.7 m). In addition, zonation becomes less marked as shelter increases. Algae commonly found intertidally are *Enteromorpha*, *Porphyra*, *Ulva lactuca*, *Caloglossa leprieurii*, *Gelidium pusillum*, *Chaetomorpha darwinii*, *Hormosira banksii*, *Centroceras clavulatum*, *Polysiphonia*, *Grateloupia filicina*, *Codium fragile*, *Petalonia fasciata*, and *Caulerpa brownii*. Invertebrates commonly found, on rock surfaces or under stones, are *Nodilittorina unifasciata*, *Bembicium auratum*, *Cellana tramoserica*, *Austrocochlea constricta*, *Austrocochlea adelaidae*, *Austrocochlea odontis*, *Patelloida alticostata* (gastropods), *Mytilus edulis planulatus* (bivalve), *Galeolaria caespitosa* (polychaete), *Actinia tenebrosa* (anemone), *Lepsiella vinosa*, *Montfortula rugosa*, *Cominella lineolata*, *Cominella eburnea* (gastropods), *Patiriella calcar*, *Patiriella brevispina* and *Tosia australis* (seastars). Species have been listed in sequence with those from the upper shore first and those from the lower littoral zone last, although the exact occurrence and zonation of species will depend on locality and prevailing conditions. For example, King *et al.* (1971) list 47 species as contributing to zonation at the entrance to the bay but only 16 species in the more sheltered waters of northern Corio Bay.

There has been considerable recreational collecting of intertidal molluscs for food and bait. Studies on three commonly collected species of grazing mollusc, *Cellana tramoserica*, *Austrocochlea constricta* and *Nerita atrementosa* showed that all were significantly larger at a protected site, where there was little or no collecting, than at sites where collecting occurred. A fourth species, *Turbo undulatus*, showed no size differences between sites. The distribution of *T. undulatus*, unlike that of the other three species, extends into the subtidal zone. The replenishment of intertidal populations, by migration from the subtidal population, may explain why intertidal collecting does not appear to have affected the size distribution of this species (Keough *et al.* 1993). Removal of molluscs through shellfish collecting also has indirect effects. These may include changes in algal abundance (where grazers are taken) or a change in the reproductive output of the population since the larger individuals, which are preferentially collected, may also be the more fecund (Sharpe and Keough 1998).

4.2.4 Estuarine environments

Estuarine conditions are localised to the immediate vicinity of freshwater inputs as only small amounts of water flow into Port Phillip Bay, and the salinity within the bay is generally high.

The Yarra River forms the largest estuary in Port Phillip Bay. The fauna of the Yarra River and associated Port facilities includes the bivalves *Arthritica helmsi* and *Notospisula trigonella*, oligochaete worms, the polychaete worms *Capitella capitata*, *Nephtys australiensis* and species of *Lumbrineris*, *Malacoceros*, *Polydora* and *Prionospio*, amphipods belonging to the genera *Corophium*, *Gammaropsis*, *Limnoporeia* and *Tethygeneia*, the crab *Halicarcinus australis* and the ascidian *Styela clava*. These species are indicative of an estuarine environment (Poore and Kudenov 1978; Knuckey *et al.* 1997; Walker *et al.* 1998). By comparison with communities in fully marine areas, those of the Yarra River and nearby docks have a low species richness but a high number of individuals, and show a higher degree of dominance by one or two particularly abundant species.

One of the most abundant species during the 1978 survey of the Yarra River was the introduced bivalve *Theora lubrica* (Poore and Kudenov 1978b). More recent studies of the Yarra River, the Maribyrnong River, Victoria Harbour and Webb Dock (Knuckey *et al.* 1997; Walker *et al.* 1998) show that *T. lubrica* remains abundant. In addition, another exotic bivalve, *Corbula gibba*, is now abundant and a third introduced bivalve, *Musculista senhousia*, is also present. These species are all widespread throughout Port Phillip Bay and, while not typically estuarine, are all capable of withstanding some degree of lowered salinity (Kikuchi and Tanaka 1978; Jensen 1988, 1990). Other species that co-exist with *Theora* in fully marine areas of the bay are absent in the estuarine areas of the Yarra River.

Several estuarine species are found near the shore off the Western Treatment Plant (WTP). These reflect the influence of discharge from the treatment plant plus freshwater discharge from the Little and Werribee Rivers (Poore and Kudenov 1978a). Two species of the amphipod family Corophiidae have been reported as abundant off Werribee, and this family is often represented in polluted estuaries in other parts of the world. Available evidence (Poore and Kudenov 1978a) shows that estuarine influence and the effects of nutrient enrichment on infauna in the Werribee area are localised.

4.3 MAJOR DISTURBANCES IN THE BAY

Port Phillip Bay is the major site of urban and industrial development in Victoria. Melbourne, Victoria's largest city (population 3.5 million), is situated on the northern shore of the bay, and its suburbs extend along the eastern and north western shores. The WTP at Werribee, on the west coast, discharges treated sewage effluent into the bay. The area south of Werribee is mainly rural but Geelong, Victoria's second largest city (population 175,000), is situated on Corio Bay.

Because of the development around its shores, and of activity within the bay itself, the aquatic environment of Port Phillip Bay has been subject to a number of major disturbances and alterations. The changes seen in the bay are typical of those seen as the result of urbanisation and industrialisation world-wide. They include elevated inputs of toxicants and nutrients and habitat modification through fishing activity, channel dredging, spoil dumping and beach replenishment. Such changes may have a direct influence on the spread of introduced species since there is some evidence that colonisation by exotic species is most successful in disturbed or modified habitats (Herbold and Moyle 1986; Ruesink *et al.* 1995).

Management strategies to reduce or ameliorate adverse impacts due to development have been, and continue to be introduced. These include increasingly more stringent controls on the discharge of effluent to the bay, tighter controls on dredging and spoil dumping, and the banning of scallop dredging.

4.3.1 Chemical contaminants

Chemical contaminants from industrial and urban sources have been introduced into Port Phillip Bay for over 100 years. Studies carried out since the late 1970's provide evidence of site-specific impacts from heavy metals, hydrocarbons and organochlorines (Phillips *et al.* 1992). The major threat to the environmental quality of the bay in the 1970's and 1980's was from gross pollution from point source discharges. Several studies during this period indicated concentrations of metals such as cadmium, mercury, zinc and copper (e.g. Phillips 1976; Walker 1979), and polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, polychlorinated biphenyls and organochlorines (e.g. Phillips *et al.* 1992; Nicholson *et al.* 1994) were elevated in nearshore sediments and biota in the bay. Following the introduction of environmental controls through a State Environmental Protection Policy (SEPP) for waters of the bay in the 1970's, point sources of gross pollution have been reduced (EPA 1997). The major sources of pollution to the bay are now limited to discharges from the WTP located on the western shore of the bay, urban stormwater, stream inputs and atmospheric deposition. The impact of contaminants that have accumulated in sediments, particularly along the shoreline of the bay, and the capacity of the bay to accommodate continuing contaminant inputs are continuing environmental issues (Harris *et al.* 1996).

Inputs

Most of Melbourne's industrial waste waters are now discharged under licence to the sewage system and are treated at the WTP. While the plant is a significant source of heavy metals, particularly copper and nickel, to the bay (Table 4.1), the concentrations of organic contaminants in the effluent are low because most are either removed by sedimentation or degraded by photolytic and microbial processes within the lagoon system (Harris *et al.* 1996).

However, inputs from the five major rivers, numerous creeks and more than 300 stormwater drains collectively represent the largest source of metals (chromium, copper, iron, nickel, lead and zinc) and organics (petroleum hydrocarbons, organochlorine insecticides (Harris *et al.* 1996). Of these, the Yarra River is the major contributor.

Waters

The concentrations of heavy metals in bay waters have been deceasing since 1988 (Harris *et al.* 1996) and are now comparable to those found in relatively unpolluted estuaries worldwide (Table 4.2).

Apart from some fluctuations near input sources (e.g. Hobsons Bay), removal processes such as sedimentation and bay flushing are effective in maintaining dissolved metals at relatively pristine concentrations. Concentrations of hydrophobic organic contaminants (petroleum hydrocarbons, polychlorinated biphenyls, and organochlorines) are extremely low in bay water, although as with metals, highest concentrations occur near point source areas such as the Yarra River mouth and oil refineries (Good and Gibbs 1995a).

Sediments

Sediments are the ultimate sink for most contaminants in the bay. Highest contaminant concentrations occur in nearshore sediments, particularly near the mouths of rivers and drains. Sediments from nearshore and input sites (e.g. Corio Bay and Hobsons Bay) have higher concentrations of cadmium, copper, nickel, lead and mercury than do sediments from the centre of the bay (Table 4.3). Similarly nearshore sediments (e.g. Corio Bay and Hobsons Bay) are contaminated with petroleum hydrocarbons (TPH), while organochlorine insecticides (DDT), polynuclear aromatic hydrocarbons (PAH) and tributyltin (TBT) are elevated in Hobsons Bay (Fabris *et al.* 1995; Table 4.4).

Biota

Contaminant levels in fish and molluscs in Port Phillip Bay have been monitored routinely over the past 25 years (Phillips *et al.* 1992; Harris *et al.* 1996). Monitoring surveys during the 1970's and 1980's showed that mussels (*Mytilus edulis planulatus*) from many shoreline areas of the bay were contaminated with cadmium, lead, zinc, petroleum hydrocarbons (TPH), polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB), while fish indicated pollution by mercury and organochlorine insecticides (OC). The highest concentrations were often recorded in Corio Bay and Hobsons Bay. Biomonitoring surveys carried out during the 1990's (e.g. Fabris *et al.* 1992) showed that contamination by these substances in the bay had declined significantly although site specific differences were still apparent (Table 4.5).

4.3.2 Nutrients

Nutrient inputs to Port Phillip have greatly increased over the past century with urban development around the bay. Following the construction of a sewage treatment system for Melbourne in the 1980's, run-off of raw sewage through drains into Hobsons Bay has been relaced by the discharge of treated sewage near Werribee. Nutrients discharged to the bay include various forms of nitrogen, phosphorus, silicate and carbon.

Nitrogen is the nutrient of greatest concern, because it has been shown to control plankton growth in the bay (Parslow and Murray 1997). About half of the annual nitrogen load of 7,000 t enters the western bay from the WTP. Other significant inputs include the Yarra River discharge into Hobsons Bay in the north and the Patterson River-Mordialloc Creek discharge into the eastern bay. Storm water also enters the bay through about 300 drains. The seasonal pattern of nitrogen discharge varies between sources. The WTP discharge is greatest in winter, while

Table 4.1. Heavy metal inputs to Port Phillip Bay (t y^{-1}) WTP: Western Treatment Plant (from Harris *et al.* 1996).

Metal	WTP	Rivers, creeks & drains (excluding Yarra River)	Yarra River
Fe	180	1235	1273
Cr	3.9	4.8	7.8
Cu	2.7	8.0	6.6
Ni	4.9	2.9	6.3
Pb	1.1	11	19
Zn	5.8	58	63
As	-	0.9	1.4
Cd	0.02	0.14	0.17
Hg	0.02	0.04	0.04

the Yarra discharge is usually greatest in spring-summer (Murray 1994).

Nutrients enter the bay principally in dissolved forms available for plankton growth. Nitrogen (N) is rapidly assimilated into plankton biomass, and recycled back to inorganic N either in the water column or in the sediment following death or grazing of the plankton. Inputs are recycled many times before eventual loss from the system (either to Bass Strait, buried in the sediments or lost to the atmosphere as N_2 (Parslow and Murray 1997). Highest nutrient concentrations are found within a couple of kilometres of the shore near Werribee and Hobsons Bay. Mixing of near-shore shallow waters with those of deep central Port Phillip Bay is rapid, and nitrogen concentrations in the centre are low (Longmore *et al.* 1996).

Table 4.2. Metal concentrations found in Port Phillip Bay compared with dissolved concentrations found elsewhere. Units are mg L^{-1} for all except Hg which is ng L^{-1} (from Fabris *et al.*1999).`

Element	Mean dissolved concentration in Port Phillip Bay	Concentration in other nearshore & estuarine areas
Cd	0.03±0.01	0.001–0.11
Cr	0.04±0.02	-
Cu	0.47±0.05	0.06–1.3
Fe	0.76±0.44	-
Ni	0.70±0.14	0.02–2.5
Pb	0.06±0.02	0.006–0.16
Zn	0.47±0.21	0.01–3.3
Hg	1.7±0.7	0.7–3.0
As	2.8±0.3	1.0–3.3

Table 4.3. Metal concentrations (μg g^{-1}) in surface sediments from Port Phillip Bay (from Fabris *et al.* 1994).

Area	Cd	Cu	Ni	Pb	Hg
Corio Bay	0.5–5.8	17–51	16–66	73–197	0.12–0.29
Hobsons Bay	0.1–1.0	9–62	13–42	52–113	0.22–0.51
Central Bay	0.1	1–12	4–40	3–26	0.05–0.16

Table 4.4. Concentration of organic compounds (μg g^{-1}) in surface sediments from Port Phillip Bay (from Good and Gibbs 1995b).

Area	TPH	PAH	DDT	PCB	Hg	TBT
Corio Bay	120–820	1–3	<0.005	0.1–0.3	0.12–0.29	0.0004
Hobsons Bay	250–810	1–4	0.02–1.1	0.1–0.2	0.22–0.51	0.03
Central Bay	<10–40	<1	0.005–0.013	<0.1	0.05–0.16	0.0001–0.002

Table 4.5. Concentrations (μg g^{-1} wet weight) of organic compounds and metals in fish (sand flathead) and mussels from Port Phillip Bay (from Phillips *et al.* 1992; Nicholson *et al.* 1994; Fabris 1995; Fabris and Theodoropoulos 1998).

Area/sample	TPH	PAH	OC	PCB	Hg	Cd	Pb	Zn
Corio Bay								
fish	0.1–464	0.04–0.06	0.1	<0.01–0.03	0.17–0.74	–	–	–
mussel						0.64	0.17	30.7
Hobsons Bay								
fish	0.1	–	0.2	<0.01	0.02–0.27	0.05	0.05	4.6
mussel						0.17	0.37	34.6
Central Bay								
fish	1.5–18.4	<0.01–0.71	<0.1	<0.01–0.03	0.06–0.73	0.05	0.05	4.5
mussel						0.54	0.21	47.4

Impacts of nutrient inputs occur on a range of spatial and temporal scales, including bay-wide, regional and local. Local impacts include seasonal, short-lived algal blooms along the Werribee coast and in Hobsons Bay, with chlorophyll concentrations increasing from a background of 1–2 mg L^{-1} to 10–20 mg L^{-1} (Longmore *et al.* 1996), increased macroalgal biomass along the western coast (Chidgey and Edmunds 1997), and a reduction in denitrification efficiency in Hobsons Bay sediments (Berelson *et al.* 1998) when compared with sediments from the rest of Port Phillip Bay. The last is a major concern as the health of the bay depends critically on maintenance of a high denitrification efficiency; declining efficiency will lead to an increasing return of nitrogen to the water column to drive algal production (Harris *et al.* 1996). The bacterial oxygen requirements associated with decomposition of increased algal biomass will eventually drive bottom oxygen concentrations lower, impacting on both infauna and fish.

Reductions in N inputs are planned to reduce the possibility of a decline in denitrification efficiency.

4.3.3 Channel dredging, spoil disposal and beach replenishment

Physical disturbances caused by dredging, spoil dumping and beach replenishment all cause similar effects on the benthos. Typically they obliterate the biota in the impacted areas, but the biota re-establishes over the following months or years. The regions in which each of these disturbances has occurred in Port Phillip Bay are shown in Figure 4.3.

There are two regions of the bay that have been significantly impacted by channel dredging and spoil disposal. More than 100 million m^3 of spoil has been dredged from approach channels and berths in the Port of Melbourne since the 1880's. Most of this spoil has been placed in the Port of Melbourne spoil ground 15 km south of the port (Figure 4.3). However, until the 1940's spoil was merely placed in the vicinity of the spoil ground rather than actually within it. In the Port of Melbourne on average 200,000 m^3 of spoil is deposited annually by the Yarra River. Maintenance dredging is undertaken as needed and major dredging works occur every few years. The Port of Geelong is situated well away from any significant river or source of sediment input so maintenance dredging of the shipping channel is less frequent and is only required about every 10 years. A large proportion of the Geelong Arm has been impacted by spoil grounds resulting from capital dredging as the shipping channel has been progressively deepened. High points along a 3 km and a 5 km section of South Channel require dredging every few years (Figure 4.3). On average 150,000 m^3 of sand is removed annually from these two sand wave fields.

The remaining dredging in Port Phillip Bay occurs in the near shore zone and is necessary to remove sand accumulated behind man made structures and to maintain navigational channels for recreational boating. At the entrance to Queenscliff harbour 90,000 m^3 of sand are dredged annually and a total of 75,000 m^3 of sediments (sand and muds) are removed annually from rivers (e.g. Werribee, Mordialloc and Patterson Rivers) and boat harbours in the bay (St Kilda marina, Brighton and Sandringham yacht clubs).

Beach replensihment has been used to reduce coastal erosion and restore beaches lost where seawalls have diminished sand supply by preventing the erosion of adjacent sandstone cliffs. Beach replenishment results in impacts at the site dredged to supply sand, on the beach itself and usually at a temporary dump site in approximately 7 m depth offshore from the replenished beach. Usually sand of suitable grain size is dumped at the temporary offshore site by a trailing suction hopper dredge and subsequently pumped onto the beach by a smaller cutter suction dredge.

4.3.4 Scallop dredging

Scallop dredging began in Port Phillip Bay in 1963 and ceased in 1996 as a result of public concerns about its environmental impact. The number of vessels engaged in the fishery increased in the early years of the fishery until nearly 200 vessels were involved when the fishery first collapsed in 1968. Subsequently the number of vessels engaged in the fishery was reduced and 84 vessels were licensed to dredge the bay for scallops until the fishery ceased. Scallops were captured using box dredges up to 3.3 m wide (mostly Peninsula dredges, MMBW and FWD 1973). All but the shallowest regions of the bay were dredged, but with varying intensities. Most scallop dredging occurred between 10 and 20 m, but after 1985 dredging was illegal in areas shallower than 10 m in the east and shallower than 5 m in the west (Currie and Parry 1999b). Dredges remove on average 0.5 cm of surface sediment (Black and Parry 1999), but removal of up to 6 cm of sediment has been measured (Black and Parry 1994). The area of Port Phillip Bay dredged varied considerably between years, but on average in the 1980's a dredge passed over 10% of the bay once annually, and a further 4% of the bay had a dredge pass over it at least twice (Currie and Parry 1996).

In an experimentally dredged area near St Leonards dredging reduced the abundance of most infauna by 20–30%, but impacted and control areas were difficult to distinguish after 3.5 months (Currie and Parry 1996). The long-term effects of dredging, particularly on epibiota, are the subject of ongoing studies.

4.3.5 Fishing

Commercial fisheries for finfish in Port Phillip Bay are valued at more than $2 million annually, and each year an estimated 2.7 million daytime angler hours are spent in recreational fishing (Coutin *et al.* 1995). Commercial fishing methods used in the bay are line-fishing, seining, trapping netting and squid-jigging. Trawling has never been permitted. The major effects of finfish fisheries are believed to be stock depletion of targeted species rather than alterations or damage to the physical habitat.

Quantitative data on fish communities in the bay before the 1970's are not available, but fishing pressure must have changed these communities considerably from their unfished state. Comparison of the results of surveys conducted during the 1970's and during 1991 (Hobday *et al.* 1999) shows several changes in fish communities over this period. A reduction in abundance of sand flathead, yank flathead, tiger flathead and several other species targeted by anglers and commercial fishers strongly suggest that fishing has reduced the abundance of these species. Over the same period there have been significant increases in the abundance of non-target species (eastern shovelnose stingaree, sparsely spotted stingaree, red mullet), further suggesting that fishing has not only reduced the abundance of some species but has increased the abundance of their competitors.

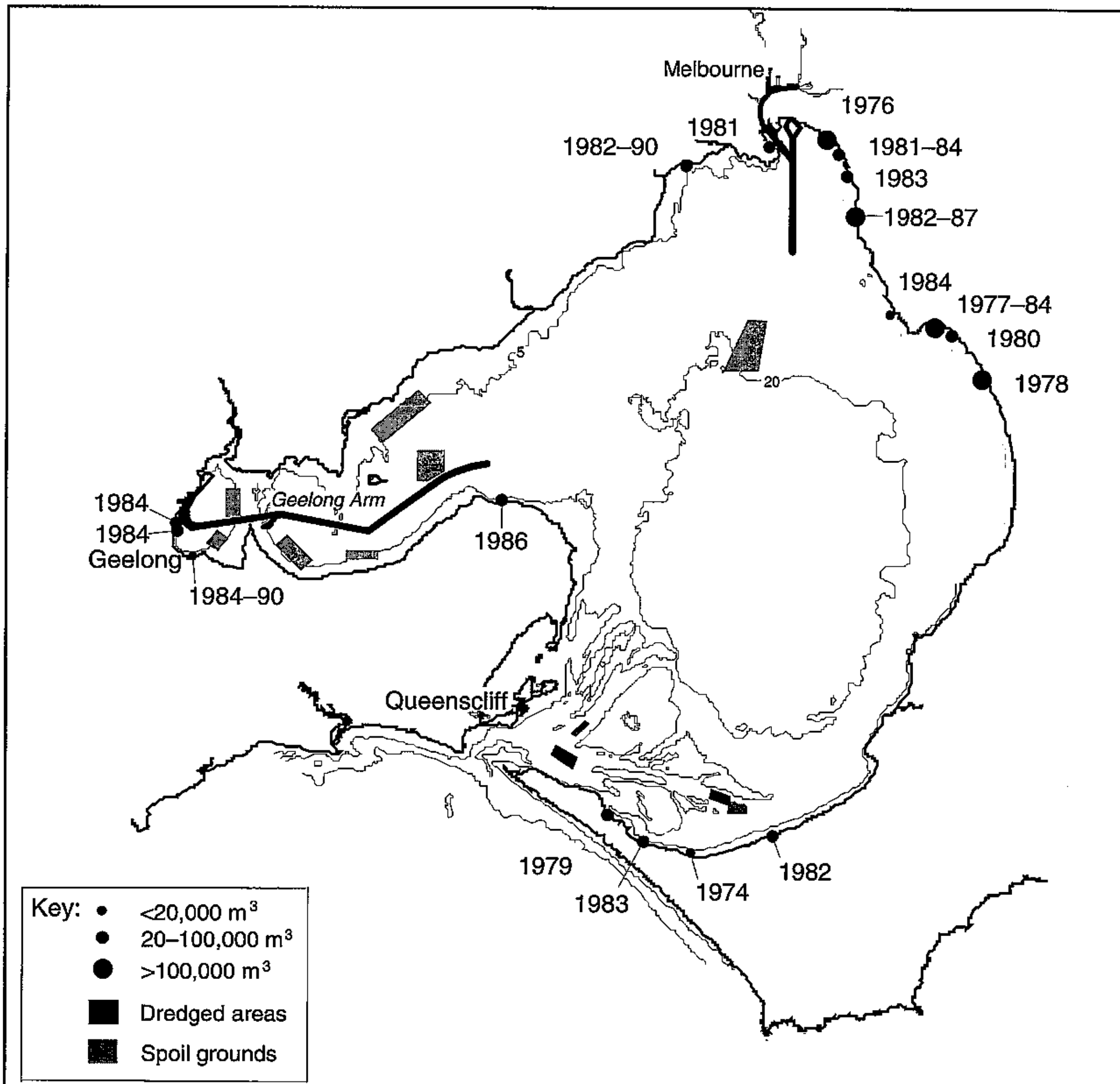

Figure 4.3. Locations of dredged channels, spoil grounds and beaches subject to sand replenishment in Port Phillip Bay. For beach replenishment areas, the years in which replenishment occurred are given and the size of the closed circles indicates the volume of sand used.

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5 VECTORS, SHIPPING AND TRADE

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5.1 INTRODUCTION

The link between introduction of exotic species into new bioregions and the release of ballast water from shipping is well documented (Smith and Carlton 1975; Carlton 1979; Carlton 1985; Simberloff 1986; Carlton *et al.* 1995; Ruiz *et al.* 1997; Shigesada and Kawasaki 1997). Despite the current recognition and acknowledgment of marine introductions via modern vectors, the historic movements of species by vessels may have led to the introduction of species prior to biological surveys. The historical movement of organisms was facilitated by wooden vessel hull fouling and boring, early mariculture (due to a lack of effective quarantine), and the discharge of semi-dry and dry ballast. Hewitt (1993; unpub. ms) further summarised the vectors into five groups: 1) hull fouling/ boring; 2) mariculture; 3) dry and semi-dry ballast; 4) ballast water; and 5) intentional and unintentional (e.g. the aquarium trade) introductions. Changes in vessel design, engines and structural stability over time have resulted in reduced travel times. This may have led to an increase in the number of recent introductions.

5.1.1 Vectors

Human mediated transport of species across biogeographic barriers is not new (Carlton 1979, 1985, 1992; Crosby 1986; Carlton *et al.* 1995; Carlton and Hodder 1995; Ruiz *et al.* 1997). The history of European expansion however is linked with the modern era of biological introductions (Crosby 1986; di Castri 1989).

Hull fouling and boring

Many fouling organisms (flora and fauna that attach to the hull of vessels), and boring organisms (fauna which bore into wooden hulls) are widely distributed with many species having near cosmopolitan, though often disjunct (e.g. present in harbours and ports) distributions. The fact that most biological surveys were conducted long after initial explorations and colonisation may have resulted in a redistribution of the world's fouling biota long before specimen collections, thus obfuscating the origins and true distributions of these species. The historic practice of careening a vessel in order to scrape the hull and replace rotten or damaged timbers may have significantly contributed to the inoculation of hull fouling and boring species. Hull fouling continues to act as a modern vector for the introduction of numerous species (Coutts 1999; Gollasch and Leppakoski 1999). In contrast, boring organisms relied explicitly on wooden hulls of vessels. The advent of steel hulls reduced this vector to smaller recreational vessels. Similarly the development and use of various chemical based anti-fouling paints has acted to reduce these vectors (however see Coutts 1999).

Mariculture

Mariculture transplants into Port Phillip Bay have a limited history. The Pacific oyster, *Crassostrea gigas*, was transferred to the bay in 1955 from Tasmania, where it was originally introduced by CSIRO. As discussed in Chapter 8, the Victorian populations of the oyster appear to have failed, though recently a population was detected in Anderson Inlet (Coleman and Hickman 1986). The blue mussel, *Mytilus edulis*, has been extensively farmed in Port Phillip Bay since the 1970's. There is no indication that international imports of this stock have occurred.

Dry and semi-dry ballast

Ballast is required to stabilise vessels, providing trim and stability. When used properly, ballast provides a vessel with greater manoeuvrability and more efficient propulsion. Vessels too light on ballast can have a greater tendency to capsize, while vessels heavy on ballast may lose speed and labour under excess weight. Before the 1840's wooden vessels used dry ballast (rocks, shingle, cobble, sand, or alternatively cargo such as timber, iron, etc) but because ballast holds tended to accumulate water either with uptake of the ballast materials, through collection of bilge water, or through leaks in the wooden hulls, semi-dry conditions resulted leading to conditions similar to intertidal habitats. As discussed below, the discharge of dry ballast was significant during the 1800's, leading to regulations controlling its disposal during deballasting. Dry and semi-dry ballast has been implicated in the introduction of a variety of species (see Chapters 9, 10, 15, 16 and 18).

Ballast water

By the mid-1840's water ballast began to be used and became more common in the 1850's when colliers were able to hold the water in purpose built compartments (Carlton *et al.* 1995). Ballast water tanks started to become integrated with the refinement of vessel designs. Although ballast water was used in the 1840's the complete change-over from dry/semi-dry ballast to water ballast occurred more than 100 years later, in the 1950's (Carlton *et al.* 1995). As discussed in depth elsewhere, ballast water is an active modern vector (Carlton 1985, 1992; Carlton and Geller 1993; Carlton *et al.* 1995; Williams *et al.* 1988) with numerous accounts of species introductions likely to have been the result of ballast water transfers (e.g. Carlton *et al.* 1990; Shushkina *et al.* 1990; Pollard and Hutchings 1990a, 1990b).

Intentional and unintentional introductions

A variety of intentional introductions other than for mariculture have occurred in Australian waters including stock enhancements and wild fisheries establishment (see Pollard and Hutchings 1990a, 1990b; Arthington and McKenzie 1997). Few of these intentional introductions have occurred in Port Phillip Bay. In contrast, numerous species are likely to have been transported and introduced unintentionally in association with mariculture activities (Pollard and Hutchings 1990b; see also Chapters 6, 7, 8, 9, 10, 12, and 13).

Vessel design changes

Wooden hulled sailing ships dominated world trade from the 14th century until late in the 19th century (1860's to 1870's). Ship designs changed significantly during this period. The common vessel in the 14th century was square-sailed with a single mast, commonly called a 'cog', used by seafarers since early history. The cog was replaced by the first truly ocean-going sailing ship, the caravel, which were used for early exploration. This exploration was largely motivated by the desire to find a sea route to the Indies and Cathay when the Ottoman Empire began blocking the land routes to the Orient (Macintyre 1972). By the middle of the 15th century, square-rigged carracks had replaced the caravel as the main trading vessel. Alterations and improvements to the square-rigged carrack focussed on warfare in the period ending with the Napoleonic Wars (1815). This produced a variety of ship types including the galleon; the 'pinnace'; the frigate (with sloop rig); and the brigantines such as the 'snow', brig, galley, 'shebek', 'turuma' and 'udema' styles (Macintyre 1972).

Merchant ships were also being refined, with 'fluyt' ships, yachts and cat-built ships with a 'hooker' rig (e.g. Captain Cook's *Endeavour*) becoming common in the early 17th century (Macintyre 1972). By the 1800's, speed had become an important focus in ship design. Speed was necessitated by the Opium trade, where vessels needed to beat the monsoons on passage from India to Europe (Macintyre 1972). The faster vessels (mostly schooners) gradually became known as 'clippers' whose rig often denoted different vessel types such as the barque and barquentine.

The clipper sailing vessel eventually superseded older vessel designs to become the dominant worldwide trade vessel (Macintyre 1972). Clippers were softwood hulled sailing vessels (often copper-sheathed to aid against marine fouling and boring worms) capable of much greater speeds than experienced previously (Lubbock 1921; Macintyre 1972). The greater speeds were due to their design and the use of lighter wood (Lubbock 1921; Macintyre 1972). The new designs and speed afforded the Clippers the ability to sail different, faster routes, known as 'great circle' tracks and composite routes devised by the American 'wind expert' Maury (Lubbock 1921).

One traditional route to Australia was the Admiralty route where a vessel kept an eastward direction while heading south, rounding close to the Cape of Good Hope and then keeping north of the forties running their easting down (Lubbock 1921). This passage would take, on average, 120 days. In contrast, when using a Great Circle Track, the Liverpool to Australia (usually Melbourne) trip was reduced by 1,000 miles, with a timesavings of 20–30 days (70-80 days transit time) (Lubbock 1921; Bach 1976; Loney 1981). The Great Circle Track also reduced the number of intermediate ports (e.g. Port Elizabeth and St. Pauls Island) on the journey. Vessels would leave Liverpool and sail non-stop, out of sight of land until they landed at Cape Otway, en-route to Melbourne (Bach 1976). Because of this speed, clippers were goldrush vessels primarily used for passenger transport (Bach 1976).

By the 1860's softwood hulled clippers were showing their age and fragility. The softwood, once seen as a great advantage, was easily damaged and after a decade of use was becoming dilapidated. Softwoods were soon replaced by the new iron hull designs. Iron hulls initially began as an iron/softwood composite, having iron frames and timber planking (Macintyre 1972; Bach 1976). As techniques were refined, all-metal hulls became more common and were better suited to the long-distance carrying trade that began to flourish in the 1870's and 1880's (Bach 1976).

A second major change in vessel design was the introduction of steam power that resulted in increased speeds and an alteration of trade routes since vessels no longer had to rely on trade winds. Steam vessels began to appear in the cargo trade in the 1860's, becoming established by the 1870's due to the invention of the screw propeller (Macintyre 1972; Bach 1976; Fitchett 1980). Despite the advent of steam powered vessels, sailing vessels continued to dominate the passenger and cargo trades (especially the wool trade until 1880's) until the late 1890's (Macintyre 1972; Bach 1976). This was in part due to the depressed conditions in the world shipping industry in the 1870's (Bach 1976). Steam vessels however, quickly became prime carriers of the mail because of their speed. The mail lines between Sydney and Britain took approximately 45 days via the Pacific route and 48 days via the Suez route by the end of the 1870's. By the 1880's, steam vessels were operating in the passenger trade and by the end of the century steam vessels had all but replaced sailing vessels on overseas routes.

Ship designs continued to be modified, as engine designs became more efficient allowing greater storage space and more speed (Fitchett 1980). By 1901 vessels were capable of travelling between London and Melbourne in 48 to 31.5 days (Bach 1976). Further engine modifications occurred in the 1920's with motor vessels replacing steam vessels and hence fuels changed from coal to oil (Dunn 1973). These changes greatly increased cargo space and lowered operating costs. During the 1920's, further changes that may have increased speed were ignored because of the generally held belief that to increase speed involved increasing length and draught. Many of the ports were capable of handling increased length but were too shallow for increased draught. Yet, the expected increase in draught was never fully realised. The next innovation was the diesel engine. From 1918 to 1939 a third of overseas tonnage entering Sydney and Melbourne was diesel powered (Bach 1976).

World shipping trades were reduced somewhat during World War I (WW I) and World War II (WW II), with a depression in shipping activity which never really vanished (Bach 1976). This depression halted the introduction of new vessel types, however the wars saw many vessel modifications that later became introduced onto the world-shipping scene. The first such modification was the bulk carrier, introduced into Australia by BHP for domestic interstate trade in 1943. During the 1950's, the bulk carrier was said to have saved the interstate shipping trade from extinction. Bulk carriers allowed a great increase of both wet and dry cargoes and again increased ship size. The 1940's also saw the development of the container ship developed to carry in the hull and on the deck standardised cargo containers, which meant that port equipment modified to handle containers could save time through better cargo handling practices.

Cost reductions became paramount during the 1940's and innovations such as Roll-On Roll-Off vessels (RO-RO), various forms of side loading ships, special purpose carriers for liquid chemicals and barge-carrying 'lash' (lighter aboard ship) ships (Bach 1976). The first full-cellular container ship service started in 1958, in Hawaii, with Australia starting to use such vessels in 1964. Container ships began making round trips between Britain and Melbourne in 1967. This container ship route was expanded in 1972 to include Europe, New Zealand and the east coast of North America. Further expansion of container ship routes occurred in 1975. By 1972, bulk cargoes accounted for 73% of world trade. By mid-1973 tankers accounted for 40% of the world fleet, ore and bulk carriers for 24%, general cargo for 27% and fishing vessels for nearly 4% (Bach 1976). Lash vessels were first seen in Australia in 1973, where they operated between the west coast of North America and Australia, with Port Phillip being their first port of call (Bach 1976). With the increase in bulk carriers the purely passenger trade declined (from 40% in 1961–62 to 21% in 1967) because alternative methods of travel proved faster, cheaper and more comfortable.

From the 1970's on-wards many shipping innovations have occurred. The primary aim of these innovations was to reduce costs associated with cargo handling and increase profits through increased speed and cargo carrying capacity. Numerous types of vessels are on the oceans today. Carlton *et al.* (1995) was one of the first publications that attempted to classify vessel forms establishing three major divisions of vessels: passenger; cargo; and specialised.

5.2 TRADE ROUTES

The following historical account of Port Phillip Bay and the trade routes that developed during its history is by no means comprehensive, but aims to give an overview of the historical sequence relevant to biological invasions. The history of Port Phillip Bay is grouped into four periods, each associated with a significant shift in the shipping activities and routes. While it is recognised that Aboriginal history pre-dates this review, it is assumed that the likelihood of introductions of marine organisms was low during this period.

5.2.1 European exploration and colonisation

The history of European influence in Australia is relatively short (Crosby 1986). In 1768, the British lay claim to 'discovering' the Australian continent, despite previous European contact much earlier by the Spanish, Portuguese and French. Van Zanden (1997) discusses the European exploration by the Dutch explorer Willem Janszoon. Other reports suggest that the Portuguese landed within Port Phillip Bay in 1522 but did not settle the area (Priestley 1984) though this is considered to be unlikely by other historians.

The first recognised European activities in the region were sealing and whaling that operated in the Bass Strait since 1796 and often used Western Port as a home base (Shaw 1997). The sealers and whalers were primarily Americans who often had contact with vessels that traveled vast distances, such as from China (Shaw 1997). Contact with such vessels was not uncommon and as a consequence, the port and city of Launceston was founded in Tasmania in 1798 in order to capitalise the trade. The

East India trade used this route around Australia to their destination in Canton rather than a stopover in Sydney as it shortened the Europe-Australia leg by 700 miles (Bach 1976).

Although Western Port was frequented regularly, Port Phillip Bay was not subject to colonial exploration until the threat of French accession of land in Australia prompted the British to explore and establish Port Phillip. This threat originated from the French explorer Nicolas Baudin, who identified Western Port and surveyed the coast west of Cape Otway but failed to explore Port Phillip Bay (Leggett 1949; Shaw 1997). The fact that the Heads of Port Phillip Bay were treacherous may have added to the bay remaining unknown to colonial nations until the British entry of the heads in 1802.

The British 'discovered' Port Phillip Bay in February 1802 when John Murray on the *Lady Nelson* entered the heads (Shillinglaw 1972; Ruhen 1976; Loney 1981; Shaw 1997). In April, of that year Matthew Flinders entered the bay on the *Investigator* and anchored near Sorrento. The next vessel to visit the bay was the *Calcutta*, bringing English convicts and settlers in 1803 (Shillinglaw 1972; Bateson 1985). The journal of Reverend Robert Knopwood recounts the voyage of the *Calcutta* as it sailed the popular 'Cape of Good Hope' Admiralty route used by the British when travelling to Sydney (Shillinglaw 1972). Typically, vessels left from Portsmouth traveling to St. Helens, on the Isle of Wight, then Yarmouth Roads, Isle of Wight, anchoring at Santa Cruz roads, Tenerife, sailing on to St. Jago (Cape de Verde Islands), passing the equator and anchoring at Rio de Janeiro. If the vessel needed either repairs or re-supply this was conducted here. From Rio de Janeiro, the vessel would pass the Tropic of Capricorn and anchor at Simon's Bay in South Africa. Simon's Bay was often used as a layover in bad weather or for careening and repair. From Simon's Bay the vessel then passed through St. Pauls Island, anchoring 19 days later in Port Phillip. The *Calcutta*'s original voyage to Port Phillip took 172 days and was disrupted by bad weather, which forced a 20 day stop-over at Rio de Janeiro and a 13 day stop-over at Simon's Bay. After arriving in Port Phillip a small settlement was established, which lasted for three months (1803-1804) before moving on to Hobart town (Shaw 1997). The next vessel to enter the Bay was the *Cumberland* in February 1803, which was the first vessel to sail around the entire bay and performed the first bay-wide biological survey (Loney 1981).

From 1803 until 1835, only three ocean-going western vessels were reported to have entered the Bay; two government vessels needing shelter during travel from Hobart to Sydney and one whaling vessel involved in whaling in the Antarctic. This may be an underestimation of visits during this time, as the Hobart built schooner *Enterprize* regularly sailed between Sydney and Launceston, and was sold in 1835 to sail the Launceston-Melbourne route. However, historical records that were reviewed indicate that no further ocean-going vessels entered the bay (Shaw 1997).

In 1835 the Launceston settlers Batman and Fawkner settled at Indented Head and Melbourne, respectively, thus beginning the Port Phillip District. Although, it wasn't until 1836 that colonial settlement was 'officially' allowed. Captain Lonsdale landed on Port Melbourne beach in 1836, arriving from Sydney on the sloop *HM Rattlesnake*. He bought with him the barque *Stirlingshire* and the brig *Martha* (Priestley 1984; Shaw 1997). They carried stores, building materials, surveyors equipment, a detachment of 30 men, three surveyors with seven convicts each, two customs officers, four constables and a further 10 convicts to begin the building of the settlement (Shaw 1997).

During these early years, the first two marine trade routes were established: running from Launceston and Hobart to Port Phillip (Pemberton 1979; Wild 1950; Shaw 1997). This initial trade was established for passengers and shipment of livestock to Point Henry (Pemberton 1979; Priestley 1984). In 1835, a smaller intrastate run between Melbourne and Geelong began (at Point Wilson), which became permanent by 1839 (Pemberton 1979; U'Ren and Turnbull 1983). A trade route soon began operating between Sydney and Port Phillip. By 1839 the trade routes had extended to encompass interstate routes between Sydney, Hobart and South Australia; intrastate routes between Geelong and Melbourne and international routes to Great Britain and New Zealand (Pemberton 1979; Shaw 1997).

The East India Company's monopoly of British trade between the Cape of Good Hope and the Straits of Magellan limited trade between British colonies (Staples 1966; Bach 1976). For the first three decades of Port Phillip's existence, these restrictions prohibited all British ships not belonging to the company, nor enjoying special concessions granted by the company, from trading with any port within its prescribed limits (Bach 1976). The British East India Company lost much of its power during the Napoleonic Wars (1800–1815); by 1813 the company also lost the Indian commercial monopoly and by 1834 had become a purely administrative authority (Staples 1966). The British/China trade monopoly thus ended in 1834, when the restrictions were repealed in Parliament. However, the British Navigation laws restricting foreign competitors, remained in place (Bach 1976).

Trade in Port Phillip Bay was primarily British at this time, although trade with the East Indies, India (Madras and Calcutta), China and Hong Kong started to develop between 1835 and 1850 (Staples 1966; Bach 1976).

Britain used three main trading areas in the Indian Ocean Region: the Indian coastal waters; the Malay Peninsula and Archipelago; and the coastal waters of Australasia. Of these trading regions, there were six British territories (Bombay, Bengal, Madras, Singapore, Ceylon and New South Wales) and the Dutch East Indies (e.g. Batavia, Java, Moluccas spice islands, Dutch Timor, South Sumatra and Banca). These territories typically dealt with the metropolitan ports of London and Amsterdam. Britain considered inter-territorial, American and other European trade, as unimportant (Staples 1966). As a rule, British ships dealt with the larger ports (such as Singapore and Bombay), while coastal traders from the islands and smaller ports brought their trade to these larger ports. When British ships dealt with smaller ports such as Java, the smaller port would often record the transaction, however when arriving at the next larger port the vessels last port of call would be ignored and instead it would be recorded as arriving from its last large port (e.g. Australia) (Staples 1966). Thus, port records of shipping through the Indian Ocean Region during this period are imprecise and ship's logs must be consulted directly to determine the actual trading practices.

Trading activity was influenced by the availability of commodities from the Indian Ocean Region included tea (China and Java), sugar and coffee (Mauritius and Java), rice and tobacco (Java) and wheat (Chile) (Staples 1966; Bach 1976). Java and India quickly replaced many traditional commodity markets from the west of Cape of Good Hope, but manufactured goods continued to originate from European and North American markets. External factors such as the Java Wars (1825–1830) and the Opium Wars (1839–1842 and 1856) in China often affected exports from the Indian Ocean Region (Staples 1966). Trading activity suffered from the worldwide collapse of maritime trade from 1830–1833, proceeded by another depression in the 1840's (Staples 1966).

5.2.2 Immigration

The first British immigrants arrived in 1839, having been sent on from Sydney in the barque *Hope* (Pemberton 1979; Shaw 1997). This year also saw the first immigrant vessel that sailed directly to Melbourne: the *David Clarke* from overseas (Strahan 1994). During 1839, 11,500 immigrants from British ports (London, Liverpool, Plymouth and ports in Ireland and Scotland), made the 3–4 month trip to Port Phillip Bay. Immigrants went through the quarantine station at Point Ormond on arrival in Port Phillip and then moved on to Melbourne or Geelong (Shaw 1997).

During the increase in shipping between 1838 and 1839 a number of ships were lost to disasters (e.g. shoaling and sinking) inside Port Phillip Bay. These losses initiated the placement of buoys, channel markers and the building of lighthouses. By 1840, Port Phillip and Geelong posted their first ballast and port regulations developed to control the discharge of dry ballast in order to prevent the creation of shoals and other shipping hazards (Thompson 1841; Kerr and Kerr 1979).

With the immigration of settlers came the establishment of port facilities. The first pier in Geelong (Stony Pier) was built in 1840, followed by the Steam Packet Wharf in 1847 (Holden and Loney 1969). Melbourne port facilities began with the left bank of the Yarra River used as a wharf (Ruhen 1976). By 1840, at least 52 overseas vessels had visited the bay, primarily by way of Sydney or Hobart (Thompson 1841; Ruhen 1976; Shaw 1997).

Immigration was high in 1841 and 1842, however the depression in 1843 resulted in few migrants arriving in Port Phillip. This shortage of migrants resulted in a shortage of labour in the settlement. To overcome this shortage the Melbourne Immigration Society brought over Tasmanian men for labour in Melbourne and Geelong (Shaw 1997). Immigration continued to rise and fall with a general decline in numbers occurring after 1847. Between 1846 and 1851 local and international immigration increased the population by 32,000. In the 1840's immigrants usually came by way of Sydney or Hobart on the *Clonmel*, *Seahorse* or *Shamrock* (Bach 1976).

Fewer new trade routes were opened, an exception being the development of a bay-wide shipping service, trade with Manila and occasional trade across the Pacific (Bach 1976; Pemberton 1979; Shaw 1997). The Manila trade supplied Australia with sugar, coffee, cordage, cigars and hats (Bach 1976). This trade followed the route to Manila via Sydney and the Torres Strait, returning around the west via Cape Leeuwin and returning to Melbourne (Bach 1976). Concurrently, trade with Calcutta expanded to include: sugar, silk, rice, canvas sacks, hemp, rum and horses.

A Pacific trade began by the late 1840's, catering for the demand of Newcastle coal in California (Bach 1976). Occasional trade for exporting whaling products was also occurring with various islands (still considered to be part of Australia at this time) and South America (Bach 1976). In 1849 the British Navigation laws were repealed, allowing foreign competitors to challenge the British monopoly (Bach 1976).

As mentioned earlier, the Opium Wars (1839–1842 and 1858) affected shipping in Australia. As a British colony, Australia was involved in these conflicts through the supply of enlisted of men and the use of vessels. The outcome of the first war was the Treaty of Nanking, which ceded Hong Kong to Great Britain and opened other Chinese ports to British residence and trade (Wallbank *et al.* 1992). The

French and Americans were soon (1844) afforded the same provisions as the Nanking Treaty. The outcome of the 1856 Opium War was the Treaty of Tientsin. This treaty again opened new ports to trading and allowed foreigners with passports to travel in the interior (Lubbock 1967; Wallbank *et al.* 1992). Thus, until the Opium Wars, Chinese ports had restricted trade and access with foreign vessels.

Convicts started to arrive in Port Phillip during the 1840's. Port Phillip received 13 convict ships between 1803 and 1849. The first convict ship was the *Calcutta*, which arrived in 1803. After the *Calcutta*, convict ships were not seen in Port Phillip until 1844. The majority of convict ships came by way of Hobart (e.g. *Sir George Seymour* in 1845; *Stratheden* in 1846; *Marion* in 1848; *Anna Maria* in 1848; *Eden I* in 1849 and *Adelaide* in 1849) although two vessels came directly via the Cape of Good Hope (*Hashemy* in 1849 and *Randolph* in 1849; Bateson 1985). Often convict voyages would take between 102 to 168 days. Convict shipping ceased by the end of the 1840's to Port Phillip, and by 1852 for Tasmania and New South Wales due to a reduction in labour shortages (Bach 1976).

5.2.3 The Gold Rush

In 1850, the Port Phillip District separated from New South Wales (NSW) and became Victoria. An announcement of gold at Clunes was made in 1851 shortly after separation. Gold was suspected at Castlemaine as early as 1838 but an announcement of the Clunes' goldfind in 1849 was suppressed until Victoria had separated from NSW (Shaw 1997). Meanwhile, the wool industry was also expanding, becoming Geelong's mainstay industry until the present (Wild 1950). Australian wool began export to Britain in 1839 (Kerr and Kerr 1979) and became one of Britain's biggest imports, its value exceeding that of cotton (Staples 1966).

The population of Victoria swelled from < 40,000 to 416,000 in five years after the announcement of gold (Bach 1976; Wild 1950). Immigrants came from England, Scotland, Ireland, China, Wales, Germany, United States, France, Italy, Spain, Poland, Denmark, Norway, Sweden and India to try their luck on the goldfields (Thompson 1841). Routes used to travel to Australia were still largely based on Great Circle Tracks, with vessels traveling via the Cape of Good Hope, Cape Horn or trans-Pacific.

Port facilities expanded with the incoming populace. Developments in Geelong included: the devotion of the Hutton wharf to ballasting vessels; the Yarra pier was built in 1852; Cunningham pier was built in 1855, only to be replaced in 1864; the Moorabool Street Pier was built (it fell into disuse in 1938 and was demolished in 1949); a magazine jetty at Limeburners Point was built in 1856; the Geelong yacht Club was established; and the bar across Corio Bay was dredged for the first time in 1856 from 10 to 13 feet (Wild 1950; Holden and Loney 1969).

The expansion of the mail service due to the gold rush was an essential service enabling immigrants to keep in contact with their homelands. The initial mail run, using the Peninsular and Oriental (P & O) Company's ships, operated from Singapore to Sydney by way of Western Australia (King George Sound) and started in 1852. A second mail contract for every alternate month to Australia via the Cape of Good Hope was tendered to the Australian Royal Mail Steam Navigation Company (Bach 1976; Fitchett 1980). P & O were offered a continuing contract at the completion of their first term in 1858 that extended their run to Aden, Mauritius, Point de Galle in Ceylon until 1866 (Bach 1976). Although the mail run had existed for many years, it was not until 1880 that a direct service began from Melbourne to Britain (Jackson 1996). The first trans-Pacific steamer service also began in 1866, running from Panama to Sydney by way of Tahiti.

Coastal shipping (domestic inter- and intra-state) expanded rapidly with the great influx of population. Steamers and sailing vessels conducted a large passenger trade between Launceston and Melbourne (Bach 1976). A run between capital cities began with 15 steamers operating by the end of 1853. Services had extended to the north with vessels travelling from Sydney to Curtis Bay and Rockhampton and returning as far south as Melbourne by 1860. A southern service also began that ran from Sydney to Two Fold Bay (Eden), to Melbourne and on to Tasmania. Melbourne's coastal shipping also extended out to Wilson's Promontory in the West and east to the Gippsland coast (Bach 1976).

The goldrush led to an increase in the number of vessels abandoned in ports and on beaches. Some abandoned ships were dismantled and others put to use as coastal lighters and prison hulks (Ruhen 1976; Loney 1981). The ship *Lysander* was one such vessel. Abandoned by her crew, it was converted by the government into a prison hulk (Loney 1981). Between 1852 and 1855 five prison hulks (*Success*, *Sacramento*, *Deborah*, *Lysander* and *President*) became a common sight on the shores of Hobson's Bay (Loney 1981; Strahan 1994). This was largely due to the failure of the tickets-of-leave system (adopted after the Tasmanian and Norfolk Island prisons had been abandoned) in controlling prisoners (Strahan 1994).

One of the changes seen in the 1850's was the development of a Conference System. Shipping services became divided into two categories (Conference and Tramp). Conference shipping was concerned with regular voyages on a specific route, while Tramp shipping had no specific schedule or route. Conference shipping carried both passengers and cargo, in accordance with a guaranteed usage of particular routes resulting in a scheduled timetable. Tramp shipping tended toward bulk cargoes of a single type, in order to occupy the majority of the ship's carrying capacity.

By the end of the gold rush years, the townships of Melbourne and Geelong had greatly expanded, yet their ports were still lacking many services. For example, no graving dock was available in Melbourne until the 1860's (Cook 1958). A small slipway existed on the river in Melbourne, one small slipway existed at Williamstown and a floating dock also existed at Williamstown. All vessels drawing more than 8.5 feet had to anchor outside the mouth of the Yarra and lighter their cargo ashore (Bach 1976).

5.2.4 Modern shipping

From 1860 until the early 1900's, the majority (93%) of total tonnage in Australian waters (and worldwide) was British. Despite the majority of shipping under the British flag, foreign vessels commonly entered Port Phillip. For example, the US Confederate Navy's ship, *Shenandoah* visited Melbourne in 1865. The *Shenandoah* was repaired at the Williamstown slip and took on food, water and recruited 42 Melbournians to aid in the US Civil War (Cook 1958; Crompton 1993; J Cossum pers. comm.). A direct trade route between New Zealand and Melbourne began in 1860. This trans-Tasman route provided a service to Otago and Canterbury, expanding in 1873 to include Bluff, Otago, Lyttelton, Wellington, Nelson, Greymouth and Hokitika (Pemberton 1979). This direct service transported troops to New Zealand for the Maori Wars (which lasted on and off for 12 years), then subsequently transported diggers (Australian Army) to the Otago goldfields in late 1862. A regular service between Sydney, Nelson, Wellington and Dunedin was established subsequently (Bach 1976). Since the 1849 abolishment of the British Navigation Laws many foreign (British, French, German, Italian, Norwegian and American) steamship lines began to operate in Melbourne (Priestley 1984).

Coastal trade continued to develop, with P & O running a service from Melbourne to Albany by way of Adelaide in 1862. Services also ran from Melbourne to Geraldton, with extensions to Shark Bay and Carnarvon until 1927. The interstate trade continued to grow in the 1860's, with Gippsland being the most significant (Bach 1976). Melbourne started to loose some of its importance because of competition with roads and the development of other more competitive ports on the coastline. With this decline, Melbourne became aware of the problem of having its city upstream. Two choices to improve their situation were either to leave the ships in the bay and transport the cargo to the city or to create a waterway to the city. A decision was finally made in the 1870's; the ships would be taken to the city.

The Port of Geelong continued to develop and upgrade their facilities. Limeburners jetty was replaced in 1866 with a wooden jetty. In 1889, Station Pier (originally known as Railway Pier) had been deepened and was thus opened to steamer vessels and vessels with large draughts (Kerr and Kerr 1979). In 1893 the Geelong Channel was finally opened, allowing more vessels into Corio Bay (Wild 1950). This was a long awaited event, with the bar across Corio Bay often being blamed for the fewer vessels that visited Geelong (Kerr and Kerr 1979; Wild 1950).

The Suez Canal opened in 1869 creating a second route for vessels traveling from England to Australia and vice versa. Prior to the opening of a waterway, vessels could take cargo to the Suez, unload and move the goods across Egypt to the port of Alexandria, once again load goods onto vessels and depart for northern destinations; this route was risky and time consuming (Staples 1966; Fitchett 1980). The British mail lines particularly favoured this practice, with P & O keeping this service going, even after the canal opened, although it was more costly. Contrary to popular belief, the Suez only shortened the Cape of Good Hope route to Australia by 900 statute miles and was used primarily because it cut almost 4,400 miles off the route to India, China, Singapore and Malaysia (Fitchett 1980).

A new trade route opened to the west coast of North America in 1870 (Pemberton 1979). This trans-Pacific route went from Melbourne to Honolulu, onto Vancouver, down to Seattle, Tacoma, Portland, San Francisco and Los Angeles before returning to Melbourne and was run by the A.S.N. company (Bach 1976; Pemberton 1979). The Fiji to Britain service ended in 1874, with the A.S.N. Company stepping in to re-establish a route between Sydney and Fiji. This route was maintained until 1928 (Bach 1976). A China trade was explored in the 1870's, however it was decided that little profit could be made and the idea of a service was shelved (Bach 1976). In 1875, the Suez Canal was deepened, although it was still shallower than the entrance into Port Phillip Bay (the Rip). By the end of the 1870's the mail lines from Sydney to Britain took approximately 45 days via the Pacific and approximately 48 days via the Suez (Bach 1976).

A Harbour Trust was eventually established in 1876. One of the first issues to be addressed was the extension and deepening of the piers at the river entrance upstream wharves. Secondly, the port facilities needed to be moved upstream. In 1878, Sir John Coode recommended that docks be set up as close as possible to railways and the commercial area of the city. This was agreed to by the Harbour Trust in 1883 and work began by the 1890's.

The first of the Boer Wars began in 1880–1881 due to the repressive policies of the British Governor of the Cape. The South African Boer Republics revolted against the annexation of the Transvaal and the Orange Free State and secured limited self-government. Tensions between the Boers and British were further aggravated when gold and diamonds were discovered in the Transvaal. Once again, the British policies created an untenable situation leading to the Boers attacking the Cape Colony and Natal in 1899. This second war lasted until 1902. During this time, services to the Cape colony were disrupted. Australia was obliged to send troops and provide vessels (such as the White Line's *Medic*) in aid of the British. This disrupted coastal and international shipping, with many coastal vessels requisitioned to transport soldiers (Bach 1976). Merchant shipping was re-routed through the Suez or around Cape Horn (South America), to avoid the dispute, with the Cape of Good Hope route being re-established after the completion of the second war.

The 1880's saw the establishment of many direct trade routes to Melbourne. As mentioned earlier, one of the first direct routes to be established was that of the Melbourne/Britain mail service. This was followed in 1881 with routes to Fiji, Papua New Guinea, New Britain and New Ireland (Pemberton 1979). Direct services to the European continent and India also began (Bach 1976; Priestley 1984). In 1883 a French Line, Messageries Maritimes, operated a direct shipping link between Europe and Melbourne, which was soon followed by a German Line in 1887 (Bach 1976). The India direct service began in 1889 and ran from Melbourne to Colombo, onto Madras and finally to Calcutta before returning (Pemberton 1979). Intrastate trade also expanded to a Lakes Entrance/Melbourne tourist service. This service saw a slump during the 1890's but had recovered by 1900 and continued to service the Lakes Entrance until the 1930's (Bach 1976).

As the amount of traffic increased, the diversity of vessel types visiting Port Phillip Bay also increased. It was soon realised that the entrance was too shallow for many vessels to safely negotiate the Rip. Between 1881 and 1883 the reef at the Rip was blasted to deepen the entrance channel. The Suez was still shallower than the Rip and hence deepening did not have to be excessive. However, plans to increase the depth of the Suez to 33 feet (11 m) by 1920 led to a long term channel plan (Bach 1976). Plans for future deepening and widening of the Rip were made with the first stage to increase the entrance draught implemented in 1901–1903. By 1913, vessels of 38 feet (12.6 m) draught began using the Cape route and had trouble entering the bay since the Rip was blasted to a maximum depth of 33 feet (11 m). Two additional blastings in 1916 occurred. However, more blasting was implemented in 1943 to deepen to Rip to 43 feet (14.3 m). By 1969 the Rip was considered safe for vessels with a draught of 38 feet (12.6 m) to enter (Bach 1976).

Expansion of shipping services continued in the 1890's. A second direct service to New Zealand and a trans-Pacific route to Canada began in 1893. By 1898 a steamer service to Singapore had also started and Japan and China were also linked with Australia (Bach 1976; Pemberton 1979). Port maintenance in Melbourne began with the completion of the 96 acre Victoria Dock in 1892, first used in 1893 (Bach 1976; Kerr and Kerr 1979). A depression (probably linked to the Boer War and increased tonnage) once again hit the port, holding up much of the work on wharfage until 1903. The Princess Pier was opened by 1915. Port improvements continued into the 1920's with a rebuilt Station Pier opened in 1922 and the Ferguson Street Pier in Williamstown opened in 1927 (Priestley 1984).

By the turn of the century, voyages from London to Melbourne had been reduced from 48 days to 31.5 days. The emphasis on the Cape of Good Hope trade route had diminished, with the majority of Australian wool, meat, fruit and butter being exported via the Suez Canal (Bach 1976). In 1913 the Cape route was still used by 75% of the regular British steamers outward bound to Australia. However, on the return journey 32% went by way of the Cape of Good Hope, 28% carried on around Cape Horn and 40% used the Suez Canal (Bach 1976). A brief direct service to Calcutta began in 1902, This was followed in 1905 with a steamer service to Norfolk and Lord Howe Islands and the New Hebrides (Pemberton 1979). Eight years after the Boer War, an extended service was established to South Africa, via Mauritius that visited Delogoa Bay, Durban, East London and Capetown (Pemberton 1979). A service to Japan began in 1912, however this service and others were soon curtailed by WWI (Pemberton 1979; Priestley 1984).

The Federation of the Australian States occurred in 1901 with celebrations around Australia. Melbourne celebrated in typical fashion, hosting foreign ships from around the world. Vessels such as the American *USS Brooklyn*, the Russian *Gromoboi*, the German ships *Kormoran* and *Hansa*, the Netherlands Navy's *Noordbrabant*, the Royal Australian Squadron with the flagship *Royal Arthur* and HM ships *St. George, Juno, Ringarooma, Wallaroo* and *Mildura* all visited Melbourne to help with the celebrations. The entire US "White Fleet" visited Melbourne in 1908 and again in 1921 (J Cossum pers. comm.).

Up until 1914, two routes operated from England to Australia: the Suez Canal and Cape of Good Hope. In 1914, a third route began across the Atlantic, through the Panama Canal and onto Australia, across the Pacific (Fitchett 1980). In 1914, six lines (Aberdeen Line, Blue Funnel Line, Orient Line, P & O Line, P & O Branch Line and White Star Line), with 42 vessels were operating along these three routes (Fitchett 1980). Aberdeen, Blue Funnel, P & O Branch and White Star operated on the Cape of Good Hope route, whilst the Orient and P & O operated via the Suez (Fitchett 1980). Each line offered different ports of call: The Aberdeen Line's usual route called at: Sydney and Melbourne, Australia; Durban and Capetown, South Africa; and Plymouth and London, England. The Blue Funnel Liners called at Sydney, Melbourne and Adelaide, Australia; Durban and Capetown, South Africa; Liverpool and Glasgow, UK. P & O Branch called at Sydney, Melbourne and Adelaide, Australia; Durban and Capetown, South Africa; and London, whilst the White Star liners ran via Sydney, Melbourne and Albany, Australia; Durban and Capetown, South Africa; Plymouth, London and Liverpool, UK (Fitchett 1980).

The First World War began in 1914 and lasted until 1918. Unlike other wars (Napoleonic, Maori, Opium and Boer), WWI interrupted trade across the globe. Similar to WWI, WII had major influences on Australian and global shipping routes and services. Vessels were requisitioned (such as the *Esperance Bay* (2), *Jervis Bay* and *Indarra*) by the Australian and British governments, which halted intrastate and interstate shipping trades activities (Dunn 1973; Bach 1976; Fitchett 1980). Defence force personnel were sent to war, leaving a depleted work force. Coastal shipping remained under the wartime control system until 1947. Immigration again escalated with an exodus of refugees in the pre- and post-war era. Australia took in the largest proportion of displaced persons, with 75,000 refugees coming to Victoria between 1935 and 1954 (Strahan 1994).

In a bid to reduce Australia's reliance on foreign shipping, after WWI, the government introduced state owned/state controlled fleets (such as the Australian Commonwealth Line and the Aberdeen and Commonwealth Line Ltd). This was unsuccessful, resulting in the fleets being sold to foreign investors during the 1920's (Bach 1976; Fitchett 1980). A new shipping depression had begun triggered by excessive tonnage. This depression lasted from 1918 to 1939. During this depression tramp shipping suffered the most (Bach 1976). Although a depression was occurring, new services continued to develop. In 1921 a service to Java and Singapore via Sourabaja and Samarang began (Pemberton 1979). This service was later (1935) extended to Hong Kong and Saigon.

In 1932, the Australian Navigation Act provisions were relaxed allowing overseas vessels to operate in the interstate tourist trade (Bach 1976). This further directly opened up Australia to vessels that had operated in other bioregions. Other changes soon took place on the Australian port scene. For example, timber decking on wharves was phased out as reinforced-concrete decks replaced the old timber decks. Dry docks were established in the Yarra and at Williamstown. The emergence of the bulk carriage vessels, after WWII, required the development of specially constructed berths, with sophisticated equipment. The berths also required dredging and approach channels needed widening and deepening (Bach 1976). By 1969, Victoria and Appleton Docks catered for vessels up to 31 feet (10.3 m) draught and Port Melbourne Pier and the oil terminal at Williamstown catered for vessels up to 37 feet (12.3 m) draught (Bach 1976).

World trade and shipping tonnage expanded greatly after 1948. Australian trade developed East Asian markets, particularly Japan. North American routes also expanded while the traditional European and British trades have been lost. Major services to Japan in 1969, included vehicle-deck and container lines (Bach 1976; Pemberton 1979). A Japanese passenger trade also began in 1962 (Pemberton 1979). Three container lines between the East Coast of North America using offset-ramp ships started in 1969 (Bach 1976). By 1972, trade services included a container ship route between Europe and Australia. This new service traveled via the Cape of Good Hope to Australia and then went on to New Zealand and back to Europe via the Panama Canal and the East Coast of the USA (Bach 1976). A trans-Pacific service to the West Coast of the USA was also operating. By 1975, a new container ship service to the Philippines, South Korea, Hong Kong and Kaohsiung had begun (Pemberton 1979). A service to Malaysia also began in 1977.

Rationalisation and specialisation had saved the coastal shipping industry in the 1960's. This rationalisation saw the disappearance of the small, short-haul intrastate coaster and specialised passenger liners and the development of the Coastal Shipping Commission, which instigated the Coastal Shipping Agreement Act (Bach 1976). New interstate services also started with the 1959 Melbourne to Devonport passenger ferry, a four-weekly service in 1960, from Melbourne to Mackay, Townsville and Cairns, a general-cargo service between Melbourne and Launceston, in 1961 and a Fremantle to Melbourne container ship service in 1964. Other services started but soon halted. For example, the Melbourne to King Island supply run started in 1954 and stopped in 1963, resulting in King Island having to rely on Tasmania for its supplies.

With the commencement of many new lines and services, some ended. In 1928, the Fiji service started in 1881 halted. 1961 saw the end of the Tasman service and the New Guinea service ended in 1968 (Pemberton 1979). Pacific services operated by Burns Philps halted in 1970, while services to the West Coast of North America expanded.

With the development of new vessel types and improved engines, travel time has been reduced. In 1969 a line operating between Melbourne, Sydney, Brisbane and four Japanese ports took only 28 days to complete a round-trip. Port facilities have had to undergo more refurbishment's to cope with the new vessel designs.

Geelong has expanded from eight to 17 piers in 1979, with further refurbishment occurring in the 1990's. Whilst Port Melbourne had 106 piers by 1952; 73 of these were upriver. Docks such as Webb, Victoria and Swanson were deepened and expanded in the 1960's to cope with overseas vessels, container-ships and RO-RO vessels (Kerr and Kerr 1979; Priestley 1984). Larger docks and repair facilities have been slow to develop, with many large vessels needing to be repaired elsewhere than Australia (usually in Indonesia) (Bach 1976).

5.3 CURRENT TRADE PATTERNS

Two of Victoria's largest shipping ports are located in Port Phillip Bay: Melbourne and Geelong. Annually, both these ports see numerous international (670) and domestic (2,323) vessels, with an estimated 2.5 million tonnes (832,000 international and 1.7 million domestic tonnes) of ballast water being received, between August 1994 to July 1995 (Walters 1996). The Port of Melbourne is Australia's largest general cargo/container port and receives the second highest quantity of ballast water in Victorian ports (Walters 1996). Geelong deals principally with bulk and specialist cargo, such as petroleum and bulk grain. The primary vessel types have shifted from grain to petroleum vessels, which discharge low amounts of ballast. Presently, Melbourne and Geelong deal with different trades and hence different vessel types, cargo types and quantities, and amounts of exports and imports. All these factors influence the actual quantity of ballast discharged (Walters 1996).

Using the data provided by Walters (1996), for 1994 and 1995, the Port of Melbourne received vessels from 14 bioregions (see Chapter 2 for bioregion descriptions; Figure 2.1). The vast majority (50%) of traffic was trans-Tasman. New Zealand, the East Asian Seas (15%) and the South Pacific (14.5%) comprised 79.5% of all international traffic into Melbourne (Figure 5.1). The remaining 20.5% of international traffic was with the Wider Caribbean, the South Pacific, the Mediterranean, the North East Atlantic, the Arabian Seas, the South East Pacific, West Africa, South Atlantic, the North West Atlantic and the Baltic. The Central Indian Ocean, East Africa, Antarctic and Arctic are the only bioregions that do not directly contribute to inbound traffic in the port of Melbourne.

Domestic vessel traffic (2,110 domestic visits) into Melbourne was more prolific than international traffic

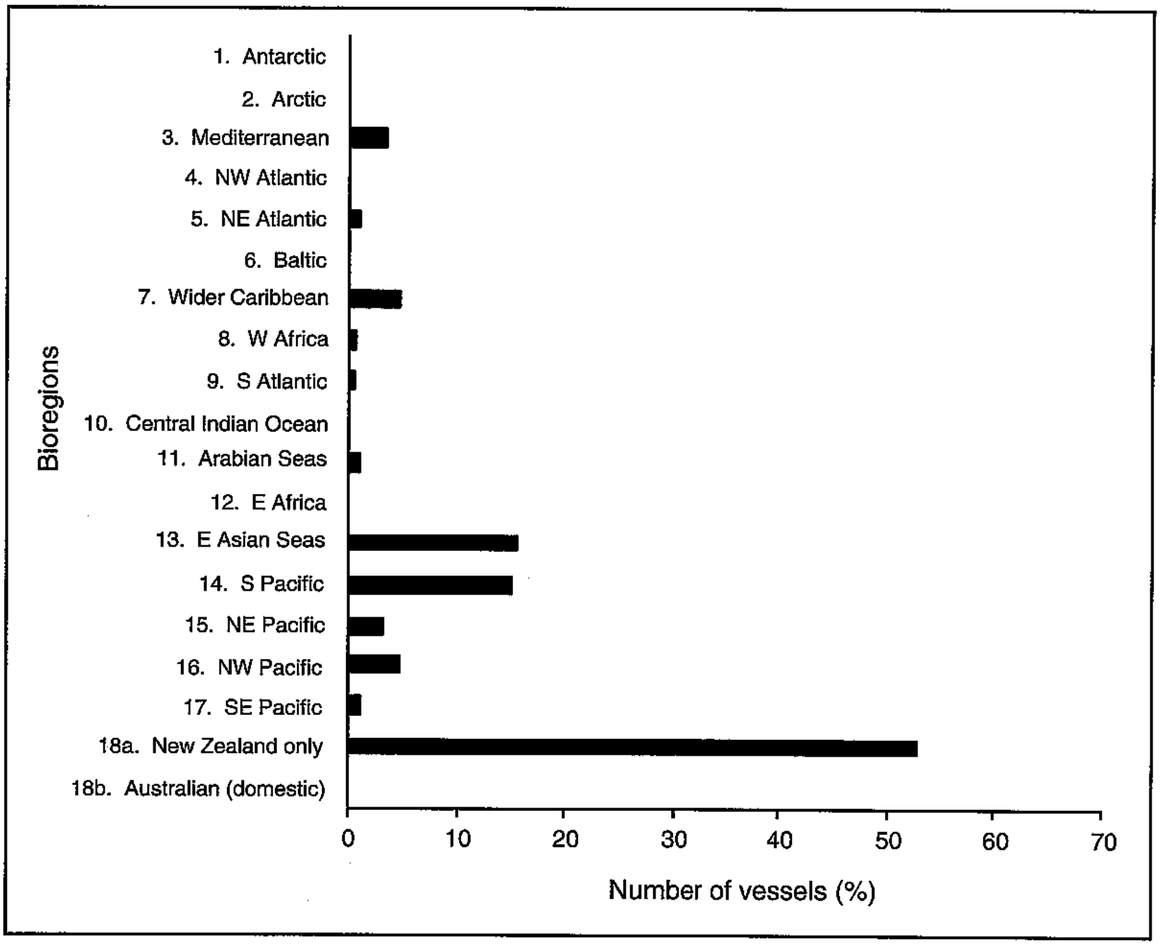

Figure 5.1. The Port of Melbourne trade (1994 and 1995) with bioregions 1–18 (after Kelleher *et al.* 1995; see Chapter 2 for discussion of bioregions, Figure 2.1).

(541 international visits). Domestically, 30.5% of inbound traffic originated in Western Australia, followed by Queensland (25.0%), New South Wales (16.7%), Tasmania (13.9%), South Australia (11.1%) and other Victorian ports (2.8%) (Walters 1996).

Unlike Melbourne, only a small percentage of Geelong's traffic deals with containerships (Port of Geelong Authority 1995; Walters 1996). Data from Walters (1996) shows that the majority (66%) of Geelong's traffic was with four bioregions: South Pacific (24%); North West Pacific (18%); East Asian Seas (13%); and the Wider Caribbean (11%) (Figure 5.2). The remaining 44% of traffic was with the Arctic, Mediterranean, North East Atlantic, West Africa, Arabian Seas, North East Pacific, New Zealand and domestic Australia (Figure 5.2). Seven bioregions (Antarctica, North West Atlantic, Baltic, South Atlantic, Central Indian Ocean, East Africa and South East Pacific) were not represented in this data, however they may have had contact with Geelong, via vessels visiting other domestic ports before entering Geelong. Thus, the last port of call would be registered as domestic, not international.

The largest proportion of visits into Geelong was domestic (214 domestic visits versus 129 international visits; Walters 1996). Geelong domestic visits contrasted vastly with Melbourne; with New South Wales (28.5%) and other Victorian ports (27.1%) providing the majority of traffic, followed by Tasmania (17.8%), Western Australia (10.7%), Queensland (10.3%) and South Australia (5.6%; Walters 1996). This reflects the different trade commodities that each port deals with. Geelong's main imports are crude oil and petroleum products (61%), fertiliser (12%), grain (11%), raw materials for aluminium smelting (5%) and woodchips (5%) (Port of Geelong Authority 1995; Walters 1996). For example, a large percentage of petroleum products came from Western Australia and all aluminium-smelting products are from Western Australia (Port of Geelong Authority 1995).

The latest shipping data available (1996 and 1997) are shown in Figures 5.3 and 5.4, and was provided by the Victorian Channels Authority (A Blott pers. comm.). Data for Geelong was unavailable. During 1996 and 1997, the Port of Melbourne received vessels from 13 bioregions (Figure 5.3) and exported to 12 bioregions (Figure 5.4). The vast majority of this is traffic is trans-Tasman. This trend has not changed since 1994 and 1995. Inbound traffic to Melbourne came primarily from domestic

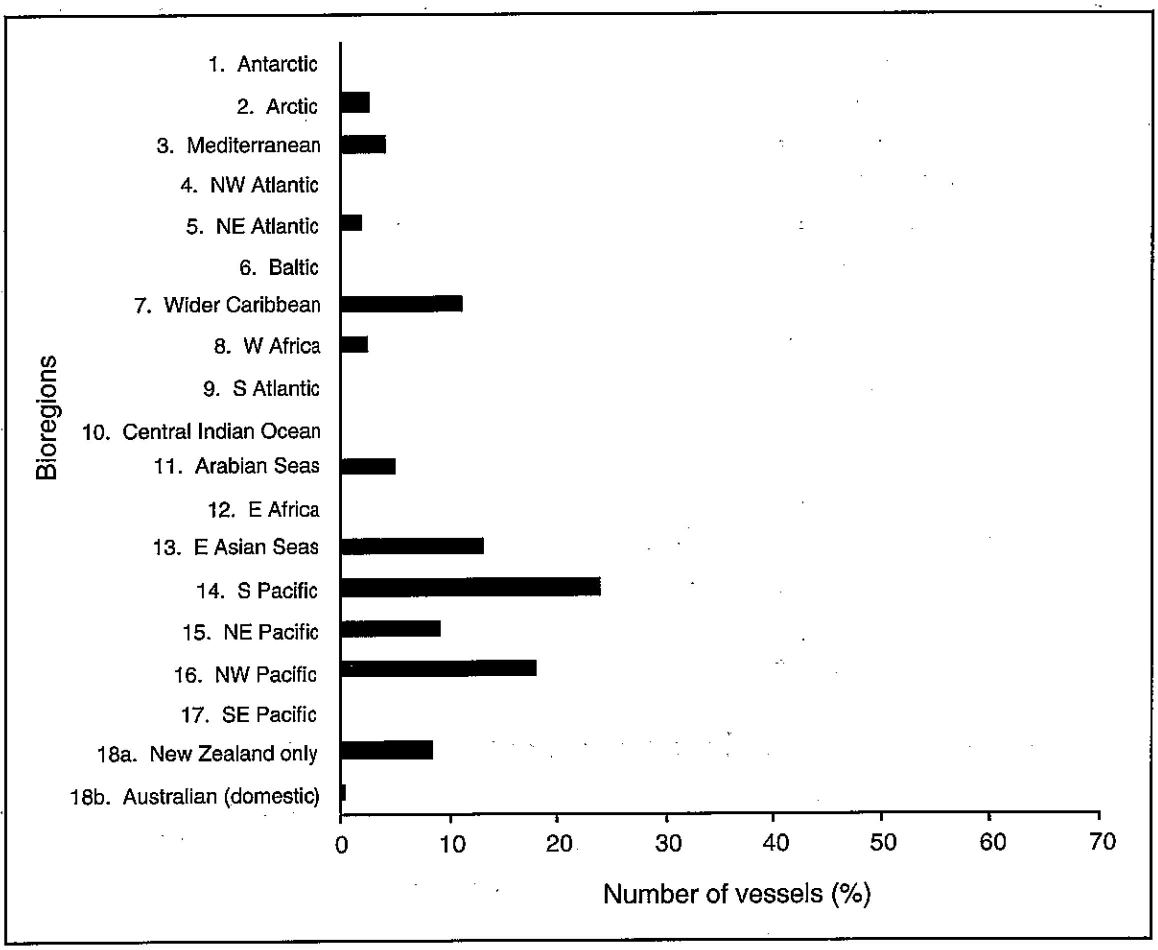

Figure 5.2. The Port of Geelong trade (1994 & 1995) with bioregions 1–18 (after Kelleher *et al.* 1995; see Chapter 2 for discussion of bioregions, Figure 2.1).

Australia (82.1%). Of the remaining bioregions, 90% of traffic were with the bioregions of New Zealand (55.5%), the South Pacific (19.7%) and the East Asian Seas (14.9%). The remaining 10% of inbound traffic originated from the Antarctic, North West Pacific, North East Pacific, South East Pacific, East and West Africa, the South Atlantic, North East Atlantic and Mediterranean and the Wider Caribbean bioregions (Figure 5.3). This pattern is similar to the 1994 and 1995 shipping data.

As well as receiving exotic species, Port Phillip Bay is capable of infecting other bioregions. Current trade (1996, 1997) indicates that 85.2% of traffic goes to domestic ports in Australia (A Blott pers. comm.). Of the international visits, 52.1% goes to New Zealand, 23.2% to the east Asian seas, 10.2% to the northwest Pacific and 9.2% to the south Pacific. The remaining bioregions receive only 14.5% of Melbourne's traffic (Figure 5.4). Information on export traffic during 1994 and 1995 was unobtainable. However, the similarity between 1994 and 1995, and 1996 and 1997 inbound traffic suggests that export traffic may also have been similar, over these periods.

Of the 19 worldwide bioregions (Kelleher *et al.* 1995; see Chapter 2, Figure 2.1), Port Phillip Bay has received exotic species from all but one bioregion: Antarctica. The majority (60%) of introductions originate from the combined bioregions of the Atlantic, the Mediterranean and Baltic Sea. The Pacific region has contributed 17% of introductions and the Central Indian Ocean, South Pacific, East Asian and Arabian Seas have combined contributions of 7%, with the remaining bioregions (New Zealand, Arctic and Cosmopolitan bioregions) contributing the final 16%.

5.4 WATERWAYS AND PORTS

5.4.1 Maintenance and management

Maintenance of port areas includes activities such as dredging, development of new wharves and piers, demolition of old wharves and piers, cleaning facilities and land reclamation. These activities are managed by several interests including port authorities, management groups, and the Victorian Channel Authority.

Dredging facilitates vessel access and maintains safe passage within a region. A number of channels within Port Phillip Bay are continually dredged, maintaining access into Geelong, Melbourne and into the bay. The port areas are also dredged to maintain berth depths. Port

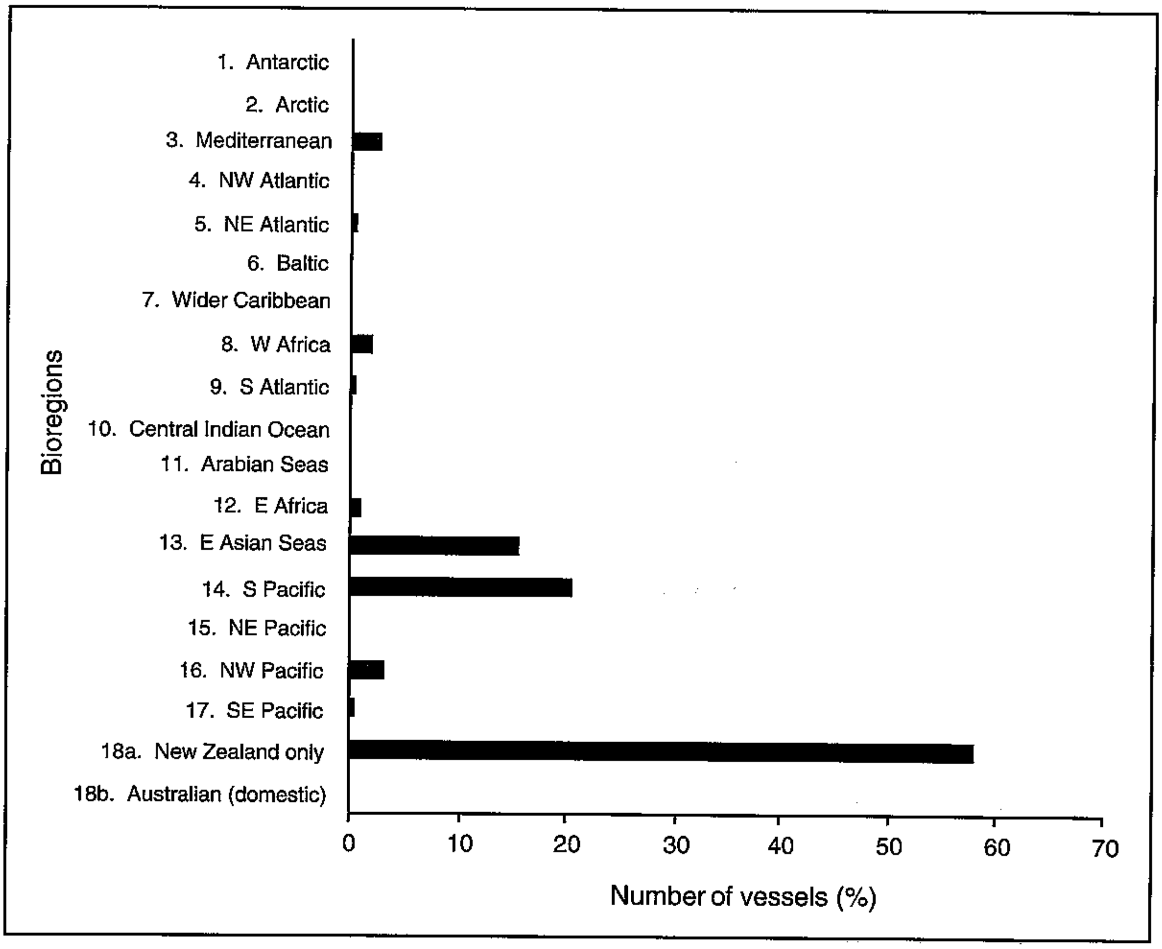

Figure 5.3. The Port of Melbourne current trade (1996 and 1997) with other bioregions 1–18 (after Kelleher *et al.* 1995; see Chapter 2 for discussion of bioregions, Figure 2.1).

dredging practices have been demonstrated to play a role in the local translocation of introduced species within a port environment (Carlton *et al.* 1990). Early dredge tailings from Port Phillip Bay were dumped inland, with taxonomists seizing the opportunity to document the marine flora and fauna found in the spoil (Wilson 1894). In recent times, dredge spoil is dumped within the bay in areas considered suitable for such activities.

The Victorian Channels Authority regulates this. Offshore (onto the continental shelf) dredge spoil dumping must meet legislative requirements specified within the Commonwealth Environment Protection (Sea Dumping) Act 1981 and is administered by the Environment Protection Group of Environment Australia. This legislation also follows the ANZECC Sea Dumping Guidelines (ANZECC 1997). At present, offshore dumping of dredge materials does not occur in Port Phillip Bay (C Gibbs pers. comm.). Typically, dredge spoil is disposed of at the Port Phillip Spoil grounds (marked on all nautical charts for Port Phillip Bay) (C Gibbs pers. comm.). Spoil grounds also exist for the recent deepening of the Geelong channel; both in Corio Bay and an outer spoil ground in Geelong Arm (C Gibbs pers. comm.). Maintenance dredging has been highlighted as a high-risk activity with the potential to re-distribute species such as *Sabella spallanzanii*, *Corbula gibba*, *Theora lubrica* and cysts of toxic dinoflagellates in Australian coastal and estuarine waters.

Port enhancement activities (e.g. maintenance dredging, berth development and revetment construction) create disturbed and novel habitats that may lead to increased invasion success. Many introduced species appear to require some form of disturbance in order to enter an existing native community (Fox and Fox 1986). For example, *S. spallanzanii* is known to rapidly colonise recently cleared or newly submerged hard surfaces (Clapin and Evans 1995; C Hewitt pers. comm.; Chapter 16). Port maintenance activities may influence the establishment of some encrusting or fouling species within Port Phillip Bay by clearing a space that may be colonised by ballast water or hull fouling organisms.

Hull cleaning activities of both large, commercial vessels and smaller recreational, either in-water (brush cart cleaning) or drydock, can lead to the inoculation and establishment of exotic species. A number of slipway facilities and one drydock facility exists in Port Phillip

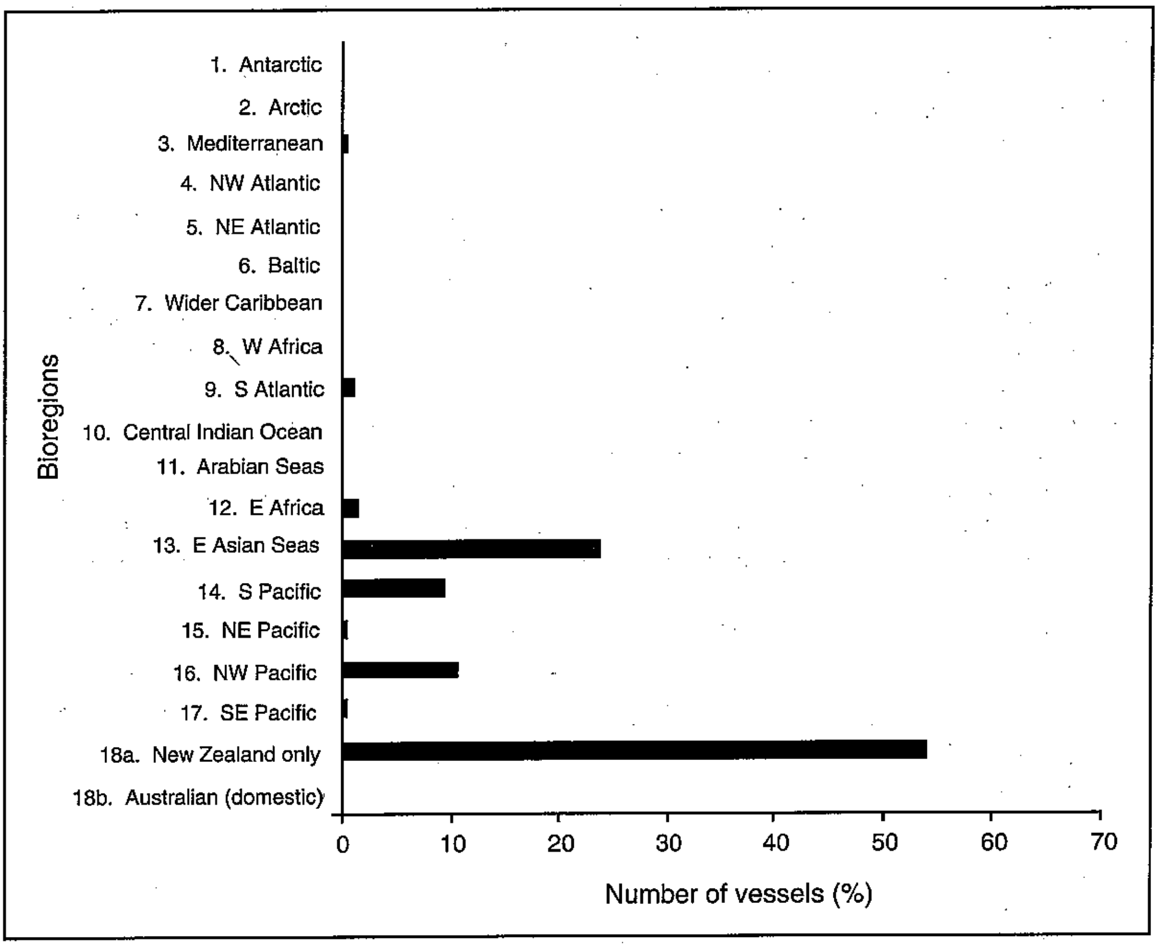

Figure 5.4. The Port of Melbourne current trade (1996 and 1997) to other bioregions 1–18 (after Kelleher *et al.* 1995; see Chapter 2 for discussion of bioregions, Figure 2.1).

(Table 5.1). All are involved in hull cleaning and painting (especially the smaller marina's, such as Runaway Bay marina) and others are involved in construction and refit activities. State environment legislation exists to ensure that debris from drydock hull cleaning (Williamstown and the Rippleside slipways) is correctly disposed (Walters 1996). Yet invariably, cleaning of vessels result in inoculation into the port environs. In 1995, only 2% of vessels in Australia, conducted in-water cleaning of hulls at Port Melbourne, with 14% of these vessels using the Geelong port (Walters 1996). Restrictions on in-water cleaning are becoming common, with authorities (both Australian and international) trying to dissuade this practice (Walters 1996). Only two of the drydocks and slipways in Port Phillip Bay deal with international traffic, Wagland and Williamstown. However, Wagland floating dock closed 5–6 years ago, leaving the Williamstown Transfield facilities as the only facility dealing with vessels that have had likely international experience.

In recent years, Geelong has implemented an environmental monitoring study (EMS) to manage the port's operations and ensure compliance with its environmental commitments. Before commencing dredging activities, plans are submitted and must receive approval, both planning and ministerial. The dredging periods are preceded by a 12-month environmental monitoring program and followed by a further five year monitoring period (Port of Geelong Authority 1995). Development of wharves and piers must also be approved and environmental studies must be done. Port Melbourne has a similar EMS in place to ensure environmental commitments are maintained (C Gibbs pers. comm.). The Victorian Environmental Protection Authority also provides environmental monitoring throughout the bay (C Gibbs pers. comm.).

In addition to port maintenance, the operation of mariculture facilities in waterways near port facilities may increase the likelihood of introduced species becoming established and spreading. Mariculture practices have the potential to transfer exotics species from one region to another (Hewitt and Martin 1996). Many exotic species such as *Turritopsis nutricula*, *Sabella spallanzanii* and *Asterias amurensis* are associated with mussel lines and hence transfer of these lines from one region to another will facilitate redistribution of these species. Portarlington and Beaumaris Bay are aquaculture regions within the bay that both have a number of established exotic species (see Chapters 2 and 14). The transfer of mariculture equipment is of prime concern and has been implicated in the transfer of organisms within and between local, national and international regions (Chew 1990; Grizel and Héral 1991; Carlton 1992; Utting and Spencer 1992).

5.4.2 Ballast practices

Heavy 'dry' materials (such as sand, boulders, and chain) were originally used for ballast. Thompson (1841; see also Kerr and Kerr 1979) reported that as early as 1840, dry ballast discharge regulations existed in Port Phillip.

> *"Melbourne, April 15, 1840*
>
> *The harbour-master of Port Phillip draws the attention of all commanders of vessels proceeding either up or down the harbour of Port Phillip to the Act (Wm. IV., No. 6) prohibiting, under heavy penalty, the discharge of ballast overboard in any of the channels leading to the harbour.*
>
> *Should any vessel happen to ground on the banks of the channels, while passing through them, it is required that the longboat shall be got out, and that the ballast or other heavy materials should be landed at high-water mark on the adjoining nearest reef.*
>
> *Notice is hereby given that the harbour-master has orders to proceed against any party who may after the publication of this notice transgress from the above regulations.*
>
> *By order of*
> *C. J. LA TROBE."*

Although these regulations were more concerned with the creation of shipping hazards, it was the beginning of ballast regulations within the Port Phillip region. Dry

Table 5.1. Drydock and slipway facilities operating in Port Phillip Bay.

Facility	Vessel origin	Operational status
Williamstown drydock (commercial)	International & domestic (Navy)	+
Victoria slipways (commercial)	Domestic	+
Appleton Dock slipways	Domestic	+
Wagland floating dock	International	-
Duke and Oars slipways (x2)	Domestic	+, -
Anne St. slipways	Domestic	+
Rippleside slipways (commercial)	Domestic	+
Mordialloc Creek slipways	Domestic (fishing fleets)	+
Moonee Ponds slipways	Domestic	+

ballast began to be replaced by water ballast in the mid 1840's (Carlton 1985; Carlton *et al.* 1995) and as early as 1908 ballast water was recognised as a potential vector for marine organisms (Carlton 1985). Dry and semi-dry ballast has been implicated in the transfer of numerous species (Carlton 1989; Carlton 1992; Mills *et al.* 1993) such as the New Zealand porcelain crab, *Petrolisthes elongatus* (King 1997) and possibly corophiid amphipods, such as *Corophium acherusicum* and *C. sextonae* (Storey 1996; see Chapter 16).

Ballast water can be carried in dedicated ballast water tanks and in empty cargo holds, which are modified for such purposes (Walters 1996). Ballast discharge is associated with the loading and unloading activity of the vessel while at berth. If a vessel loads a large volume of cargo only (e.g. ore carrier), it will discharge ballast water to maintain trim. Vessels that both load and unload cargo (e.g. container vessel) at berth require minimal ballasting. Thus, the type of vessel and its capacity to load and/or unload cargo controls the potential discharge of ballast water (Walters 1996). Presently in Australia, AQIS manages ballast water from international vessels. However, there are no standard ballast regulations for coastal shipping in Australia (ENRC 1997).

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6 A REVIEW OF THE OCCURRENCE OF EXOTIC MACROALGAE IN SOUTHERN AUSTRALIA, WITH EMPHASIS ON PORT PHILLIP BAY, VICTORIA.

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6.1 INTRODUCTION

As with most sessile epibenthic or fouling organisms, many macroalgae are potential candidates for transoceanic transport. Algal spores are able to settle on bare substrates, such as unprotected parts of ship hulls, and, once attached, survive vegetatively in transit until conditions are found in a foreign port which permit spore production or vegetative propagation.

Early reports of macroalgal introductions were from countries where the marine flora was comparatively well known and new species therefore more easily recognised. One of the earliest reports is of the introduction of the red alga *Bonnemaisonia hamifera* to Britain from Japan in 1870 with the alga subsequently spreading to other parts of Britain and then Europe (Jones 1974).

The red alga *Asparagopsis armata*, considered native to southern Australia and New Zealand, was first reported in 1923 on the southern Atlantic coast, at Cherbourg, France and in Algeria (Elton 1958). Over the next thirty years this species spread widely along the Atlantic and Mediterranean coasts of Europe and northern Africa and to Ireland and Britain as far north as Scotland. Other reported macroalgal introductions to Europe include *Antithamnionella spirographidis* (1910), *Colpomenia peregrina* (1906), *Codium fragile* (ssp. *atlanticum* 1808; ssp. *tomentosoides* 1900), *Grateloupia filicina* var. *luxurians* (late 1940s), *Grateloupia doryphora* (1968), *Undaria pinnatifida* (1971) and *Sargassum muticum* (1973).

Throughout the world, at least 95 species of macrophyte are known to have spread regionally and at least four large-scale invasions, between ocean basins and between hemispheres, by temperate algae are known: *Codium fragile* ssp. *tomentosoides*, *Sargassum muticum*, *Undaria pinnatifida* and *Laminaria japonica* (Trowbridge 1995). Replacement of dominant native macroalgae by introduced species may result in shifts in communities and their trophic food webs, but to date these effects have not been well studied nor understood (Walker and Kendrick 1998).

Although several deliberate attempts have been made to introduce and domesticate exotic species for aquaculture (Neushul *et al.* 1989), the translocation of macroalgae into geographically distant regions has generally been considered "accidental" and attributed to either transport with shellfish for mariculture or on shipping. The large brown alga *Sargassum muticum* is thought to have been introduced to western North America in shipments of oysters from Japan in the early 1940's (Silva 1979). First collected in British Columbia in 1944, it subsequently spread both northwards, and southwards as far as southern California. The species was discovered in southern England in 1973, and here the source was considered to be shipments of Japanese oysters from British Columbia.

Ship fouling was considered the likely means of introduction of *Codium fragile* ssp. *tomentosoides* into New Zealand (Dromgoole 1979). Characteristics of the subspecies considered to facilitate this process were its propensity to grow on floating structures, its ability to grow on surfaces with little surface relief, and its perennial basal holdfast which would allow the plant to survive transoceanic transport.

The rapid dispersal of the green alga *Caulerpa taxifolia* through the Mediterranean Sea has also been attributed to boat transportation (Sant *et al.* 1996) but not necessarily on vessel hulls. The species is capable of regeneration from small plant fragments and experiments demonstrated that plants could resist emersion for periods up to 10 days in conditions similar to that found in anchor lockers or in a heap of fishing nets.

A number of features appear common to macroalgae which have colonised geographically distant locations. These include broad physiological tolerances, rapid growth rates, and high reproductive potential. In addition, the plants appear to be either tolerant of lengthy periods of emersion and able to regenerate from plant fragments (e.g. *Caulerpa taxifolia*), or to have a microscopic phase in the life history (e.g. *Undaria pinnatifida*) or a persistent basal disc (e.g. *Codium fragile* ssp. *tomentosoides*) which enables the species to withstand long sea voyages.

A full and accurate census of macroalgal introductions to Australia is difficult for several reasons. First, macroalgae have more than likely been arriving on ships since the first explorers visited our shores. Antifouling measures were far less effective during the 19th and early part of the 20th century than they are today and the potential for transport was therefore significant. The second difficulty is the degree of knowledge of our marine flora. Early botanists were, quite justifiably, more fascinated with the unique and diverse flora found on our open coastlines and scant attention was paid to our harbours and embayments, the most likely sites for new colonists.

Much early taxonomic work also focussed on the larger plants, the plants that persisted and were collected as drift on beaches, plants that were also unlikely candidates for transport. Only in relatively recent years have there been comprehensive censuses and checklists produced for specific geographic areas which may be used as reliable guides to determine more recent introductions. Where species are now known to occur both within Australia and at other, either widespread or disjunct localities, it is difficult to determine whether the distribution is natural or the result of transport by shipping over the last century or two.

This report collates records of those macroalgae which, all in relatively recent years, have been reported as possible introductions to southern Australian waters. These are listed in two parts: the first for species reported to occur in Port Phillip Bay; and the second for species reported elsewhere in southern Australia but yet to be found in Port Phillip Bay. In these two sections collection locations in southern Australia are listed, relevant literature including references to illustrations cited, and a brief description furnished to assist in identification of future collections. A third section lists species found in Port Phillip Bay which have overseas type localities. Most of these species now have a widespread distribution through temperate seas but are possible introductions to the Port Phillip Bay flora in the period since international shipping first entered the region. A description of these species is not furnished but references to descriptions and illustrations are given.

The regions of the bay delineated in this report (Northern, Corio Bay, South-western, Central, Eastern, Southern and Port Phillip Heads (PPH) are those used in reports on algal distribution in the 1957–1963 Port Phillip Bay surveys (Womersley 1966; King *et al.* 1971).

6.2 MACROALGAE CONSIDERED TO BE POSSIBLE INTRODUCTIONS TO PORT PHILLIP BAY

Phylum Rhodophyta
Order Gigartinales
Family Phyllophoraceae

Schottera nicaeensis (Lamouroux *ex* Duby) Guiry and Hollenberg 1975: 153, Figures 4–9, 11–15. — Dixon and Irvine 1977: 230, Figure 84. — Lewis 1977: 217; 1983: 262. — Lewis and Kraft 1979: 226, Figures 2–7. — Lewis and Womersley 1994: 263, Figures 83 C–F.

Synonymy and taxonomy

Halymenia nicaeensis Lamouroux *ex* Duby;
Gymnogongrus nicaeensis (Lamouroux *ex* Duby) Ardissone and Strafforello;
Rhodymenia nicaeensis (Lamouroux *ex* Duby) Montagne;
Petroglossum nicaeense (Lamouroux *ex* Duby) Schotter.

Type

From Marseilles, France.

First recorded collection in Port Phillip Bay

1975: Gellibrand Pile Light, northern Port Phillip Bay (*O'Brien and Kraft*, 30.x.1975, MELU, A39480).

Port Phillip Bay distribution

Northern: northern Port Phillip Bay, 5-9 m deep on mussels and boulders under Gellibrand Light (*Kraft and Lewis*, 18.i.1976, MELU, A23162; *Lewis*, 19.v.1976, MELU, A39482). Port Phillip Heads: Queenscliff, 1.5 m deep on jetty piles (*McCauley*, 10.ii.1990, AD, A60173); Portsea, 3-5 m deep on jetty piles (*O'Brien and Kraft*, 16.iii.1979, MELU, A39482); The Abyss, 28-30 m in sponge (*Kraft, Saunders and Strachan*, 20.ii.1995, MELU, K10,499).

Australian distribution

Victoria: Port Phillip Bay (see above); Portland, 5–7 m deep on boulders (*Kraft*, 27.iv.1990, MELU, K8284); Apollo Bay, 2–3 m deep in shade under jetty (*Riddle*, 6.ii.1990, AD, A60173). South Australia: Glenelg, on *Amphibolis* (*Kraft*, 22.xii.1970, MELU, K3056). New South Wales: Jibbon Reef, off Port Hacking, 23 m deep on sandstone (*Watson*, ix.1976, MELU, A23396). Tasmania: Orford, 4–5 m deep (*Kraft*, 15.xii.1992, MELU, A40590); Tinderbox, 6–9 m deep on shells (*Kraft and Sanderson*, 7.xii.1993, MELU, K10,133.

Extra-Australian distribution

Native: Mediterranean, southern and western British Isles to Portugal.

Possible introduction: South Africa.

Description

Light to medium brown-red, with flat, simple to subdichotomous or irregularly laterally proliferous fronds, 1–4 cm high and 2–4 mm broad, arising from slender branched stolons (often within sponge or sediment), apices of main blades rounded (or with terete proliferations), proliferations basally constricted and terete to 2 mm broad. Tetrasporophytes with sori of catenate rows of tetrasporangia near frond apices. Life history triphasic, with isomorphic sexual and tetrasporophyte generations. [Lewis and Womersley 1994]

Comments

Lewis and Kraft (1979) considered *S. nicaeensis* to be a likely introduction to Port Phillip Bay and speculated on its possible transport from the Mediterranean on a ship's hull. At its collection site at Gellibrand Light, *Schottera* was one of the few algal species to tolerate the combined effects of siltation, low light and competition with the mussel *Mytilus*.

Erect fronds of *Schottera nicaeensis* have the potential to produce numerous terminal and marginal proliferations, which can develop into creeping axes capable of producing new erect fronds. This ability to perennate by creeping axes enabled plants to compete with growing mussels and to withstand periods of heavy siltation. These characteristics may similarly have facilitated its transport on ship hulls, enabling a stolon or blade to survive sub-optimal conditions during trans-ocean transport, then to generate a new fertile blade when environmental conditions allowed.

Annual sea temperature ranges measured at the Gellibrand Light site (9°–23° C) compared favorably with reported ranges of 9°–17° C and 13°–25° C at *Schottera*'s northern European limits and in the western Mediterranean respectively (Lewis and Kraft 1979). Since its first discovery in Australia at Gellibrand Light, *Schottera* has been found growing at a number of other locations in southern Australia, often on piles or in shaded areas under jetties, and also South Africa (Norris and Aken 1985; Wynne 1986).

Related or morphologically similar species

Stenogramme interrupta (C. Agardh) Montagne. Lewis and Womersley 1994: 260, Figure 82A–D;

Rhodymenia spp. (Rhodymeniales, Rhodymeniaceae) Womersley 1996: 68, Figures 24–30.

The above species all have similar flattened blades and, in section, have a compact medulla of ovoid cells with a smaller celled cortex. Certain identification often requires having fertile plants, with cystocarps forming a mid-rib like line down the thallus in *Stenogramme* and external pustules in *Rhodymenia*. In the Phyllophoraceae tetraspores develop in chains in surficial nemathecia, whereas in *Rhodymenia* they are scattered within the outer cortex. The ability of *Schottera* to produce stolonate outgrowths from the margins and apices of erect blades is distinctive.

Gymnogongrus crenulatus (Turner) J. Agardh 1851: 320. — Dixon and Irvine 1977: 217, Figure 78. — Lewis and Womersley 1994: 269, Figure 85A–C.

Synon/my and taxonomy

Fucus crenulatus Turner;
Fucus norvegicus sensu Turner;
Chondrus norvegicus J. Agardh (in part);
Gymnogongrus norvegicus J. Agardh (in part);
Fucus devoniensis Greville;
Gymnogongrus devoniensis (Greville) Schotter;
Chondrus celticus Kützing;
Actinococcus peltaeformis Schmitz.

Type

From Oporto, Portugal.

First recorded collection in Port Phillip Bay

1969: Portarlington (Corio Bay), sublittoral (*King*, 16.x.1969, MELU, 4733).

Port Phillip Bay distribution

Northern: Kirk Point, Werribee (*Brown*, 20.i.1982, MELU, A39455); Altona, 2 m deep (*Brown*, 6.ix.1983, MELU, A39454); Williamstown, 2 m deep at Gloucester Reserve (*Brown*, 13.viii.1974, MELU, A21815), upper sublittoral on rocks below Breakwater Pier (*Lewis*, 1.xi.1976, MELU, A39456); St Kilda, 3 m deep (by diver, 23.ii.1976; MELU, A22272). Corio Bay: Portarlington (see above); Pt. Wilson (*King*, 2.ii.1970, MELU, 4863).

Australian distribution

Victoria: Port Phillip Bay (see above). South Australia: Topgallant I., 10 m deep (*O'Leary*, 20.I.1992, AD, A61673); Henley Beach, Adelaide, drift (C. and G. *Kraft*, 6.iii.1971, MELU, A39475); Port Noarlunga, lowest eulittoral, shaded, just N of jetty (*Ricci and Womersley*, 8.ii.1973, AD, A61799); Robe, pool near jetty (*Womersley*, 7.xii.1991, AD, A61543). New South Wales: Port Jackson (Sydney), low intertidal in Botanic Gardens (*Kraft*, 21.xi.1983, MELU, A39469).

Extra-Australian distribution

British Isles (southern and western shores) to Mauretania; Mediterranean; and North West Atlantic (New Brunswick, Canada to N. Massachusetts, USA).

Description

Thallus medium to dark red-brown, 3–8 cm high, cartilaginous, subdichotomous at intervals of 0.5–3 cm, more or less complanately branched, branches flat, 2–4 mm broad, margins straight to slightly crenulate, slightly narrower basally, axils broad, apices rounded, often with small proliferous fronds from lower parts; holdfast discoid, with one to few fronds. Chains of 5-10 tetrasporangia, with 1–2 terminal sterile cells, formed in pustules usually on lower branches, 1–3 mm across and 1–2 mm high [Lewis and Womersley 1994].

Comments

The Australian specimens attributed to *G. crenulatus* agree well with British material and are considered by Lewis and Womersley (1994) to be possible adventives, since most collections are from nearby harbours. Until recently, the genus *Gymnogongrus* included species both with erect gametophytes and free-living crustose tetrasporophytes and with a crustose tetrasporophyte developing directly as a pustule on the surface of the female gametophyte, apparently without the formation of an internal cystocarp. In 1992, Silva and DeCew erected the genus *Ahnfeltiopsis* to accommodate the species with internal cystocarps and free-living tetrasporophytes. *G. crenulatus* remains in the genus *Gymnogongrus*, along with the type of the genus, *G. griffithsiae*, which is also a European species now reported from a number of locations in southern Australia (Lewis and Womersley 1994).

Other species within the Phyllophoraceae have previously been thought to be transported via shipping. Maggs *et al.* (1992) undertook a molecular and morphological analysis of the *Gymnogongrus devoniensis* (= *Ahnfeltiopsis devoniensis)* complex in the northern Atlantic. Two distinct species were identified: *Gymnogongrus devoniensis*, present only on the North Atlantic coasts of Europe, and an unnamed *Gymnogongrus* sp. which grew on both sides of the Atlantic. The molecular similarity of populations of the latter from the disparate locations, and the observation that the populations could not have been connected by continuous distribution since 5–25 million years ago, suggested that one or other of the North Atlantic populations represented a trans-Atlantic introduction.

The probable vector was considered to be shipping between Northern Ireland and Nova Scotia during the early 19th century, when ships carried timber for shipbuilding between these locations. Characteristics considered to favour the transoceanic transport of this species were its apomictic life history, the occurrence of abrasion-resistant hypobasal tissue in the crustose phases, and the ability of both crusts and blades of *Gymnogongrus* sp. to remain alive for several weeks out of water if kept cool and damp.

In a study of the resistance of intertidal communities to sand movement, Daly and Mathieson (1977) discuss morphological and reproductive adaptations common to psammophytic ("sand-loving") macroalgal species, among which these authors include the phyllophoracean species *Gymnogongrus linearis (=Ahnfeltiopsis linearis), Ahnfeltia concinna* (=*Ahnfeltiopsis concinna*) and *Phyllophora* spp. In southern Australia, *Gymnogongrus griffithsiae, Ahnfeltiopsis fastigiata* and *A. humilis* have all been found on intertidal rocks subject to sand scour, and *G. crenulatus* is reported to be tolerant of sand cover in Britain (Dixon and Irvine 1977).

As highlighted by Daly and Mathieson, morphologically these plants are tough and wiry and reproductively they can be capable of extensive regeneration from basal holdfasts. In addition to the characteristics discussed by Maggs *et al.* (1992) this latter character may also have facilitated the transport and survival of phylloporacean species, including *G. crenulatus*, on shipping.

Related or morphologically similar species

Gymnogongrus griffithsiae (Turner) Martius. Lewis and Womersley 1994: 269, Figure 84G, H;
Ahnfeltiopsis spp. Lewis and Womersley 1994: 265, Figures. 84A–F;
Rhodymenia spp. (Rhodymeniales, Rhodymeniaceae) Womersley 1996: 68, Figures 24–30.

G. griffithsiae differs from *G. crenulatus* in having terete to slightly compressed branches less than 0.9 mm broad, as does *Ahnfeltiopsis fastigiata. A. humilis* has flattened branches but is a smaller plant, mostly 1–2 cm high, which forms internal cystocarps. As with *Schottera*, some *Rhodymenia* spp. can appear morphologically similar to *G. crenulatus*, and certain identification may require fertile material. However, in colour *G. crenulatus* is often a darker, more brownish red than species of *Rhodymenia*.

Family Solieriaceae

Solieria filiformis (Kützing) Gabrielson 1985: 275.

Synonymy and taxonomy

Solieria tenera (J. Agardh) Wynne and Taylor 1973: 100, Figures 1–6. — Gabrielson and Hommersand 1982: 31, Figures 2–4, 13–20, 2, 25, 28, 29, 31, 39, 40–45. — Womersley 1994: 343, Figures 111B, C, 112H, I.

Type

From the West Indies.

First recorded collection in Port Phillip Bay

1957: off Mentone (Eastern Bay) (*Port Phillip Survey*, 26.v.1957, MELU, unnumbered).

Port Phillip Bay distribution

Northern: Power Station Outfall, Hobsons Bay, 3 m deep (*Watson*, 1.v.1972, AD, A42350); Williamstown, on rocks in sand off Gloucester Reserve (*Kraft*; 19.i.1975, MELU, K5109; *Lewis*, 1.iv.1975, MELU, A21966; *Lewis, O'Brien and Kraft*, 7.i.1976, MELU, A22019); St Kilda, 5 m on southernmost reef (Unnamed diver, 26.ii.1976, MELU, A22,307). Eastern: (as above). Corio Bay: Werribee Treatment Farm, drift at north end (*Kraft*, 13.x.1994, MELU, K10,368).

Australian distribution

Victoria: Port Phillip Bay (see above).

Extra-Australian distribution

Western Mediterranean, western Europe and tropical west Africa and North Carolina, USA, to southern Brazil.

Description

Thallus medium red-brown, 10–20 cm high, much branched irregularly with numerous laterals of varying length, branches terete, 1–1.5 mm in diameter below, decreasing to 200–400 mm in branchlets, basally constricted and tapering gradually to acute tips. Holdfast small, probably fibrous; epilithic on pebbles or shells. [Womersley 1994].

Comments

Only known in Australia from Port Phillip Bay, Womersley considers *S. tenera* (= *S. filiformis*) a probable adventive which may not have spread or established in the area. The morphology and life history (isomorphic alternation of gametophytes and tetraporophytes) of *S. filiformis* do not suggest any obvious characteristics which would favour the transport of this species on shipping, nor are any related species reported as introductions elsewhere. Considering the morphology of the plant, with its narrow, terete and irregularly branched thallus, a possible mechanism may have been entanglement around the grate of a seawater intake or other protrusion from the underwater hull of a vessel. Release of spores from such a plant, or regeneration from plant fragments, may then have occurred when the ship moored or berthed in Port Phillip Bay.

S. filiformis (as *S. tenera*) is recorded as an adventive in southwestern England (Farnham 1980), as are two other solieriaceous algae, *Solieria chordalis* and *Neoagardhiella gaudichaudii*. Farnham comments that, in all three of these species, although spores have been discharged from fertile material in culture, none has ever germinated. He considers this could indicate that these species may reproduce more by vegetative propagation than by spore development. *S. chordalis*, in particular, has been observed to fragment and undergo rhizoidal reattachment. This would support the mechanism proposed above for introduction of *S. filiformis* into Port Phillip Bay.

Related or morphologically similar species

Solieria robusta (Greville) Kylin. Womersley 1994: 340, Figures 111A, 112A–G.

S. robusta is widely distributed in southern Australian waters including Port Phillip Bay. Morphologically it differs from *S. filiformis* in having more robust branches (2–5 mm in diam. cf. 0.2–0.4) and fewer small laterals. *Solieria* spp. can be distinguished from other terete, branched rhodophytes such as *Rhabdonia coccinea*, *Hypnea filiformis* and *Gracilaria* spp. by their multiaxial apices and lax medulla of longitudinal and cross-linking filaments.

Order Ceramiales

Family Ceramiaceae

Antithamnionella spirographidis (Schiffner) Wollaston 1968: 345, Figure 29. — Lewis 1977: 217; 1983: 262. — Maggs and Hommersand 1993: 17, Figure 5. — Athanasiadis 1996: 121, Figure 57. — Womersley 1998: 168, Figures 77C–E, 78J–S.

Synonymy and taxonomy

Antithamnion spirographidis Schiffner.

Type

From Trieste, Italy.

First recorded collection in Port Phillip Bay

1976: Breakwater Pier, Hobsons Bay (Northern Bay), 3 m deep, in algal turf on mussels (*Lewis*, 1.xi.1976, MELU, A42535).

Port Phillip Bay distribution

Northern: see above, also: Gellibrand Light, northern Port Phillip Bay, 4–5 m deep in algal turf on mussels (*Lewis*, 21.i.1977, MELU, A42536). Corio Bay: Pt. Wilson, drift (*Brown*, ii.1981, AD, A52041).

Australian distribution

Victoria: Port Phillip Bay (see above). South Australia: Port Adelaide, on an anchored barge (*Womersley*, 11.vii.1957, AD, A21323; 12.ix.1958, AD, A22033). New South Wales: Rozelle, on intake screens of White Bay Power Station (*Collector not specified*, 15.ix.1953, AD, A29888).

Extra-Australian distribution

Adriatic Sea; Plymouth Sound, Britain; and Cherbourg, France.

Description

Small, delicate, red filaments, with creeping, prostrate axes bearing flexuous, free branches, up to 1 cm long, from every 4th (occasionally 3rd) cell. Axial cells 3–6 times as long as broad, 180–230 µm by 30–50 µm, and bear 2 (occasionally 1 or 3) opposite, unbranched (usually distichously arranged) whorl-branchlets about 250 (-380) µm long when mature. Gland cells, 10–12 µm in diam., which curve partly around the parent cell, are cut off from the upper side of the 2nd and/or 3rd cells of whorl branchlets in the upper parts of the thallus. Attachment of the prostrate axes is by the secondary development of rhizoidal attachment filaments from the basal or second cell of whorl branchlets. [Wollaston 1968]

Comments

Wollaston's record of *Antithamnionella spirographidis* was the first from Australian waters and she considered the species a likely introduction to Port Adelaide waters via shipping from Europe. The species had previously been found associated with dockyards and harbour activities at Devonport Dockyard, Plymouth Sound, on the south coast of Britain where sea temperatures range from 14° to 24° C (Westbrook 1934) and at Cherbourg, France (Feldmann 1937). Water temperatures in northern Port Phillip Bay have an annual range of approximately 9° to 22° C.

At Port Adelaide, tetrasporangial development commenced in July, with an increase in the proportion of tetrasporangial plants until November, when nearly all plants were fertile and a few sexual plants were also found (Wollaston 1968). In Port Phillip Bay, plants were recorded from November to January, with tetrasporangial plants found only in January (Lewis 1977).

A. spirographidis is a diminutive, filamentous plant with creeping prostrate axes that could easily be transported on the hull of a vessel. The collection of plants from the intake screens of a power station in NSW and within the algal turf growing on mussels in northern Port Phillip Bay supports the possibility of the plant being introduced on the seawater intakes of ships or in fouling growth. On arrival, colonisation could result from either spore release triggered by favourable sea temperatures, or the secondary attachment and growth of detached fragments.

Although first described from the Adriatic Sea in 1916, its origin is not certain with Jones (1974) citing its origin as from the Southern Hemisphere. The first European collection of the species appears to be from around Cherbourg in France in 1910 with no collections of the species from the same area in the latter part of the last century. It subsequently became quite abundant in this area and also spread to the British Isles (1920's) where it is now considered to be a well-established member of the marine flora (Farnham 1980).

Related or morphologically similar species

Antithamnionella ternifolia (Hooker and Harvey) Lyle. Wollaston 1968: 340, Figure 28 (as *A. tasmanica*); *Antithamnionella glandifera* Wollaston 1968: 347, Figure 30; *Antithamnieae* and *Heterothamnieae* spp. Wollaston 1968. *A. spirographidis* and *A. glandifera* differ to *A. ternifolia* in having lateral branches at regular intervals along axes, usually every 3rd or 4th cell, rather than irregular intervals, and whorl-branchlets in whorls of 1 or 2, sometimes 3, rather than 3 or 4. Whorl-branchlets in *A. spirographidis* are usually unbranched with gland cells on the 2nd or 3rd cell, whereas in *A. glandifera* branches on the lower part of the thallus are branched and can bear up to 20 gland cells. *Antithamnionella* spp. are different to other southern Australian genera of the Heterothamnieae in having both prostrate and erect axes. Genera of the Antithamnieae with prostrate and erect axes, *Antithamnion* and *Acrothamnion*, bear whorls of 2 or 4 pinna-like branchlets on axial cells and have cruciately, rather than tetrahedrally divided tetraporangia.

Deucalion levringii (Lindauer) Huisman and Kraft 1982: 178, Figures 2–20. — Lewis 1977: 218 (as *Propagula secunda*); 1983: 262. — Millar and Kraft 1993: 39. — Adams 1994: 252, Plate 93. — Womersley 1998: 305, Figures 143G, H, 144.

Synonymy and taxonomy

Callithamnion levringii Lindauer.

Type

From Pihama, Taranaki, New Zealand.

First recorded collection in Port Phillip Bay

1975: Gellibrand Light, northern Port Phillip Bay (Northern Bay), 4–5 m deep in algal turf on mussels (*Kraft, O'Brien and Lewis*, vii.1975, MELU,).

Port Phillip Bay distribution

Northern: see above, also: Gellibrand Light, 5–6 m on mussels (*Kraft, Lewis and O'Brien*, 30.x.1975, MELU, K5496). Port Phillip Heads: Portsea Pier (*Huisman, Kraft and Ricker*, 19.ix.1980, MELU, A23824).

Australian distribution

Victoria: Port Phillip Bay (see above); Portland, 1–2 m deep in algal turf (*Kraft*, 30.xii.1976, MELU, K6303); Flinders Pier, Western Port Bay (*Huisman and Gabrielson*, 3.ix.1981, MELU, A24019). New South Wales: Jibbon Bombora, Port Hacking, 23 m deep, infrequent in turf (Watson, ix.1976, MELU; also *Millar and Richards*, 7.x.1989, NSW, A009652); Worong Point, Twofold Bay (*Millar and Richards*, 7.ii.1992, A010803 - A010806). Tasmania: Bicheno, in bryozoan turf, 20–22 m deep (*Kraft*, 18.xii.1992, MELU, A66649); Arch Rock, Ninepin Point, 1–10 m deep (*Andrews*, 21.x.1994, AD, A63905).

Extra-Australian distribution

New Zealand.

Description

Thallus to 10 cm high, filamentous, uncorticated, erect; axis monosiphonous, alternately distichously branched with branches arising from the distal end of each central axial cell and curving away from the axis; lateral branching mostly adaxially secund although terminal segments may be alternate-distichous. Asexual reproduction by three-celled, ovoid propagules borne on sporophytes; sporophytes also producing polysporangia containing 24–36 spores which, in culture, give rise to procarpic and spermatangial gametophytes isomorphic with the sporophyte generation. [Huisman and Kraft 1982]

Comments

Huisman and Kraft (1982) noted that all the Australian collection localities were in, or in the vicinity of, enclosed harbours or bays in regions of intense shipping activity. On this basis they considered that the alga may have been introduced comparatively recently from New Zealand waters.

The small filamentous thalli may have facilitated trans-Tasman transport of this alga, with the asexual propagules enabling colonisation of the Australian sites. The alga appears quite tolerant of environmental variables occurring in Port Phillip Bay with sporophytes collected throughout the year. In culture, germlings grown from propagules tolerated a wide range of light and temperature regimes. In contrast gametophytes, which had not been found in the field, only grew beyond the 5-celled stage under a single set of environmental conditions (Huisman and Kraft 1982).

Related or morphologically similar species
Anotrichium spp. Baldock 1976;
Mazoyeralla, Pleonosporium spp. Huisman and Kraft 1982.
Deucalion levringii is superficially similar to a variety of monosiphonous, uncorticated species within the Ceramiaceae such as species of *Anotrichium, Mazoyerella* and *Pleonosporium.* The 3-celled propagules and branching pattern clearly differentiates *D. levringii* from other species.

Medeiothamnion lyalli (Harvey) Gordon 1972: 59, Figures 16–18, 56A. — Lewis 1977: 218; 1983: 260. — Womersley 1998: 92.

Synonymy and taxonomy
Wrangelia lyalli Harvey.

Type
From Ruapuke Is., Foveaux Strait, New Zealand.

First recorded collection in Port Phillip Bay
1962: Rickett's Point (Eastern Bay), (*P. Halder*, Oct. 1962, MELU A677 (A37242).

Port Phillip Bay distribution
Northern: Brighton, drift (*M. Cappelli*, 18.vi.1965, MELU A2191 (A37244)); Pt Ormond, drift (*Price*, 26.vii.1965, MELU A2215); Gellibrand Light, 5–6 m deep on south boulder slope (*Kraft, O'Brien and Lewis*, 24.vii.1975, MELU K5711; 12.ix.1975, MELU K5484), frequent in turf on mussels, 5–6 m (*Lewis*, 19.viii.1976, MELU L0947; 23.xii.1976, MELU L0952); Lagoon Pier, Hobsons Bay, dominant in drift and occasional on piles below 2 m deep (*Lewis*, 13.x.1976, MELU L0949). Eastern: (see above).

Australian distribution
Victoria: Port Phillip Bay (see above). Tasmania: ?Sarah I., Bathurst Channel, 2–5 m deep (*Edgar*, 11.iii.1995, AD A64258) (see Womersley 1998, p. 92).

Extra-Australian distribution
South Island, Ruapake and Stewart Islands, New Zealand.

Description
Thallus filamentous, 10–20 cm long, sparsely to richly branched, exhibiting several intergrading forms; one form with branching alternate to subdistichous with up to 3 equally spaced whorl branchlets per axial cell, the whorl branchlets regularly to irregularly pinnate; in other forms the branching regularly opposite and distichous, with two opposite whorl branchlets per axial cell, the whorl branchlets mostly pinnate and distichous, with whorl branchlets and indeterminate branches less distinct. The main erect branches arising from prostrate, branched axes attached to the substrate by haptera; intertwining of the prostrate axes and the cortical rhizoids from the lower parts strengthen attachment. Apical cells about 50 mm in diam, axial cells to 4 mm long near the base of the plant; median cells of the whorl branchlets 60-90 mm in diam., and 2– times as long as wide; terminal parts of the whorl branchlets not tapering markedly. In lower parts of the main axes, the basal cells of the whorl branchlets and lateral branchlets each produce several rhizoids, which form a loose cortication, the rhizoids adhering to the axis by haptera. [Gordon 1972]

Comment
Medieothamnion lyalli is one of a number of species recorded for the first time in Australian waters at Gellibrand Light (Lewis 1983). The species was subsequently also collected from jetty piles and in the drift at Lagoon Pier in Hobsons Bay. The proximity of Gellibrand Light to shipping lanes entering the Port of Melbourne, and the occurrence of at least 8 putative exotic species at this site, was considered to add further indirect evidence for the introduction to Australian waters of exotic macroalgae on ship hulls.

A check of specimens in MELU found several specimens collected in the drift at several nearby sites in the 1960's. Initially identified as *Antithamnion*, these plants were subsequently recognised to be *Medeiothamnion* but not specifically assigned to *M. lyalli.* These specimens, along with the more recent collection of the species as a dominant component of the drift in Hobsons Bay, suggest that the species is well established in deeper waters in this region. However, the species appears restricted to this relatively small area and has not, for example, been collected at intensively studied sites on the Williamstown coastline to the west of Hobsons Bay.

Related or morphologically similar species
Medeiothamnion protensum (Harvey) Gordon. Gordon 1972: 51, Figures 11–13, 55A;
M. halurum (Harvey) Gordon. Gordon 1972: 57, Figures 14, 15, 55B.
M. lyalli differs to the above species of *Medeiothamnion*, both of which are known from Port Phillip Bay, in having 2–4 rigid whorl branchlets per cell, not markedly inwardly curved nor tapering, and tetrasporangia sessile on most cells of the whorl branchlets.

Family Rhodomelaceae

Polysiphonia brodiaei (Dillwyn) Sprengel 1827: 349. — Lewis 1977: 219; 1983: 262. — Womersley 1979: 496, Figure 11 A–E. — Fletcher 1980: 51, Pl. 23 Figures 1–6. — Adams 1994: 325, Plate 110.

Synonymy and taxonomy
Conferva brodiaei Dillwyn.

Type
From Bantry Bay, Ireland.

First recorded collection in Port Phillip Bay
1959: Swan I. Naval Depot (South Western Bay), 0–0.5 m deep on barge (*Womersley*, 8.iv.1959, AD, A22608).

Port Phillip Bay distribution

Northern: 0–2 m deep on mussels growing on wooden piles of Gellibrand Light (*Kraft and O'Brien* 30.x.1975, MELU, K5510); Lagoon Pier, Hobsons Bay, 0–0.5 m deep on piles (*Lewis*, 29.xi.1976, MELU, L1058). South Western Bay: Swan I. Naval Depot (see above).

Australian distribution

Victoria: Port Phillip Bay (see above); Apollo Bay, drift (*Womersley*, 31.viii.1971, AD, A39481), 0–0.5 m deep on pipeline in harbour (*Kraft and Owen*, 1.ix.1971, AD, A39523). South Australia: St Vincent Gulf, 60 m deep (AD, A1209); Robe, on ramp in boat harbour, low tide level (*Womersley*, 24.viii.1973, AD, A44594), on slipway reef, upper sublittoral (*Womersley*, 14.ii.1978, AD, A49156). Tasmania: Bellerive (*Perrin*, Nov.1940, MEL, 46013; *Cribb*, 28.iii.1950, AD, A16005); Blackmans Bay, drift (*Cribb*, 22.ix.1950, AD, A16248); Taroona, 1–3 m deep (*Shepherd*, 19.iii.1975, AD, A46224); Bicheno, lower eulittoral (*Skinner*, 22.ii.1978, AD, A49203).

Extra-Australian distribution

N Europe and Japan.

Possible introduction: Washington and California.

Description

Thallus filamentous, 4–12 (–17) cm high, profusely and irregularly branched, with several percurrent main branches, fastigiate above, dark red-brown in colour. Axial cells surrounded by a ring of pericentral cells equal in length to the axial cell, giving the filaments a segmented appearance. Pericentral cells 7–8, elongate throughout, branches becoming completely corticate with filaments cut off from the pericentral cells, cortical layer several cells thick on lower branches and axes. [Womersley 1979]

Comments

Womersley (1979) concluded that the Australian material agreed well with material from Britain and, as it was usually found in or near harbour areas, the possibility of its spread by shipping deserved consideration. In northern Port Phillip Bay, *P. brodiaei* was common on the wooden piles supporting both Gellibrand Lighthouse and Lagoon Pier (Lewis 1977, 1983). Hollenberg (1944), in describing the occurrence of the species in central California, observed that it was mostly collected from wharf pilings and floats in harbours. He comments that as *P. brodiaei* was frequently found on boat bottoms it may have been an introduction to the Pacific coast of North America, although he felt its absence on the Atlantic coast cast some doubt on the proposition.

P. brodiaei also occurs in New Zealand (Adams 1991), with all but two of the collections from busy ports where the plants were growing on harbour structures. The exceptions were records from Fiordland and Stewart Island. Adams comments that these areas were regularly used by whalers and sealers in the early part of the 19th century, particularly for repairing or careening sailing vessels. *P. brodiaei* in New Zealand is therefore regarded as an adventive. *P. brodiaei* is also considered to have been introduced to Newfoundland (Hooper and South 1977). In his account of North Atlantic fouling algae, Fletcher (1980) reports *P. brodiaei* as occurring on moderately exposed floating substrates, especially during spring and early summer.

The propensity of *P. brodiaei* to grow in harbours and in particular on floating structures suggests the species to be a prime candidate for transport on shipping. Rapid growth rates and the short time required for the maturation and release of spores would facilitate colonisation of new harbour locations.

Related or morphologically similar species

Polysiphonia spp. Womersley 1979.

P. brodiaei differs to other southern Australian *Polysiphonia* spp. in having 7 (–8) pericentral cells and all of the plant except the upper branchlets corticated.

Polysiphonia senticulosa Harvey 1862: 169. — Nelson and Maggs 1996: 449, Figures 1, 2A–C.

Synonymy and taxonomy

Polysiphonia pungens Hollenberg 1942: 774, Figures 1, 10. — Lewis 1977: 220; 1983: 262. — Womersley 1979: 472, Figure 3A–D. — O'Brien 1981: 189.

Type

From Orkas I., Washington, USA.

First recorded collection in Port Phillip Bay

1969: Williamstown (Northern Bay), lower eulittoral (*King*, 28.viii.1969, MEL 45986, MELU 4613).

Port Phillip Bay distribution

Northern: Williamstown (see above); Hobsons Bay, on mussels below Breakwater Pier (*Lewis*, 3.ix.1976, MELU L1101); Lagoon Pier, Hobsons Bay, 0.5 m on pile (*Lewis*, 29.xi.1976, MELU L1105); Williamstown, 3–5 m deep on boulders at seaward edge of Gloucester Reef (*Kraft and Cowling*, 28.iv.1995, MELU 10,658). Eastern Bay: Ricketts Point, lower eulittoral (*King*, 30.ix.1969, MEL 45988, MELU 4697). Corio Bay: Kirk Point, drift (*Womersley*, 11.viii.1970, AD A36032 and 30.viii.1971, AD A39519).

Australian distribution

Victoria: Port Phillip Bay (see above); Apollo Bay, on *Sargassum vestitum* on pipeline in harbour (*Owen*, 1.ix.1971, AD A39494).

Extra-Australian distribution

Vancouver Is., Canada; and Alaska, USA.

Description

Thallus filamantous, to 12 cm high, slender and lax, much branched, arising from slight prostrate and entangled basal filaments, dark red-brown in colour. Pericentral cells 4, ecorticate. Branches near apices arising every 2–5 segments, with most remaining as simple, determinate, gently tapering and acuminate branchlets. [Womersley 1979]

Comments

Womersley (1979) found that "the Australian specimens agree well in every way with Hollenberg's descriptions and illustrations, and with the type specimen in UC". He considered that the disparate distribution and the occurrence in Australia in the proximity of harbours raised the possibility of spread by shipping. The slender, filamentous habit (consistent with rapid growth rates) and recorded occurrence near the water surface on jetty piles are characters suggesting potential for transport on shipping.

Nelson and Maggs (1996) illustrate this species from New Zealand for the first time and record it from Wellington Harbour and Picton. They note that it has been found growing both epiphytically and epilithically and that it is particularly abundant in late winter/early spring.

Related or morphologically similar species

Polysiphonia spp. Womersley 1979.

P. pungens differs to other southern Australian ecorticate *Polysiphonia* spp. with 4 pericentral cells in the virtual absence of trichoblasts in vegetative parts, rhizoids not cut off from the pericentral cells, and the spinous tipped branchlets of relatively limited growth with segments distinctly shorter than those in the parent branch.

Chondria arcuata Hollenberg 1945: 447, Figures 2–4. — Lewis 1977: 219 (as *Chondria sp.*); 1983: 262 (as *Chondria dasyphila*). — Gordon-Mills and Womersley 1987: 551, Figures 24D, E, 27.

Type

Laguna Beach, Orange County, California.

First recorded collection in Port Phillip Bay

1975: Gellibrand Light (Northern Bay), 6–8 m deep on mussels (*Kraft*, 9.xii.1975, MELU, K5695).

Port Phillip Bay distribution

Northern: Gellibrand Light (as above), 4–6 m deep (*Lewis*, 25.xi.1976, MELU, L1036); Hobsons Bay, 1–2 m deep at Breakwater Pier (*Lewis*, 27.i.1977, MELU, L1039); off Gloucester Reserve, Williamstown, 3–4 m on *Mesophyllum* (*Kraft and Saunders*, 3.iii.1995, MELU, K10, 556).

Australian distribution

Victoria: Port Phillip Bay (as above); Apollo Bay, on floating pipeline in boat harbour (*Kraft and Owen*, 2.ix.1971, MELU, K3718a).

Extra-Australian distribution

California and Pacific Mexico.

Description

Thallus pinkish red with many terete axes 3–7 cm high, arising from intertwining stoloniform axes that anastomose through small rhizoidal haptera. These lower axes bind debris, other small creeping algae, bryozoa and byssal threads of associated mussels. The branching may be irregularly radial, or the terminal parts of erect axes may be transformed into stoloniform axes by the production of haptera along one side in the place of regular laterals, while ordinary laterals emanate form the other side. Terminal parts of main axes or ultimate branchlets are frequently curved. Axillary branching absent and apices depressed. [Gordon-Mills and Womersley 1987]

Comments

C. arcuata has been collected at the same two Victorian localities as *Polysiphonia pungens* (also from Pacific North America) and, as with this latter species, Gordon-Mills and Womersley (1987) consider this *Chondria* as probably introduced to southern Australia by shipping. The occurrence of *C. arcuata* within mussel communities and its ability to perennate by secondary attachments near apices are characters that may have facilitated its transport within fouling attached to ship hulls.

In northern Port Phillip Bay, *C. arcuata* fertile plants were present from late spring through to autumn (Lewis 1977).

Related or morphologically similar species

Chondria spp. Gordon-Mills and Womersley 1987.

Chondria arcuata differs to other *Chondria* spp. with fully terete axes in its size, having upper axes mostly less than 250 mm in diameter, in having depressed apices, and perhaps most distinctively in its ability to produce haptera near the apices which transform into creeping axes.

Phylum Phaeophyta

Order Ectocarpales

Family Ectocarpaceae

Sorocarpus micromorus (Bory) Silva 1950: 256. — King *et al.* 1971: 116. — Clayton 1974: 799, Figure 32. — Womersley 1987: 36, Figures 6B, 7E–F.

Synonymy and taxonomy

Botrytella micromorus Bory;

Sorocarpus uvaeformis Pringsheim;

Ectocarpus siliculosus ssp. *uvaeformis* Lyngbye.

Type

From Hofmansgave, Denmark.

First recorded collection in Port Phillip Bay

1970: Mornington (Eastern Bay), rare in the upper sublittoral zone (*Clayton*, 21.ix.1970, MELU 20519, AD A39499).

Port Phillip Bay distribution

Eastern: (as above).

Australian distribution

Victoria: Port Phillip Bay (as above).

Extra-Australian distribution

N Europe, North West Atlantic and N Japan.

Description

Thallus of medium brown, tufted uniseriate filaments, 1–4 cm long, irregularly branched with bare lower main branches. Plurilocular sporangia conical to ovoid, densely clustered in groups along the branchlets or on short laterals 2–3 cells long and thus forming irregularly shaped to subglobular sori. [Womersley 1987]

Comments

This species is only known from the record of King *et al.* (1971) and is considered by Womersley (1987) to be a possible introduction on shipping. As with other ectocarpoid species, the small filamentous habit, fast growth rates and rapid maturation would facilitate introduction into new locations via shipping. The single collection record for this species suggests that it has been unable to successfully establish in Port Phillip Bay.

Related or morphologically similar species

Ectocarpoid spp. Womersley 1987: 26.

Sorocarpus differs from other genera of the Ectocarpaceae in having sori grouped in irregular, lobed lateral sori.

Stictyosiphon soriferus (Reinke) Rosenvinge 1935: 9, Figures 9–19. — Lewis 1977: 214; 1983: 261. — Skinner and Womersley 1983: 63, Figures 1B, 2G–L. — Womersley 1987: 314, Figures 109C, 113E–J.

Synonymy and taxonomy

Kjellmania sorifera Reinke.

Type

From the West Baltic Sea.

First recorded collection in Port Phillip Bay

1969: Williamstown (Northern Bay) (*King*, 28.viii.1969, MELU 4630).

Port Phillip Bay distribution

Northern: Williamstown (as above); Gellibrand Light (*Lewis*, 20.x.1976, MELU L0805). Corio Bay: Kirk Point, uppermost sublittoral (*Womersley*, 30.viii.1981, AD A53230); Geelong, drift (*Clayton*, 4.ix.1970, MELU 21035). Southwestern Bay: Swan Bay (*Clayton*, 18.ix.1969, MELU 21054).

Australian distribution

Victoria: Port Phillip Bay (see above). Western Australia: Princess Royal Harbour, Albany (*Womersley*, 21.viii.1979, AD A51388). South Australia: Billy Lights Point, Port Lincoln, 12 m deep on *Pinna* (*Shepherd*, 23.viii.1975, AD A46532).

Extra-Australian distribution

North Atlantic and Mediterranean.

Description

Thallus light to medium brown, 10–15(–30) cm high, slender, terete, much branched irregularly alternately, tapering gradually from base to apices; with long, uniseriate apices becoming polystichous below by longitudinal cell divisions [Womersley 1987].

Comments

S. soriferus is considered a probable introduction from the North Atlantic (Womersley 1987). Along with *Striaria attenuata* and *Arthrocladia villosa*, Skinner and Womersley (1983) considered that the three species, all well known as European and British species and common in harbours, were probable introductions to Australia on shipping as the Australian collections are also near harbours. *Stictyosiphon* has a heteromorphic life history with a pulvinate, filamentous microthallus the alternate stage to the slender, branched macrothallus, although the macrothallus can reproduce directly. The microthallus would facilitate transoceanic transport, but equally so too could the slender, fast growing macrothallus and capacity for direct development.

Related or morphologically similar species

Striaria attenuata Greville. Womersley 1987: 312, Figures 109B, 113A–D.

Both *Striaria* and *Stictyosiphon* have slender cylindrical thalli with polystichous branches tipped by terminal uniseriate filaments. Branches in *Stictyosiphon* remain solid with a medulla of four large cells in sectional view, unlike *Striaria* in which the branches become hollow and the medulla is only 1(–2) cell(s) thick.

Family Punctariaceae

Asperococcus compressus Griffiths *ex* Hooker 1833: 278. — O'Brien 1981: 185. — Womersley 1987: 318, Figures 114B, 115E, F.

Synonymy and taxonomy

Haloglossum compressum (Griffiths) Hamel.

Type

From Sidmouth, England.

First recorded collection in Port Phillip Bay

1976: Gloucester Reserve, Williamstown (Northern Bay) (*Kraft*, 27.iii.1976, MELU A35177, A35178).

Port Phillip Bay distribution

Northern Bay: (as above).

Australian distribution

Victoria: Port Phillip Bay (as above); Flinders, ocean side (*Clayton*, 11.viii.1986, MUCV Algae 2306, AD A57205).

Extra-Australian distribution

Britain, Europe, Mediterranean and South Africa.

Description

Thallus medium-brown, flat, 10–20(–25) cm long, (1-)1.5–3(–4) cm broad and 250–500 μm thick with slightly thickened margins, linear or tapering slightly above with a rounded to truncate (often disintegrating) apex, tapering below to a cuneate base and short slender stipe 3–10 mm long, with 1–4(–8) fronds arising from a small discoid holdfast. Internal structure with two membranes, 3–4 cells thick, lying closely adjacent with a slight central cavity crossed by irregular filaments of long cells. [Womersley 1987]

Comments

A. compressus is only known from the Port Phillip and Flinders locations and thought by Womersley (1987) to be a likely adventive which has become established in this part of Victoria. *Asperococcus* has a heteromorphic life history with the macrothallus alternating with branched, filamentous microthallus, potentially a mechanism for ship-borne transport.

Related or morphologically similar species

Asperococcus bullosus Lamouroux. Womersley 1987: 320, Figures 114C, 116A,B, 117A;

A. fistulosus (Hudson) Hooker. Womersley 1987: 322, Figures 114D, 116C, D.

A. compressus differs from the other two species in having a flat, not terete to irregularly inflated, thallus and a narrow internal cavity crossed by filaments.

Order Laminariales

Family Alariaceae

Undaria pinnatifida (Harvey) Suringar 1873: 77, pls. vi–vii. — Sanderson 1988: 13; 1990: 153. — Sanderson and Barrett 1989: 1. — Hay 1990: 301, Figure 1. — Adams 1994: 113, Plate 34. — Furlani 1996. — Edgar 1997: 56 (illustr.). — Campbell and Burridge 1998.

Synonymy and taxonomy

Alaria pinnatifida Harvey.

Type

From Japan.

First recorded collection in Port Phillip Bay

1996: 2 km northeast of Point Wilson (Corio Bay), on basalt reef and rock/shell rubble in 2-4 m of water (*Campbell*, 8.vii.1996).

Port Phillip Bay distribution

Corio Bay: (as above).

Australian distribution

Victoria: Port Phillip Bay (as above). Tasmania: Orford, 1–2 m (*Kraft*, 15.xii.1992, MELU K9264); also Triabunna, Coles Bay, Schouten Passage and southwards through the Mercury Passage; Blackman Bay and Fortescue Bay; Tinderbox and northern D'Entrecasteaux Channel.

Extra-Australian distribution

Japan, Korea and China.

Introduced to France, Spain, Italy, Britain, Argentina and New Zealand.

Comments

Sporophyte stipitate, of a thin, golden brown, membranous, pinnatifid blade, 1–2 (–3) m long, with a strap-like, 1–3 cm wide midrib running the full length of the thallus. Pinnae 50–80 cm long. Holdfast of dichotomously branched, slender, root-like haptera. Fertile plants with sporangia formed on lobed sporophylls that coil around the main stem. Gametophyte microscopic, filamentous.

Discussion

Hay (1990) discusses the introduction of *Undaria* to Europe, Australia and New Zealand. In France, *U. pinnatifida* was first discovered in l'Ètang de Thau, near Sète on the French Mediterranean coast in 1971. This lagoon is important for oyster cultivation and *Undaria*, along with *Sargassum kjellmanianum* (syn. *S. muticum*) and *Laminaria japonica*, is thought to have been introduced accidentally with the Pacific oyster. Subsequently, *Undaria* was intentionally introduced to the French Atlantic coast off Brittany in 1983 to assess possibilities for commercial cultivation. By 1987, wild populations had established and in 1988, the wild population within one bay was estimated to contain about 20,000 plants. *Undaria* has also been found in Spain (Santiago Caamano *et al.* 1990), Italy (Curiel *et al.* 1994), Argentina (Piriz and Casas 1994; Casas and Piriz 1996) and attached to floating pontoons of a marina in the Solent region on the south coast of England (Fletcher 1995).

The first record of *Undaria* in the Southern Hemisphere was in Wellington Harbour, New Zealand, in 1987, at which time it was distributed almost continuously along 7–8 km of shore at depths ranging from the low intertidal to 5–7 m in Lambton Harbour, the main commercial region of Wellington Harbour (Hay and Luckens 1987; Hay 1988, 1990; Stapleton 1988). No oyster cultivation occurs in this area and the introduction was therefore thought to be in ballast water or as hull fouling.

A search of other New Zealand harbours in 1988 found the plant to be growing on wharf piles, retaining walls and moorings at the port of Timaru on the east coast of the New Zealand South Island. Local divers had observed the plant to be present for several years and suggested it may have been introduced into the area in the early 1980's when the hulls of Japanese fishing hulls that lay alongside Timaru wharves were first cleaned with high pressure hoses (Hay 1990).

Evidence was collected which suggested that *Undaria* was being spread in New Zealand by coastal shipping (Hay 1990). *Undaria* grows commonly on floating or suspended objects including the hulls of vessels where the plants usually grow at, or just below the waterline. Observations on vessels fouled with *Undaria* demonstrated that established plants could survive lengthy ocean voyages, hull cleaning and short term emersion, possibly in the form of germlings or at the microscopic gametophyte stage, and were most likely to establish on the hulls of vessels moored or laid up for extended periods rather than fast turn around vessels.

Undaria pinnatifida was first discovered in Australia in 1988 at Rheban, 10 km south of Triabunna, on

Tasmania's east coast (Sanderson 1988). Subsequent surveys found the plant to occur along 10 km of coastline, from Triabunna to Rheban, and anecdotal evidence suggested the plant had been in the area since at least 1982 (Sanderson 1990). Ships transporting woodchips from Triabunna to Japan are considered the most likely source for the introduction.

The first record of *Undaria* in Port Phillip Bay was reported more recently (Winkler 1996; Campbell and Burridge 1998). Immature plants were first discovered in July 1996 off Point Wilson, with mature, reproductive plants collected from the same area in the following month. Plants were generally restricted to hard or semi-consolidated substrates: rock, consolidated sediment, abalone and bivalve shells and encrusting algae. Some very small plants were attached to seagrass blades and unconsolidated large-grain sediments. Sporophytes were not found in January 1997.

Characters listed by Hay (1988) which have favoured the spread of *Undaria* are its weed-like behaviour, rapidly colonising new or disturbed substrates, its ability to produce spores through most of the year, and its propensity for colonising floating or suspended objects. *Undaria* can also tolerate a wide range of environmental conditions including wave exposure (sheltered marinas to the open coast), depth (low intertidal to 18 m deep) and irradiance (full sunlight to 5-6 m deep in silty harbour water) (Hay and Villouta 1993).

Related or morphologically similar species

Ecklonia radiata (C. Agardh) J. Agardh. Womersley 1987: 332, Figures 120, 121I–K, Plate 4 Figure 2.

Laminarian kelps can be distinguished from other large brown macroalgae by their much-divided holdfasts. Two families are represented in southern Australia: the Lessoniaceae (*Macrocystis* spp. and *Lessonia corrugata*) and the Alariaceae. Blades in the Lessoniaceae are deeply divided and several blades arise from a single holdfast, whereas in the Alariaceae the blades do not have deep longitudinal splits and only a single blade arise from a single holdfast. The only native species of the latter family is the common *Ecklonia radiata*. *Undaria pinnatifida* is easily distinguished by its flattened stipe extending into the blade as prominent midrib and in fertile plants by the lobed sporophylls that coil around the stipe.

Phylum Chlorophyta

Order Ulvales

Family Ulvaceae

Ulva fasciata Delile 1813: 297, pl. 58, fig. 5. — Womersley 1984: 146, Figures 46B, 47D–G. — Phillips 1988: 434, Figures 15–17. — Millar and Kraft 1993: 423.

Type

From Alexandria, Egypt.

First recorded collection in Port Phillip Bay

1978: Station Pier, Hobsons Bay (Northern Bay) (*Parish*, 2.ii.1978, MUCV 1328).

Port Phillip Bay distribution

Northern: (as above).

Australian distribution

Victoria: Port Phillip Bay (as above). Western Australia: Swan R. Estuary (Allender, 7.iii.1966, UWA A921); Fremantle (*Congdon*, 8.I.1982, MUCV 1578, 1579). South Australia: Wanna, near Port Lincoln (*Womersley*, 19.ii.1959, AD 22437, A22438); West Lakes (*MacFarlane*, 10.xi.1980, AD A51836). New South Wales: Byron Bay (*Phillips*, 5.vi.1980, MUCV 1575); Hastings Point (*Phillips*, 27.I.1979, MUCV 1576); Coffs Harbour (*Millar and* Huisman, 6.I.1981, MELU AM446, AM447); Tamarama Bay, Sydney (*King*, 28.iii.1984, UNSW 16116); Turimetta Head (*King*, 20.x.1976, UNSW 13873, AD A53995).

Extra-Australian distribution

Tropical and subtropical seas.

Description

Thallus divided to the basal region into three to many narrow, relatively flat, sometimes subdichotomously branched lacinae; margin sometimes dentate. Cells in surface view polygonal or quadrangular in shape, arranged in no observable order. Cells in transverse section rectangular throughout the thallus. Chloroplast parietal on the outer face of the cell wall, covering half to whole of the cell face in surface view. Pyrenoids one to four. [Phillips 1988]

Comments

With its disjunct distribution in the temperate waters of southern Australia, and collection only in the summer months in the vicinity of ports, Phillips (1988) considered *U. fasciata* to be a probable introduction to this region on shipping. Apparently it is a common species on the northern coastline of New South Wales, where it grows on the vertical faces of basalt boulders and in rock pools of the mid and lower intertidal zones in rough water localities.

Related or morphologically similar species

Ulva spp. Phillips 1988.

The linear thalli of *Ulva fasciata* distinguish it from *U. rigida* and *U. lactuca* which both have orbicular, ovate or lobed thalli. *U. stenophylla* and *U. laeteverens* can also have linear thalli. The former has deeply ruffled margins and, in transverse section, basal cells are bullet shaped; the latter has undulating margins and conical basal cells. *U. fasciata* has a relatively flat thallus and rectangular basal cells.

Order Cladophorales

Family Cladophoraceae

Cladophora prolifera (Roth) Kützing 1843: 271. —

van den Hoek 1963: 208, pl. 51, Figures 677–682, pl. 52. — van den Hoek and Womersley 1984: 193, Figures 62A, 63A,B.

Synonymy and taxonomy

Cladophora rugulosa Martens. Womersley 1956: 359. — King *et al.* 1971: 113.

Type

From the Mediterranean Sea.

First recorded collection in Port Phillip Bay

1964: Pt Nepean (Port Phillip Heads), upper littoral rock pool (*Ducker*, 5.iv.1964, MELU A1332).

Port Phillip Bay distribution

Eastern Bay: Beaumaris reef, growing on rocks (*T.P. Farrell*, 31.v.1968, MELU A4308); Mount Martha (*V. Boater*, 6.vii.1969, MELU A 4915). Port Phillip Heads: as above, also: Pt Lonsdale, low intertidal/upper subtidal flats and pools, dominant green (*Kraft and Millar*, 25.iii.1988, MELU K7823); Pope's Eye, common on southern side (*O'Brien*, 20.I.1976, MELU A23,076); The Rip, 16–23m deep along the sides of the channel off the quarantine station on Point Nepean (*Kraft, Saunders and Strachan*, 10.v.1995, MELU K10,662); Point Nepean, on sandy bottom in upper littoral rock pool on front beach (*Ducker*, 16.I.1970, MELU A4828).

Australian distribution

Victoria: Warranambool, mouth of Hopkins R., mid-littoral (*Adams*, 8.xii.1968, MELU A4165); Port Phillip Bay (as above); Sorrento, Koonya Beach, shaded intertidal pool (*Womersley*, 15.I.1974, AD A44661); Flinders, exposed and in low intertidal pools on Mushroom Reef (*Kraft and Botany 207 class*, 14.ii.1997, MELU K10,523). Western Australia: Rottnest I., lower littoral pools (*Cribb* in AD); Esperance, upper sublittoral pools (*Woelkerling*, 21.ix.1968, AD A33944). South Australia: Off St Kilda, 5 m deep (*R. Lewis*, 4.ix.1972, AD A42743); Granite I., Victor Harbour (*Womersley*, 16.iv.1976, AD A47202).

Extra-Australian distribution

Warm temperate Europe, Mediterranean, tropical Africa and America, Solomon Is., and New Zealand.

Description

Thallus dark green, sometimes light brown-green in lower eulittoral plants, forming dense spreading tufts to 15 cm high, with many stipes from a matted rhizoidal holdfast; filaments branched from almost every cell. Growth entirely acropetal with lateral branches arising usually from the subapical cell, and with one or commonly two (and then opposite) or occasionally three to five laterals (at acute angles) from each parent cell, less so in older parts. Basal and lower cells of stipes and older branches each producing a descending rhizoid which may branch; lower branch cells often with annular constrictions over the lower 0.2-0.5 of their length.

Apical cells cylindrical with rounded to slightly tapering tips (70–) 100–220 mm in diameter, L/B 3–13; ultimate branch cells of similar diameter, L/B 2.5–13; basal stipe cells slightly clavate, 350–420 mm in maximum diameter, L/B 5–22, sometimes tapering into a rhizoid; ratio of basal cell to apical cell diameters 1.5–3 (–5) in plants with narrow apical cells); cell walls relatively thin near apex (3–6 mm), below 10–12 mm thick and 20–30 mm thick near base. [van den Hoek and Womersley 1984]

Comments

Womersley (1956) considers a collection from Rottnest Island, identified as *C. rugulosa*, to be the first Australian record of this species. The first published records of the species occurring in Port Phillip Bay are those of King *et al.* (1971) who refer to the specimens in MELU from Pt Nepean, Beaumaris and Mt Martha. The species is well established in the Port Phillips Heads region and is commonly found intertidally and subtidally on the exposed sandstone rock platforms on both sides of the Heads.

The occurrence of *Cladophora prolifera* has been linked with that of the introduced opisthobranch *Aplysiopsis formosa*, considered to be an introduction from the North Atlantic/Mediterranean (Fuhrer 1981; see Chapter 9). The local distribution of this algae differs to that of many other recognized introductions in that it has colonized and is locally abundant on exposed coastal rock platforms and in deep water, such as around Port Phillip Heads. However, these locations are close to international shipping lanes and shipping must be considered a potential vector for the species' introduction. Vegetative characteristics of the plant conducive to transport in this way are the filamentous thallus and rhizoidal holdfast.

Related or morphologically similar species

Cladophora spp. van den Hoek and Womersley 1984. *Cladophora prolifera* is classified in Section Longiarticulatae, species of which are characterised by the basal and lower cells being many times longer than apical cells. Two other southern Australian species, *C. bainesii* and *C. feredayi* also belong in this section. *C. prolifera* differs to these species in its dark, rather than light to medium green colour and in having apical cells mostly over 100 mm in diameter. Annular constrictions are also absent from lower cells of the other two species.

Order Codiales

Family Codiaceae

Codium fragile (Suringar) Hariot ssp. ***tomentosoides*** (van Goor) Silva 1955: 567, text-Figures 2, 3. — Adams 1994: 47, Plate 13. — Furlani 1996.

Synonymy and taxonomy

Codium mucronatum J. Agardh var. *tomentosoides* van Goor 1923: 134, Figure 1c.

Type

From Huisduinen, The Netherlands.

First recorded collection in Port Phillip Bay

1997: Corio Bay (36°6685S 144°2335E), in trawl (*Parry*, 25.ii.1997, MELU L2882).

Port Phillip Bay distribution

Corio Bay (as above).

Australian distribution

Victoria: Port Phillip Bay (as above); Corner Inlet (*R. Williams*, June 1995, MELU A042537, A042538; *AHG 8120 400 130*, 8.x.1996, MELU L2876); Newhaven, Western Port Bay (*Campbell*, 4.iii.1998, MELU L2883). Tasmania: North West Bay, D'Entrecasteaux Channel (C Trowbridge pers. comm.).

Extra Australian distribution

Japan, western Europe, Scandinavia, North West Atlantic and New Zealand.

Description

Thallus of one to several erect robust fronds arising from broad, spongy, basal disc; fronds 15–25 (–50) cm high, dichotomously branched, branches terete (at times flattened at base), tapering from base to apex. Utricles irregularly cylindrical or more often clavate, frequently with broad constriction at or just below middle, (105–) 165–325 (–400) mm max. Diam., 550–1050 mm long, usually 2.5–5.5 x long as broad; apices rounded-apiculate; wall of utricle approx. 1.5 mm thick, thicker at apex (–12 mm), prolonging point into mucron up to 68 mm long. Hairs (or hair scars) common, one or two per utricle, borne 160–260 mm below apex. Gametangia ovoid, oblong, or fusiform, 72–92 mm diam., 260–330 mm long, one or two per utricle, each borne on protuberance near middle of utricle (415–560 mm below apex). Medullary filaments mostly 26–68 mm diam. [Silva 1955]

Comments

Silva (1955) considered that both *Codium fragile* ssp. *atlanticum* and *Codium fragile* ssp. *tomentosoides* were most likely introduced to Europe from the Pacific within historical time. While collections of ssp. *atlanticum* are known from the early 1800's, ssp. *tomentosoides* appears a more recent invader, being first collected in Holland in 1900, Denmark in 1920, Sweden in 1938, England in 1939, Atlantic France in 1946 and Norway in 1952. Silva considered the most likely place of origin to be Japan. The subsequent spread of ssp. *tomentosoides* to the north east coast of North America has been variously attributed to accidental importation with seed oysters (Wood 1962; Taylor 1967) or on the hulls of European freighters (Loosanoff 1975). *Codium fragile* ssp. *tomentosoides* was first recorded from the west coast of North America, in San Francisco Bay, by Silva in 1979.

Scattered small plants of *Codium fragile* ssp. *tomentosoides* were first found in New Zealand in 1973 on the seawall of a newly constructed container terminal in Auckland Harbour (Dromgoole 1975). Twelve months later plants had spread extensively over a distance of 70 m and over the next 5 years spread to other locations in the lower reaches of the Hauraki Gulf (Dromgoole 1979). By 1993 the plant was distributed widely in Hauraki Gulf and had also spread to wave protected shores as far north as the Bay of Islands and southward to Taurangi Harbour (Trowbridge 1995).

The rapid growth and spread of the plants and the high population densities observed by Dromgoole were not considered characteristic of the native form, and reflected the ability of this subspecies to perennate from persistent bases, to regenerate from plant fragments or even isolated utricles (Ramus 1972), and to develop asexually from released swarmers. Wherever studied, the populations have been shown to be solely female, with the female gametes capable of parthenogenetic development (Silva 1979). The percentage of swarmers which develop into filaments was also found to be high (Dromgoole 1979).

Silva (1979) considered *Codium fragile* ssp. *tomentosoides* to be a weed in the sociological sense of a plant that grows rankly in unwanted places. This "weediness" he attributed to its broad physiological tolerance and unusually great reproductive capacity.

Dromgoole (1975) considered the subspecies' ability to tolerate a wide range of light and temperature conditions and its ability to grow on many substrates as conducive to its transport on shipping and considered this to be the most likely means of introduction to New Zealand waters. Dromgoole subsequently (1979) listed the features that he considered made *Codium fragile* ssp. *tomentosoides* eminently suitable for carriage on shipping. These were:

- its ability to colonise floating substrates which are imperfectly coated with antifouling paints (e.g. marina pontoons, navigation buoys);
- its ability to colonise substrates with little surface relief; and
- its perennial basal holdfast which would allow plants to survive the hydrodynamic stress of a transoceanic voyage.

Codium fragile ssp. *tomentosoides* can also grow in an undifferentiated "vaucherioid" stage that is known from many hard substrata, including rocks, rafts, macroalgae, barnacles, gastropods, and bivalves (Trowbridge 1998). This juvenile stage may also facilitate transport on ship hulls.

Trowbridge (1995) predicted that, because the introduction of ssp. *tomentosoides* to New Zealand signified its inadvertent dispersal across the equatorial region, which often acts as a barrier for temperate zone species, the alga could readily spread to Australia, South America and South Africa. Discovery of the alga in Victoria and Tasmania has proven this true. The broad temperature tolerance of the species suggests that the alga could spread widely through wave-protected bays and harbours in both New Zealand and Australia. However, monitoring this spread may be complex given the moderate to dense populations of the morphologically-similar native ssp. *novae-zelandiae* in many Australian and New Zealand harbours (Trowbridge 1995, 1996).

Trowbridge (1998) reviews aspects of the morphology, physiology and ecology of invasive and non-invasive subspecies of *Codium fragile*. The primary vectors for spread of ssp. *tomentosoides* is considered to be shellfish and ship hulls. Ballast water introductions are considered highly unlikely given the short duration of gametes (< 1 day).

Related or morphologically similar species

Codium fragile ssp. *tasmanicum* (J.Agardh) Silva. Womersley 1984: 238, Figure 80D;

Codium fragile ssp. *novae-zelandiae* (J.Agardh) Silva. — Womersley 1984: 238, Figure 80E;

Codium galeatum J. Agardh. Womersley 1984: 235, Figures 77E, 78F;

Codium duthieae Silva. Womersley 1984: 235, Figures 77F, 78G;

Codium harveyi Silva. Womersley 1984: 236, Figures 79A, 80A;

Codium muelleri Kuetzing. Womersley 1984: 236, Figures 79B, 80B;

Codium australicum Silva. Womersley 1984: 238, Figures 79C, 80C.

Of the above erect, dichotomously branched *Codium* species found in southeastern Australia, only *Codium fragile* has mucronate utricles. The two native subspecies differ to ssp. *tomentosoides* in having narrow, cylindrical utricles mostly longer than 1 mm and without the constriction often characteristic of utricles in the adventive subspecies.

6.3 MACROALGAE CONSIDERED TO BE POSSIBLE INTRODUCTIONS TO SOUTHERN AUSTRALIA BUT AS YET NOT RECORDED IN PORT PHILLIP BAY

Phylum Rhodophyta

Order Ceramiales

Family Ceramiaceae

Antithamnion cruciatum (C. Agardh) Nägeli 1847: 200. — Athanasiadis 1996: 168, Figure 81. — Womersley 1998: 117, Figure 51.

Type

From Trieste, Italy.

Australian distribution

South Australia: Whyalla, in channel with tidal flow, 0.5 m deep (*Harbison*, 10.v.1994, AD A63545).

Extra-Australian distribution

Widespread in temperate Atlantic and European waters.

Description

Thallus filamentous, ecorticate, medium to dark red-brown, densely tufted, 5–25 mm high, with limited prostrate axes bearing much branched erect axes with opposite, decussate, laxly branched whorl branchlets. Attachment by rhizoids with digitate multicellular haptera, arising from basal cells of whorl branchlets; epilithic. Apical cells 6–12 μm in diameter, with densely tufted apices, enlarging to mature axial cells 60-110 μm in diameter. Whorl-branchlets 700–1200 μm and 14–20 cells long, with opposite or unilateral, mostly erect, pinnules 200–500 μm long, pinnules simple or occasionally with a short gland cell bearing branch; gland cells borne on short 2–4-celled branches on the pinnules, alongside 2 or 3 pinnule cells, ovoid when mature. Lateral branches arising on basal cells of whorl-branchlets. Tetrasporangia pedicellate. [Womersley 1998]

Comments

Womersley found these plants, sampled several times in 1994 from a single population, to agree well with descriptions of *A. cruciatum* from Europe, and the identification was supported by Dr C Maggs. Whyalla is an industrial port and the species is considered by Womersley to most likely be adventive.

Related or morphologically similar species

Antithamnion spp. Womersley 1998: 99 *et seq*.

Womersley (1998) describes 10 other species of *Antithamnion* from southern Australia. *A. cruciatum* is characterised by having decussately arranged whorl branchlets, densely branched with relatively lax pinnae and terminal cells with rounded ends, the pinnules opposite below, often unilateral above, and separated on the rachis. Tetrasporangia are pedicellate. *Antithamnion* differs to other genera of the Antithamnieae in having whorl-branchlets in single pairs per axial cell, and gland cells on short 2–4 celled lateral branches on pinnules.

Phylum Phaeophyta

Order Chordariales

Family Elachistaceae

Elachista orbicularis (Ohta) Skinner 1983: 98, Figures 1–3; 1985: 155. — Womersley 1987: 78, Figure 21 A–C.

Synonymy and taxonomy

Gonodia orbicularis Ohta.

Type

From Tappi, Aomori Pref., Japan.

Australian distribution

Western Australia: King Head, Rottnest Island, 3–4 m deep (*Engler and* Clarke, 6.ix.1979, AD A50841).

South Australia: Port Noarlunga, drift (*Skinner and Thomas*, 28.v.1976, AD A47215); Rosetta Bay, Victor Harbour, 5–6 m deep (*Clarke and Engler*, 20.iii.1979, AD A50315). New South Wales: Garie Beach, Royal National Park (*King*, 27.iv.1983, AD, A54928).

Extra-Australian distribution

Japan.

Description

Thallus dark brown, tufted, with a pulvinate base surmounted by long, free exserted filaments, 2–8 mm across and high, epiphytic on *Ecklonia radiata*. Basal layer of radiating, closely adjacent filaments, more or less circular, sometimes with short projections between the host cells. Medulllary filaments arising from each cell of the basal layer, of two types: subdichotomous filaments producing determinate cortical filaments and sporangia, and unbranched filaments which continue as long assimilatory filaments. [Womersley 1987]

Comments

This tufted filamentous alga is found in Australia as an epiphyte on *Ecklonia radiata*. Womersley remarks that *E. orbicularis* is common on *Ecklonia* at the cited localities in South Australia throughout the year, but has not been observed on herbarium sheets of *Ecklonia* collected before 1976. It is therefore considered a likely introduction from Japan, where it grows on *Undaria*.

Related or morphologically similar species

Elachista claytoniae Skinner. Womersley 1987: 78, Figure 21D-G;

Elachista australis J Agardh. Womersley 1987: 80, Figures 22, 27A.

E. orbicularis differs to the other species of the genus found in southern Australia in having long, unbranched assimilatory filaments and the plurilocular sporangia borne on separate, shorter branched filaments.

Order Sphacelariales

Family Choristocarpaceae

Discosporangium mesarthrocarpum (Meneghini) Hauck 1885: 525, Figure 236. — Womersley 1987: 146, Figures 45A, 46A–E.

Type

From Dalmatia, Adriatic Sea.

Australian distribution

South Australia: off Grange, 20 m deep on *Micropeuce* growing on artificial tyre reef (*Branden*, 7.iii.1985, AD A56425); off Glenelg, 18 m deep on tyres and epiphytic (*Reimers*, 17.vi.1986, AD A57123; *Branden*, 20.v.1987, AD A57486).

Extra-Australian distribution

Adriatic and Gulf of Naples, Mediterranean.

Description

Thallus greenish-brown, 3–15(–40) mm long, tufted and fastigiate, slightly to moderately branched irregularly laterally and usually several cells apart, with branches originating just below the cross wall. Growth apical, with the apical of similar size to lower cells. Filaments slender, (14–)16–25 mm in diameter, uniseriate, not tapering. Reproduction by sessile, plate-like plurilocular sporangia attached laterally to lower filaments. [Womersley 1987]

Comments

Prior to the South Australian collections, the monospecific genus *Discosporangium* was only known from the Mediterranean Sea. The deep-water collection sites are unusual for adventives introduced on shipping. However the proximity of the sites to a major port and the association of the alga with artificial substrata, in this case tyre reefs, points to a possible link to shipping. Plants agreeing well with *Sphacella subtilissima* Reinke, another deep water brown alga previously known only from the Mediterranean, have also been collected in South Australian water (Womersley 1987, 1990). However, the collection localities off Pearson Island and in the Investigator Strait makes any link with international shipping seem tenuous.

Related and morphologically similar species

Sphacella subtilissima Reinke. Womersley 1987: 148, Figures 45B, 46F–H;

Sphacelaria spp. Womersley 1987: 150 *et seq.*

Discosporangium differs to species of *Sphacella* and *Sphacelaria* in the absence of subdivision of the subapical cells. Cells in *Sphacelaria* also divide longitudinally. The sessile, plate-like sporangia are particularly characteristic of *Discosporangium.*

Order Desmarestiales

Family Arthrocladiaceae

Arthrocladia villosa (Hudson) Duby 1832: 18. — Skinner and Womersley 1983: 65, Figures 1C, 3. — Womersley 1987: 266, Figures 94C, 96F–H.

Type

From Cornwall, England.

Australian distribution

South Australia: Port Stanvac, 4–5 m deep, but not attached (*Clarke*, 28.xii.1981, AD A52837).

Extra-Australian distribution

Temperate N Atlantic and Mediterranean.

Description

Thallus medium brown, 15–20 cm long, filiform, slender, with long simple branches. Structure of a distinct axial filament surrounded by a large-celled medulla and outer small-celled cortex bearing whorled fascicles of filaments. Growth trichothallic at base of a single filament terminating each branch. Fronds terete, largely oppositely branched, 0.5–1 mm thick below, tapering slightly to 0.1–0.2 mm thick near the apices, bearing more or less whorled, determinate fascicles 0.4–2(–3) mm long, giving the branches a fuzzy appearance. [Womersley 1987]

Comments

This species is only known from a single collection in 1981, when a number of plants were present (Womersley 1987). The plant is considered to have possibly arrived on ships visiting the Port Stanvac Oil Refinery, but was unable to establish in the area. The gametophyte of *Arthrocladia* is filamentous and microscopic, possibly facilitating ship-borne transport.

Related or morphologically similar species

Desmarestia ligulata (Lightfoot) Lamouroux. Womersley 1987: 264, Figures 94B, 96A–E.

The most closely related species to *Arthrocladia villosa* in southern Australia is *Desmarestia ligulata*. The Arthrocladiaceae differs to the Desmarestiaceae in having laterals in whorls of four, not opposite, and sporangia in moniliform chains on branched filaments instead of in or on the thallus surface.

Order Dictyosiphonales

Family Striariaceae

Striaria attenuata Greville 1828: synop. 44. — Skinner and Womersley 1983: 60, Figures 1A, 2A–F. — Womersley 1987: 312, Figures 109B, 113A–D. — Nelson and Maggs 1996: 451, Figure 3.

Type

From the Isle of Bute, Scotland.

Australian distribution

South Australia: West Lakes, Adelaide, 1 m deep (Steffenson, 20.x.1978, AD A49759). New South Wales: Pambula, in mangrove swamp (*King and Wheeler*, 28.ix.1983, UNSW 15243, AD A54426). Tasmania: Southport, on jetty piles (*Cribb*, 23.ix.1950, AD A16249); Coles Bay, uppermost sublittoral on *Caulocystis cephalornithos* (Womersley, 19.x.1986, AD A57213).

Extra-Australian distribution

Temperate N Atlantic, southern New Zealand, South America and Japan.

Description

Thallus light to medium brown, 10–15(–30) cm high, much branched irregularly radially to oppositely, branches terete, basally constricted, and tapering gradually to their apices; attachment by a small discoid holdfast. Growth of terminal filament trichothallic, with diffuse growth below the uniseriate apex. [Womersley 1987]

Comments

Womersley (1987) suggests that *S. attenuata* may be an introduction to southern Australia which may not have yet established itself at the collection localities. Again, *Striaria* has a microscopic, filamentous gametophyte that may have facilitated ship-borne transport. In New Zealand the species is known from Otago Harbour and Stewart Island and more recently has been found growing subtidally near an old ship slipway in Wellington Harbour (Nelson and Maggs 1996).

Related or morphologically similar species

Stictyosiphon soriferus (Reinke) Rosenvinge. Womersley 1987: 314, Figures 109C, 113E–J.

As discussed under *Stictyosiphon* both this species and *Striaria* have slender cylindrical thalli with polystichous branches tipped by terminal uniseriate filaments. *Striaria* differs in having branches, which become hollow and a medulla only 1(–2) cell(s) thick, unlike *Stictyosiphon* in which the branches remain solid with a medulla of four large cells in sectional view.

Phylum Chrysophyta

Order Vaucheriales

Family Vaucheriaceae

Vaucheria piloboloides Thuret 1854: 389. — Womersley 1987: 452, Figure 169F.

Type

From Saint-Vaast-La Houge, Normandy, France.

Australian distribution

South Australia: O'Sullivan Beach, just south of Port Stanvac, 2 m deep in harbour, epiphytic and on detritus (*Cannon*, 18.ix.1986, AD A57155).

Extra-Australian distribution

Widespread in temperate seas.

Description

Thallus medium to dark green, forming loose tufts on detritus or epiphytic, with erect filaments above. Filaments sparingly branched, 45–90 mm in diameter, coenocytic. Monoecious, with the sex organs on adjacent branches of erect filaments, the antheridia below the oogonia. [Womersley 1987]

Comments

In southern Australia, this species of *Vaucheria* is only known from the harbour at O'Sullivan Beach, just south of Port Stanvac, and Womersley (1987) therefore considers the species a possible adventive.

Related or morphologically similar species

Vaucheria spp. Womersley 1987: 449; Entwisle 1988.

V. piloboloides differs to other species of *Vaucheria* in having antheridia subtended by a basal, empty cell and monoecious thalli with oogonia and antheridia adjacent on vegetative filaments.

Phylum Chrysophyta

Order Caulerpales

Family Caulerpaceae

Caulerpa filiformis (Suhr) Hering 1841: 91. — Papenfuss 1940: 201, Figure 2. — May 1976: 137, pl. 11. — Millar and Kraft 1993: 437. — Furlani 1996. — Edgar 1997: 37 (illustr.).

Synonymy and taxonomy

Amphibolis filiformis Suhr;

Caulerpa ligulata Harvey *ex* J. Agardh;
Caulerpa flagelliformis forma *ligulata* Weber van Bosse.

Type

From Algon Bay, Cape Province, South Africa.

Australian distribution

New South Wales: Collaroy, Port Jackson and Botany Bay.

Extra-Australian distribution

South Africa.

Description

Thallus with a creeping rhizome bearing dense, erect fronds 30 cm or more in height. Fronds elongate, flat, glabrous, sparingly dichotomously branched; petiole of fronds somewhat terete, annulate; apical tips truncate or somewhat obtuse. [De Toni 1889: 447]

Comments

This species appears to have a very localised distribution and May (1976) reports a marked increase in abundance of the species over a comparatively short period of time. She considered that this may reflect either spread of the species after introduction, or a response to local increased pollution.

The habit and life history of *Caulerpa* species do not appear conducive to transoceanic transport on ship hulls. The spread of *Caulerpa taxifolia* in the Mediterranean was attributed to the plant's ability to regenerate from small fragments and resist emersion for extended periods in damp conditions such as found in anchor lockers. Similar characteristics in *C. filiformis* may have facilitated its introduction to eastern Australia.

Related or morphologically similar species

Caulerpa spp. Womersley 1984: 254.
The linear, strap-like fronds of *C. filiformis* distinguish this species from other southern Australian *Caulerpa* spp.

6.4 MACROALGAE IN PORT PHILLIP BAY WITH COSMOPOLITAN DISTRIBUTIONS WHICH ARE POSSIBLE INTRODUCTIONS

Phylum Rhodophyta
Class Bangiophyceae
Order Porphyridiales
Family Porphyridiaceae

Stylonema alsidii (Zanardini) Drew 1956: 72. — Womersley 1994: 24, Figure 1D, E.

Type

From the Adriatic Sea.

Port Phillip Bay distribution

Northern: Lewis 1977: 215 (as *Goniotrichum elegans*). O'Brien 1981: 186 (as *G. elegans*).

Distribution

Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Virtually cosmopolitan.

Order Compsopogonales
Family Erythrotrichiaceae

Erythrotrichia carnea (Dillwyn) J. Agardh 1883: 15. — Womersley 1994: 28, Figure 2A–D.

Type

From Wales.

Port Phillip Bay distribution

Southwestern: Womersley 1994: 28.

Distribution

Australia: WA, SA, Vic, NSW and Qld.
Elsewhere: Cosmopolitan.

Order Bangiales
Family Bangiaceae

Bangia atropurpurea (Roth) C. Agardh 1824: 76. — Fletcher 1980: 46, Pl. 18 Figures 1–3. — Womersley 1994: 34, Figure 3D–H.

Type

From Bremen, Germany.

Port Phillip Bay distribution

Northern, Corio, Port Phillip Heads: (as *Bangia fuscopurpurea*) King *et al.* 1971: 120. Lewis 1977: 215. O'Brien 1981: 186.

Distribution

Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Cosmopolitan.

Class Florideophyceae
Order Acrochaetiales
Family Acrochaetiaceae

Audouinella simplex (Drew) Garbary *et al.* 1983: 51, Figure 21. — Woelkerling and Womersley 1994: 50, Figure 8D–J.

Type

From Santa Monica, California.

Port Phillip Bay distribution

Northern: (as *A. pectinata*) Lewis 1977: 216; 1983: 261. O'Brien 1981: 186.

Distribution

Australia: SA and Vic.
Elsewhere: Pacific coast of North America; and ?South Africa.

Audouinella pacifica (Kylin) Garbary 1979: 490. — Woelkerling and Womersley 1994: 58, Figure 11E–I.

Type

From Puget Sound, Washington.

Port Phillip Bay distribution

Northern: (as *Colaconema pacificum*) O'Brien 1981: 186.

Distribution

Australia: WA, SA, Vic and NSW.
Elsewhere: Pacific coast of North America.

Order Nemaliales
Family Liagoraceae

Nemalion helminthoides (Velley) Batters 1902: 59. — Womersley 1994: 78, Figures 18A, B, 19A–F.

Type
From Portland, England.
Port Phillip Bay distribution
Eastern, Port Phillip Heads: King *et al.* 1971: 120.
Distribution
Australia: SA, Vic, Tas and NSW.
Elsewhere: Widespread in temperate waters.

Order Gelidiales
Family Gelidiaceae

Gelidium pusillum (Stackhouse) Le Jolis 1863: 139. — Womersley and Guiry 1994: 133, Figures 35E, 39E–K.
Type
From Sidmouth, England.
Port Phillip Bay distribution
Northern, Eastern, Corio, Port Phillip Heads: King *et al.* 1971; 120. O'Brien 1981: 186.
Distribution
Australia: WA, SA, Vic, Tas and NSW.
Elsewhere: Cosmopolitan.

Pterocladia capillacea (S.G. Gmelin) Bornet *in* Bornet and Thuret 1876: 57, pl. 20 Figures 1–7. — Womersley and Guiry 1994: 139, Figures 40C, 41F–J.
Type
From the Mediterranean.
Port Phillip Bay distribution
Northern, Port Phillip Heads: Womersley 1966: 145. King *et al.* 1971: 120. O'Brien 1981: 186.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread on temperate and sub-tropical coasts.

Order Hildenbrandiales
Family Hildenbrandiaceae

Hildenbrandia rubra (Sommerfelt) Meneghini 1841: 10. — Womersley 1994: 143, Figure 42A.
Type
From Venice, Italy.
Port Phillip Bay distribution
Northern: (as *H. prototypus*) O'Brien 1981: 187.
Distribution
Australia: SA and Vic.
Elsewhere: Widespread in temperate and tropical waters.

Hildenbrandia occidentalis var. ***yessoensis*** (Yendo) Ardré 1959: 227.
Type
From Japan.
Port Phillip Bay distribution
Northern: O'Brien 1981: 187.
Distribution
Australia: Vic.
Elsewhere: Japan and Portugal.

Order Gigartinales
Family Peyssonneliaceae

Peyssonnelia conchicola Piccone and Grunow in Piccone 1884: 317, pl. VII, Figures 5–8. — Cribb 1983: 40, Plate 9, Figure 3.
Type
From Massawa, Ethiopia.
Port Phillip Bay distribution
Northern: O'Brien 1981: 187.
Distribution
Australia: Vic and Qld.
Elsewhere: Red Sea, Tropical Indo-West Pacific and West Indies.

Order Ceramiales
Family Ceramiaceae

Gymnothamion elegans (Schousboe *ex* C. Agardh) J. Agardh 1892: 28, pl. 1 Figures 11–14. — Millar and Kraft 1993: 41. — Womersley 1998: 130, Figure 57B–E.
Type
From Tangier, Morocco.
Port Phillip Bay distribution
Port Phillip Heads: Millar and Kraft 1993: 41. — Womersley 1998: 130.
Distribution
Australia: Vic and Tas.
Elsewhere: Widespread in warmer seas.

Antithamnionella ternifolia (Hooker and Harvey) Lyle 1922: 350. — Maggs and Hommersand 1993: 19, Figure 6. — Athanasiadis 1996: 128, Figure 61. — Nelson and Maggs 1996: 451, Figure 4A–D. — Womersley 1998: 166, Figures 76, 77A, B, 78A–I.
Type
From St Martin's Cove, Cape Horn, Chile.
Port Phillip Bay distribution
Northern: (as *Antithamnionella tasmanica*) Lewis 1977: 217; 1983: 262. — O'Brien 1981: 188.
Distribution
Australia: WA, SA, Vic, Tas and NSW.
Elsewhere: Europe, South Africa, New Zealand, Macquarie Is., and South America.

Centroceras clavulatum (C. Agardh) Montagne 1846: 140. — Price and Scott 1992: 81, Figure 25A–E. — Adams 1994: 276, Plate 96.
Type
From Callao, Peru.
Port Phillip Bay distribution
Northern, Corio Bay, Port Phillip Heads: King *et al.* 1971: 123. — Lewis 1977: 218. — O'Brien 1981: 188.
Distribution
Australia: WA, SA, Vic, Tas, NSW, Qld and NT.
Elsewhere: Widespread in temperate and tropical waters.

Ceramium flaccidum (Kützing) Ardissone 1871: 40. — Womersley 1978: 234, Figures 4A–D, 14E–H. — Womersley 1998: 410, Figures 188E–H, 190A–D.

Type

From Kilkee, Co. Clare, Ireland.

Port Phillip Bay distribution

Northern: O'Brien 1981: 188.

Distribution

Australia: WA, SA, Vic, Tas and NSW.

Elsewhere: Widespread in cold temperate to tropical seas.

Ceramium rubrum (Hudson) C. Agardh 1811: 17. — Fletcher 1980: 49, Pl. 21 Figures 1–4. — Womersley 1979: 217, Figures 2A, 7. — Womersley 1998: 389, Plate 2 Figure 3, Figures 179, 182A.

Type

From Britain.

Port Phillip Bay distribution

Northern: O'Brien 1981: 188.

Distribution

Australia: WA, SA, Vic and Tas.

Elsewhere: Widespread in temperate seas, especially in the Northern Atlantic.

Family Rhodomelaceae

Polysiphonia subtilissima Montagne 1840: 199. — Womersley 1979: 469, Figure 2f–i.

Type

From Cadiz, Spain.

Port Phillip Bay distribution

Northern, Corio: Lewis 1983: 262. Womersley 1979: 469.

Distribution

Australia: SA, Vic, Tas and NSW.

Elsewhere: Tropical and subtropical Pacific coasts of America; and Hawaii.

Phylum Phaeophyta

Order Ectocarpales

Family Ectocarpaceae

Acinetospora crinita (Carmichael) Kornmann 1953: 205. — Fletcher 1980: 37, pl. 10 Figures 1–3. — Womersley 1987: 46, figs 10A, 11A–E.

Type

From Appin, Scotland.

Port Phillip Bay distribution

Eastern, Corio, Southern, Port Phillip Heads: King *et al.* 1971: 115. Clayton 1974: 749.

Distribution

Australia: SA, Vic and NSW.

Elsewhere: Europe, western North Atlantic, Japan.

Ectocarpus siliculosus (Dillwyn) Lyngbye 1819: 131, Pl. 43B,C. — Fletcher 1980: 38, pl. 11 Figures 1–4. — Womersley 1987: 33, Figures 2D, 5A–E.

Type

From England.

Port Phillip Bay distribution

Northern, Eastern, Southern, Port Phillip Heads: Womersley 1966: 139 (as *E. confervoides*). King *et al.* 1971: 115. Lewis 1977: 213; 1983: 261. O'Brien 1981: 184.

Distribution

Australia: WA, SA, Vic, Tas, NSW and Qld.

Elsewhere: Widespread in tropical and temperate seas.

Ectocarpus fasciculatus Harvey 1841: 40. — Fletcher 1980: 38, pl. 11 Figures 5–6. — Womersley 1987: 34, Figures 2E, 5F–I.

Type

From Britain.

Port Phillip Bay distribution

Eastern, Port Phillip Heads: King *et al.* 1971: 115.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Widespread in temperate and colder waters.

Feldmannia globifera (Kützing) Hamel 1939: xvii, Figure 61G. — Fletcher 1980: 37, pl. 10 Figures 4–6. — Womersley 1987: 43, Figures 6F, 9A–D.

Type

From Spalato (Split), Yugoslavia.

Port Phillip Bay distribution

Northern, Eastern, Southern: Womersley 1966: 139. King *et al.* 1971: 115. Lewis 1977: 213.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Widespread in temperate seas.

Feldmannia irregularis (Kützing) Hamel 1939: xvii, Figure 61F. — Womersley 1987: 42, Figures 6D, 8A–C.

Type

From the Adriatic Sea.

Port Phillip Bay distribution

Eastern, Southwestern, Corio, Port Phillip Heads (as *Giffordia irregularis*): King *et al.* 1971: 115. Clayton 1974: 777.

Distribution

Australia: WA, SA, Vic, NSW and Qld.

Elsewhere: Widespread in temperate seas.

Feldmannia lebelii (Crouan and Crouan) Hamel 1939: xvii. — Womersley 1987: 44, Figure 9E–J.

Type

From Brest, France.

Port Phillip Bay distribution

Port Phillip Heads: King *et al.* 1971: 115.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Europe and the Mediterranean.

Hincksia granulosa (J E Smith) Silva 1987: 130. — Fletcher 1980: 39, pl. 12 Figures 1–3 (as *Giffordia* *granulosa*). — Womersley 1987: 54, Figures 10E, 13A–D (as *G. granulosa*).

Type

From England.

Port Phillip Bay distribution

Northern, Eastern, Corio, Port Phillip Heads (as *G. granulosa*): King *et al.* 1971: 115. Clayton 1974: 771. Lewis 1977: 213; 1983: 261.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Widespread in temperate seas.

Hincksia mitchellae (Harvey) Silva 1987: 130. — Fletcher 1980: 40, pl. 13 Figures 5–6 (as *Giffordia mitchellae*). — Womersley 1987: 52, Figures 10D, 12E–G 6 (as *G. mitchellae*).

Type

From Nantucket, Massachusetts.

Port Phillip Bay distribution

Northern, Eastern, Port Phillip Heads (*as G. mitchellae*): King *et al.* 1971: 115. Clayton 1974: 779. Lewis 1977: 213; 1983: 261. O'Brien 1981: 184.

Distribution

Australia: WA, SA, Vic, Tas, NSW and Qld.

Elsewhere: Widespread in temperate and tropical seas.

Hincksia ovata (Kjellmann) Silva 1987: 130. — Womersley 1987, 54, Figures 14A–C (as *Giffordia ovata*).

Type

From the Swedish west coast.

Port Phillip Bay distribution

Northern, Eastern (*as G. fuscata* or *G. intermedia*): King *et al.* 1971: 115. Clayton 1974: 767. Lewis 1977: 213; 1983: 261.

Distribution

Australia: Vic.

Elsewhere: Northern cold temperate to subarctic waters.

Hincksia sandriana (Zanardini) Silva 1987: 130. — Fletcher 1980: 40, pl. 13 Figures 1–4 (as *Giffordia sandriana*). — Womersley 1987: 50, Figures 10C, 12A–D (as *G. sandriana*).

Type

From the Adriatic Sea.

Port Phillip Bay distribution

Northern, Eastern (as *G. sandriana*): King *et al.* 1971: 116. Clayton 1974: 782. Lewis 1977: 213; 1983: 261. O'Brien 1981: 184.

Distribution

Australia: SA, Vic and NSW.

Elsewhere: Widespread in temperate seas.

Kuckuckia spinosa (Kuetzing) Kuckuck 1958: 172, Figures 1–4. — Womersley 1987: 32, Figures 2C, 4D–I.

Type

From Spalato, Italy.

Port Phillip Bay distribution

Eastern, Corio: King *et al.* 1971: 116. Clayton 1974: 794.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Mediterranean.

Pilayella littoralis (Linnaeus) Kjellman 1872: 99. — Fletcher 1980: 40, pl. 14 Figures 1–3. — Womersley 1987: 38, Figures 6C, 7G–I.

Type

From Europe.

Port Phillip Bay distribution

Eastern, Corio: King *et al.* 1971: 116. Clayton 1974: 798.

Distribution

Australia: SA, Vic, Tas and NSW.

Elsewhere: Widespread in temperate and cooler seas.

Order Chordariales

Family Myrionemataceae

Myrionema strangulans Greville 1827: pl. 300. — Womersley 1987: 62, Figures 15A, 16A–C.

Type

From Appin, Scotland.

Port Phillip Bay distribution

Southwestern, Corio, Port Phillip Heads: King *et al.* 1971: 117.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Widespread in temperate seas.

Family Leathesiaceae

Petrospongium rugosum (Okamura) Setchell and Gardner 1924: 12. — Womersley 1987: 100, Figures 29A–C.

Type

From Japan.

Port Phillip Bay distribution

Port Phillip Heads: King *et al.* 1971: 117.

Distribution

Australia: Vic and NSW.

Elsewhere: Japan, North East Pacific and New Zealand.

Leathesia difformis (Linnaeus) Areschoug 1847: 376. — Womersley 1987: 102, Figures 27C, 29D–F.

Type

From Sweden.

Port Phillip Bay distribution

Port Phillip Heads: King *et al.* 1971: 117.

Distribution

Australia: SA, Vic, Tas and NSW.

Elsewhere: Widespread in cool temperate seas.

Order Sphacelariales

Family Sphacelariaceae

Sphacelaria fusca (Hudson) Gray 1821: 333. — Womersley 1987: 168, Figures 51E, 54H–J.

Type

From Sidmouth, England.

Port Phillip Bay distribution
Northern: Lewis 1977: 214; 1983: 261. — O'Brien 1981: 184.
Distribution
Australia: WA, SA and Vic.
Elsewhere: Widespread in temperate seas.

Family Cladostephaceae

Cladostephus spongiosus (Hudson) C. Agardh 1817: xxvi. — Womersley 1987: 185, Figures 60D, 62E–G.
Type
From England.
Port Phillip Bay distribution
Northern, Southern, Corio, Port Phillip Heads: Womersley 1966: 140 (as *C. verticillatus*). — King *et al.* 1971: 116 (*as C. verticillatus*). — O'Brien 1981: 184.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread on temperate coasts of the North Atlantic and Southern Hemisphere.

Order Dictyotales

Family Dictyotaceae

Dictyota dichotoma (Hudson) Lamouroux 1809: 42. — Fletcher 1980: 43, Pl. 16 Figures 1–3. — Womersley 1987: 194, Figures 64H–M, 65A, B.
Type
From England.
Port Phillip Bay distribution
Northern, Eastern, Southern, Corio: Womersley 1966: 140. — King *et al.* 1971: 116. — Lewis 1977: 214; 1983: 261. O'Brien 1981: 184.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread in temperate seas and extending into subtropical and colder waters.

Order Cutleriales

Family Cutleriaceae

Cutleria multifida (Smith) Greville 1830: 60, pl. 10. — Womersley 1987: 260, Figures 94A, 95.
Type
From Yarmouth, England.
Port Phillip Bay distribution
Northern, Eastern, Corio: Womersley 1966: 139. — King *et al.* 1971: 116. — Lewis 1977: 214; 1983: 214. — O'Brien 1981: 184 (*Aglaozonia* stage).
Distribution
Australia: WA, SA, Vic, Tas and NSW.
Elsewhere: Widespread in temperate seas.

Order Scytosiphonales

Family Scytosiphonaceae

Petalonia fascia (Müller) Kuntze 1898: 419. — Fletcher 1980: 42, Pl. 15 Figures 1–4. — Womersley 1987: 292, Figures 106A, 108A,B.
Type
From Christiansund, Norway.
Port Phillip Bay distribution
Northern, Eastern, Corio: King *et al.* 1971: 118. — Lewis 1977: 214.
Distribution
Australia: WA, SA, Vic, Tas and NSW.
Elsewhere: Widespread in temperate seas.

Scytosiphon lomentaria (Lyngbye) Link 1833: 232. — Fletcher 1980: 41, Pl. 14 Figures 4–6. — Womersley 1987: 294, Pl. 3 Figure 3, Figures 106B,C, 108C, D.
Type
From Quivig, Faroe Is.
Port Phillip Bay distribution
Northern, Eastern, Corio: King *et al.* 1971: 118. — Lewis 1977: 214; 1983: 261. — O'Brien 1981: 185.
Distribution
Australia: WA, SA, Vic, Tas and NSW.
Elsewhere: Widespread in temperate seas.

Colpomenia sinuosa (Mertens *ex* Roth) Derbés and Solier 1851: 95. — Womersley 1987: 297, Figures 107A, 108E, F.
Type
From Cadiz, Spain.
Port Phillip Bay distribution
Northern, Eastern, Southern, Southwestern, Corio, Port Phillip Heads: Womersley 1966: 142. — King *et al.* 1971: 118.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread in most seas.

Colpomenia peregrina (Sauvageau) Hamel 1937: 201. — Womersley 1987: 298, Figures 107B, 108G, H.
Type
From Brittany, France.
Port Phillip Bay distribution
Northern, Corio, Port Phillip Heads: King *et al.* 1971: 118. — O'Brien 1981: 185. — Womersley 1987: 298.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread in temperate seas.

Order Dictyosiphonales

Family Punctariaceae

Punctaria latifolia Greville 1830: 52. — Womersley 1987: 316, Figure 114A, 115C,D.
Type
From Sidmouth, England.
Port Phillip Bay distribution
Northern, Eastern, Corio: King *et al.* 1971: 118. — Lewis 1977: 214; 1983: 261. — O'Brien 1981: 185.

Distribution
Australia: SA, Vic and Tas.
Elsewhere: Widespread in cool temperate seas.

Phylum Chlorophyta

Order Ulvales

Family Ulvaceae

Enteromorpha compressa (Linnaeus) Greville 1830: 180. — Womersley 1984: 158, Figures 50B,C 51D–F.
Type
From Hoburgen, Baltic Sea.
Port Phillip Bay distribution
Northern: Lewis 1977: 214; 1983: 261. — O'Brien 1981: 183.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread in all seas.

Enteromorpha intestinalis (Linnaeus) Link 1820: 10. — Fletcher 1980: 32, Pl. 7 Figures 1, 2. — Womersley 1984: 161, Figures 50D, 51G, H.
Type
Locality uncertain.
Port Phillip Bay distribution
Northern: O'Brien 1981: 183.
Distribution
Australia: SA, Vic and Tas.
Elsewhere: Reported to be widespread in all seas.

Ulva lactuca Linnaeus 1753: 1163. — Fletcher 1980: 33, Pl. 8 Figures 1,2. — Womersley 1984: 141, Figures 44A, 45A–C. — Phillips 1988: 437, Figures 18–20.
Type
From the west coast of Sweden.
Port Phillip Bay distribution
Northern: Womersley 1984: 141.
Distribution
Australia: Vic.
Elsewhere: Reported to be widespread in all seas.

Ulva rigida C. Agardh 1823: 410. — Fletcher 1980: 33, Pl. 8 Figures 3–6. — Womersley 1984: 142, Figures 44D, 45G–J. — Phillips 1988: 445, Figures 2, 3, 24–26.
Type
From Cadiz, Spain.
Port Phillip Bay distribution
Northern: Lewis 1983: 261.
Distribution
Australia: WA, SA, Vic, Tas and Qld.
Elsewhere: Widespread in temperate and tropical seas.

Ulva stenophylla Setchell and Gardner 1920: 282, Plates 26, 29. — Phillips 1988: 450, Figures 5, 27–29.
Type
Monterey, California.
Port Phillip Bay distribution
Port Phillip Heads: Phillips 1988: 450.
Distribution
Australia: SA and Vic.
Elsewhere: Pacific North America and New Zealand.

Order Cladophoraceae

Family Cladophoraceae

Chaetomorpha aerea (Dillwyn) Kützing 1849: 379. — Womersley 1984: 172, Figures 54B, 55H–J.
Type
From Cromer, England.
Port Phillip Bay distribution
Northern, Eastern, Southern, Corio, Port Phillip Heads: King *et al.* 1971: 112. — Lewis 1977: 212. — O'Brien 1981: 183.
Distribution
Australia: WA, SA, Vic, Tas, NSW and Qld.
Elsewhere: Widespread in all seas.

Chaetomorpha capillaris (Kützing) Boergesen 1925: 45, Figure 13. — Fletcher 1980: 28, Pl. 4 Figures 5,6. — Womersley 1984: 178, Figures 56C, 57E, F.
Type
From Nice, France.
Port Phillip Bay distribution
Northern: Lewis 1983: 261.
Distribution
Australia: SA and Vic.
Elsewhere: Mediterranean and North Atlantic.

Chaetomorpha linum (Müller) Kützing 1843: 204. — Fletcher 1980, 28, pl. 4 Figures 1–4. — Womersley 1984: 176, Pl. 13 Figure 2, Figures 54D, 57A.
Type
From Lolland, Denmark.
Port Phillip Bay distribution
Northern: O'Brien 1981: 183.
Distribution
Australia: WA, SA and Vic.
Elsewhere: Widespread in all seas.

Order Derbesiales

Family Bryopsidaceae

Bryopsis plumosa (Hudson) C. Agardh 1823: 448. — Fletcher 1980: 35, Pl. 9 Figures 1,2. — Womersley 1984: 282, Figures 96C, 97A.
Type
From Exmouth, England.
Port Phillip Bay distribution
Northern, Corio: Womersley 1966: 136; 1984: 282. King *et al.* 1971: 113. Lewis 1977: 214; 1983: 261. O'Brien 1981: 183.
Distribution
Australia: WA, SA and Vic.
Elsewhere: Widespread in temperate seas.

Family Derbesiaceae

Derbesia marina (Lyngbye) Solier 1846: 453. — Fletcher 1980: 35, Pl. 9 Figures 5–6. — Womersley 1984: 288, Figures 98C–G, 99A.

Type

From Quivig, Faroe Is.

Port Phillip Bay distribution

Northern: Lewis 1977: 214; 1983: 261. O'Brien 1981: 183.

Distribution

Australia: SA, Vic and Tas.

Elsewhere: Widespread in cold temperate seas.

6.5 DISCUSSION

The relatively recent discovery of *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides* in southern Australia has attracted considerable attention and concern. However, a search of the literature has found another 20 species of macroalgae which are thought to have been introduced to southern Australia from overseas in recent times. Further records are also possible, as groups such as the red algal family Ceramiaceae are more closely examined. Sixteen of the southern Australian introductions have been collected within Port Phillip Bay. A further 50 species collected in Port Phillip Bay have overseas type locations and many of these species may also represent introductions.

The introduction of macroalgae is therefore unlikely to be a new phenomenon. For marine macroalgae, the most likely vector for introduction has been within fouling communities on the underwater hulls of ships. Macroalgae are a common component of the near surface fouling community on both artificial structures and on shipping with ineffective or spent antifouling protection.

Shipping has been visiting Port Phillip Bay for nearly two centuries and for much of this time antifouling measures were less than optimal. Even in recent years vessels painted with antifouling paints containing effective antifouling biocides, such as the organotins, can be fouled at the water line by algae such as *Enteromorpha*. Furthermore, the faster speed of modern shipping subjects attached organisms to shorter periods at sea when unfavourable conditions may be encountered, such as passage through tropical waters for temperate species (Farnham 1980).

Various vegetative and reproductive characteristics appear to contribute to an algal species' ability to initially attach to a vessel's hull, to survive transoceanic transport, and to then successfully colonise a foreign port. A comparison of the species reported as introductions suggests four life form characteristics may be important in this regard: a fast growing filamentous, or sheet-like thallus facilitating rapid maturation, a crustose habit, a heteromorphic life history with a microscopic filamentous or encrusting phase in the life history, and the ability to perennate vegetatively from basal crusts or stolons.

A recent detailed study of fouling scraped from ship hulls visiting Tasmania has found algal filaments, crusts and microscopic life history phases all to occur within the fouling communities (Coutts and Lewis unpub. data). The presence and absence of these characters in macroalgal species reported as introductions are summarised in Appendix A (Table A1.1), and species with overseas type localities in Appendix A (Table A1.3). These tables also indicate whether the species has previously been reported as a fouling species.

The origin of the macroalgae introduced to Port Phillip Bay is worthy of some discussion. The type localities and distribution in the major ocean regions of species reported as known or likely introductions are summarised in Appendix A (Table A1.2). The majority of type locations are in the North Atlantic (mostly European coasts) with a significant number also from the Mediterranean and the northern Pacific.

In his consideration of aliens in the marine flora of southern England, Farnham (1980) comments that many of both the established and recent introductions to this region originated in the Pacific. He adds that movement of immigrant species is not a one-way process, citing the introduction of the barnacle *Balanus amphitrite* and the alga *Schottera nicaeensis* from the Atlantic into the Pacific, and this process is also clearly illustrated in the present review.

For the Port Phillip Bay species with exotic type locations that have not been generally classified as adventives because of their widespread distribution and longer history of occurrence in southern Australian waters, the region of origin is less clear. However, looking at their type localities (Appendix A, Table A1.3), by far the greatest proportion is from Europe. If these species, or at least a significant proportion of these species, are indeed long established adventives, then their presence in Port Phillip Bay corresponds with historical shipping activity as the majority of international ship visits, in all but comparatively recent years, would have originated in Europe. The greater northern Pacific origin of species recognised as relatively new to the southern Australian marine flora (Appendix A, Table A1.4) would fit with the increasing trade with Japan and other north-western Pacific countries in recent decades.

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7 REVIEW OF HYDROIDS INTRODUCED TO VICTORIAN WATERS

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7.1 INTRODUCTION

7.1.1 Hydroid collections in Australia

Major hydroid collections are held in the Australian Museum, the Queensland Museum, the Western Australian Museum, the South Australian Museum, the Museum of Victoria and in the private collection of the author (J E Watson).

Of these, two are the most historically and geographically important. The Museum of Victoria holds a world-class collection including much type and voucher material dating from last century, notably the Australian collection of W M Bale who published on Hydrozoa between 1872 and 1929. The Australian Museum holds a substantial Bale collection, much of it preserved specimens whereas the Museum of Victoria collection is permanently (Canada Balsam) mounted microslides. The Natural History Museum of London also holds some duplicate Bale microslide material.

The Museum of Victoria also holds a substantial dried collection of original Kirchenpauer material collected in the 1860's, donated some years ago by the National Herbarium, Melbourne. The Museum of Victoria also holds type and voucher microslides of local hydroid species deposited by R E Trebilcock and schizoholotypes of some *Challenger* material also donated by Trebilcock. The Museum of Victoria holds the Mawson BANZARE Antarctic collection on loan from the Natural History Museum London.

The Museum of Victoria holds type and voucher specimens of the Australian hydroid fauna deposited by J E Watson. An extensive collection including contemporary material from shallow to deep water from around Australia, Papua New Guinea and New Zealand is held privately by the author.

7.1.2 Early southern Australian records

The earliest records of hydroids from southern Australia are those of Lamarck (1816), Lamouroux (1824), Busk (1852), Hincks (1861) and Kirchenpauer (1864). Most species described by these authors are large, hardy colonies easily collected by dredging or found among the drift on beaches.

W M Bale, a microscopist, was pre-eminent in Australian hydroid taxonomy at the end of last century and into the early years of this century. Bale was the Senior Inspector of Excise in the colony of Victoria, with headquarters on the esplanade at Williamstown (Smith and Watson 1969). His position allowed him access to boats and the Hobsons Bay foreshore for collection of specimens. His interests ranged throughout the bay to Port Phillip Heads where he also collected hydroids from the John Bracebridge Wilson dredging expeditions.

Later researchers included J F Mulder and R E Trebilcock from Geelong, who published on hydroids from Port Phillip and the Bellarine ocean coastline from 1909 to 1916. Ralph (1966) and Watson and Utinomi (1971) published accounts of hydroids collected by the National Museum of Victoria Survey (1957–1963) in Port Phillip Bay. Some later publications by and Watson (1978, 1982, 1984, 1985, 1992a, 1992b, 1993, 1994) include descriptions and records of species collected in Port Phillip Bay. There has however, been no comprehensive account of the hydroid fauna or its distribution in Port Phillip Bay or in Bass Strait waters.

7.1.3 Means of introduction

There are a number of potential means of introduction for hydroids into Australian waters. Introduction of exotic marine species to Victorian waters is listed as a potentially threatening process under the Victorian Government's Flora and Fauna Guarantee Act, 1988.

Shipping

Ships from the Northern Hemisphere have regularly visited southern Australian waters since the late 18th century. Any hydroids that may have been introduced to Port Phillip Bay in the early years of settlement would have arrived as colonies among the fouling community on ships' hulls. Since early this century, ballast water has been a potential vector for dispersal of species (Williams *et al.* 1988).

The most likely hydroid candidates for transport on ships' hulls are small, cryptic, epiphytic or epizoic species tolerant of currents and turbulence generated by movement of the hull through the water. Candidates for hull transport would also need to be tolerant of temperature extremes as the ship passes through cool temperate to tropical regimes, and must have a reasonably long life history. Being static predators, most hydroids prefer habitat with good water movement and thus easily fulfill the first criterion. There is information on life histories of some species; however, thermal tolerance of most species apart from seasonality is virtually unknown.

Transport in ballast water offers a further pathway for dispersal. In this context, introduction is more likely to be through larval or medusoid stages, rather than by colonies. Nevertheless it is possible that fragments of fertile colonies could be discharged in ballast water and still be able to colonise and reproduce in a new habitat.

Semi-dry ballast is an unlikely vector for introduction of exotic hydroids since being delicate organisms, colonies, larvae and medusae would be intolerant of any degree of hypersalinity induced by processes of evaporation. Furthermore, as there is no encystment phase in the hydroid life cycle, there is no likelihood of hydroids surviving dessication.

Mariculture

There are no reports in the literature of mariculture being a vector for transport of hydroids either locally or regionally. However there is no reason why this should not occur with transport of consignments of aquaculture organisms from one site to another. For example, cryptic hydroids and their larvae could possibly survive for several days in favourable microhabitat provided by crevices in molluscan shells transported in seawater.

Such may have occurred some 50 years ago when living oysters together with their associated cryptic fauna were introduced into the D'Entrecasteaux Channel in Tasmania from New Zealand. Within a few years, burgeoning populations of the gastropod *Maoricolpus roseus,* probably introduced with the oysters, irrevocably changed the community structure of the channel. Although hydroids may well have been among the fauna transported to the channel there is no prior information upon which to base comparisons.

Mariculture in Port Phillip Bay is limited to farming of mussels *Mytilus edulis* and experimental farming of Pacific oysters (*Crassostrea gigas*). As cultured mussel stocks are taken from indigenous wild stocks in the bay there is no possibility of introduction of exotic species. The hydroid predominantly associated with *M. edulis* is *Obelia dichotoma*, a species that may have been introduced last century.

Pacific oysters have been cultured for several years in abandoned salt evaporation pans at Avalon in the Geelong Arm of Port Phillip Bay. As the saltpans are isolated from Port Phillip Bay and the oysters spawn only in hypersaline water, there is no escape of oysters to the bay. It is most unlikely that any hydroid fauna is associated with the oyster project as the oysters were imported as spat, and hypersalinity in the pans would be deleterious to most hydroid species.

Marine aquaria

There are no reports in the literature of introduction of hydroids from one region to another through the medium of the aquarium trade. While possible, such a vector seems unlikely since marine aquarists fall into two groups: those interested in temperate water aquaria and those who maintain tropical aquaria. Temperate water aquarists usually stock their tanks from locally collected marine species, hence no introductions would occur from tank contents being returned to the sea. Should any tropical hydroids be introduced to local waters by tank cleaning, thermal shock would immediately kill any species.

7.1.4 Published reports of possible hydroid introductions

The only means of determining whether a species may have been introduced is to examine the records from last century. However, these records are of limited use, since the earliest introductions, if such occurred, would have preceded the first reports of hydroids by some 70 years.

Until the upsurge of interest in marine introductions in recent years, there was little information and few references in world scientific literature to hydrozoans transported by shipping (e.g. Allen 1953).

South Africa

The hydroid fouling community on ships' hulls was investigated by Millard (1952, 1959) who examined 26 vessels in dry dock at Cape Town, South Africa between the years 1946 and 1950. She recorded five species (*Tubularia warreni, Sarsia eximia, Obelia bicuspidata, Obelia dichotoma* and *Kirchenpaueria pinnata*) from ships that had visited ports outside South Africa. Some families such as the Bougainvilliidae, Tubulariidae and Campanulariidae were well represented in numbers but not in species, while other families were absent.

Although Millard was unable to give a reason for the absence of many hydroid families from the fouling community it seems logical to assume that athecate or cryptic species, which include those recorded by her, are more suited to transport on ships' hulls than larger, more robust species belonging to other families.

USA

References from the USA include survival of unidentified hydromedusae for four days in transit in ballast water in Carlton (1985). A list of 11 species (*Ectopleura crocea, Sarsia tubulosa, Blackfordia virginica, Cladonema uchidai, Clava multicornis, Corymorpha sp., Garveia franciscana, Gonothyraea clarki, Maeotias inexspectata, Obelia ?bidentata, Obelia ?dichotoma* and *Cordylophora caspia*) are listed from San Francisco Bay (Cohen & Carlton 1995) and six species (*Ectopleura crocea, Gonothyraea clarki, Blackfordia virginica, Sarsia tubulosa* and *Cordylophora caspia*) have been recorded from Coos Bay, Oregon (C Hewitt pers. comm.).

Coles *et al.* (1997) recorded seven species (*Clytia hemispherica, Obelia bidentata, Obelia dichotoma, Plumularia goodei, Garveia humilis, Pennaria disticha* and *Turritopsis nutricula*) from Pearl Harbour in Hawaii.

Britain

Present records from British waters include only two species (*Gonionemus vertens* and *Clavopsella navis*; Eno *et al.* 1997).

New Zealand

Eight athecate hydroids (*Sarsia eximia, Sarsia japonica, Amphinema dinema, Coryne pusilla, Ectopleura larynx, Eucodonium brownei, Pennaria disticha* and *Cordylophora lacustris*) have been suggested as possible introductions into New Zealand waters and therefore may also occur in Port Phillip Bay (Cranfield *et al.* 1998).

Of the species on this list, only *Sarsia eximia* (= *Sarsia radiata*) is recorded from Port Phillip Bay. It is possible that some of the other species may also be present in the bay but because of their generally cryptic habit and especially the lack of specialists working on the group, they could easily be overlooked. *Pennaria disticha* is a large, warm water species restricted in Australia to latitudes north of 35°S and thus does not occur in Victorian waters (J E Watson unpubl. data).

Cordylophora lacustris is a fresh to brackish water species that does not occur in Port Phillip Bay. As it is abundant in some fresh and brackish water lakes of the Western District of Victoria (J E Watson pers. obs.) it is thus quite likely to also occur in the estuarine reaches of the Yarra and Maribyrnong river systems.

It is interesting to speculate upon the mode of introduction to Australia of this cosmopolitan species: is it a geologically ancient species that drifted with the forming Australian continent during the break-up of Gondwanaland or did it arrive in the water casks of the earliest explorers from the old world? Since it has left no fossil record, the question cannot be answered.

Australia

There is only one report in the literature of possible introduction of a hydroid to Australian waters. Briggs (1931) reported *Bougainvillia ramosa* (= *Bougainvillia muscus*) from Sydney Harbour, remarking on the gradual spread of the species around the harbour and its invasion of the fouling community on wharves since 1918. Briggs speculated on the possibility of recent transport of *B. ramosa* to Sydney Harbour on ships' hulls. However, in his description of a new medusoid species, *Margelis trinema* from Sydney Harbour, von Lendenfeld (1885) considered that it may be conspecific with, and a developmental stage of the medusa of *Bougainvillia ramosa*. Von Lendenfeld's comment, which implied that *B. ramosa* was already well established in the harbour by the 1880's, was overlooked by Briggs. Allen (1953) considered these records indicative of two separate invasions of Sydney Harbour by *B. ramosa*. It is more likely however, that the absence of records for the intervening four decades was due to lack of collectors with expertise in the Hydrozoa.

In their investigation of ballast water introductions between Japan and Australia, Williams *et al.* (1988) give four instances of living, but unidentified cnidarian medusae found in ballast water of vessels at Eden NSW, and one occurrence at Triabunna, Tasmania. These may have been hydrozoan medusae but the species were not identified.

There is only one report in the literature on the detection of an Australian hydroid in the Northern Hemisphere. This is a report of a fragment of *Stereotheca elongata* found drifting off the Scottish coast (Ritchie 1907). This southern Australian species has an extremely durable, feathery perisarc and the photograph accompanying the report clearly shows the colony attached to a stem of the endemic southern Australian seagrass *Amphibolis*. As *S. elongata* was extensively used in popular seaweed montages last century (J E Watson unpubl. data) the specimen was probably somehow lost from a ship returning to England from Australia.

7.1.5 Potential for introduction

The major problem in deciding if a species is exotic or indigenous is that the most likely candidates are already cosmopolitan in distribution, have estuarine affinities and to be an introduction in ballast water must have a fairly long-lived medusoid or larval phase in the life cycle. These criteria are generally those which have mediated natural spread of species around the globe over geological time.

Taxonomic uncertainties

The morphological similarities between certain species considered endemic to Australia with species from the northern hemisphere, opens the taxonomically vexing question of whether a local species has been introduced and is displaying rapid speciation or if it is a closely related but nevertheless endemic species. Three such examples are the hydroids *Sarsia radiata, Obelia australis* and *Tubularia ralphi*, regarded as endemic to southern Australia. *Sarsia radiata* is considered in this report as conspecific with the cosmopolitan *Sarsia eximia*, known from Western Australia (Watson 1997) and New Zealand (Schuchert 1996). *Obelia australis* is here regarded as a synonym of *Obelia dichotoma* and *Tubularia ralphi* is provisionally considered to be a variant of *Ectopleura crocea*, a common fouling organism in Northern Hemisphere estuaries and ports and now also reported from New Zealand (Schuchert 1996).

Criteria for introduction

The primary criterion for transport by ships is that a species must be known from estuarine and coastal habitats in other parts of the world. For transport on ships' hulls a species must:

- have colonies with flexible, low-growing stems;
- have a tendency towards a cryptic life-style;
- have a reasonably long colonial life-span;
- be known from other parts of the world;
- be able to tolerate a wide temperature range; and
- have no obligate association with any invertebrate or algal species known to be endemic to Australia.

To be transported in ballast water medusae or larvae must:

- have a relatively long-lived larval or medusa stage;
- have the ability to survive darkness during transport; and
- be able to tolerate a wide temperature range.

These criteria eliminate the majority of Southern Australian hydroid species.

7.1.6 Hydrozoan charactersitics relevant to introductions

Hydrozoan morphology relevant to introduction is discussed briefly below.

The colony

Since hydroids have no hard skeleton the stems are thus highly flexible, permitting adaptation to strong currents. Ships' hulls, especially slow-moving vessels, thus offer an attractive habitat for colonization.

Cryptic species are those which are small enough to be hidden among other larger, hull-fouling organisms. Many smaller epizooitic or epiphytic hydroids and larval stages of larger species are cryptic. As all hydroid colonies begin life from a single hydranth, juvenile colonies of taller-growing species could potentially enter the fouling community. At port, fertile colonies or colony fragments may be released into the water column by abrasion at the berth or during hull-cleaning operations; receptive physical environs would encourage colonisation of port structures by such species.

Hydroids are attached to the substratum by a superficial rooting system, the hydrorhiza. Stems can break off from the hydrorhiza and fertile fragments could be drawn into ballast water and be released into new habitat at the port of destination. However, there is no information as to whether this has ever occurred.

Life history

The life cycle of hydroids includes a colonial (polyp) phase and reproduction either by release to the plankton of free-swimming medusae or ova, planula or actinula larvae. Ova may be fertilized while in the colony or soon after release and planulae and actinulae may live from hours to days before metamorphosis in suitable habitat. Medusae are the sexual phase and may live from days to weeks in the plankton.The complete life histories of relatively few hydroid species and their medusae or larval stages is known. Some common medusa are reasonably documented, e.g. *Turritopsis nutricula* which spends several months in the plankton.

Growth rates can vary from production of a few to many hydranths per day. Some larger species that develop slowly live for many years (pers. obs.). In general, the smaller species are usually those with the fastest growth rates and it is these which are also the best candidates for transport. Many faster-growing species with seasonal life-histories become reproductive as the colonies grow. Such strategies may be an advantage in migration, it being possible that some could pass through more than one life-cycle during hull transport.

The life of planulae is probably a matter of days, and of some actinula larvae, only hours (Watson 1980, 1985, unpub. data). Such reproductive strategies lend themselves to parochialism, the pathway to endemicity. Species with long larval stages are better candidates for transport in ballast water. Species with a medusoid phase tolerant of short periods of darkness are also likely candidates for introduction by this means; however there is no information on the effects of prolonged darkness on hydrozoan medusae.

Distribution

To meet the criteria for transport, a hydroid species must have been known from another part of the world prior to its being reported from Australia. Most of the hydroids recorded from Australian type localities by the earliest workers (e.g. Lamarck 1816; Lamouroux 1824) can thus be reasonably assumed to be endemic. Cryptogenic species are likely to be cosmopolitan in distribution (Carlton 1996). The best candidates for transportation are those tolerant of a range of salinities and high water turbidity such as found in estuaries and many ports around the world. These criteria substantially reduce the number of candidate species for introduction.

Temperature tolerance

Many hydroids are seasonal in occurrence and are thus adapted to a narrow band of summer or winter temperatures. Others with a life span of years are obviously able to withstand a larger annual differential in temperature.

Some species have a short colonization period over a narrow temperature range. An example is *Obelia dichotoma* which in Port Phillip Bay colonises mussels and other substrates over winter to late spring in water temperatures of 9°–17° C, virtually disappearing over summer after release of medusae (Watson unpubl. data).

Obligate associations

Many species enter into obligate or near-obligate associations with a particular species of substrate or range of substrates (Shepherd and Watson 1970; J E Watson pers. obs.). If the obligate substratum, whether algal or invertebrate is an Australian endemic, it is probable that the hydroid species is also endemic, thus eliminating many possible candidates. Conversely, it is also possible that an introduced species could arrive together with its introduced obligate substrate. However, there is no information in the hydroid literature or from observations (J E Watson) that this may have ever occurred in Australian waters.

7.2 POSSIBLE INTRODUCTIONS

Based on the above considerations, the most likely candidates for introductions to the Victorian coastline and to Port Phillip Bay in particular, are listed in Table 7.1. Species listed in Table 7.1 are described and figured with notes given on their ecology and distribution. Authors of original descriptions and relevant synonymies are given in the reference list. Diagrams showing basic descriptive terms used in hydrozoan taxonomy are provided.

7.2.1 Identification of species

Colonies of some larger species are sufficiently unique in morphology and colour to be readily recognisable in the field. Smaller species (several of which are included in Table 7.1) are not often easily recognisable and therefore must be examined in the laboratory under stereo and compound microscopic.

Hydroids generally do not survive well out of their natural habitat and unless examination takes place within a few hours of collection, it is best to preserve specimens immediately. Preservation of both hydroids and medusae is done by fixing and hardening in (approximately) 10% solution of formaldehyde in seawater. Transfer to alcohol can be done later.

Some of the listed species can be identified in a petrie dish in water under stereo-microscope. However, most species will require mounting for examination under compound microscope. Temporary mounts can be prepared using a water-based medium such as Berlese solution. Permanent mounts require preliminary staining of the specimen to facilitate later identification of features. This is followed by dehydration and clearing by passing the specimen through a graded series (at least four) of washes of alcohol followed by a similar series of washes in xylene. Each wash should preferably be for at least one hour. Specimens are then mounted in a permanent medium.

Microscopic examination under high power is then undertaken. It should be noted that some of the species listed are morphologically similar to other endemic species. An example is *Monotheca obliqua* which, without taxonomic expertise, can be misidentified.

If medusae are collected in the plankton, fixation can be done immediately using formalin solution as recommended above for hydroids. Medusae can be examined under high power stereomicroscope. Relaxation can be achieved by placing the living specimen in a 1:1 mixture of a 7.5% solution of magnesium chloride and seawater before fixing. There is usually no need for permanent mounts. Long term storage is in alcohol.

7.2.2 Morphology and classification

The basic morphological characters shown in Figure 7.1A–B are necessary for interpretation of descriptions of hydroids and their medusae. A glossary of terms is

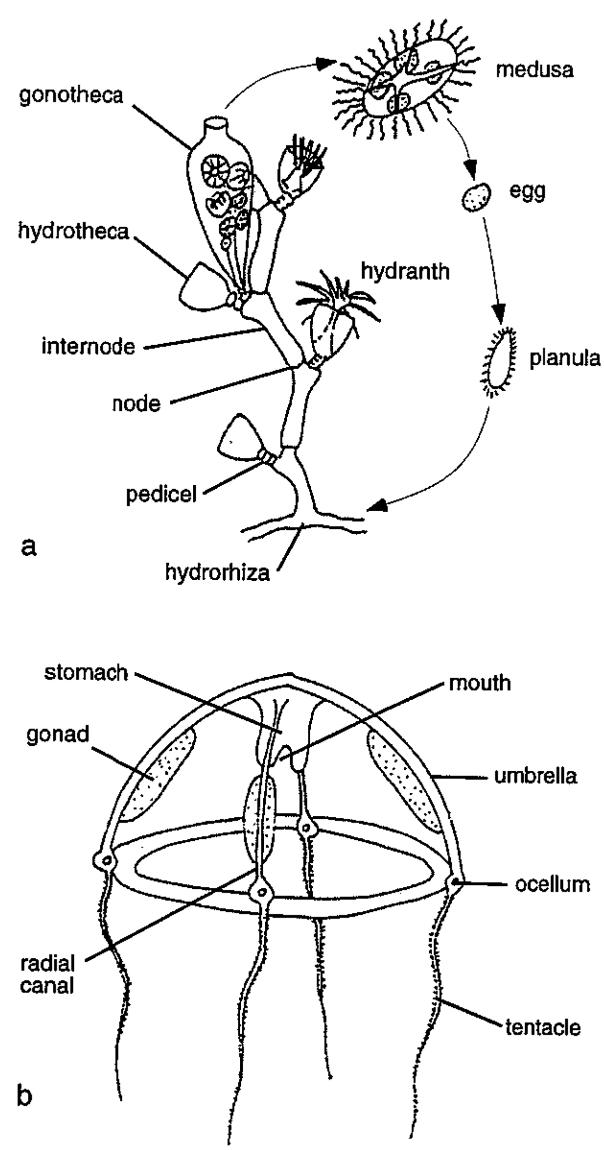

Figure 7.1. Generalised morphology and life cycle of hydroids: a) basic morphology of a hydroid colony; and b) basic morphology of a medusa (redrawn from Cornelius 1995).

Table 7.1. Hydroids that are possible introductions to Port Phillip Bay.

Species	Location in Port Phillip Bay	Mode of reproduction	World distribution
Ectopleura crocea (L. Agassiz, 1862) ?= *Ectopleura ralphii* (Bale, 1884)	northern, southern bay	actinula larva	cosmopolitan
Turritopsis nutricula McGrady, 1856	all bay	medusa	temperate/tropical circumglobal
Sarsia eximia (Allman, 1859) ?= *Sarsia radiata* von Lendenfeld, 1885	all bay	medusa	cosmopolitan
Bougainvillia muscus (Allman, 1863)	northern bay	medusa	cosmopolitan
Phialella quadrata (Forbes, 1848)	mid to northern bay	medusa	temperate circumglobal
Halecium delicatulum Coughtrey, 1876	mid to southern bay	planula	temperate/tropical circumglobal
Filellum serpens (Hassall, 1848)	southern bay	planula	cosmopolitan
Obelia dichotoma (Linnaeus, 1758))	all bay	medusa	cosmopolitan
Clytia hemisphaerica (Linnaeus, 1767)	mid to southern bay	medusa	cosmopolitan
Clytia paulensis (Vanhöffen, 1910)	all bay	medusa	southern circumglobal north Atlantic
Amphisbetia operculata (Linnaeus, 1758)	mid to southern bay	planula	cosmopolitan
Antennella secundaria (Gmelin, 1791)	mid to southern bay	planula	cosmopolitan
Plumularia setacea (Ellis, 1755)	mid to southern bay	planula	cosmopolitan
Monotheca obliqua (Johnston, 1847)	mid to southern bay	planula	temperate circumglobal

provided (see Section 7.6). Cornelius (1995a and 1995b) is recommended for more detailed information on hydroid and medusan morphology.

The classification of hydroids used in this report is as follows:

Phylum CNIDARIA
- Subphylum MEDUSOZOA
  - Superclass HYDROZOA
    - Class LEPTOLIDA
      - Subclass ANTHOATHECATAE
      - Subclass LEPTOTHECATAE

7.3 DESCRIPTION OF SPECIES

7.3.1 Subclass Anthoathecatae

Family Tubulariidae

Ectopleura ?crocea (L. Agassiz 1862)

Figure 7.2

?*Tubularia ralphii* Bale 1884:42. — Watson 1980 60, Figures 25–37;

Tubularia crocea L. Agassiz 1862: pls 23, 23a. — Pennycuik 1959: 157;

Ectopleura crocea: — Petersen 1990: 174, Figure 27. — Schuchert 1996: 107, Figure 64a–g.

Description

Colonies growing in hand-sized tufts to 12 cm high, comprising up to several hundred stems growing from a matted hydrorhiza. Stems tubular, straight, each bearing a naked terminal hydranth. Hydranth ranging up to 15 mm diameter across the outstretched tentacles. Two groups of tentacles on hydranth: 15–25 oral tentacles a few mm long, arranged in a tuft around the mouth and 16–27 long aboral tentacles arranged around the base of the hydranth. Gonophores hanging in pendulous clusters between the two sets of tentacles, each gonophore with an apical process consisting of up to eight transparent crests. Ripe ova developing into actinula larvae clearly visible inside female gonophore. Actinulae settle and rapidly metamorphose; often within the same colony, the larvae attaching to stems of adults.

Colour

Stems and tentacles pale greenish-white, body of hydranth and gonophores usually orange-red, but often variations from golden to brown or pale green.

Remarks

Ectopleura crocea is listed here provisionally. Watson (1980) redescribed *Tubularia ralphii* Bale, 1884 from large colonies growing on channel beacons near the mouth of the Yarra River in Hobsons Bay. While noting the strong resemblance in colony morphology with *Ectopleura crocea* from Chesapeake Bay, USA, on the basis of minor differences in the cnidome (kinds of nematocysts in the tentacles) she kept the two species separate. Recent records of *Ectopleura crocea* from New Zealand (Schuchert 1996) indicate that the two are probably conspecific. Molecular testing of specimens

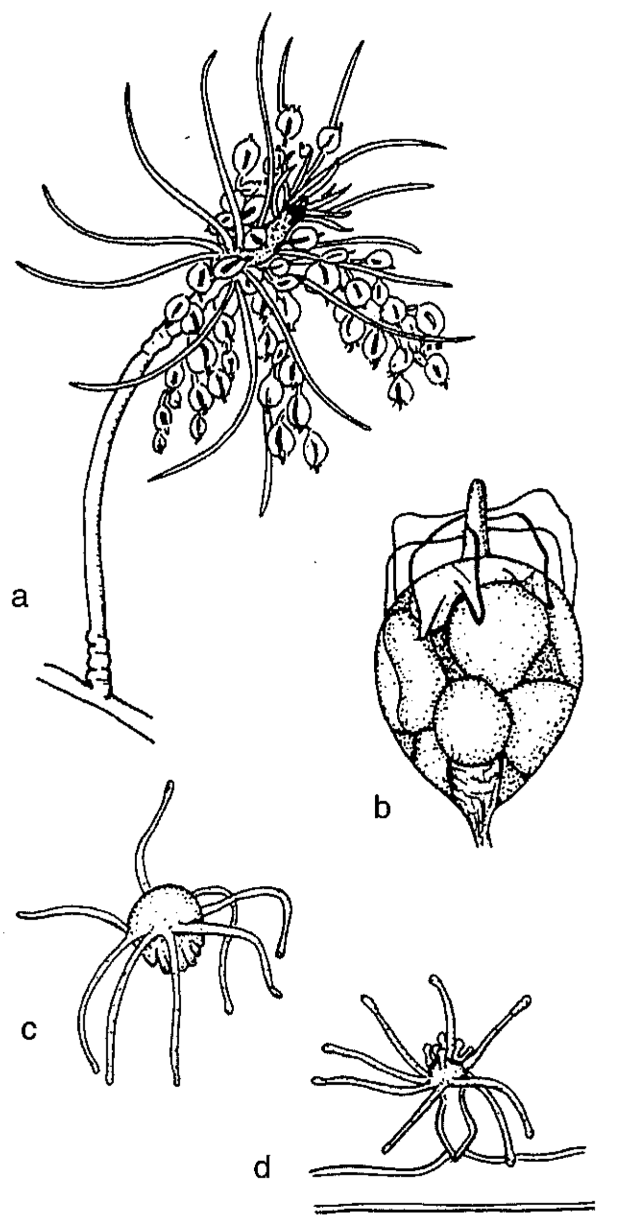

Figure 7.2. *Ectopleura ?crocea*: a) single hydranth with gonophores; b) gonophore with apical crests and developing ova; c) newly released actinula larva; and d) newly metamorphosed larva with developing tentacles.

world-wide would determine global relationships and whether one or more species is involved.

Clusters of this common fouling species grow rapidly over summer on hulls of vessels at estuarine and port moorings on the Victorian coast. It has also been recorded from the seawater cooling systems of submarines based in Sydney Harbour (Lewis and Smith 1990).

Distribution

New South Wales: Sydney Harbour, Port Kembla; Western Australia: Fremantle; and Victoria: Yarra River entrance to Hobsons Bay.

World distribution: as *E. crocea*, almost cosmopolitan, in ports.

First record from Port Phillip Bay

Bale 1884 (as *Tubularia ralphii*).

Family Clavidae

Turritopsis nutricula McGrady 1856

Figure 7.3

Turritopsis nutricula McCrady 1856: 55, pls 4-5. — Millard 1975: 76. Figure 24F-G. — Watson 1978: 308, Figure 3D, E: 1982: 89, Figure 4.7b, c, pl. 8.3. — Southcott 1982: 130, pl. 14.1;

Dendroclava dohrni Weismann 1883-26,: 215, pl 12, Figures 6-9. — Blackburn 1937: 178, Figures 15, 16.

Description

Colonies erect, 3–4 cm high, bushy, branched and straggling, stems fascicled, covered in a firm perisarc. Branches jointed to stem for a short distance before diverging. One hydranth 1–2 mm long, terminal on each branch, hydranth body naked, with scattered filiform tentacles. Medusa buds borne on the body of hydranth, pear-shaped with eight marginal tentacles at release. Adult medusa deep bell-shaped, 1–2 cm wide, stomach cross-shaped, surrounded by four large gonads, mouth with four elongated lobes. Margin of bell with up to 100 tentacles.

Colour

Perisarc of colony buff coloured, hydranths pink, tentacles white. Bell of medusa transparent, gonads rose red.

Remarks

Turritopsis nutricula colonies are seaonally common in sheltered habitats, especially jetty pilings. Colonies mature over winter and medusae are released in summer. They sometimes swarm in the summer plankton. The medusa is easily recognised by its relatively large size, the colour of the gonads and its energetic swimming.

Distribution

Hydroids and medusae occur in: New South Wales; and Victoria: Bass Strait, Western Port and Port Phillip Bay. World distribution: circumglobal, tropical and temperate oceans.

First record from Port Phillip Bay

Southcott 1982.

Family Corynidae

Sarsia eximia (Allman 1859)

Figure 7.4

Coryne eximia Allman 1859: 151;

Sarsia eximia: — Ralph 1953: 74, Figure 24. — Millard 1975: 52. Figure 20A-D. — Schuchert 1996: 125, Figures 77a-h, 78. - Watson 1997: 506, Figure 2A;

Syncoryne eximia: — Bale 1924: 229. — Ralph 1953: 68;

Sarsia radiata von Lendenfeld 1885a: 583, pl. 20, Figures 31, 32. — Watson 1978: 305, Figure 2A-D.

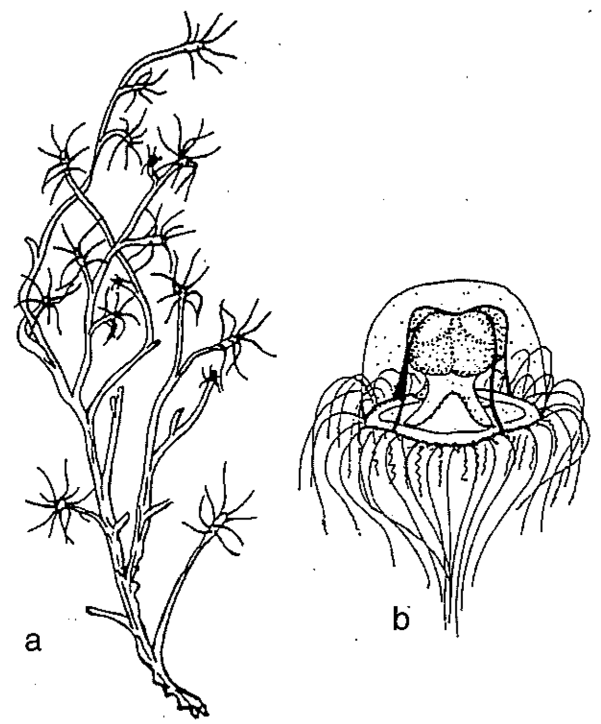

Figure 7.3. *Turritopsis nutricula*: a) living colony showing naked hydranths with extended filiform tentacles; and b) medusa.

Description

Colony consisting of stems to 15 mm high arising singularly from a creeping hydrorhiza. Stems may be single or branched once or twice, perisarc thin, annulated, ridged or smooth. Each stem or branch with one terminal, naked hydranth about 1 mm in length, body elongated, with 12–16 scattered capitate tentacles. Medusa buds borne on body of the hydranth between the tentacles. Newly released medusa deep bell-shaped, about 0.75 mm high, jelly moderately thick, stomach a simple tube, bell with four tentacles, one at base of each radial canal, nematocysts scattered over the bell. In growing medusa gonads develop around the stomach.

Colour

Perisarc of colony pale honey-brown to clear, hydranth clear to pink, tentacles clear, sometimes pale pink. Umbrella of medusa clear, stomach deep orange to golden, ocelli at base of the tentacles deep orange.

Remarks

Sarsia radiata was formerly considered endemic to southern Australia (Watson 1978); however recent studies in New Zealand (Schuchert 1996) and Western Australia (Watson 1996, 1997) have demonstrated that this species is almost certainly the cosmopolitan *Sarsia eximia*. Colonies usually creep on sponges, other hydroids or on ropes during winter months. Medusa are released freely from the colonies in late winter to early summer in Port Phillip Bay. The juvenile medusa and the life history (in aquaria) of *S. eximia* are described by Schuchert (1996).

Distribution

As *Sarsia radiata*, recorded from: New South Wales: Sydney Harbour (von Lendenfeld 1885a); and Victoria: Port Phillip Bay, Western Port, and Bass Strait (von Lendenfeld 1884; Watson 1978, unpub. data).
World distribution: as *Sarsia eximia*, cosmopolitan.

First record from Port Phillip Bay

von Lendenfeld 1884.

Family Bougainvilliidae

Bougainvillia muscus (Allman 1863)

Figure 7.5

Eudendrium ramosum van Beneden 1844: 57, pl. 4, Figures 10–13;
?*Margelis trinema* von Lendenfeld 1885b: 918, pl. 41;
Bougainvillia ramosa:— Millard 1975: 97, Figure 33E–H. - Briggs 1931: 281. — Southcott 1982: 131;
Perigonymus muscus Allman 1863: 12;
Bougainvillia muscus:— Calder 1988: 24, Figures 19, 20. — Schuchert 1996: 31, Figure 15a–e.

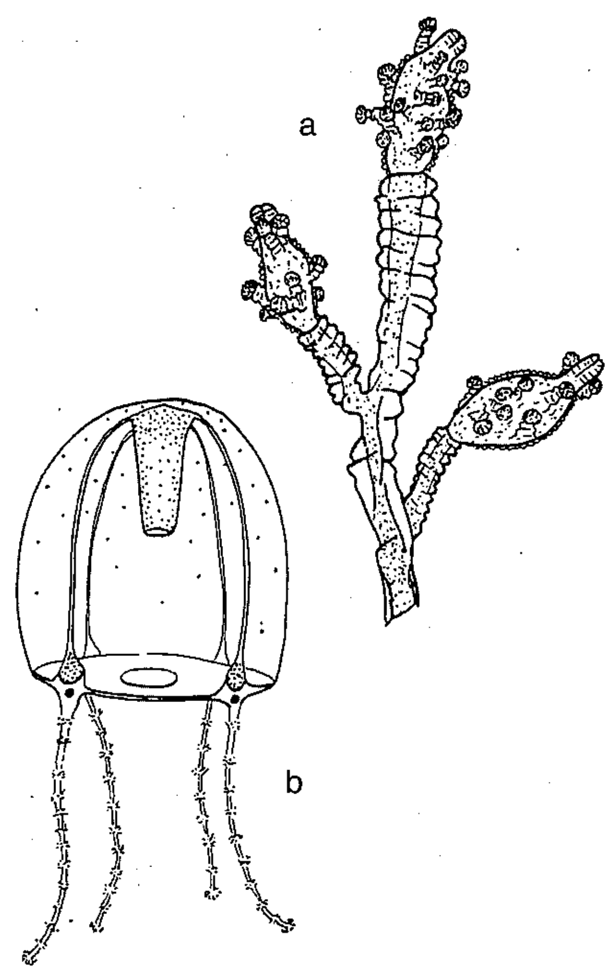

Figure 7.4. *Sarsia eximia*: a) distal end of colony, showing naked hydranth with capitate tentacles. (drawn from preserved material); and b) newly released medusa.

Description

Colonies bushy, reaching a height of 5 cm. Stems erect, sometimes weakly fascicled, branching profuse and irregular, branches forming an acute angle with the stem. Perisarc wrinkled or corrugated at the origin of branches and hydranth pedicels but otherwise smooth. Perisarc of stem continues over the lower part of the hydranth as a shallow cup-shaped dish (pseudohydrotheca); hydranth with a bunch of 9–15 long, filiform tentacles protruding from the pseudohydrotheca.

Medusa buds pear-shaped, arising from the hydranth pedicels and smaller branches. Medusa at liberation elongate globular, about 0.4 mm in diameter, stomach short, spherical, mouth with 4 capitate tentacles terminating in nematocyst clusters. Margin of bell with 4 large marginal bulbs, one at the base of each radial canal, each with two tentacles and two ocelli. Jelly of adult medusa thick, each marginal bulb now with 4–9 tentacles, oral tentacles dichotomously branched and gonads surrounding the stomach.

Colour

Colony white, body of hydranth orange, tentacles white. Colour of the living medusa in local waters unknown.

Remarks

The hydroid was first recorded from Sydney Harbour by Briggs (1931) and the medusa from Port Phillip Bay by Southcott (1971). Taxonomy was recently revised by Schuchert (1996) in description of the species from New Zealand.

The hydroid was found in eastern Bass Strait in 1992 (unpub. data) and was recorded for the first time in Port Phillip Bay on pilings of the Point Wilson Explosives Jetty in the Geelong Arm during the winter of 1995 (unpub. data). In both instances colonies were among mussels and intergrown with the bryozoan, *Bugula* sp. Colonies of *B. muscus* are not easily recognised underwater as they are easily confused with *Turritopsis nutricula*.

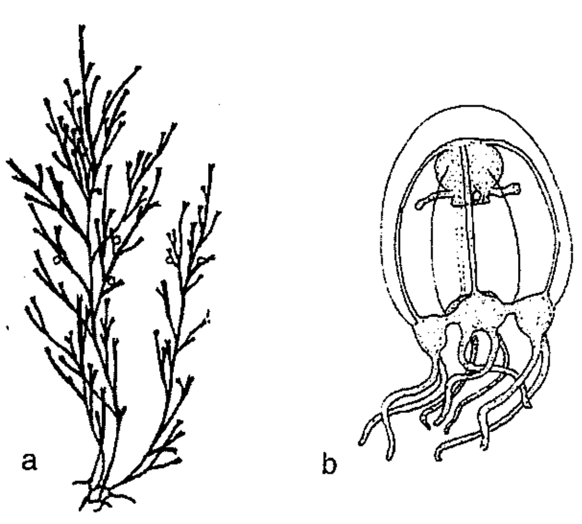

Figure 7.5. *Bougainvillia muscus*: a) colony; and b) newly released medusa; (after Millard 1979).

Distribution

New South Wales: Sydney Harbour; and Victoria: Port Phillip Bay.

World distribution: cosmopolitan.

First record from Port Phillip Bay

Southcott 1971.

7.3.2 Subclass Leptothecatae

Family Phialellidae

Phialella quadrata (Forbes 1848)

Figure 7.6

Thaumantias quadrata Forbes 1848: 43, pl. 9, Figure 2;
Eucope annulata von Lendenfeld 1885a: 602, pl. 28, Figures 52–57;
Eucope hyalina von Lendenfeld 1885b: 920, pl. 42, Figures 16–18;
Lovenella briggsi Mulder and Trebilcock 1915: 57, pl. 9, Figures 3-3f;
Phialella quadrata: — Ralph 1957: 848, Figure 8g–i. — Kramp 1968: 84, Figure 226. — Southcott 1982: 135, Figure 4.26d. — Watson 1994: 149, Figure 1B–G. — Cornelius 1995a: 177, Figure 70.

Description

Hydrorhiza tubular, loosely adherent to the substrate. Colonies small, to 10 mm high, stems consisting of single pedicels or may be erect and sparingly branched, all occurring in the same colony. Stems unfascicled, perisarc thin, corrugated, branched stems often with two to four hydrothecae given off from a pedicel or bunch of pedicels on the same stem internode. Hydrotheca terminal on the branch, deep and almost cylindrical, young hydrotheca with a conical operculum of eight very delicate wedge-shaped segments meeting at the top in a blunt apex. Hydranth with about 16 long filiform tentacles. Gonothecae borne on the hydrorhiza and stems, varying in shape from almost cylindrical to top-shaped, perisarc thin and smooth, containing one nearly mature and one developing medusa.

Medusa very small at liberation, dome-shaped, stomach saccate, mouth with four short quadrate lips, radial canals with rudimentary gonads and one long tentacle at the base of each canal. Adult medusa up to 3 mm high with 16 tentacles, gonads enlarged and occupying most of the length of the radial canals.

Colour

Colonies transparent white. Medusa at liberation transparent, stomach and tentacle bulbs yellow to pale brown.

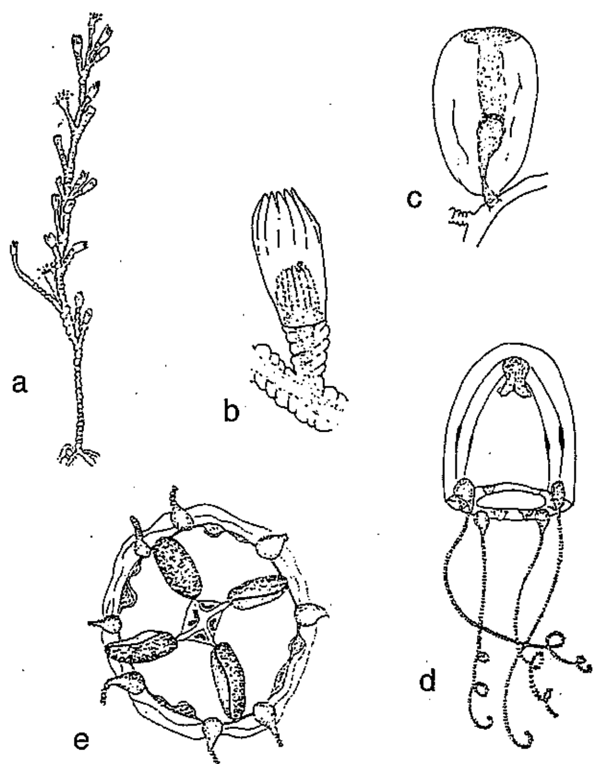

Figure 7.6. *Phialella quadrata*: a) living colony; b) hydrotheca enlarged, showing segmented operculum; c) gonotheca enlarged; d) newly released medusa; and e) nearly mature medusa with well developed gonads.

Remarks

Phialella quadrata is an opportunistic species growing on a wide variety of substrates including algae, invertebrates and other hydroids. It is very common under jetties. The colonies grow over winter and begin liberating large numbers of medusae to the plankton in late summer.

The life span of the medusa is unknown. Mature medusae at the 16-tentacle stage have been recorded in May from the plankton of eastern Bass Strait (Watson 1994) and in Port Kembla New South Wales (unpub. data), suggesting that the medusa may live for several weeks.

Although individual stems in the colonies are very small, the colonies themselves are often prolific, covering large areas of substrate and can thus be seen *in situ*. Medusae are readily liberated in the laboratory.

Distribution

Victoria: Port Phillip Bay, Western Port and Bass Strait. World distribution: circumglobal in cool temperate to temperate seas.

Voucher material

Material held in the Museum of Victoria: one microslide F51791, part of colony; F51792, young medusae formalin preserved.

First record from Port Phillip Bay

Mulder and Trebilcock 1915.

Family Haleciidae

Halecium delicatulum Coughtrey 1876

Figure 7.7

Halecium delicatulum Coughtrey 1876: 26, pl. 3, Figures 4, 5. — Ralph 1958: 334, Figure 11e, h–n, 12a–p; 1966: 158. — Millard 1975: 145, Figure 47F–L. — Watson 1973: 166: 1975: 159;

Halecium gracile Bale 1888: 759, pl. 14, Figures 1–3;

Halecium parvulum Bale 1888: 760, pl. 14, Figures 4, 5.

Description

Colonies grow to 4 cm high, stems flexuous, profusely and irregularly branched. Stems usually fascicled, segmented,

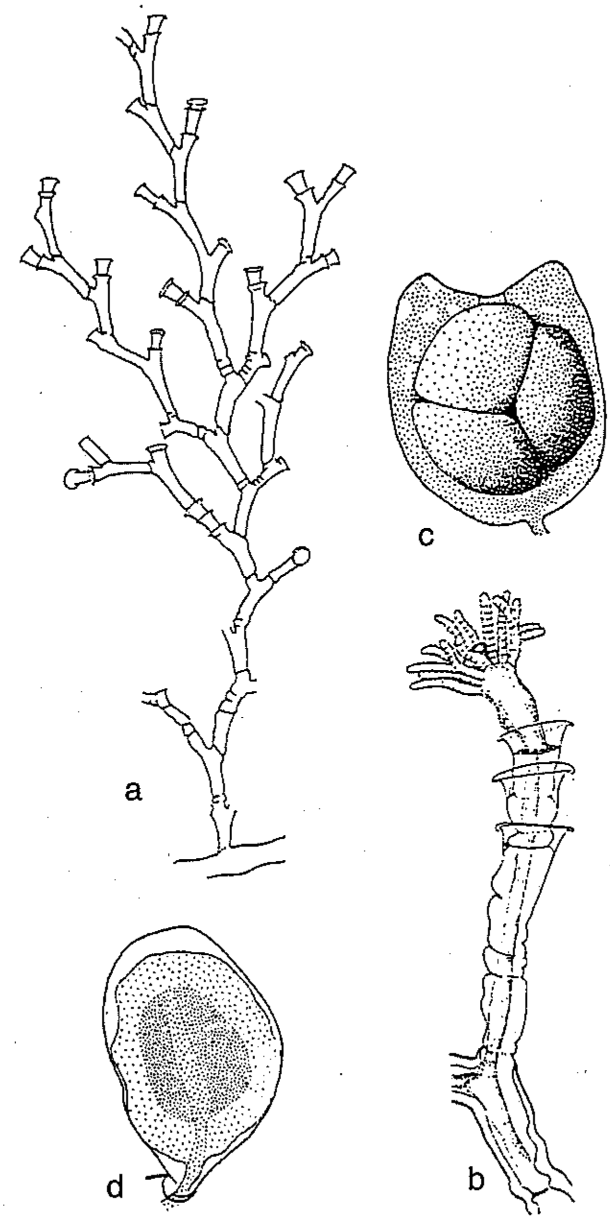

Figure 7.7. *Halecium delicatulum*: a) living colony; b) branch enlarged showing primary, secondary and tertiary hydrothecae and hydranth; c) female gonotheca with three ova; and d) male gonotheca; (after Ralph 1958).

each stem or branch internode bearing a hydrotheca near its distal end, hydrothecae alternate, given off in one plane. Several hydrothecae may grow successively each from the interior of the preceding one, the primary and secondary hydrothecae pedicellate, later (younger) hydrothecae shallow, saucer-shaped and expanding to the margin. Hydranth with one whorl of about 16 filiform tentacles, too large to retract into the hydrotheca.

Gonothecae borne profusely on the stems and branches, male and female on different colonies. Male compressed, elongate-oval, walls smooth, female of the same compressed shape, with two opposite distal lobes, one on each side of a small terminal aperture. Female containing numerous ova.

Colour

Colonies usually yellow to pale orange, ova often pink.

Remarks

The species is epizoic, mostly associated with soft-textured sponges but sometimes growing on bryozoans. It favours shaded locations and occurs in great abundance on jetty piles. It is easily recognised by its colour and association with sponges. Fertile colonies occur throughout the year.

Distribution

Victoria: Port Phillip Bay, Western Port and Bass Strait. World distribution: circumglobal including New Zealand, South Africa, Japan, Morocco and the Antarctic.

First record from Port Phillip Bay

Ralph 1966 (collected by National Museum of Victoria Survey 1957–63).

Family Lafoeidae

Filellum serpens (Hassall 1848)

Figure 7.8

Campanularia serpens Hassall 1848: 2223;

Filellum serpens: — Hincks 1868: 214, pl. 41, Figure 4. — Cornelius and Ryland 1990: 135, Figure 4.13.

Description

Hydrothecae given off a tubular, torturously creeping hydrorhiza. Hydrotheca tubular, sessile on the hydrorhiza for about half its length then becoming free and bent outwards, free part up to 1 mm long. Upper surface of the fixed part of the hydrotheca transversely ridged. Hydrothecal margin smooth and slightly everted.

Gonothecae aggregated into a cylindrical structure of tangled appearance (coppinia) adherent to the substrate. Accessory tubes of the coppinia long and twisted, overtopping the gonothecae. Gonothecae closely packed, slipper-shaped, each with a terminal aperture through which larvae are released.

Colour

Usually bright yellow but may be straw coloured.

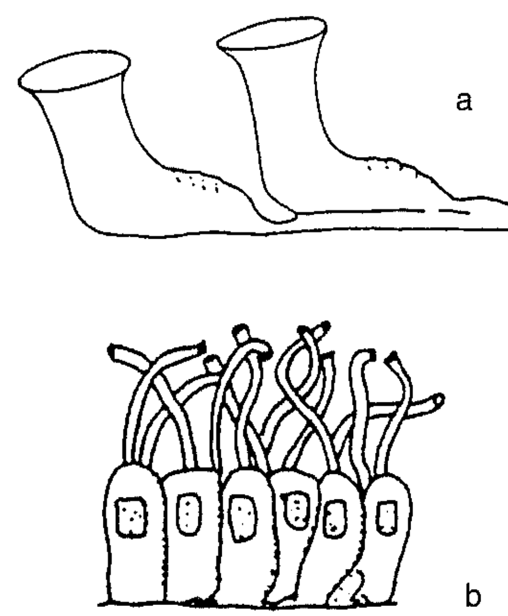

Figure 7.8. *Filellum serpens*: a) two hydrothecae; and b) transverse section through part of coppinia.

Remarks

The species is rare in local waters, and being very small is only detectable under stereo microscope. Colonies are usually epizoic, creeping on the stems of larger hydroids although it sometimes occurs on algae with a firm cuticle, e.g. *Caulerpa* sp.

Although this is a very widespread hydroid, virtually nothing is known of its reproductive season, larval settlement or metamorphosis. Being small, it will only be found incidentally during examination of other material.

Distribution

Victoria: Bass Strait and southern Port Phillip Bay. World distribution: Southern Hemisphere circumglobal.

First record from Port Phillip Bay

Watson 1999 (this report). First collected by Watson 1984.

Family Campanulariidae

Obelia dichotoma (Linnaeus 1758)

Figure 7.9

Sertularia dichotoma Linnaeus 1758: 812;

Obelia dichotoma: — Hincks 1868: 156, pl. 28, Figures 1a–b. — Cornelius 1995: 296, Figure 69;

Obelia australis von Lendenfeld 1885a: 604; 1885b: 920, pl. 43, Figures 19–22. — Bale 1924: 231. — Ralph 1957: 830, Figures 4a–h; 1966: 158. — Watson 1982: 92, Figure 4.7f, g.

Description

Colonies grow about 8 cm high from a ramified, creeping hydrorhiza. Stems are usually profudely and irregularly branched, perisarc distinctly annulated at the origin of the branches. Hydrothecae funnel-shaped with a smooth

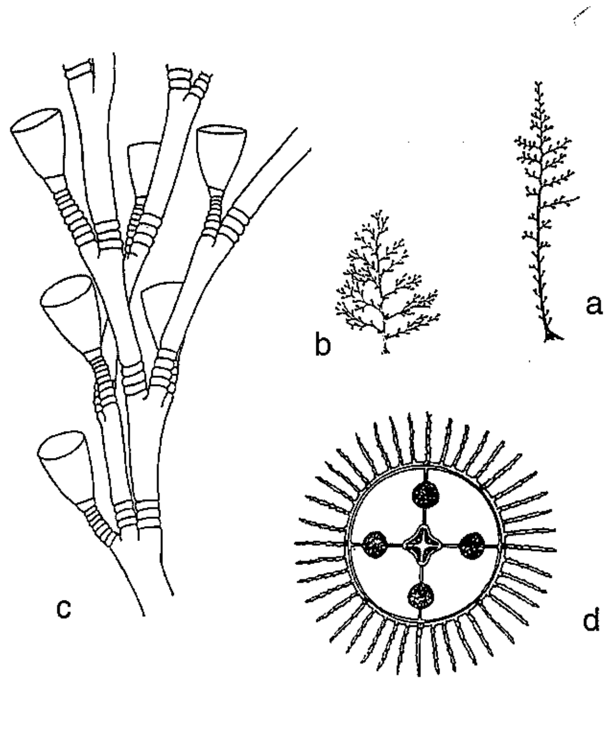

Figure 7.9. *Obelia dichotoma*: a,b) two growth forms of the species; c) part of colony, enlarged; and d) diagrammatic view of medusa showing tentacles and gonads on radial canals; (after Cornelius 1995).

margin, borne on short pedicels given off from the branches. Hydranth with up to 20, long, filiform tentacles.

Gonothecae borne prolifically on the branches, urn-shaped with a small distal orifice surrounded by a short collar. Gonotheca contain several medusae in various stages of development. At liberation, the medusa is very small and shallow saucer-shaped, stomach saccate, mouth quadrate, radial canals with small gonads, the margin of the bell fringed with about 24 short, equidistant tentacles. The medusa swims upside down with the stomach exposed.

Colour

Overall colour of the colonies is white; perisarc of older stems and branches brown. The medusa is transparent.

Remark

Laboratory and *in situ* studies of European *Obelia dichotoma* communities (unpub. data) indicate that, although varying in some minor morphological aspects, *O. australis* is a synonym of *O. dichotoma*.

O. dichotoma in southern Australia is an extremely opportunistic species growing in a wide range of habitats including some algal and many invertebrate substrates and old shell on the sea bed. A favoured substrate in Port Phillip Bay is on the common blue mussel *Mytilus edulis*. Colonies are also abundant in northern Port Phillip Bay on the polychaete *Sabella spallanzanii*, introduced in the early 1980's.

Colonies grow over the winter months at water temperatures of 9°–17° C, releasing medusae in early spring. Release of medusae is easily observed in laboratory. Residence time of the medusa in the plankton in Australian waters is unknown.

Distribution

Victoria: hydroid very common in Port Phillip Bay, Western Port and Bass Strait; to New South Wales: Sydney; medusae common in autumn plankton of Bass Strait (unpub. data). Present in southern Australia at least since the 1880's.

World distribution: cosmopolitan.

Type material

Microslide, F59284, Museum of Victoria collection, presumed syntype.

First record from Port Phillip Bay

Ralph 1966 (collected by National Museum of Victoria Port Phillip Bay Survey 1957–63).

Clytia hemisphaerica (Linnaeus 1767)

Figure 7.10

Medusa hemisphaerica Linnaeus 1767: 1098;
?*Campanularia serrulata* Bale 1888: 757, pl. 12, Figure 4. — Stechow 1919: 46, Figure M. — Calder 1991: 56;
Phialidium hemisphaericum: — Russell 1953: 285–294, pl. 16, Figure 1, pl. 17, Figure 6, text Figures 172–179. — Kramp 1965: 60; 1968: 76, 150–152, Figure 201;
Clytia hemisphaerica: — Watson 1982: 93, Figure 4.7k; 1994: 151, Figure 2A–E. — Cornelius 1995b: 252, Figure 57.

Description

Hydrorhiza tubular, loosely attached to the substrate. Stems simple, to 5 mm high, usually unbranched, or sometimes branched once or twice. Perisarc of stems delicate, shining, annulated at the origin and distally below the hydrotheca. Hydrotheca deep conical, expanding evenly from the base to margin. Margin dentate with 8–10 evenly spaced cusps, these variable in shape from sharply pointed to blunt, with wide incisions between. Hydranth with 12–16 filiform tentacles.

Gonothecae borne on the hydrorhiza, barrel-shaped, walls smooth or sometimes slightly undulated, truncated and constricted distally, summit concave gonotheca containing one to three developing medusae.Medusa almost hemispherical at liberation, bell rather thick with scattered nematocysts or nematocysts in a band (showing as bright spots) around the mid region. Stomach short, mouth with four poorly defined lips armed with nematocysts. Radial canals narrow with rudimentary gonads situated about the middle. Four tentacles around the margin, each arising from an oval marginal bulb at the base of the radial canal. Adult medusa with about 32 tentacles and measuring up to 20 mm diameter across bell (Cornelius 1995b).

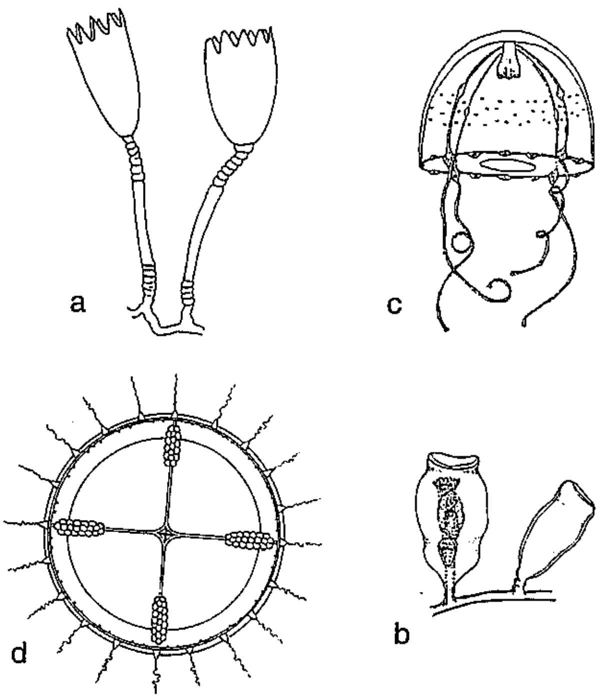

Figure 7.10. *Clytia hemisphaerica*: a) two hydrothecae showing dentate margin and annulated pedicels; b) two gonothecae, one containing developing medusae; c) newly released medusa; and d) diagrammatic view of medusa showing tentacles and gonads on radial canals. (Figure 7.10d after Cornelius 1995).

Colour

Colonies colourless to translucent white. Medusa bell transparent, tentacle bulbs, gonads and stomach pale yellow.

Remarks

Clytia hemisphaerica has been recorded under other synonyms from subtropical Queensland (Pennycuik 1959), southern Australia (Watson 1994) and Western Australia (Stechow 1924, 1925). The hydroid is highly opportunistic in choice of habitat, the low growing, almost transparent colonies occurring on many invertebrate and red algal substrates as well as man-made structures. Colonies on natural substrates are usually small, comprising a few to tens of stems while those on artificial substrates, for example ropes and buoys, may be luxuriant, reproducing prolifically. The hydroid rafts in local waters on drift algae and seagrass stems.

The medusa has been recorded from the Tasman Sea (Kramp 1965). Although the developmental stages of the medusa in the Northern Hemisphere plankton are well known (Russell 1953), there is little information on its actual life span. Colonies may be present throughout the year and are fertile in early to late winter in Bass Strait and surrounding waters. The life span of the medusa in Australian waters is unknown.

Distribution

Victoria: Bass Strait, Port Phillip Bay and Western Port. World distribution: near cosmopolitan in coastal waters.

Voucher material

Microslide F51793, part of colony; F51801, young medusa, formalin preserved, Museum of Victoria collection.

First record from Port Phillip Bay

Watson 1999 (this report). First collected by Watson 1980.

Clytia paulensis **(Vanhöffen 1910)**

Figure 7.11

Campanularia paulensis Vanhöffen 1910: 298, Figure 19; *Clytia paulensis*: — Stechow 1925: 211. — Millard 1975: 221, Figure 73a–d. — Cornelius 1982: 88–91, Figure 14.- Watson 1994: 153, Figure 2F, G. — Cornelius 1995b: 258, Figure 59.

Description

Single stems or sparingly branched stems given off at intervals from a tubular hydrorhiza. Stems slender, straight, annulated proximally and distally, single stems usually less than 1 mm long, branched stems to 3 mm, perisarc smooth and shining. Hydrotheca deep conical, margin with six pairs of bidentate cusps, each cusp in the pair with a slightly blunt apex, a shallow saddle separating each pair and a deep U-shaped incision between the pairs, an indistinct ridge often passing from the base of the incision down into the hydrotheca. Hydranth with 12–16 long tentacles.

Gonotheca borne on hydrorhiza, elongated with a short, annulated pedicel and a truncated distal end, containing 5–8 medusa buds. The medusa (visible inside the gonotheca) has about 16 tentacles. Medusae released in October; life history of the medusa after release is unknown.

Colour

The colonies are colourless and transparent. There is no information on the medusa.

Remarks

The type locality of *Clytia paulensis* is the island of St. Paul in the southern Indian Ocean. The species was first recorded in Australia from Shark Bay by Stechow (1924, 1925). It was first noted in Port Phillip Bay about 15 years ago where it is now a common species (unpub. data).

Clytia paulensis is an epizoite of other hydroids Cornelius (1982). It has been recorded from *Obelia australis*, *Bougainvillia muscus* and sponges in Port Phillip Bay (Watson 1994). Colonies appear as an almost transparent fringe on some soft-textured sponges. Because of their fragility and the loose adherence of the hydrorhiza to the substrate, specimens can only be successfully collected by sealing in a container *in situ*.

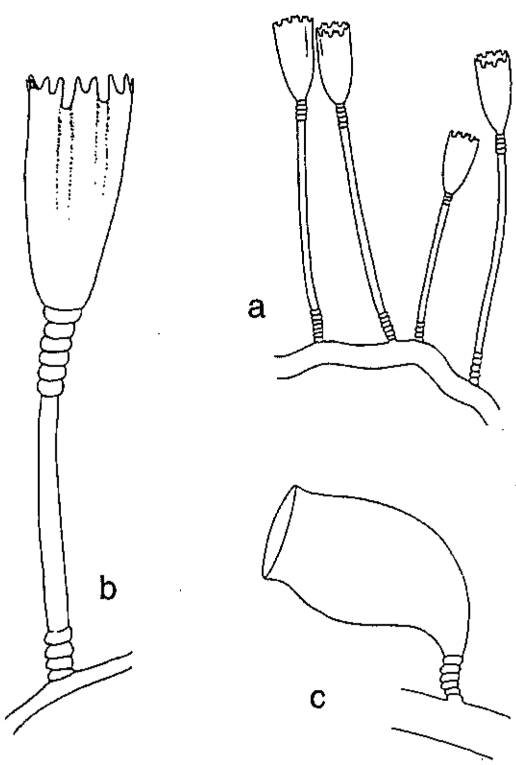

Figure 7.11. *Clytia paulensis*: a) group of four hydrothecae; b) hydrotheca, enlarged showing marginal dentition; and c) gonotheca.

Distribution

Victoria: Port Phillip Bay; and Western Australia: Shark Bay.

World Distribution: South Africa, North Atlantic, British Isles and Gibraltar.

Voucher material

Microslide, F51794, part of colony, Museum of Victoria collection.

First record from Port Phillip Bay

Watson 1999 (this report). First observed by Watson 1985.

Family Sertulariidae

Amphisbetia operculata (Linnaeus 1758)

Figure 7.12

Sertularia operculata Linnaeus 1758: 808. — Bale 1884: 67, pl.6, Figure 1, pl. 19, Figure 3;

Amphisbetia operculata: — Ralph 1961: 775, Figure 8I–k; 1966: 159. — Millard 1975: 251, Figure 83A–E. — Watson 1982: 96, Figure 4.8j, k, pl. 10.5. — Cornelius 1995b: 30, Figure 4.

Description

Colonies tall, to 25 cm high, usually comprising many thin, wiry, irregularly arranged branches without obvious main stem. Perisarc thick and tough, hydrothecae tubular, situated in opposite pairs on the branches, one pair per internode, the internodes separated by distinct joints. Hydrothecae facing upward and outward, margin with two long, opposite, upwardly pointed cusps. Gonotheca elongate–oval, widest at the top, flattened, perisarc smooth, the distal aperture surmounted by a low collar and closed by an operculum. Reproduction is by release of planula larvae.

Colour

Colonies greenish-yellow to honey brown but are often overgrown by a film of pink coralline algae.

Remarks

Colonies of *A. operculata* from southern Australia are tall and wiry, differing from the more branched and compact colonies of those reported from the northern hemisphere. As the microscopic characters of both the northern and southern hydroids are identical, the two are considered conspecific. *A. operculata* can be easily recognised by its tall wiry stems and the harsh texture of the perisarc. It prefers open sea floor, often growing on old shell and rubble in strong current flow. The colonies are fertile from early spring to autumn.

Distribution

Victoria: southern Port Phillip Bay, Western Port and Bass Strait.

World distribution: temperate and subtropical seas of both hemispheres.

First record from Port Phillip Bay

Bale 1884.

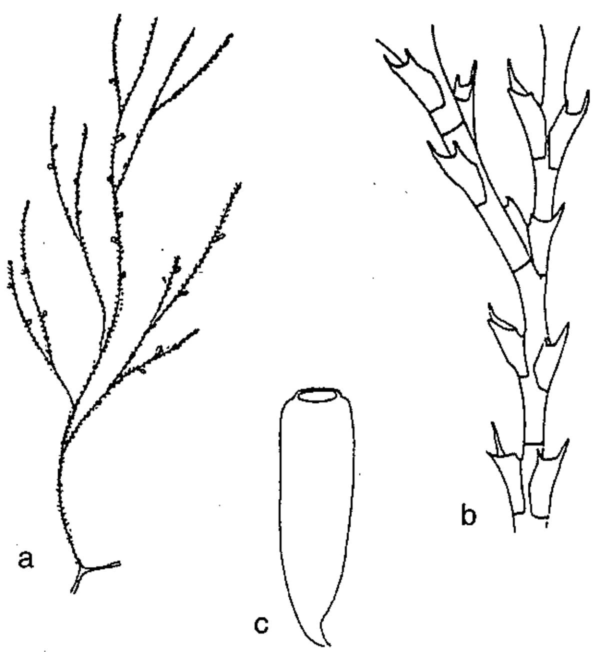

Figure 7.12. *Amphisbetia operculata*: a) living colony; b) part of stem, enlarged, showing hydrothecae; and c) gonotheca. (Figures 7.12b and 7.12c after Cornelius 1995).

Family Plumulariidae

Antennella secundaria (Gmelin 1791)

Figure 7.13

Sertularia secundaria Gmelin 1791: 3854;

Antennella secundaria: — Millard 1975: 332, Figure 107F–L. — Cornelius 1995b: 121, Figure 28;

Antennella secundaria ssp. *dubiaformis* Mulder and Trebilcock 1910. — Watson 1973: 183, Figures 45, 46.

Description

Stems are simple unbranched hydrocladia about 15 mm high growing from a creeping hydrorhiza. Stems begin with short internode without hydrothecae, internodes thereafter alternately hydrothecate and athecate, the athecate internodes terminated by strongly oblique nodes. Athecate internodes with one or two median two-chambered nematothecae; hydrothecate internodes with one, two-chambered nematotheca behind the hydrotheca, one, very small, inserted in front of the hydrotheca and two, on long pedicels, one at each side of the hydrotheca. Hydrotheca cup-shaped, sides almost parallel, base seated on the internode, margin facing forward.

Gonotheca borne beside a hydrotheca, pear-shaped, with two large two-chambered nematothecae near the base. Female gonotheca with a large distal orifice closed by an opercular flap. Reproduction by brooding of planula larvae.

Colour

Colonies usually yellow-green.

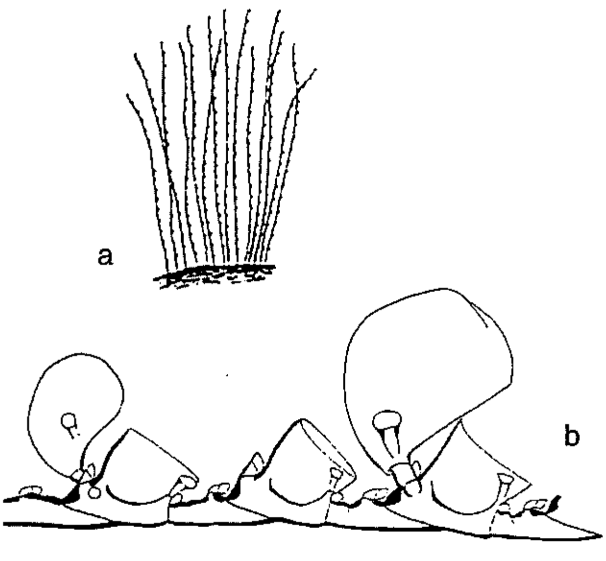

Figure 7.13. *Antennella secundaria*: a) colony consisting of clumps of simple, thread-like hydrocladia; and b) part of hydrocladium, enlarged, showing hydrothecae, nematothecae and male (smaller) and female (larger) gonothecae. (Figure 7.13a after Cornelius 1995; 7.13b after Millard 1975).

Remarks

The fine, hair-like stems usually grow in tufts on small flabellate red algae but are sometimes found on invertebrate substrates. Colonies are never common. Colonies are fertile for a restricted period over summer.

Distribution

Victoria: Bass Strait, southern Port Phillip Bay and Western Port.

World distribution: near cosmopolitan in temperate to subtropical seas.

First record from Port Phillip Bay

Mulder and Trebilcock 1910.

Plumularia setacea (Ellis1755)

Figure 7.14

Corallina setacea Ellis1755: 19, pl. 2, 16a, A, pl. 38, Figure 4;

Sertularia setacea Linnaeus 1758: 813;

Plumularia tripartita von Lendenfeld 1885a: 477, pl. 12, Figures 8–10;

Plumularia setacea: — Hincks 1868: 296, Figure 34, pl. 66, Figure 1. — Bale 1888: 778, pl. 20, Figures 14–18. — Ralph1961: 33, Figures 3e, 4a, c–d. — Millard 1975: 399, Figure 124E–K.

Description

Stems tall, pinnate, to 40 mm high, bearing alternate hydrocladia, one hydrocladium to each stem internode. Hydrocladia divided into alternately athecate and hydrothecate internodes by transverse or slightly oblique nodes. Hydrothecate internode with three two-chambered nematothecae, one behind and one at each side of the hydrotheca, athecate internode with one, sometimes two median two-chambered nematothecae on top of the internode. Hydrotheca cup-shaped to nearly triangular, base completely adnate to the internode, margin smooth, facing forward.

Gonothecae borne in a row along the main stem, ampule-shaped, the male with a narrow tubular neck, the female with a longer, more tubular neck and larger orifice. Gonotheca containing about eight ova. Ova develop into planulae in the gonotheca.

Colour

Colonies white.

Remarks

Plumularia setacea is a fairly tall and conspicuous hydroid although not particularly common. The row of gonothecae along the main stem and hydrothecae completely attached to the hydrocladium along one wall distinguish it from the similar related Australasian species *Plumularia setaceoides*. It is also distinguished from a morphologically similar species, *Nemertesia wattsi* by its planar branching, not spiral as in *N. wattsi*. It is reported

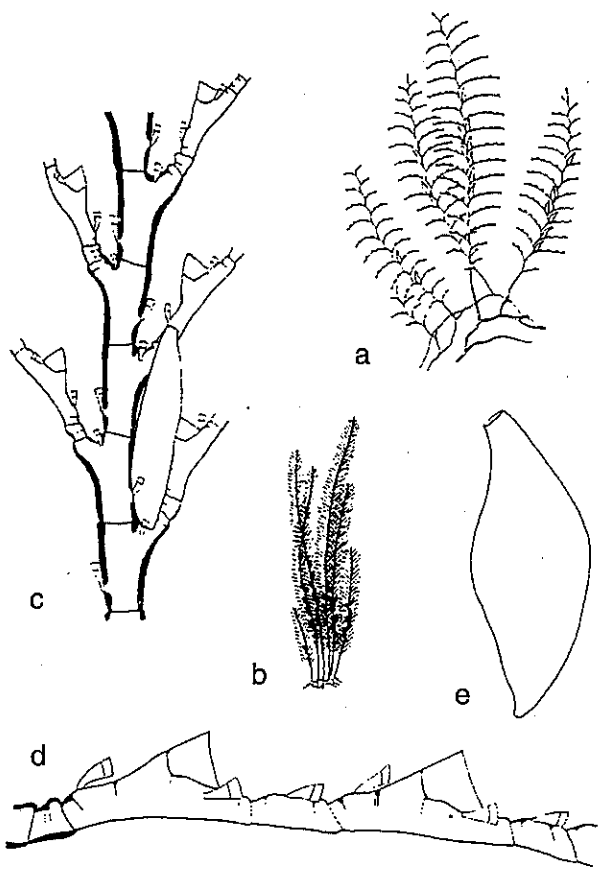

Figure 7.14. *Plumularia setacea*: a, b) two growth habits, a) showing widely spaced hydrocladia; b) more densely branched colony; c) part of stem, enlarged showing hydrocladia (branches), hydrothecae and male gonotheca; d) detail of hydrocladium; and e) female gonotheca. (Figure 7.14a, c, d after Millard; 7.14 b, e after Cornelius 1995).

to be intolerant of reduced salinity (Cornelius 1995b). Reproduction is by planula larva, brooded in the female gonotheca. Colonies are fertile in spring.

Distribution

Victoria: widespread although uncommon along the Victorian coastline and Port Phillip Bay.

World distribution: near cosmopolitan in subtropical and temperate and seas.

First record from Port Phillip Bay

von Lendenfeld 1885.

Monotheca obliqua (Johnston 1847).

Figure 7.15

Laomedea obliqua Johnston 1847: 106, pl. 28, Figure 1; *Plumularia obliqua*: — Bale 1884: 138, pl. 12, Figures 1–3. — Pennycuik 1959: 180. — Millard 1975: 396, Figure 125A–B;

Monotheca obliqua: Cornelius 1995b: 143, Figure 33.

Description

Stems simple, up to 5 mm high, arising at regular intervals from a creeping hydrorhiza. Stems bearing alternate simple, short hydrocladia given off in one plane. Stem internodes with two, two-chambered nematothecae, one in the axil of the hydrocladium and one about halfway along the internode. Hydrocladium short, beginning with an athecate internode without hydrothecae or nematothecae followed by a distal internode with a terminal hydrotheca. Hydrotheca bell-shaped, base adnate to the hydrocladium, margin facing forward, slightly convex. Hydrothecate internode with one, two-chambered nematotheca behind the hydrotheca and two, two-chambered nematothecae side by side, in front of the hydrothecal margin.

Gonotheca very large compared with colony size, borne on a short pedicel low on the stem, conical, expanding distally, truncated at the top, containing a single planula larva.

Colour

Colonies white to straw-coloured, gonotheca usually light brown.

Remarks

The species is not common but occurs on small, flabellate red algae as well as on sponges. Gonothecae are borne sparingly in early summer. *M. obliqua* belongs to a group of small plumularian hydroids having only one terminal hydrotheca on each hydrocladium. The species comprising this group (of which there are six in southern Australia) can only be distinguished by detailed taxonomic examination of whole mounts.

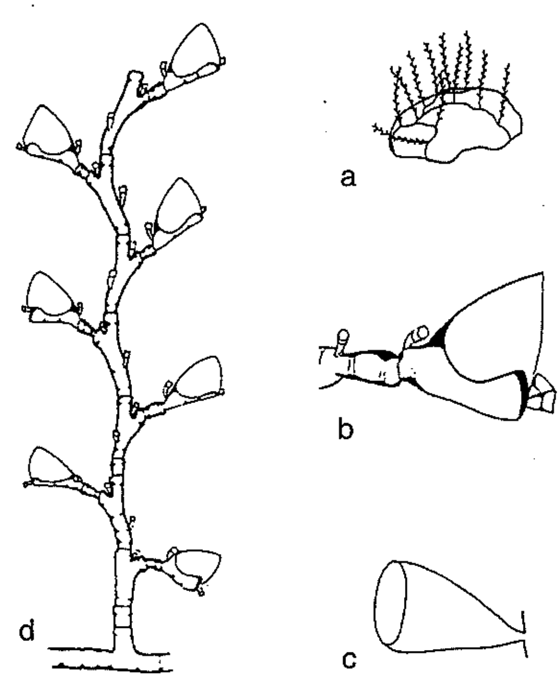

Figure 7.15. *Monotheca obliqua*: a) colony of many simple stems; b) whole stem, enlarged showing alternate hydrocladia, hydrotheca and nematothecae; c) hydrotheca, enlarged; and d) gonotheca. (Figure 7.15a after Cornelius 1995; 7.15b and 7.15c after Millard 1975).

Distribution

Victoria: southern Port Phillip Bay and Bass Strait.
World distribution: near cosmopolitan in temperate to subtropical seas.

First record from Port Phillip Bay

Bale 1884.

7.4 DISCUSSION AND CONCLUSIONS

7.4.1 Introductions to Port Phillip Bay

The most likely mode of introduction to Port Phillip Bay in the historical past would have been transport on ships' hulls. Fertile hydroids among the hull fouling community could shed ova, sperm and larvae at any place along the ship's journey. Thus, settlement and recolonisation could have occurred in stages between ports.

The group of hydroids selected as possible introductions are mostly those with estuarine affinities which have a potential to colonise estuarine environments such as Hobsons Bay at the head of Port Phillip Bay. It is logical to conclude that some of the numerous sailing vessels that anchored off Sandridge Beach during colonial times brought with them some of the so-called cosmopolitan species.

Ballasting by intake of seawater at the port of departure has been common practice since the early years of the century. In Port Phillip Bay, ships in ballast dock in the Yarra River, at Webb Dock in Hobsons Bay and at the Port of Geelong. Ballast water may be taken on at many places in the world: for example, grain and woodchip arrive at the Port of Geelong in ballast, from any one of 167 previous ports (Port of Geelong Authority pers. comm.). Although AQIS guidelines request that ships change ballast before entering Australian ports, there is no certainty that this is done, nor if carried out, whether water is completely or only partially discharged.

Given the general intolerance of most hydroid medusae and larvae to freshwater (pers. obs.) it seems likely that shock of salinity reduction associated with deballasting into the upper water column of the Yarra would be fatal to most species. Deballasting into fully marine water at Webb Dock and Corio Bay is unlikely to have deleterious effects on planktonic organisms that survived the discharge process. This is borne out by the finding of cnidarian medusae by Williams *et al.* (1988) in ballast water samples from vessels at Eden, NSW and Triabunna Tasmania. Each of the species listed in Table 7.1, if indeed introduced, has probably had an equal opportunity over the years of invading habitats in Port Phillip Bay. *Sarsia eximia*, *Bougainvillia muscus* (as *B. ramosa*), *Phialella quadrata*, *Obelia dichotoma* and *Plumularia setacea* were known from Sydney Harbour in the 1880's and *Phialella quadrata*, *Halecium delicatulum*, *Amphisbetia operculata*, *Plumularia setacea* and *Monotheca obliqua* (some under other synonyms) from Port Phillip Bay since that time. Several small, delicate species e.g. *Clytia hemisphaerica* and *Clytia paulensis* were first recorded from south-western Australia in the 1920's, while *Antennella secundaria* (as ssp. *dubiaformis*) and other species have been reported in the literature more recently. Although *Fillellum serpens* has not previously been reported from Port Phillip Bay, and *Clytia paulensis* and *Clytia hemisphaerica* only in recent publications, all have been known from the bay by the author for some 20 years (J E Watson pers. obs.).

7.4.2 Ecological effects

As discussed above, the group nominated as potential introductions are all hydroids with small to medium-sized, free-growing or cryptic colonies, seasonal in occurrence. One of the most wide-spread and abundant species in the winter hydroid fauna of Port Phillip Bay is *Obelia dichotoma.* While this species does grow on a variety of substrates, its preferred habitat is mussels.

Turritopsis nutricula, Bougainvillia muscus, Phialella quadrata, Halecium delicatulum and *Obelia dichotoma* prefer the sheltered habitat of jetty pilings but also occur in other habitats. The remaining species listed in Table 7.1 have more specific habitat requirements and are less widespread in Port Phillip Bay, Western Port and coastal Bass Strait.

Because of their relatively small size and low biomass, none of the listed species are likely to have had any significant ecological effects such as physical displacement of other species from their habitats. Hydroids are static predators of the micro-plankton (and sometimes seston) and medusae are micro-zooplankton carnivores, and because of their small size, are unlikely to have little significant competitive impact on food resources of local marine communities. The listed species (if these are indeed introduced) are now part of local marine communities and as such, have more than likely augmented, rather than reduced biodiversity.

7.4.3 Control of introduced species

Various methods for control of organisms in ballast water have been suggested, the two most frequently proposed being chlorination and heat treatment. Because of general deleterious effects to marine communities, the first method is not favoured by scientists. The second, because of modification costs to ships, is not favoured by the shipping industry. Either of these methods if implemented, would be adequate to control introduction of hydroids or medusae.

Modern hull antifouling paints, whether TBT or copper-based are usually sufficiently toxic to deter settlement of most hydrozoans. For example, a concentration of 100 μg L^{-1} copper in seawater is reported to discourage settlement of *E. ?crocea* in seawater intakes of submarines in Sydney Harbour (Lewis and Smith 1990). Nevertheless, there is always the possibility that poorly antifouled vessels may carry sessile colonies to Australian ports.

7.4.4 Need for research

The primary need is to determine what are the species of Cnidaria entering Australian ports in ballast water. The species of cnidarians reported in the ballast water of woodchip ships from Japan (Williams *et al.* 1988) are unknown. An investigation of entry into Australian ports would require a comprehensive sampling program of ballast water before and during discharge from ships at Webb Dock and the Port of Geelong. Such a study would require a good background of research in the systematics of hydrozoan medusae and hydroid species.

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7.6 GLOSSARY

Athecate: stem or hydrocladium without hydrothecae.

Capitate: short, usually stout tentacle with a club-shaped end.

Coppinia: an agglomerated structure of tubes and capsules protecting the reproductive products.

Dentate: teeth-shaped incisions in the margin of the hydrotheca.

Distal: the upper end, in description of a hydroid colony.

Fascicled: several more or less parallel, adherent tubes forming the stem of some hydroids.

Filiform: long, straight, tapering tentacle.

Gonad: reproductive sacs on the medusa.

Gonotheca: chitinous capsule protecting the reproductive products.
Hydranth: hydroid polyp.
Hydrocladium: branch (in certain families) given off the main stem and bearing hydrothecae. in some families.
Hydrotheca: the chitinous outer cup sheltering the hydranth.
Hydrorhiza: extensions of the stem, attaching the colony to the substrate.
Internode: distinct segment of a hydroid stem or branch.
Medusa: the free-swimming "jellyfish" phase of some hydroids.
Nematocyst: stinging capsules embedded in the tentacles of hydroid and medusa.
Nematotheca: chitinous cup protecting nematocysts of hydroids of the family Aglaopheniidae.
Node: joint in the perisarc separating the hydroid stem into internodes.
Ocelli: small, light sensitive organs on the margin of the bell of the medusa.
Oral: (tentacles) surrounding the mouth of the medusa.
Pedicel: a short stem supporting the hydrotheca or gonotheca.
Perisarc: flexible, chitinous outer sheath of the stems and hydrothecae of the hydroid colony.
Proximal: the lower end, in description of a hydroid colony.
Radial canal: four equidistant radial lines running from the top of bell of the medusa to the margin.
Sessile: attached to the substrate, or to another part of the colony.

8 ANNELIDA: POLYCHAETA OF PORT PHILLIP BAY

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8.1 INTRODUCTION

8.1.1 Background

Polychaetes are segmented, mostly marine worms which are frequently among the most numerous and species-rich taxa in marine communities, especially those of soft sediment macrobenthos (Knox 1977; Rainer 1991). A series of recent papers have investigated the relationships of polychaetes to other invertebrates, their status as a monophyletic taxon, and presented a new cladistic analysis of relationships among polychaete families (Rouse and Fauchald 1995, 1997; Fauchald and Rouse 1997). Fauchald (1977a, 1977b) recognise about 81 polychaete families, and about 45 of these are commonly represented in shallow water benthic communities world wide. Many polychaete genera, as currently defined, also have global distributions and are apparently of palaeozoic origin (Fauchald 1984). Informative biogeographic patterns are thus only likely to be detected by analysing cladistic relationships within genera, but such studies are as yet rare among polychaetes.

8.1.2 Scope of this review

This review is a treatment of the introduced status of the soft-bottom fauna of Port Phillip Bay, and is based for the most part on the material collected from Smith-McIntyre Grab samples collected during a resurvey of Port Phillip Bay during 1994–95 (Wilson *et al.* 1996). This material has been extended to include several other species known to occur in Port Phillip Bay soft sediments but for various reasons were not encountered by Wilson *et al.* (1996). However, resources were not available to review the introduced status of the polychaete fauna of other habitats in Port Phillip Bay, notably hard substrates such as pier piles. It is very likely that other introduced species of polychaetes, such as the serpulid *Ficopomatus enigmaticus*, will be encountered when these communities are taxonomically evaluated.

8.2 POLYCHAETA IN PORT PHILLIP BAY

The species of polychaetes taken in the Port Phillip Bay Environmental Survey phase 1 survey (PPBES-1) were identified by Drs Jerry Kudenov and Sebastian Rainer largely using the keys to species of South African polychaetes in Day (1967). Fewer than one quarter of the species, and many of these were (and remain) incorrect use of species names from foreign (usually European) localities based on the then accepted cosmopolitan species concept (Fauchald 1984). Most of these Port Phillip Bay taxa are probably undescribed species, southern Australian representatives of cosmopolitan species complexes.

In the 20 years since results of PPBES-1 were reported, major revisions of families and descriptions of Australian polychaete material have taken place. Appendix A (Table A2) lists the 227 species of benthic polychaetes now recognised. The most significant in the context of treatment of PPBES material have been studies of Dorvilleidae (Glasby 1984), Eunicidae (Fauchald 1986, 1992), Nephtyidae (Rainer and Hutchings 1977), Nereididae (Hutchings and Turvey 1982; Wilson 1984, 1985; Hartmann-Schröder 1985), Onuphidae (Paxton 1986), Orbiniidae (Day 1977), Phyllodocidae (Wilson 1988; Eibye-Jacobsen 1991), Spionidae (Blake and Kudenov 1978; Wilson 1990) and Terebellidae (Hutchings and Glasby 1986, 1987, 1988). Other families remain poorly known in Port Phillip Bay (and elsewhere in southern Australia), but the major treatments cited above permit three generalisations about the southern Australian polychaete fauna:

1. Most so-called cosmopolitan species have been shown to comprise a number of distinct species wherever adequate study has been completed;
2. Most Port Phillip Bay polychaetes are species endemic to southern Australia; and
3. The Port Phillip fauna is distinct from the more diverse fauna of Bass Strait, and includes a number of species that only occur in fully marine embayments in southern Australia and are uncommon or absent on the continental shelf or in estuaries.

Species with wide distributions remain, and these fall into three groups:

1. Numerous taxa, which require taxonomic revision but are still frequently cited under historical names (e.g. *Capitella capitata, Glycera americana, Lumbrineris latreilli, Owenia fusiformis*). These are very likely incorrect identifications, but because most of these names have been widely reported in the literature for

at least 100 years it seems unlikely that these misidentifications conceal many human introductions. The indiscriminate use of such species names means that any human introductions of species in such cosmopolitan species complexes might by now be undetectable;

2. Several well-studied species with wide and continuous distributions are known. Detailed taxonomic study has failed to discriminate these populations, which probably represent genetically distinct but morphologically conservative species complexes (e.g. *Paralepidonotus ampulliferus* (Grube 1878) (Hanley 1991), *Phyllodoce longipes* Kinberg 1865 (Pleijel 1993), *Prionospio dubia* Day 1961 (Wilson 1990; Sigvaldadottir and Mackie 1993). The wide distribution of these species on continental shelves remote from human disturbance suggests that there are no human introductions among these few well-studied examples; and
3. Several species with wide but disjunct distributions whose known distribution in Port Phillip Bay and elsewhere in southern Australia appears to radiate from major shipping ports. These have been shown to be human introductions or are probably so. The few examples among Port Phillip Bay benthic polychaetes are *Boccardia proboscidea* and *Pseudopolydora paucibranchiata* (Spionidae), *Neanthes succinea* (Nereididae), and *Sabella spallanzanii* (Sabellidae), each of which is discussed in detail separately.

A more detailed treatment of taxonomic knowledge and the likelihood of introduction is covered for each of the Port Phillip Bay benthic polychaete families in the following section.

8.3 TRANSLOCATION POTENTIAL

Polychaetes are too diverse to usefully summarise at such a high taxonomic level those aspects of their biology that relate to their potential for accidental introduction. Instead, notes on biology are provided at family level in the treatments below.

Ampharetidae

Systematics

Two new genera of ampharetids have been described recently from shelf habitats in southern California (Williams 1987), and there have also been a number of single species descriptions, notably from hydrothermal vent communities. Nevertheless, there has not been a review of the family at generic level since Day (1964), and the validity of that revision has been questioned by Fauchald (1977a). It is likely that at least some of the four species known from Port Phillip Bay benthos are currently referred to incorrect genera. Only one species, currently referred to *Samythella*, is common in Port Phillip Bay benthos. There is little likelihood of recognising any introduced species, should they exist in Port Phillip Bay, in a family that is so poorly known taxonomically. The Ampharetidae are currently being revised by Dr P Hutchings, Australian Museum.

Biology

Ampharetids are tube dwelling surface deposit feeders, predominantly occurring on soft sediments, especially in the deep sea. Studies of reproductive biology of ampharetids from a diverse range of habitats indicate that lecithotrophic larvae, which undergo demersal development is the most common mode of reproduction in the family (Zottoli 1974; McHugh and Tunnicliffe 1994). If so, it would seem that the dispersal potential of ampharetid larvae is low.

Arenicolidae

Systematics

Fournier and Barrie (1987) provided a partial review of the systematics of *Branchiomaldane*, including two specimens from PPBES-1 now registered in the Australian Museum (AM W16310). The Port Phillip material was identified by these authors as allied to *B. simplex* (Berkeley and Berkeley 1932) from the Pacific coast of North America. Additional material in the MoV ... "*Branchiomaldane* sp.1 (PPB sp.514)" from Port Phillip Bay is either *B. simplex*, with a distribution throughout the Pacific, or may represent an undescribed southern Australian species. "*Branchiomaldane* sp.1 (PPB sp. 514)" has not been collected since the 1969–1973 PPBES-1 study, where it was known from only three lots.

Abarenicola assimilis devia Wells 1963 also occurs in Port Phillip Bay but is an intertidal species which has not been collected in PPBES survey stations. *Abarenicola* is a genus restricted to the Southern Hemisphere, and the subspecies recorded from southern Australia by Wells (1963) are endemic to Australia.

Biology

Arenicolids are subsurface deposit feeders. The best known species are in the genera *Arenicola* and *Abaranicola* (lugworms), which are well-known bioturbators of intertidal estuarine sediments (e.g. Hobson 1967). The reproductive biology of *Branchiomaldane* species is unknown, but eggs (of *Arenicola* species) are either incubated in burrows or in mucus cocoons (warm water species) and larvae typically settle after 4–5 days (Newell 1949; Bailey-Brock 1984). It is very unlikely that any of the arenicolid species occurring in Port Phillip Bay represent human introductions.

Capitellidae

Systematics

The systematics of the Capitellidae is unstable. Many characters presently used to define genera have been shown to be variable and unreliable (Warren 1991), and some genera now recognised will thus probably become junior synonyms. At the species level, numerous undescribed species are known, but their nomenclature remains uncertain because of the large number of cryptic species that require reproductive, genetic or ultrastructural data for accurate discrimination (Grassle and Grassle 1976; Eckelbarger and Grassle 1987). Since nearly all of the 150+ species now known omit these data from species diagnoses, much of the literature on the group cannot be used to compare local faunas at the species level. Identification of species of capitellids is thus so difficult as to exclude the possibility of detecting human introductions. About 13 species of Capitellidae have been identified from Port Phillip Bay benthic collections.

Biology

Capitellids are deposit feeders; there are no comparative studies of feeding biology that would allow generalisations about specific feeding preferences. Reproductive biology and life history studies reveal a diverse range of strategies, including brooding species, direct development from lecithotrophic larvae and planktotrophic larvae with a significant dispersal phase (Eckelbarger and Grassle 1987). At least one capitellid with planktotrophic larvae can delay larval development until optimal size food particles are present in the water (Hansen 1993). Such species would be well adapted to dispersal in ship ballast water (and by natural means), but detecting such introductions would require a major international research effort.

Chaetopteridae

Systematics

Two chaetopterid species are known from Port Phillip Bay benthos: *Chaetopterus variopedatus* and *Phyllochaetopterus socialis*. Both species are currently attributed with cosmopolitan distributions and require revision (Petersen 1984). Without a taxonomic revision that includes redescription of type material of *C. variopedatus* and *P. socialis* it is impossible to determine the identity of the Port Phillip Bay material.

Biology

Larvae of *Chaetopterus* and *Spiochaetopterus* may exist in the plankton for several months as metatrochophores, and *Spiochaetopterus* larvae have been maintained in the laboratory for one year (Scheltema 1974). The Chaetopteridae therefore have very considerable dispersal potential and are well able to cross oceans without assistance from humans. This family contains truly cosmopolitan species, and gene flow between distant populations is maintained by the long-lived planktonic larvae (Scheltema 1974).

Chrysopetalidae

Systematics

There were only two records of chrysopetalids from PPBES-1, both identified as *Paleanotus chrysolepis*. As noted by Watson Russell (1986), taxonomic knowledge of this family is such that even generic level identifications in the literature require verification. The group remains poorly known in southern Australia, but the same nominal species was first reported from Australian waters (Western Australia) by Augener (1913). No chrysopetalid species have been recorded from Port Phillip Bay in more recent benthic surveys and there is no indication either from distribution or expanding range that the species is introduced.

Biology

Chrysopetalids are carnivores with eversible probosces (Fauchald and Jumars 1979). No information relevant to dispersal potential is available on the Chrysopetalidae, whose reproductive biology is poorly known.

Cirratulidae

Systematics

Cirratulids are common in Port Phillip Bay benthos, as in most soft bottom communities. Seventeen species and six genera are estimated to occur in Port Phillip Bay but the family remains poorly known taxonomically. Several species have been described from NSW by Hutchings and Murray (1984), but those authors did not examine material from Port Phillip Bay. The most recent major taxonomic study is that of Blake (1991), who questioned the validity of definitions of three widespread bipalpate genera. Recognition of any possible introductions is not possible in the absence of major revisory studies of the family on a global scale. There is evidence that at least one species of cirratulid with widespread records in fact represents a sibling species complex (Christie 1985).

No new cirratulid species have been recognised in 1994–1995 PPBES collections, although the poor state of preservation and missing voucher specimens from PPBES-1 collections means that not all species could be identified.

Biology

Cirratulids are surface deposit feeders that are almost always found in soft sediments. Members of the genus *Dodecaceria* may reproduce asexually, by fragmentation (schizogenesis) into over 30 fragments, and this process appears to be a major contribution to recruitment in some populations (Gibson and Clark 1976). Parthenogenetic production of larvae also occurs in the genus *Dodecaceria* (Caullery and Mesnil 1898). However, sexual reproduction is more common and lecithotrophic eggs are apparently universal in the family. All species of *Cirriformia*, *Cirratulus* and *Tharyx* studied thus far have direct development of larvae (Christie 1985).

Thus, although the potential for asexual reproduction in species of *Dodecaceria* suggests that any introduced species may proliferate swiftly, the lack of a significant dispersal phase and preference of adults for soft sediment communities indicates that cirratulids are unlikely to be accidentally introduced by human activity.

Dorvilleidae

Systematics

Dorvilleids from Australian waters have been revised recently by Glasby (1984). The three species recorded from PPBES collections are all endemic Australian species. Interstitial species in the genera *Corralliotrocha* and *Pettiboneia* also occur in Australia (Westheide and von Nordheim 1985) but are presently only known from tropical waters and in any case would not be caught on the 1.0 mm screens used in the PPBES surveys. There appear to be no introduced species among dorvilleids presently known from Port Phillip Bay benthic collections.

Biology

Useful studies of reproductive biology of dorvilleids are limited to *Ophryotrocha* and other interstitial genera, in which reproductive strategies have a major role in initiating speciation (Akesson 1984). Most known species of *Ophryotrocha* brood developing larvae, which thus have little opportunity for larval dispersal (Akesson 1984). The reproductive biology of larger taxa is unknown.

Eunicidae

Systematics

The genus *Eunice* has been revised based on type material by Fauchald (1986, 1992). *Eunice antennata* Quatrefages 1866 was reported from PPBES-1 but this name is a junior homonym and Fauchald (1986) showed that the correct name for this species is *E. laticeps* Ehlers 1868. *Eunice laticeps* is widely reported from Australia, although many of these records require verification (Fauchald 1986).

The other genera of Eunicidae recorded from Port Phillip Bay are *Lysidice, Marphysa* and *Nematonereis*. None of these genera has been revised systematically. Recent studies have shown that many eunicids show considerable size-related morphological variability (Fauchald 1991; Parapar *et al.* 1993), thus most species descriptions in the literature are difficult to interpret in the absence of a major revision. Nevertheless, there are numerous records of similar or identical species of *Lysidice* and *Marphysa* from Australia dating from the early 1900's and earlier (Day and Hutchings 1979), and no evidence for any introductions among Port Phillip Bay eunicids.

Biology

Eunicids inhabit reefs including coral reefs and sandy substrates; they are less common in muddy sediments. The family probably includes carnivorous and herbivorous species (Fauchald and Jumars 1979). Reproductive biology has been studied in only a few species, which appear to have a planktonic larval phase of a few days (Gathof 1984). Dispersal potential would thus appear to be low.

Flabelligeridae

Systematics

Flabelligerids are poorly known polychaetes. None of the three genera recorded from PPBES collections is well enough studied globally to enable confident identification. The most common flabelligerid in Port Phillip Bay is a species of *Pherusa,* probably *P. cincta* Haswell 1883 or *P. horsti* Haswell 1883, both of which were described from Australian waters for over 100 years. There is no reason to believe that any Port Phillip Bay flabelligerid is introduced by humans.

Biology

Flabelligerids are deposit feeders, which are found only in soft sediment communities; they do not occur as fouling organisms and are thus unlikely to be introduced as adults. There are no useful studies of life history of flabelligerids.

Glyceridae

Systematics

The two species of Glyceridae recorded from Port Phillip Bay in PPBES-1 are *Glycera americana* (type locality, east coast USA) and *G. capitata* (type locality, Greenland). O'Connor (1987) reviewed North Atlantic records of *G. capitata* and indistinguishable species from global localities and suggested that a complex of species was represented. *Glycera americana* has not yet been so studied, although glycerids from Port Phillip Bay will be incorporated in a revision of the genus by Markus Boeggeman, University of Frankfurt, that is currently underway. Both species have been reported from cosmopolitan localities for at least 100 years and there is no evidence to suggest that any glycerid species have been introduced to Port Phillip Bay by humans.

Biology

Many glycerid species produce larvae that may endure in the plankton for at least two weeks, beyond which time aquarium-kept larvae die (Klawe and Dickie 1957). Glycerids are probably thus capable of dispersal over significant distances both through natural processes and human intervention. Many *Glycera* species are known to form breeding swarms in surface waters, but non-breeding adults of *G. dibranchiata* (in the northeast USA) also swim in surface waters in significant numbers possibly contributing to dispersal (Dean 1978). Despite these observations, genetic studies elsewhere suggests that these processes do not usually result in significant gene flow between populations, at least among the estuarine species studied (Bristow and Vadas 1991).

Goniadidae

Systematics

The Goniadidae is less well studied than the Glyceridae; the only critical revisionary work is that of Hartman (1950) who described species from the west Pacific. The Port Phillip Bay fauna includes one species of *Goniada* and one species of *Glycinde*. The *Goniada* species is tentatively referred to *G. antipoda* Augener 1927; although two other species of *Goniada* are known from Australia (Day and Hutchings 1979). The only species of *Glycinde* described from the region is *G. dorsalis* Ehlers 1905 from New Zealand. The range of morphological variability attributed to that taxon through Australia and New Zealand indicates the presence of more than one species (Hartman 1950) and the genus is not known sufficiently to identify the Port Phillip Bay species of *Glycinde*.

Biology

There are no studies of reproductive biology and dispersal potential in the family Goniadidae.

Hesionidae

Systematics

Five species of Hesionidae are described from southern Australia (Day and Hutchings 1979). The five species known from Port Phillip Bay belong to four genera, but the poor state of the material (hesionid specimens are unusually fragile) and the lack of relevant revisionary studies makes it impossible to accurately identify the Port Phillip Bay fauna, including any introduced species.

Biology

Hesionids occur on hard and soft substrates; several species are common in disturbed habitats (Zunarelli-Vandini 1971). Large species of Hesionidae are probably carnivores, while many smaller taxa may be deposit feeders (Fauchald and Jumars 1979). Reproductive strategies are diverse, and include species whose larvae undergo direct demersal development to species with planktotrophic larvae (Haaland and Schram 1982; Schram and Haaland 1984). Larvae may exist in the plankton for 1–2 months in some species (Haaland and Schram 1983), thus the family has considerable dispersal potential in the larval phase of some species.

Lumbrineridae

Systematics

A single species, widely cited as *Lumbrineris latreilli* (type locality, France), is known from Port Phillip Bay, although three species of *Lumbrineris* with type localities in southern Australia are known (Day and Hutchings 1979). In the absence of a global revision of this species group accurate identification of the Port Phillip Bay species is impossible. Colbath (1989) moved *Lysarete* to the Lumbrineridae, but no species of *Lysarete* has yet been confirmed from PPBES benthic samples.

Biology

Lumbrinerids are common deposit feeders of soft sediment communities. Those few species studied appear to emerge from gelatinous egg masses as partially developed demersal larvae (Pettibone 1963; Sato *et al.* 1982). The family thus appears to have low dispersal potential.

Magelonidae

Systematics

The family Magelonidae comprises a single genus, *Magelona*, with three or four species in Port Phillip Bay. It appears that only one of these species is described, and there is no evidence that this or any of the others are introduced by humans.

Biology

Magelonids are deposit feeders that burrow in soft sediments; their dispersal potential as adult fouling organisms is low. However, magelonid larvae exist as pelagic organisms for several weeks and are frequently collected in plankton tows (Wilson 1982). Thus there would seem ample potential for introduction of magelonid species through ballast water but there is no evidence that this has occurred in Port Phillip Bay.

Maldanidae

Systematics

Six species of maldanids belonging to five genera are recorded from Port Phillip Bay benthic collections. Three species are endemic to southern Australia, *Petaloproctus terricola* (type locality, France) is a "cosmopolitan species complex" requiring revision, and the two species referred to *Praxillella* and *Rhodine* cannot yet be identified and may be undescribed. There is no reason to believe that any introduced species of Maldanidae occur in Port Phillip Bay.

Biology

Maldanids are deposit feeders that occur exclusively in soft sediments. Reproductive biology has been studied in several species, which have lecithotrophic larvae with short development times and spend little or no time in the plankton (Read 1984). Several species brood the eggs within the tube of the adult (Wilson 1983; Read 1984). Maldanid adults and larvae have low dispersal potential.

Nephtyidae

Systematics

Australian species of Nephtyidae are well studied (Rainer and Hutchings 1977; Rainer and Kaly 1988). Only two species are recorded from Port Phillip Bay benthic collections and both are endemic to Australia. Three Australian species of nephtyids with wider distributions are also known; these have Southern Hemisphere or Indo-Pacific distributions (no Australian nephtyids are known with distributions extending to the North Atlantic or Europe).

Biology

Nephtyids are carnivorous polychaetes, which do not construct a permanent tube. They inhabit a range of soft sediment communities, but are more common in sandy sediments. I have no information on dispersal potential of nephtyid larvae.

Nereididae

Systematics

The Nereididae are among the best known polychaete families, both through generic-level revisions (Hartmann-Schröder 1985; Fitzhugh 1987; Glasby 1991), and through studies of the southern Australian fauna including dominant taxa from soft sediments (Hutchings and Glasby 1982; Hutchings and Turvey 1982; Wilson 1984, 1985). Ten species of nereidids have been identified with confidence from PPBES survey collections. Of these, seven are endemic to southern Australia and two (*Ceratonereis australis* and *Platynereis dumerilii antipoda*) have Southern Ocean distributions and are members of species complexes. The remaining species, *Neanthes succinea*, is apparently introduced to Port Phillip Bay and elsewhere in southern Australia; this species is discussed in detail elsewhere.

Biology

The only life history studies of Australian nereidids are of estuarine species, *Australonereis ehlersi*, *Simplisetia aequisetis* and *S. limnetica*, all of which complete their life cycle in 1–1.5 years. *Australonereis ehlersi* apparently has a planktonic larva, but *Simplisetia* species brood larvae within the tubes of the adult (Dorsey 1981; Glasby 1986). Allozyme studies of estuarine nereidid species have shown considerable genetic variation between populations, but it is not clear whether this is due to restricted gene flow between estuaries or to high selective pressure (Mustaquim 1988; Hateley *et al.* 1992). Studies elsewhere of marine species indicate that development of larvae to a demersal juvenile stage of 3–6 segments may occur in 4–40 days (Reish 1957), thus at least some species have the potential to disperse larvae in ship ballast water (or passively on ocean currents).

Adult nereidids of some species may also occur in fouling communities. Review of these taxa is beyond the scope of the present study, but studies of nereidid taxa from such communities has not revealed the presence of any further potentially introduced species (Hutchings and Turvey 1982; Hutchings *et al.* 1991).

Oenidae (previously Arabellidae)

Systematics

Colbath (1989) revised the Lysaretidae, resulting in the genus *Oenone* being moved to Arabellidae. Since the name Oenonidae has priority over Arabellidae Hartman 1944, the former now applies to those genera previously placed in the Arabellidae. Colbath (1989) also moved all former Lysaretidae genera except *Lysarete* to Oenonidae. According to this expanded family concept, five species and four genera of Oenonidae are recorded from PPBES benthic survey collections. Two species were known from only a few specimens, none of which can now be located. The most common Port Phillip Bay oenonid, *Arabella iricolor iricolor* (Montagu 1804) appears to be the same as *Arabella iricolor* recorded from New South Wales by Augener (1927).

Two remaining genera, *Drilonereis* and *Notocirrus*, are known from Port Phillip Bay, but (with 40 and 10 nominal species, respectively) are so poorly known globally that recognition of any introduced taxa would be an unrealistic goal.

Biology

The Oenonidae include species parasitic on other polychaetes (Pettibone 1957; Uebelacker 1978), but parasitic genera are not yet recorded from Australia. All other Oenonidae are free-living deposit feeders or scavengers that predominantly inhabit soft sediments. Nothing is known of the reproductive biology or dispersal potential of oenonids or their larvae.

Onuphidae

Systematics

Onuphid genera have been revised recently by Paxton (1986). The only species known from adequate material for taxonomic study from PPBES collections belongs to *Nothria*. *Nothria* was revised recently by Fauchald (1982), but the Port Phillip Bay species cannot be identified using the key provided by Fauchald and appears to be undescribed.

Biology

Onuphids are scavengers and are mostly found on soft sediments. The family includes species that brood their young in the tubes of the adult, as well as species with plankonic larvae (Paxton 1986, 1993); at least some species will therefore have significant dispersal potential as larvae, though probably not as adults. Nothing is known of the reproductive biology of Australian *Nothria* species.

Opheliidae

Systematics

Six species of Opheliidae, in four genera, are recorded from Port Phillip Bay benthos. *Travisia forbesi* and *Polyophthalmus pictus* are probably cosmopolitan species complexes that require revision (Dauvin and Bellan 1994). The remaining species belong to the genera *Armandia* and *Ophelia* and cannot be identified until a critical review of type material from global localities is completed.

Biology

Opheliids are deposit feeders (Fauchald and Jumars 1979); they occur only in soft sediments and are uncommon in fouling communities. Opheliids include species with direct development and lecithotrophic larvae, as well as planktotrophic larvae with an unknown duration in the plankton (Riser 1987).

Orbiniidae

Systematics

Australian Orbiniidae have been revised (Day 1977). Four species are known from PPBES benthic surveys. Two, *Leitoscoloplos bifurcatus* and *L. latibranchus*, are endemic to Australia. *Scoloplos (Leodamas) ohlini* was described from South America but is now recorded from Australia and New Zealand; it is evidently a Gondwanan taxon and seems unlikely to have been introduced by humans. The fourth species is an unidentified species of *Nainereis* known only from a single specimen that cannot now be located.

Biology

Orbiniids are deposit feeders common in soft bottom communities but rare in substrates lacking sediment. Many species of orbiniids produce eggs in gelatinous cocoons, although some species release eggs directly into the water column. Larvae may have a planktotrophic larval phase, but many species undergo direct development within the gelatinous egg mass (Schroeder and Hermans 1975).

Oweniidae

Systematics

Two species of Oweniidae, belonging to the genera *Myriochele* and *Owenia*, are known from Port Phillip Bay. Both require revision on a global scale before identification of Australian material will be possible.

Biology

Oweniids are suspension feeders, although some species may also be deposit feeders (Fauchald and Jumars 1979). Most species inhabit shallow depths and soft sediments where they make sediment-encrusted tubes. Oweniids produce trochophore larvae which may remain in the plankton for up to four weeks (Pettibone 1982b) so the family has significant dispersal potential.

Paraonidae

Systematics

Seven species of Paraonidae are recorded from PPBES benthic collections. These belong in four genera according to the review of the family by Strelzov (1979). However, three taxa known from Port Phillip Bay belong in cosmopolitan species complexes and cannot be resolved without further taxonomic revisions on a global scale. Another Port Phillip Bay paraonid, *Paraonides* sp. MoV 1360, cannot be identified and may be undescribed. The remaining specimens are known from inadequate material and cannot be identified. The family is especially difficult to identify in quantitative samples, and there is little chance of recognising any introduced species that may exist.

Biology

Paraonids are deposit feeders, common on soft sediments, especially muds. Their reproductive biology is almost unknown. The first reliable record of planktonic larvae for the family is that of Bhaud (1983) but the duration of the planktonic phase is unknown. Previous authors have suggested that direct development may occur. Paraonid eggs are typically large and few in number (Strelzov 1979). Hartman (1944) suggested that direct development may occur. Until further studies are undertaken the dispersal potential of paraonids remains unknown.

Pectinariidae

Systematics

A single species of Pectinariidae, *Pectinaria antipoda*, is recorded from PPBES benthic samples. This species is widely reported from southeastern Australia (Day and Hutchings 1979). Australian Pectinariidae are currently being revised by Dr P Hutchings, Australian Museum.

Biology

Pectinariids are deposit feeders that occur as adults only in soft sediments. Pectinariid larvae typically have a planktonic phase of about four weeks (Irlinger *et al.* 1991), thus have the potential to be distributed by ship ballast water, as well as by ocean currents.

Phyllodocidae

Systematics

The identity of many Port Phillip Bay Phyllodocidae has been clarified by a recent review of the family (Pleijel 1991) and revisions of some genera (Pleijel 1988, 1990; Wilson 1988; Eibye-Jacobsen 1991). Most Port Phillip Bay species are southern Australian endemics, although two species of Phyllodoce have wide or cosmopolitan distributions. These wide distributions are based in part on records dating back at least 100 years (Day and Hutchings 1979; Pleijel 1988) and would thus seem unlikely to represent human introductions. Several taxa collected from PPBES-1 remain unidentified due to missing voucher specimens or the poor state of preserved material.

Biology

Larval development of phyllodocids has been described for *Eteone dilatae*, *E. picta*, *E. longa*, *Eulalia viridis*, *Phyllodoce maculata* and *P. mucosa* (Blake 1975; Olive 1975; Cazaux 1985; Lacalli 1986; Zavarzina and Tzetlin 1986). In these species larvae develop through one or two trochophore and two metatrochophore stages before settling as 5- to 9-segmented larvae. Trochophores are the strongly phototactic and swim actively by beating the ciliated prototroch; swimming activity has been observed to decrease in the latter stages of larval development (Olive 1975; Cazaux 1985). Length of larval life before settlement varies at least from eight to 65 days. Phyllodocids thus have considerable dispersal potential both through natural means and through human intervention, an observation supported by the wide distribution of several *Phyllodoce* species or species complexes (see above).

Pilargidae

Systematics

A single species of pilargiid was collected during PPBES-1 but has not been encountered since. The family requires revision before Australian material can be identified. Such a revision is currently being undertaken by Dr C Glasby, NIWA, Wellington, New Zealand.

Biology

There are few studies of pilargiid biology relevant to the dispersal potential of the family, although pelagic larvae and even adults are known (Pettibone 1966; Bhaud 1973). However, these predominantly soft bottom inhabitants are rarely common and are unlikely candidates for accidental human introduction.

Poecilochaetidae

Systematics

The record of *Poecilochaetus* from PPBES-1 (Poore *et al.* 1975) is the first and still the sole record of the family from Australia, although additional species occur in Bass Strait (unpubl. data) and in New Zealand (Read 1986). The Port Phillip Bay *Poecilochaetus* is apparently undescribed and cannot be considered a possible human introduction.

Biology

Poecilochaetids are capable of suspension and deposit feeding; they construct sediment-encrusted tubes in a variety of substrates (Fauchald and Jumars 1979). Larvae of *Poecilochaetus* are planktonic, and apparently remain in the plankton for extended periods prior to settling (Milligan and Gilbert 1984). The dispersal potential of the family is thus significant.

Polynoidae

Systematics

Polynoidae from PPBES benthic collections have been the subject of taxonomic studies by Kudenov (1977), Hanley (1987, 1991), and Pettibone (1993). *Paralepidonotus ampulliferus* (Grube 1878) has been verified as having a wide distribution, and is recorded from a wide range of Indo-Pacific localities, many of which are remote from human disturbance and major shipping harbours (Hanley 1991). There is no reason to believe that the wide distribution of *P. ampulliferus* is the result of human introductions. Other Port Phillip Bay polynoids are either endemic species (described or undescribed) or appear to belong to Gondwanan species or species complexes (*Harmothoe spinosa*).

Biology

Polynoids are mostly carnivorous, and live on a wide range of substrates. Most species are free-living, but some are commensal, especially with echinoderms or other (tube-dwelling) polychaetes (Fauchald and Jumars 1979). Planktotrophic larvae are common in the Polynoidae, although species that brood larvae beneath the elytrae are also known (Weston 1984). Polynoids occur on such a wide range of substrates that their dispersal as adults in fouling communities should also be considered.

Sabellidae

Systematics

Recent taxonomic studies of the Sabellidae include major revisions of higher taxa (Knight-Jones 1983; Fitzhugh 1989, 1990a, 1990b) but relatively few treatments of Australian species (Rouse 1990, 1993; Fitzhugh 1992). Few sabellid individuals and species were collected during PPBES-1, but this material has not been included in the above revisionary studies and several Port Phillip Bay species remain unidentified. Collections made during PPBES-3 include most of the taxa recorded during PPBES-1, as well as two species not previously recorded.

Sabella spallanzanii, is treated briefly elsewhere, and in more detail by Clapin and Evans (1995). *Euchone limnicola*, a very different and much smaller sabellid with passing resemblance to an endemic species, *Euchone variabilis*, has also been introduced to Port Phillip Bay and is also treated in more detail below. There is no evidence for human introductions among other species of Sabellidae in Port Phillip Bay.

Biology

Species of Sabellidae occur on hard substrates as well as in soft sediments. Sabellids are filter feeders that capture suspended particles in a funnel formed by the branchial crown (Fauchald and Jumars 1979). Reproductive biology observed in the family includes brooding of direct developing larvae in some fabriciine species (Knight-Jones and Bowden 1984; Rouse 1993), although planktonic larvae are more common in the family (Pettibone 1982a). Many sabellids, including the introduced *Sabella spallanzanii*, probably have greater dispersal potential as adult fouling organisms than as larvae.

Scalibregmatidae

Systematics

Scalibregmatidae (also referred to under the name Scalibregmidae in the literature) are poorly known taxonomically. Two specimen lots have been collected during the course of Port Phillip Bay benthic studies, and this material belongs in *Asclerocheilus* but cannot be identified with any of the four described species. There is no reason to suspect that scalibregmatid species have been introduced by humans to Port Phillip Bay.

Biology

Scalibregmatids are deposit feeders that occur on soft sediments, predominantly in the deep sea. There are no studies of reproductive biology in the family relevant to the dispersal potential of scalibregmatid species.

Serpulidae

Systematics

Papers relevant to the study of Australian Serpulidae include Knight-Jones (1973), Knight-Jones *et al.* (1974), ten Hove and Jansen-Jacobs (1984) and ten Hove and Smith (1990).

The serpulid *Ficopomatus enigmaticus*, with type locality France and a confirmed distribution including southern Australia, South Africa, Uruguay, Argentina, Japan, California and Europe (ten Hove and Weerdenburg 1978), was once thought to be introduced to Australia (Hutchings *et al.* 1987). However, the most recent evaluation of the distribution records indicates that the species is endemic in the temperate Southern Hemisphere (possibly southern Australia) and is recently introduced to Europe and California (Read and Gordon 1991; Zibrowius 1992). According to this hypothesis, *F. enigmaticus* was described from France by Fauvel (1923) shortly after it became established there, and the type locality in this case may not indicate the endemic range of the species. *Ficopomatus enigmaticus* cannot on the present evidence be considered an introduction to Australia, and the original distribution of the species prior to dispersal by humans remains uncertain. It is clear, however, that *F. enigmaticus* has been recently introduced to New Zealand, where it was unknown until about 1969 (Read and Gordon 1991; Probert 1993).

It is probable that this species also occurs in Port Phillip Bay in areas of reduced salinity and where suitable hard substrates are found (such as pier piles in the vicinity of the Yarra and Patterson Rivers), but I have not examined any samples from such habitats and the species is not treated further here.

Biology

Serpulidae are collected occasionally from quantitative benthic samples in Port Phillip Bay but they are fouling organisms which only occur in soft sediments when they are able to settle on haphazardly distributed hard substrates projecting from the sediments. They have thus not been treated systematically in PPBES-3.

Sigalionidae

Systematics

Relevant taxonomic studies of Sigalionidae include Pettibone (1971), Mackie and Chambers (1990) and Pettibone (1992). Dr P Hutchings is revising some Australian species of Sigalionidae. Records of Sigaliolidae from Port Phillip Bay benthic studies are all referrable to *Sigalion* cf. *bandaeensis* Horst 1917, widely recorded by Hutchings and Murray (1984) from eastern Australia (the species also occurs in Banda, India, the type locality). This species appears to be an Indo-Pacific endemic, and cannot be considered a human introduction.

Biology

Sigalionids are predators that occur most commonly on soft sediments, especially well-sorted sands (Fauchald and Jumars 1979). Studies of reproductive biology of sigalionids are restricted to two species, which have both been found to have planktonic larvae (Heffernan 1985; Murina 1991). The duration of the planktonic phase and the dispersal potential of most sigalionids remains unknown.

Sphaerodoridae

Systematics

Sphaerodorids are soft sediment animals that occur occasionally in shallow water but are more common in the deep sea. The family has been reviewed by Fauchald (1974). Only two specimens are known from PPBES benthic collections, neither of which could be located for further study. However, given their relative rarity in shallow waters and harbours, it is extremely unlikely that any species of Sphaerodoridae has been or will be introduced to Australian waters.

Biology

Reproduction has been studied in *Sphaerodorum gracilis*, a species with lecithotrophic larvae which show direct development (Christie 1984), as occurs in other sphaerodorids (Mileikovsky 1967). Dispersal potential of sphaerodorids is low, both as larvae and as adult worms.

Spionidae

Systematics

Recent revisions of spionids that have included Australian material now allow most Port Phillip Bay spionids to be identified (Blake and Kudenov 1978; Hutchings and Turvey 1984; Maciolek 1985; Wilson 1990)

Biology

Spionids are surface deposit feeders that may also feed on suspended particles using their paired palps (Fauchald and Jumars 1979). Spionid species occur on a variety of soft sediments, while polydorid spionids may occur on muds or in holes bored in mollusc shells or other calcareous skeletons (such as corals) (Blake and Evans 1973). Adult polydorids, such as species of *Boccardia*, *Polydora* and *Pseudopolydora* may thus have considerable dispersal potential if they are transported among oyster shells or in fouling communities. Reproductive biology ranges from brooding and direct demersal development to species with extended planktonic larval phases (Blake 1969). Some polydorid species are particularly adaptable to accidental transmission in ship ballast water through having larvae which are able to greatly prolong their larval life by cannibalising other forms of co-occurring larvae from the same egg capsules (Blake and Kudenov 1981). It is species in this group, in the genera *Boccardia* and *Pseudopolydora* that appear to be introduced to Port Phillip Bay.

Syllidae

Systematics

Syllids are among the most diverse, morphologically variable and taxonomically difficult of polychaete families. They are also among the most poorly known, with very few large-scale systematic revisions (Riser 1991; San Martin 1991, 1992). Australian syllids have been little studied (Haswell 1920; Kudenov and Dorsey 1982). At least 40 nominal species of syllid are recorded from Port Phillip Bay benthic collections, but about half of these are known from only one or two lots. The state of knowledge of the family globally is such that identification of any introduced taxa would be impossible.

Biology

Syllids have a diverse range of feeding strategies, but most appear to be variations on a carnivorous theme (Fauchald and Jumars 1979). The reproductive biology of the family covers the range from: brooding; parental brood care; and asexual reproductive strategies (Uebelacker 1984). However, although syllids lack a planktonic larval phase, they may have significant dispersal potential as adults, since many species occur cryptically in fouling communities.

Terebellidae

Systematics

The Australian Terebellidae are relatively well known (Hutchings and Glasby 1986, 1987 and 1988). Several nominal Port Phillip Bay taxa are not yet identified due to incomplete or missing material; many of these are single records and are probably synonymous with more common Port Phillip Bay species of terebellids. Among Port Phillip Bay terebellids, only *Amaena trilobata* is still credited with a wide distribution despite revisionary studies (this species is recorded from most Australian states as well as North America, Japan, Europe and the Arctic (Hutchings and Glasby 1986). It is still possible that the wide range of morphological variability recorded by Hutchings and Glasby (1986) indicates additional species among the material now referred to *A. trilobata*. However, no introduced species of terebellids is known from Port Phillip Bay.

Biology

Terebellids are surface deposit feeders that collect food particles on their feeding tentacles (Fauchald and Jumars 1979). A wide range of reproductive modes is known (including direct development of benthic lecithotrophic larvae and brooding), although planktotrophic larvae are probably the most common (Schroeder and Hermans 1975). Some terebellid species may thus have significant dispersal potential but the biology of most species is unknown.

Trichobranchidae

Systematics

There is no systematic revision of Australian trichobranchids, although Dr P Hutchings, Australian Museum, is currently undertaking such a revision. Australian species have been described (Knox and Cameron 1971). Williams (1984) reviewed Australian records of *Terebellides stroemi*, which were shown to represent probably two undescribed species. Only a species of *Trichobranchus* known from Port Phillip Bay benthic samples remains unidentified, but there is no evidence that any trichobranchid is introduced to Australia by humans.

Biology

Like the Terebellidae, trichobranchids are surface deposit feeders that collect food particles on their feeding tentacles (Fauchald and Jumars 1979). No free-living planktonic larval stage is known (Thorson 1946), and the dispersal potential of species of Trichobranchidae appears low.

8.4 SPECIES INTRODUCED TO AUSTRALIA

Although there are numerous species of polychaetes recorded world-wide in bays and shelf environments, few have been confirmed as introductions to Australia. Confirmed introduced polychaetes should not be confused with misidentified Australian records which have extended to Australia the nominal distribution of species endemic to other regions, especially northern Europe. This practice in polychaete systematics is referred to in the above introduction as the cosmopolitan species problem, and most such nominal cosmopolitan distribution patterns indicate species complexes that are in need of critical taxonomic revision (Fauchald 1984). Those few instances of confirmed polychaete introductions to Australian waters are listed briefly here, while those relevant to Port Phillip Bay are treated in more detail below.

The nereid species, *Neanthes succinea*, is apparently introduced to Port Phillip Bay and elsewhere in southern Australia; this species is discussed in detail below.

In reviewing Australian Orbiniidae Day (1977) recorded *Phylo fimbriatus* (Moore 1903) from Western

Port, Victoria. Previously, this species was known only from northern Japan, and Day (1977) noted "its discovery in Australia is surprising". If confirmed, this may represent a further introduction to Australian waters, but no specimens matching Day's description have been recorded yet from Port Phillip Bay.

Two species of the family Sabellidae are known to be introduced to Australia, and both occur in Port Phillip Bay. *Sabella spallanzanii*, a large sabellid or feather duster worm that is a conspicuous member of fouling communities, is treated briefly below, and in more detail by Clapin and Evans (1995). McArthur (1997) has confirmed *Euchone limnicola*, a much smaller species that occurs in soft sediments, as an introduction to Australia and is also treated in more detail below.

Two species of Spionidae appear to be introduced to Australia; these are both polydorids, *Boccardia proboscidea* and *Pseudopolydora paucibranchiata* and are treated in detail in a separate section of this report.

8.5 INTRODUCED SPECIES IN PORT PHILLIP BAY

Of 681 species of polychaetes recorded in benthic surveys in Port Phillip Bay only five are confirmed introductions. Other polychaete groups contain additional introduced species but taxonomic problems in these groups prevent critical treatment with the resources and materials available. A prime example is the taxonomically challenging polydorid group of genera in the family Spionidae (*Boccardia*, *Carazziella*, *Polydora* and related genera). Many polydorids bore into mollusc shells and other substrates and have probably been translocated with the establishment of aquaculture industries in Australia and elsewhere. The long history of this practise and the poor taxonomic knowledge of the endemic southern Australian fauna means that other techniques, such as molecular systematics, will probably be required if the taxonomic problems in these genera are to be resolved. In the absence of a significant research effort along these lines, it will not be possible to identify possible Australian introductions among these genera. Many polydorids are pests of oyster and other aquaculture industries around the world (Blake and Evans 1973).

8.5.1 Taxonomy and systematics

Nereididae

Neanthes succinea (Leuckart 1847)
Figure 8.1

Synonymy and taxonomy

Nereis succinea Leuckart 1847: 154, pl. 2 Figures 9, 11;
Nereis (Alitta) oxypoda von Marenzeller 1879: 120–122, pl. 2 Figure 3;
Neanthes succinea: – Wilson 1984: 218–221, Figure 4A–F (more complete synonymy); 1988: 4–10 (list of Australian records).

This species appears in Japanese and Chinese literature under several names which were shown by Wilson (1988) to be junior synonyms of *Neanthes succinea* (descriptions of these junior synonyms were based on epitokes). There is some confusion created by these junior synonyms from Japan and China, and because the stem species has been variously assigned to the genera *Nereis* and *Neanthes*. Nevertheless the nomenclature has always been stable through Europe and North America, where this species

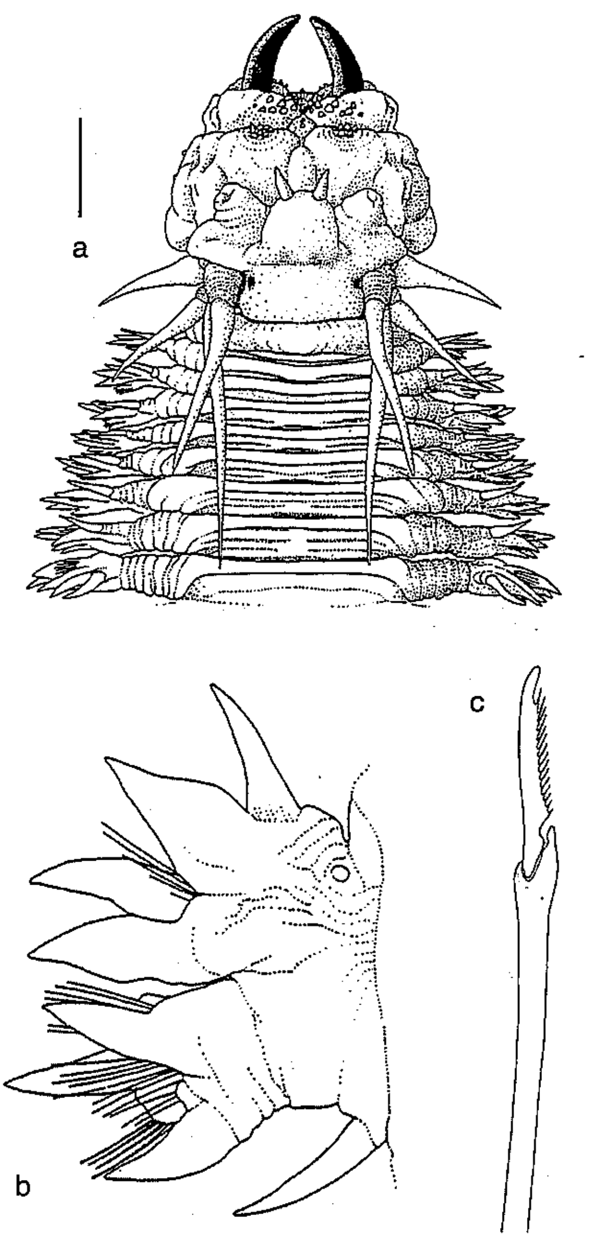

Figure 8.1. *Neanthes succinea*: a) dorsal view of anterior segments and everted proboscis (scale bar = 2 mm); b) anterior parapodium; and c) ventral neuropodial falciger.

has always been cited as *Nereis succinea* or *Neanthes succinea*.

Material

Victoria: River at Westgate Bridge, coll. 10 April, 1984, 9 m, NMV F50128; Yarra R at Newport Powerhouse site, many, male and female epitokes, NMVG 1109; Port Phillip Bay off Yarra River mouth coll. 20 Oct. 1978, 1, subepitoke, NMV F50081 Maribrynong River, at Sims Street, coll. 4 May 1981, subepitoke, NMV F50129. New South Wales: Port Hacking: Stn 630, AMW195244 (2 specimens); Stn 631, AMW195222; Stn 641, AMW195305 (2 specimens). Hawkesbury River: Stn D2-2, AMW196461; Stn D2-3, AMW196462 specimens); Stn D4-3, AMW196463. Lake Macquarie *Zostera* beds, AMW17830. (Full locality data given in Hutchings and Murray 1984) (Wilson 1984).

Origin and present Australian distribution

Neanthes succinea is known originally from the North Sea (the type locality), but has been spreading for many decades throughout northern Europe and is also introduced to the Salton Sea, California (Spassky 1945; Smith 1963; Kuhl and Oglesby 1979; Abbiati 1991).

The first record of the species in Australian waters is from the Swan River, WA, in 1930; other records are all from southern Australia, including Port Phillip Bay, and Port Hacking, Lake Macquarie and the Hawkesbury in NSW (Wilson 1984). There appear to have been no surveys since 1930 that would monitor the abundance of the species in WA. Hutchings and Murray (1984) reported that *N. succinea* (as *Neanthes oxypoda*) is rare in NSW estuaries, where the species was first recorded in 1980. All Australian records are from estuaries associated with or adjacent to major shipping harbours, although *N. succinea* is not restricted to estuarine salinities. No dispersal mechanism has been suggested for the introduction of *Neanthes succinea* to Australian waters, but it appears that the larvae must have arrived in ballast water, since adults are soft sediment inhabitants and are not usually part of ship-bottom fouling communities.[1]

Distribution in Port Phillip Bay

Neanthes succinea occurs only sporadically and in low numbers in Port Phillip Bay since the first record in 1978. Attempts to collect additional specimens in the Yarra River where *N. succinea* was most abundant in the 1970's failed when these stations were revisited in 1995. Within Port Phillip Bay, all records are in the vicinity of the Port of Melbourne.

Diagnosis

Nereididae with paragnaths in distinct groups on both oral and maxillary rings: I = 0–5 (usually 2–3); II = 7–23; III = 2–42 (usually 20–30); IV = 13–34; V = 0–4 (usually 2–3 in a triangle); VI = 6–14 in a roughly circular group; VII–VIII = 36–62 in 2–3 rows. Three similar sized notopodial lobes on anterior setigers, median lobe reducing in size posteriorly, dorsal notopodial lobe becoming expanded on posterior setigers and with dorsal cirrus subdistally attached. Notosetae homogomph spinigers only. Neurosetae include homogomph and heterogomph spinigers and heterogomph falcigers with long blades (Wilson 1984).

Distinguishing features in Australia

Among Australian nereidids, *Neanthes succinea* is the only species with three acute notopodial lobes of similar length in anterior setigers and paragnaths in separate groups in Areas V, VI and VII–VIII on the oral ring of the eversible proboscis. These characters can be seen in juvenile worms, immature adults and epitokes. The long-bladed falcigers are also unique.

Ecology

Neanthes succinea reproduces by swarming as epitokes and broadcast spawning larvae which enter the plankton for an uncertain time interval (Banse 1954). Complex exogenous cues and secretion of sex pheremones coordinates this behaviour (Zeeck *et al.* 1990), but it appears that this reproductive strategy is not successful in Port Phillip Bay, where *N. succinea* occurs only sporadically. In contrast, *Boccardia proboscidea* and *Sabella spallanzanii* with benthic or benthic and planktonic larvae have both become established in higher numbers.

Nevertheless, *Neanthes succinea* has become established in many other locations and continues to spread in Northern Hemisphere seas (see references below), and I expect that this relatively slow spread will also occur in southern Australia. Low levels of genetic exchange between Mediterranean populations of *N. succinea* have been reported by Abbiati and Maltagliati (1992); these populations can be considered reproductively isolated according to Nei's genetic identity index, providing further evidence that dispersal in this species does not occur rapidly.

Comments

Papers by Abbiati (1991), Banse (1954), Birstein (1956), Bishop (1974), Dykens and Mangum (1984), Fong (1987, 1991), Freel *et al.* (1973), Hanson (1972), Hardedge *et al.* (1990), Hardedge *et al.* (1991), Kuhl and Oglesby (1979), Neuhoff (1979, 1983), Poff *et al.* (1974), Smith (1963), Spassky (1945), Stark (1959), Tenore (1982), Zeeck *et al.* (1994) are studies of *Neanthes succinea* in Northern Hemisphere waters ranging from physiology and genetics to behaviour and the energetics of deposit feeding. No parasites or other potential biological control agents have

[1] Editor's note: *Neanthes succinea* is common in the fouling community of the North East Pacific and from ship fouling (Carlton 1979; C Hewitt unpub. data).

been recorded from *N. succinea*, nor does it seem likely that such agents exist, given the wide success of the species in colonising seas through out the Northern Hemisphere, South America (Dei Cas and Mañé Garzózon 1973) and southern Australia.

Spionidae

Boccardia proboscidea Hartman 1940

Figure 8.2

Synonymy and taxonomy

Boccardia proboscidea Hartman1940: 382. — Blake and Kudenov 1978: Figures 33a–c (more complete synonymy).

The genus *Boccardia* includes at least 16 species. Blake and Woodwick (1971) provided a key to all species known at that time, and Australian species can be identified with Blake and Woodwick (1976) and Blake and Kudenov (1978). Blake and Kudenov (1978) had examined live specimens of *Boccardia proboscidea* from Port Phillip Bay and from California, and were in no doubt that the same species was present in both locations.

Material

Victoria: See Blake and Kudenov (1978) for material from Werribee, Port Phillip Bay.

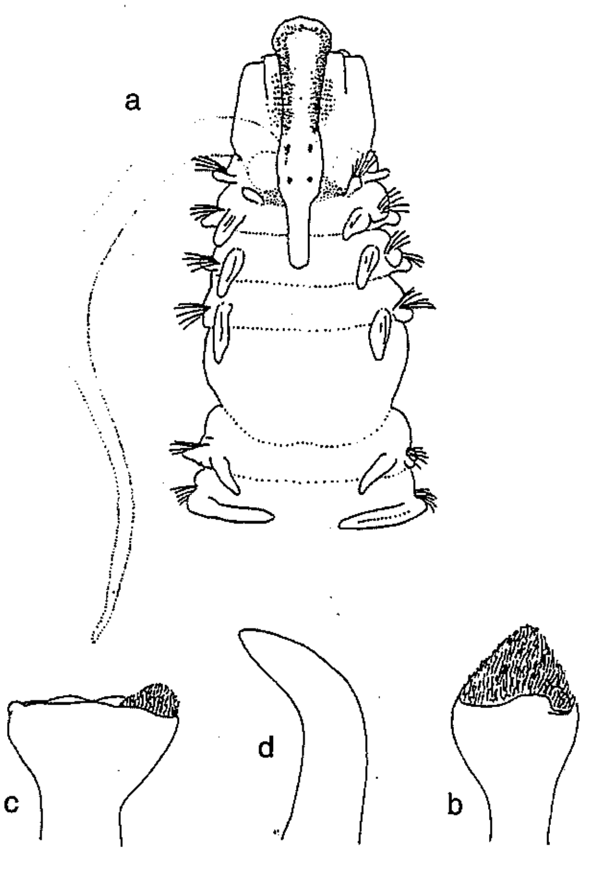

Figure 8.2. *Boccardia proboscidea*: a) dorsal view of anterior segments and prostomium; and b–d) specialised setae, setiger 5. (Based on figures in Light 1977).

Origin and present Australian distribution

Boccardia proboscidea was described from California (Hartman 1940), but has since been reported from Japan, Panama and Port Phillip Bay (Imajima and Hartman 1964; Fauchald 1977b; Blake and Kudenov 1978).

The record of *Boccardia proboscidea* from Port Phillip Bay is the first Australian and first Southern Hemisphere record of the species (Blake and Kudenov 1978). A dispersal mechanism has not been proposed for spread of this species, but polydorids are cryptic inhabitants of oyster shells and fouling communities, so they have the potential to spread as larvae as well as adults.

Distribution in Port Phillip Bay

Blake and Kudenov (1978) recorded *B. proboscidea* only from Werribee region in Port Phillip Bay, adjacent to the sewage outfall drain. *Boccardia proboscidea* was studied by D Petch for his Ph.D. thesis at Melbourne University, and at that time was also collected from immediately adjacent to Boags Rocks ocean outfall sewage drain (D Petch pers. comm.). *Boccardia proboscidea* was not collected from benthic stations occupied during PPBES-3 and probably still only occurs in significant numbers in shallow areas of organic enrichment.

Diagnosis

Spionidae with prostomium rounded to weakly incised on anterior margin (Figure 8.2); caruncle extends to end of setiger 3; 4 eyes. Setiger 1 with notosetae and neurosetae; setiger 5 strongly modified with reduced parapodial lobes and 2 types of major spines, simple and bristle-topped. Bidentate hooded hooks begin setiger 7, branchiae on setigers 2, 3, 4, 6 and thereafter, absent from posterior third of body. Pygidium with 4 lobes, dorsal pair smaller than ventral. [After Blake and Kudenov (1978)]

Distinguishing features in Australia

Numerous other species of polydorids occur in southeastern Australia; all of the above characters should be verified to confirm identification of *Boccardia proboscidea*.

Ecology

Boccardia proboscidea is reported as an opportunist species, both in California and in Port Phillip Bay (Johnson 1970; Blake and Kudenov 1978) where it is often the numerically dominant polychaete. In Port Phillip Bay *B. proboscidea* appears to be favoured by high nutrient levels at drain outfalls, whereas this is not necessarily so in the type locality in California. As reported by Petch (1991), *B. proboscidea* produces both planktonic and benthic larvae in a single egg capsule. The proportions of planktonic larvae increase in populations breeding in suboptimal conditions, while benthic larvae with higher growth rates are produced in greater numbers in enriched habitats. Thus strong selection is occurring in Port Phillip

Bay populations, and the strategy described (Petch 1991) is likely to result in further dispersal in southern Australia and high local abundances in areas where conditions are optimal.

Comments

There is no information on parasites occurring on *B. proboscidea*, or other potential biological control agents. *Boccardia proboscidea* only occurs in high numbers in a few disturbed habitats in southern Australia and there is no evidence that the species presents an ecological problem.

Pseudopolydora paucibranchiata (Okuda 1937)

Figure 8.3

Synonymy and taxonomy

Polydora (Carazzia) paucibranchiata Okuda 1937: 231; *Pseudopolydora paucibranchiata*: – Blake and Kudenov 1978: 268 Figures 33a–c (first Australian record and more complete synonymy);
Pseudopolydora cf. *paucibranchiata*: – Read 1975: 414–416 (first New Zealand record).

Material

See Blake and Kudenov (1978) for material from New South Wales: Botany Bay; and Victoria: Port Phillip Bay and Western Port.

Origin and present Australian distribution

The type locality of *Pseudopolydora polybranchiata* is Japan, but the species is widely distributed through the Pacific including California, New Zealand and Australia (Blake and Kudenov 1978; Read 1975). It is not clear what the original range of the species was before human dispersal intervened. In Australia the species is recorded from Botany Bay, Port Phillip Bay and Western Port (Blake and Kudenov 1978).

The first record of *P. polybranchiata* from Australia is that of Blake and Kudenov (1978) who remarked that the specimens agreed well with material from California. Blake and Kudenov (1978: 268) noted that the species "is widely distributed in bays throughout the Pacific and is possibly introduced into Australia" but no dispersal mechanism was proposed. Like other polydorids, *P. paucibranchiata* is a cryptic inhabitant of oyster shells and fouling communities, which has the potential to spread as larvae as well as adults.

Distribution in Port Phillip Bay

Pseudopolydora polybranchiata occurred sparsely across Port Phillip Bay in PPBES-1 being recorded from eight stations (Blake and Kudenov 1978). It was most abundant in Hobsons Bay and the Yarra River, stations that were not surveyed during PPBES-3. *Pseudopolydora polybranchiata* was not collected during PPBES-3 in 1994–95, although several poorly preserved unidentified polydorids could be that species. If *Pseudopolydora*

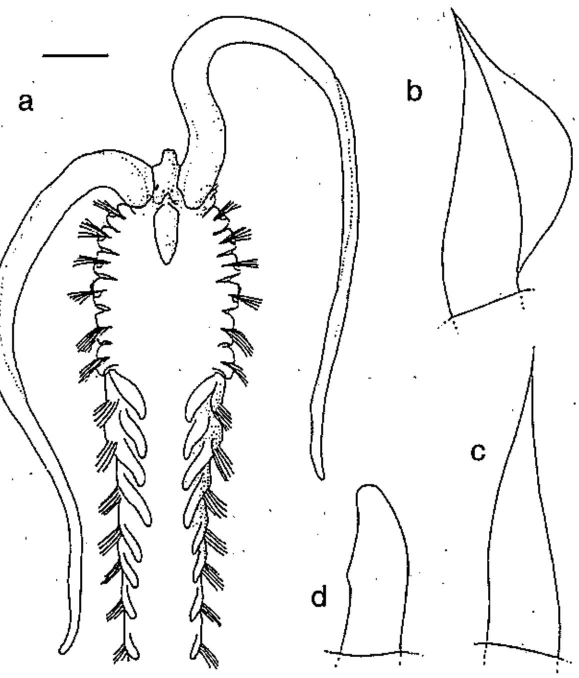

Figure 8.3. *Pseudopolydora paucibranchiata*: a) dorsal view of anterior segments and prostomium (scale bar = 0.2 mm); and b–d) specialised setae, setiger 5. (b after Light 1977).

polybranchiata continues to spread in Port Phillip Bay this is probably occurring in habitats that were not a part of the PPBES-3 monitoring study design.

Diagnosis

Spionidae with prostomium entire, extending posteriorly as a caruncle to setiger 3; occipital tentacle present. Setiger 1 reduced, lacking notosetae. Setiger 5 not greatly modified of enlarged, with distinct parapodial lobes similar to adjacent setigers, with major spines in a U-shaped line. Major spines of setiger 5 consist of 12–14 pennoned curved spines and simple spines in equal numbers. Hooded hooks from setiger 8, completely replacing neuropodial capillary setae. Branchiae from setiger 7 continue to about setiger 35. Pygidium with small ventral collar-like disk with large dorsal gap. [After Blake and Kudenov (1978)]

Distinguishing features in Australia

Among Australian polydorids with only slightly modified fifth setiger, *Pseudopolydora polybranchiata* is the only large species (reaching at least 20 segments and 6 mm length) with an entire prostomium. Nevertheless, polydorids are diverse and all of the above characters should be verified to confirm identification of *P. polybranchiata*.

Ecology

Although there have been several studies of reproduction and larval development in *Pseudopolydora* *paucibranchiata*, the most significant work in the context of introduced species studies is that of Tanaki (1985). He showed that adult populations greatly influence recruitment of an opheliid polychaete (*Armandia* sp.), apparently by predation by *P. paucibranchiata* adults on larvae. Although this is the only experimental study of its type, it is likely that interactions of this type also occur throughout the range of this widely introduced species.

Sabellidae

Euchone limnicola Reish 1959

Synonymy and taxonomy

Euchone limnicola Reish 1959: 717–719;

Jasminiera sp.: — Currie and Parry 1996: 131–150 including Tables and Figures (Port Phillip Bay Scallop Dredge Effects Survey records);

Euchone sp.: — MoV 1755 Wilson *et al.* 1996: Table 4 etc (Port Phillip Bay Environmental Study Phase 3 records);

Euchone limnicola: — McArthur 1997: 1–32.

Material

Victoria: Port Phillip Bay, (38° 16.30'S, 144° 55.00'E) 21, Smith MacIntyre Grab, Wilson and Walker-Smith, G, 20 Oct 1994, (PPBES-3 317 5); (38° 16.30'S, 144° 55.00'E) 21, Smith MacIntyre Grab, Wilson and Walker-Smith, G, 20 Oct 1994, (PPBES-3 317 2); (38° 07.00'S, 144° 55.00'E) 23, Smith MacIntyre Grab, Wilson and Walker-Smith, G, 19 Oct 1994, (PPBES-3 313 3); (37° 59.77'S, 144° 57.43'E) 17, Smith MacIntyre Grab, Wilson and Walker-Smith, G, 19 Oct 1994, (PPBES-3 306 2); (38° 16.30'S, 144° 55.00'E) 21, Smith MacIntyre Grab, Wilson and Walker-Smith, G, 20 Oct 1994, (PPBES-3 317 1) [selection of material from over 200 specimen lots, Port Phillip Bay, MoV unregistered].

Origin and present Australian distribution

Euchone limnicola was described from southern California, the type locality (Reish 1959). Within Australia, *E. limnicola* is known from Botany Bay, NSW, and Port Phillip Bay, Portland Harbour and Port Fairy in Victoria.

Distribution in Port Phillip Bay

Widespread on sandy and muddy sediments.

Diagnosis

Sabellidae with anal depression over 4–12 posterior-most setigers, 7–9 preanal depression abdominal setigers, anal depression lacking flange.

Distinguishing features in Australia

Small species of Sabellidae are numerous in southern Australia, but only *Euchone limnicola* and *Euchone variabilis* Hutchings and Murray 1984 have an anal depression. *Euchone variabilis* was described from the Hawkesbury River, NSW, but also occurs in Port Phillip Bay together with the introduced species *E. limnicola*. *Euchone limnicola* can be distinguished by lacking a flange around the anal depression by having an anal depression of 4–12 setigers and 7–9 abdominal setigers preceding the anal depression (*E. variabilis* has an anal depression of 7–14 setigers and 11–15 preceding abdominal setigers).

Ecology

Euchone limnicola was studied by McArthur (1997) who found that the dominant food source in Port Phillip Bay was resuspended organic matter collected from the sediment water interface.

Comment

Euchone limnicola was among the most abundant macrobenthic species in grab samples from Port Phillip Bay in 1994–95 (Wilson *et al.* 1996) but appears to have been absent during an earlier survey in 1969–73. The first Australian records are from 1984 in Port Phillip Bay (McArthur 1997).

Sabella spallanzanii (Gmelin 1791)

Synonymy and taxonomy

Spirographis spallanzanii Gmelin 1791. — Viviani 1805. — Fauvel 1908. — Hartman 1959: 567;

Sabella spallanzanii: — Carey and Watson 1992. — Clapin and Evans 1995.

The genera *Sabella* and *Spirographis* are probably synonymous and are being revised by Knight-Jones and Perkins (in prep.). That paper will provide a more complete synonymy (P Knight-Jones pers. comm.). Although *Sabella spallanzanii* is more widely cited as a member of the genus *Spirographis*, the identity of the species is not in question in the Mediterranean Sea (the type locality).

Material

Victoria: Port Phillip Bay, Geelong Arm, coll. J Watson and J Carey1984, MoV unregistered.

Origin and present Australian distribution

Clapin and Evans (1995) discussed the origin and distribution in Australia.

Distribution in Port Phillip Bay

The Smith-McIntyre Grab sampling design for PPBES-3 was designed for infaunal monitoring and these data do not provide an accurate summary of the present distribution of large species such as *S. spallanzanii* (although several specimens were collected during this program).

Diagnosis

Body up to 100 mm long and 8 mm wide with about 200 abdominal and 8 thoracic segments; crown up to 60 mm additional length. Radioles formed from 2 asymmetrical involuted spirals, each of 34–100 radioles with short basal membrane (about 5 mm). Ventral collar with 2 large fleshy lappets; Setae of thoracic fascicles in oblique series; curved slender collar setae and seperior setae on following thoracic segments; thoracic and abdominal uncini avicular, with finely toothed crest; companion setae geniculate. A more complete description can be found in Clapin and Evans (1995), and a description and designation of a neotype will be published by Knight-Jones and Perkins (P Knight-Jones pers. comm.).

Distinguishing features in Australia

Sabella spallanzanii is the only large (size in excess of 30 mm) sabellid known in southern Australian waters which has radioles arranged in conspicuously asymmetrical spirals (Clapin and Evans 1995).

Ecology

Clapin and Evans (1995) discussed the ecology of the species in Australia and many of the references listed below deal with ecology of this species.

Comments

Parasites of *Sabella spallanzanii* have been described (Carton unknown year). Gregarine parasites are known from other sabellids (Beneden 1971) and other polychaete families, including the serpulid *Mercierella enigmatica* of uncertain origin but widely introduced around the world (see Serpulidae treatment). There is no evidence that these parasites would control populations of *S. spallanzanii*, and a significant research effort would be required to ensure that such parasites would not have an adverse effect on other polychaetes or other invertebrates in Australian waters, should biological control of *S. spallanzanii* populations be considered.

8.6 DISCUSSION AND CONCLUSIONS

There is no reason to believe that introductions of polychaete species to Australian waters have ceased, or that additional introduced species will not be found. To the contrary, the apparent rate of introduction and discovery has accelerated, with all five known introduced polychaete species being first discovered in Port Phillip Bay during the 1970's and 1980's. This is hardly surprising, since quantitative studies of the soft bottom benthos of Port Phillip Bay only began in 1969. Nevertheless, these studies have at least resulted in the soft bottom fauna being relatively well studied over that period. In contrast, polychaetes of reefs, pier piles and other fouling communities have been barely studied at all, yet these habitats are just as likely to contain introduced species. The recent spread of aquaculture (particularly mussel and oyster farms) in sheltered embayments in southern Australia provides another poorly known habitat. Mussel and oyster farms should be high priorities for surveys of introduced species, since various polydorid genera, in particular, are well known as hole-borers in mollusc shells and are sometimes pests in shellfish industries (see Spionidae treatment). These worms are readily translocated and there would seem to be ample potential for a commercially disastrous outbreak. Families other than Spionidae may also be a threat: a species of Sabellidae bores into abalone shells and is a serious pest in California (K Fitzhugh pers. comm.; R Day pers. comm.; Culver *et al.* 1997). This species is fortunately not yet known in Australia, but nor has anyone looked for it.[2]

8.7 ACKNOWLEDGEMENTS

I thank CSIRO Centre for Research on Introduced Marine Pests for supporting this review, and to the CSIRO Port Phillip Bay Environmental Study and Melbourne Water for supporting the environmental studies on which this review is based. Greg Parry and David Currie (Marine and Freshwater Research Institute, Queenscliff) were generous with specimens and data from their Scallop Dredge Effects Study in Port Phillip Bay. Pat Hutchings and Anna Murray of the Australian Museum, Sydney, and John Moverley of the Musuem of Victoria were similarly helpful with material of *Euchone limnicola* from new localities in New South Wales and Victoria. Matt McArthur (now of the Marine and Freshwater Research Institute, Queenscliff) gave access to the original taxonomic work in his Honours thesis, which I have drawn on for the treatment of *Euchone limnicola*. And it is a great pleasure to thank Kate Thompson for her skillful illustrations.

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[2] Editor's note: CRIMP has examined several abalone farms for the presence of this sabellid in 1997/1998 (Kuris and Gurney unpub. ms).

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9 THE INTRODUCED MOLLUSCA OF PORT PHILLIP BAY

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9.1 INTRODUCTION

9.1.1 Background

This review of the introduced molluscs of Port Phillip Bay is based largely on material collected during the Port Phillip Bay Environmental Study Phase 1 (PPBES-1 1969–73; see Chapter 2). As such, the review focuses almost entirely on the soft-bottom fauna of the bay. Some additional material collected during PPBES Phase 2 (PPBES-2 1973–75) and Phase 3 (PPBES-3 1994–95), and the Scallop Dredging Effects (SDE) study (1991–92) has also been included. Descriptions are provided for three species, not collected during any of these studies, that are believed to be introduced to Port Phillip Bay.

9.1.2 Potential means of translocation

As outlined in Chapter 5, the vectors responsible for the translocation of exotic species can be summarised into 5 groups: hull fouling/boring; mariculture; dry and semi-dry ballast; ballast water; and intentional introductions. The potential for molluscs to be translocated by each of these vectors is discussed briefly below.

Dry and semi-dry ballast

Shipping has been identified as one of the prime global mechanisms for the potential introduction of non-indigenous molluscs (Chew 1990; Carlton 1992). While historical shipping introductions have been poorly documented, both dry and semi-dry ballast are likely vectors for the introduction of exotic mollusc species into Port Phillip Bay. Ballast of this type commonly consisted of timber, rock, cobble, shingle or sand, generally collected from the littoral zone of the port of origin. The earliest ships to enter Port Phillip Bay carried dry ballast, which may have contained benthic, intertidal or marsh molluscs. Because of the lack of comprehensive data on the endemic marine fauna of the region around this time, any introductions are likely to have gone unnoticed.

Ballast water

While ballast water began to replace solid ballast over 100 years ago as a means of reducing time and expense of ballast loading and unloading, it was not until World War II that significant volumes began to move around the world. The environmental conditions found within ballast tanks are generally conducive to the survival of a wide range of organisms (Schormann *et al.* 1990) and ballast water translocation is likely to be a primary mechanism for the introduction exotic molluscan species to new port environments. Carlton *et al.* (1990) found viable bivalve veligers in ballast water collected from Japanese cargo vessels arriving in Oregon, USA. Williams *et al.* (1988) found that bivalve and gastropod veligers were the most frequently occurring taxa in samples taken from the ballast tanks of ships arriving in Australia from Japanese ports.

Hull fouling/boring

Hull fouling (in its broadest sense) remains an important mechanism for the transport of marine molluscs. While some molluscan species, such as oysters, mussels and chitons, have the ability to attach to the exterior of ships hulls, other species may be transported in less exposed areas on a vessel such sea chests and anchor chain lockers. For example, several hundred adult specimens of the introduced European corbulid *Corbula* cf. *gibba* were found in the sea chest of a ship that frequents Port Phillip Bay (K Moore pers. comm.).

Both the anchor and anchor chain can become fouled by a variety of organisms that may then be deposited into the chain locker along with any associated sediments. Schormann *et al.* (1990) noted that where anchor lockers were insufficiently washed, sediments remain in the damp environment of the locker. While there have been no studies on the survival of organisms in these environments over extended periods of time, it is likely that the damp conditions are suitable for the survival of some adult molluscs and egg masses.

The close association between some exotic opisthobranchs and arborescent fouling bryozoans has been cited as evidence for the introduction of these slugs via hull fouling. Both the Mediterranean/European species *Janolus hyalinus* and the distinctive South American species *Thecacera pennigera*, because of their close association with the fouling bryozoan *Bugula*, are thought to have been introduced to Australia by this vector (Willan 1976; Miller and Willan 1986).

Boring organisms such as shipworms (*Teredo* and

Bankia) and boring clams (pholads) have been distributed globally since the earliest wooden sailing vessels began trans-oceanic voyages. There have been 38 species of the wood boring Teredininae identified from Australian-New Guinea waters (Turner 1971), and many of these are found throughout the world. Macpherson and Gabriel (1962) note the presence of *Nototeredo edax* and *Bankia (debenhami) australis* at Portsea pier; Edgar (1997) regarded the latter species as being the most abundant shipworm in Victorian waters.

Mariculture

Since the turn of the century, live shellfish have been transplanted around the world to enhance or develop new fisheries or marine farming industries. Whilst the intention of such introductions is to establish a single commercially viable species, there have been numerous records of secondary unintentional introductions of associated fauna and flora (Carlton 1987; Grizel and Heral 1991; Carlton 1992; Minchin *et al.* 1993). It is estimated, for example, that at least 22 species of molluscs have been unintentionally introduced to the Pacific coast of North America through oyster importation (Carlton 1992).The presence in Tasmanian waters of several New Zealand bivalves, including *Venerupis (Paphirus) largillierti* and *Neilo australis*, along with numerous other taxa, are thought to be linked to attempts to introduce the New Zealand oyster *Ostrea lutaria* to that state in the 1880's (Dartnall 1969).

Intentional introductions

Crassostrea gigas was first introduced into Tasmania and Western Australia in the late 1940's and early 1950's. While the Western Australian population failed to become established, a thriving industry has since been established in the north, east and south of Tasmania. The first record of *C. gigas* in Victorian waters resulted from the transfer of oysters from southern Tasmania to Mallacoota Inlet in October 1955 (Thomson 1952). Like the Western Australian population, these too eventually declined and died out and there have been no subsequent official attempts to introduce Pacific oysters to Victoria. In June 1985, a wild population of *C. gigas* was located in Anderson Inlet (Coleman and Hickman 1986); the source of this population is unknown. While farming of *C. gigas* is currently not permitted in Victorian waters, oysters were in the past grown in isolated saline ponds at Avalon near Geelong (Coleman and Hickman 1986).

9.1.3 Records of molluscan introductions

Molluscan introductions have been reported in most parts of the world. The summary below is not exhaustive but provides an indication of the range of taxa and species involved in introductions in different regions.

USA

Cohen and Carlton (1995) recorded 31 introduced mollusc species in San Francisco Bay. These are listed in Table 9.1. Coles *et al.* (1997) reported 15 introduced molluscs from Pearl Harbour. These included *Diodora ruppelli, Crepidula aculeata, Crucibulum spinosum, Vermetus alii, Crassostrea virginica, Saccostrea cucullata, Chama* cf. *elatensis, Chama fibula, Chama lazarus, Chama pacifica, Abra* sp., *Venerupis* (*Ruditapes*) *philippinarum, Sphenia* sp., *Martesia striata* and *Teredo bartschi.* Five introduced species, *Crassostrea gigas, Mya arenaria, Myosostella myosotis, Tenellia adspersa* and *Cumanotus beaumonti* are known from Coos Bay, Oregon (C Hewitt pers. comm.).

United Kingdom

Nine introduced molluscs (*Crepidula fornicata, Urosalpinx cinerea, Potamopyrgis antipodarum, Crassostrea gigas, Tiostrea lutaria, Ensis americanus, Mercenaria mercenaria, Petricola pholadiformis Mya arenaria*) have been reported in Britain (Eno *et al.* 1997).

New Zealand

Cranfield *et al.* (1998) reported 24 introduced mollusc species (see Table 9.2) in New Zealand.

Baltic Sea

Records of introductions into the Baltic Sea include 12 molluscs: *Mya arenaria, Dreissena polymorpha, Crassostrea virginica, Potamopyrgus jenkinsi, Congeria cochlea, Crepidula fornicata, Teredo navalis, Paphia philippinarum, Theodoxus fluviatilis, Crassostrea gigas, Ensis directus* and *Petricola pholadiformis* (S Gollasch pers. comm.).

South Africa

Studies over the past 43 years, document 15 introduced molluscs (Table 9.3) that have established in South Africa (Korringa 1956; Kilburn and Rippey 1982; Muller 1985; De Moor and Bruton 1988; Griffiths *et al.* 1992).

9.2 MOLLUSCS OF PORT PHILLIP BAY

9.2.1 Status of taxonomic knowledge

At the time of the PPBES–1, the mollusc fauna of Port Phillip Bay was well known and documented. The comprehensive taxonomic guide of Macpherson and Gabriel (1962) was used to identify most species. Their classification and the misidentification of one exotic bivalve species in Macpherson (1966) were followed uncritically by Poore and Rainer (1974) and Poore *et al.* (1975).

Published knowledge of the bivalve fauna of southern Australian has not been extensively updated in recent years. There have been a few review papers on particular families or genera (see below) and these include Victorian

Table 9.1. Introduced molluscs in San Francisco Bay. Records from Cohen and Carlton (1995).

Introduced species	First record	Possible origin
Littorina littorea	1968	NE Atlantic
Littorina saxatilis	1993	N Atlantic
Arcuatula demissa	1894	NW Atlantic
Corbicula fluminea	1924	China, Korea and Japan
Gemma gemma	1893	NW Atlantic
Lyrodus pedicellatus	1871	?
Macoma petalum	<1988	NW Atlantic
Musculista senhousia	1924	Japan and China
Mya arenaria	1874	N Atlaintic
Mytilus galloprovincialis	1947	Mediterranean
Petricolaria pholadiformis	1927	NW Atlantic
Potamocorbula amurensis	1986	China, Siberia and Japan
Teredo navalis	1913	?
Theora fragilis	1968	W Pacific
Venerupis philippinarum	1924	W Pacific
Busycoptypus canaliculatus	1938	NW Atlantic
Cipangopaludina chinensis malleata	1900	China and Japan
Crepidula convexa	1898	NW Atlantic
Crepidula plana	1901	NW Atlantic
Ilyanassa obsoleta	1907	NW Atlantic
Melanoides tuberculata	1972	Africa to East Indies
Urosalpinx cinerea	1890	NW Atlantic
Boonea bisulturalis	1977	NW Atlantic
Catriona rickettsi	1974	?
Cuthona perca	1979	?
Eubranchus misakiensis	1962	Japan?
Okenia plana	1950	Japan
Philine auriformis	1992	New Zealand and Australia?
Sakuraeolis enosimensis	1972	Japan
Tenellia adspersa	1953	Europe
Ovatella myosotis	1871	Europe?

material. Australian species in a number of families have been treated in Lamprell and Whitehead (1992). S Boyd has compiled extensive unpublished data on nominal species described from the region and has commenced documenting a checklist. Nomenclatural changes and details of available literature are presented below in the review of bivalve families.

There has been considerable additional research on Australian prosobranchs in recent years. This work has included a better understanding of the status and distributions of southern Australian species. The works by Wilson (1993, 1994) provide a synthesis of the relevant research and provide an excellent guide for identification. With few exceptions, mollusc publications do not provide keys.

Opisthobranchs were only a minor part of the PPBES-1 fauna. The southern Australian species have been documented, in part, by Burn (1989) but a comprehensive checklist of the Victorian fauna is not yet available.

There has been significant work in recent years on the taxonomy of southern Australian chitons but the fauna is still considered in need of review (Ludbrook and

Table 9.2. Introduced molluscs in New Zealand. Records from Cranfield *et al.* (1998).

Introduced species	First record	Possible origin
Aeolidiella indica	?	Japan
Crassostrea gigas	1964	N Pacific
Cuthona alpha	1962	Japan
Cuthona beta	1958	Japan
Cuthona perca	<1960	Brazil, Jamaica, Florida and Barbados
Cypraea caputserpentis	1975	Tropical Indo-Pacific
Cypraea erosa	1975	Tropical Indo-Pacific
Eubranchus agrius	1959	Chile
Goniodoris castanaea	1913	Europe and Mediterranean coasts
Janolis hyalina	<1981	Europe and the Mediterranean
Limaria orientalis	1972	Japan, Philippines and the Indo-Pacific
Lyrodus mediolobatus	?	Circumtropical
Lyrodus pedicellatus	?	Cosmopolitan
Microtralia insularis	<1933	?
Musculista senhousia	1978	E Asia
Nototeredo edax	?	Tropical Pacific
Okenia pellucida	~1960	Australia
Okenia plana	?	Japan
Ostrea edulis	1869	European coastal waters
Phytia myosotis	Pre-1980	Spain, England and Europe
Polycera hedgpethi	1970's	Now cosmopolitan (?)
Theora lubrica	1971	Japan, China, Thailand, tropical Pacific, Philippines, Indonesia, and Australia
Thecacera pennigera	1973	Temperate cosmopolitan (?)
Teredo princessae	1979	Tropical Indo-Pacific

Gowlett-Holmes 1989). Kaas and van Belle (1985a, 1985b, 1987, 1990, and 1994) have reviewed all major groups in the class worldwide, including southern Australian material. Publications on the southern Australian fauna include Cochran (1988, 1993), Gowlett-Holmes (1987, 1990a, 1990b) and Ludbrook and Gowlett-Holmes (1989).

The Port Phillip Bay fauna includes many cephalopods but only a single species of this group was recorded from only one site during PPBES–1. The sampling technique used during this survey were not appropriate for collecting cephalopods. There has been extensive work in recent years on the Australian cephalopod fauna by Dr C C Lu and others based at the Museum of Victoria.

9.2.2 Review of molluscan families

A checklist of all molluscs reported from the PPBES studies (phases 1-3) is provided in Appendix A (Table A3).

(i) Bivalves

Most bivalve families, and many of the genera, have a cosmopolitan distribution. However, the distribution of southern Australian species is, with few exceptions, almost entirely endemic (Wilson and Allen 1987). There are very few known undescribed species in the southern Australian shallow water bivalve fauna. In the 1960's, most families were well documented on a state by state basis, but there was limited recognition in these works that the populations were part of a more widely distributed regional fauna. Many species are very broadly distributed across southern Australia, often with ranges extending from approximately the area around Perth, WA, to central NSW.

Most bivalves are gonochoristic with a free-living larval stage. Some are hermaphrodite and a few incubate the young.

Class Bivalvia

Subclass Protobranchia

Family Nuculidae

Nut shells. Nuculids are deposit feeders living in sandy

Table 9.3. Introduced molluscs in South Africa. Records from Korringa (1956), Kilburn and Rippey (1982), Muller (1985), De Moor and Bruton (1988), Griffiths *et al.* (1992).

Introduced species	First record	Possible origin
Bedeva paivae	1968	South Australia
Crassostrea gulata	?	?
Crassostrea gigas	?	NW Pacific and the East Asian Seas
Haliotis rufescens	?	California
Harpa ventriculosa	1985	?
Helisoma duryi (?)	1969	N America
Latiaxis mawae	1985	?
Littorina saxatilis	1974	Europe, Mediterranean and west coast Africa
Lymnaea columella (fw)	1944	N America
Mytilus galloprovincialis	pre-1970	W Europe and Mediterranean
Ostrea edulis	?	Europe
Physa acuta (fw)	1956	N America
Polydora sp	?	?
Tapes philippinarum	?	Manila
Thais haemastoma	1983	?
Urosalpinx sp	?	Cosmopolitan

silt substrates. Bergams (1978) reviewed most Australian species. PPBES–1 recorded *Pronucula concentrica* Cotton 1930 and *P. hedleyi* (Pritchard and Gatliff 1904). Bergams (1978) included both species in the synonymy of Nucula *pusilla* Angas 1877. Phase 1 recorded *Leionucula obliqua* (Lamarck 1819); Keen (1969a) included *Leionucula* as a subgenus of *Nucula*. Allan and Hannah (1986) included *Leionucula* as a synonym of *Nuculoma,* a genus reported by Newell (1969) as restricted to the Jurassic. As the Allen and Hannah (1986) did not include diagnoses, nor any comment on temporal distribution, it is considered premature to assign *N. obliqua* a genus other than *Nucula.*

Subclass Pteriomorphia

Family Arcidae

Ark shells. This family is represented by many species in tropical waters. The southern Australian fauna includes only a few species. Species are shallow burrowers in sand or mud, or byssally attached rock nestlers.

Family Limidae

This small, poorly known family is represented in southern Australia by only a few species. Members are recorded as larviparous. The record of *Limaria* sp. is based on a single badly damaged specimen. Macpherson and Gabriel (1962) recorded the genus from Victoria, as *Promantellum,* a junior synonym of *Limaria* Cox and Hertlein 1969.

Family Mytilidae

Mussels. This large family is represented in southern Australia by many species, including the introduced *Musculista senhousia.* Most species are sedentary with a well-developed byssus. Wilson (1967) has studied some groups of southern Australian mytilids. PPBES–1 recorded *Modiolus albicostatus* Lamarck 1819, renamed *Modiolus delinificus* Iredale 1924. Examination of the type specimen confirms the Iredale decision.

McDonald *et al.* (1991), using electrophoretic data, reassigned the southern Australian populations of *Mytilus edulis planulatus* to *Mytilius galloprovincialis* Lamarck 1819, previously only reported from the Northern Hemisphere. This decision has not been followed by Wilson (pers. comm.), who has undertaken extensive research on Australian members of this family.

PPBES–1 recorded *Gregariella barbatus* (Reeve). Soot-Ryen in Cox (1969) recognises the genus *Trichomusculus* (type species *Lithodomus barbatus* Reeve) as distinct from *Gregariella.*

Amygdalum beddomei Iredale 1924 was collected by the SDE study. It has previously been recorded from other Victorian localities including Western Port and Lakes Entrance (Macpherson and Gabriel 1962).

Family Ostreidae

Oysters. Only two species of this large family are found in southern Australia. The Pacific oyster *Crassostrea gigas* (Thunberg 1793) was intentionally introduced into all southern Australian states (except South Australia) between the late 1940's and early 1950's and in South

Australia in 1970. Wild populations became established in Tasmania and New South Wales (Coleman 1986). In 1985 specimens were collected at Andersons Inlet (Coleman 1986) but the extent of its distribution in Victoria now is not known. There are no records of this species from Port Phillip Bay.

Family Pectinidae

Scallops. *Pecten alba* Tate, is now considered a junior synonym of *P. fumatus* Reeve (Woodburn 1990).

Family Pteriidae

The family, which includes pearl oysters, is represented in the southern Australian fauna by a single small species.

Family Solemyidae

Date shells. PPBES–1 specimens of *Solemya australis* Lamarck 1818 have not been located, so it is not possible to comment on the identification. The species is recorded from a number of Victorian localities (Macpherson and Gabriel 1962; MoV[1] collections). Reid and Brand (1987) stated that as many as three species have been identified as *Solemya australis*. The only specimens in the Museum of Victoria collections from Port Phillip Bay are small and are probably *S. velessiana* Iredale 1931, whose type locality is Sydney Harbour, NSW.

Subclass Heterodonta

Family Cardiidae

Cockles. Cardiids are shallow burrowers in sand or mud. Most Australian species are found in tropical waters and the Victorian fauna is limited to three species. The southern Australian species were included in the revision of the Western Australia members (Wilson and Stevenson 1977).

Family Carditidae

Little heart shells. Carditids are reported as gonochoristic and ovoviviparous, brooding the young on the gills.

Family Condylocardiidae

This poorly known family of very small bivalves includes over 50 nominal species in southern Australia. The number of biological species is anticipated to be considerably fewer. A revision of the species is needed to define and document the taxa. A number of genera appear to be endemic to the Australasian region. Like the carditids, some species are reported to brood their young.

Family Corbulidae

The family was not reported in PPBES–1 although endemic species were known. The introduced species, *Corbula* cf. *gibba* (Olivi 1792) is treated in detail below (section 9.3).

Family Crassatellidae

The family is represented by very few species in the southern Australian fauna. It has been suggested that some species in the family brood their young.

Family Cyamiidae

This small family of minute bivalves is very poorly known. The family is known only from the Southern Hemisphere. A number of genera appear to be endemic to the Australasian and Antarctic regions. The PPBES–1 specimens of this family were either not located in Museum of Victoria collections (*Cyamiomactra balaustina*) or were damaged and difficult to identify (most *C. nitida*, all *C. mactroides*). *C. nitida* was not included in Poore *et al.* (1975) but a specimen of this species was found from PPBES–1. The record of *C. communis* Hedley 1905 was based on the SDE study.

Family Gastrochaenidae

A single species of the family is recorded from Victoria. Species are recorded as larviparous.

Family Hiatellidae

This family was not recorded in PPBES–1 but has been previously reported from Port Phillip Bay (Macpherson and Gabriel 1962). The record of *Hiatella australis* (Lamarck 1818) from the SDE study requires confirmation. One lot was examined and found to be misidentified.

Family Lasaeidae

Melliteryx acupuncta was listed in the Erycinidae by Poore *et al.* (1975); Vaught (1989) included Erycininae as a subfamily of Lasaeidae.

Family Lucinidae

There are approximately 50 nominal species described or recorded from southern Australia. The number of biological species is anticipated to be considerably fewer. Some species are larviparous.

Family Mactridae

Many species are recorded in the southern Australian fauna. The introduced species *Raeta* (*Raetellops*) *pulchella* (Adams and Reeve 1850) is documented in detail below (section 9.3).

Family Mesodematidae

Mesodesma elongata (Deshayes) was recorded during PPBES–1 and was assigned to *Paphies* (*Amesodesma*) by Beu and de Rooj-Schilling (1982). *Mesodesma nitida* Reeve 1854 is a junior synonym.

Family Montacutidae

Specimens listed as *Mysella* sp. 1 and *Mysella* sp. 2 from PPBES–1 are *Mysella donaciformis*.

Family Psamobiidae

Sunset shells. Poore *et al.* (1975) included *Soletellina donacoides* Reeve 1857 in the family Sanguinolariidae, now assigned subfamily rank (Vaught 1989). Willan (1993) provided a comprehensive review of the family in

[1]Museum of Victoria

Australasia, including *S. donacoides* Reeve as a junior synonym of *S. alba* (Lamarck 1818).

Family Semelidae

The introduced species *Theora lubrica* (Gould 1861) is documented in detail below (section 9.3).

Family Solenidae

A single species of this family is found in southern Australia.

Family Sportellidae

Only one species of the family has been recorded from southern Australia. A number of species are found in the New Zealand fauna (Ponder 1971).

Family Tellinidae

This large family includes many species in the southern Australian fauna. Generic assignment of the species follows Ponder (1975), and Lamprell and Whitehead (1992).

Family Ungulinidae

Ten nominal species of this family are recorded from southern Australia. The number of biological species is uncertain.

Family Veneridae

This large family is represented by many species in southern Australia. Generic assignments follow Lamprell and Whitehead (1992). The literature is confused on the status of *Pullastra fabagella* Deshayes 1854 (type locality, New Zealand) recorded during PPBES–1. The evidence suggests that the southern Australian species is *Venerupis anomala* (Lamack 1818). Although *Placamen placidum* (Phillippi 1844) was first collected during surveys by the SDE study the species had previously been recorded from Port Phillip Bay (Macpherson and Gabriel 1962).

Subclass Anomalodesmata

Family Myochamidae

Several of the approximately 15 species of the family recorded worldwide occur in southern Australia.

Family Periplomatidae.

This small family includes less than 30 species in the recent fauna worldwide but is represented by only a single species in the southern Australian fauna. Periplomatids are free sedentary burrowers. PPBES–1 included *Offadesma angasi* in the family Laternulidae. The genus is included in this family by Keen (1969b).

Family Thraciidae

Several species of this family are recorded from southern Australia.

(ii) Gastropods

The prosobranch gastropods are the most diverse group of molluscs. The diversity includes shell and body form, habitat, feeding types and reproductive strategies. Typically, there is a planktonic veliger larval stage, but many have direct development.

There are no records of introduced prosobranchs in the Victorian fauna.

Class Gastropoda

Subclass Prosobranchia

Family Acmaeidae

Acmaeid limpets. This family is represented in the Victorian fauna by several species. Most are found on intertidal rocky shores and are browsers on the algae growing on rocks (Wilson 1993). Ponder and Creese (1980) revised three genera. PPBES–1 recorded *Actinoleuca calamus* (Crosse and Fischer 1864) which has been re-assigned to *Patelloidea profunda calamus* (Ponder and Creese 1980).

Family Barleeidae

Badepigrus was reported in the Rissoidae in PPBES–1. Ponder (1983) assigned the genus to the Barleeidae and placed *B. petterdi* (Brazier 1889) in the synonymy of *B. pupoides* (Adams 1865).

Family Buccinidae

All members of this large family are carnivores, some preying on other molluscs (Wilson 1994). PPBES–1 specimens of buccinid sp. (MoV 1725) were not located.

Family Calyptraeidae

Shelf or slipper shells. PPBES–1 recorded *Sigapatella calyptraeformis* (Lamarck 1822). Wilson (1993) considers the use of *Sigapatella* for Australian species to be incorrect and assigns the species to *Calyptraea.*

Family Cerithiidae

Creeper shells. The family is more common in shallow tropical waters but represented by several species in the Victorian fauna. Most members are gregarius detrital feeders and live in sandy or muddy substrates, scraping fine particles of detritus, micro-algae and bacteria from the substrate surface (Healy and Wells 1998).

Family Columbellidae

Dove shells. This classification follows Vaught (1989), in assigning family status to this group rather than subfamily status as proposed by Ponder and Waren (1988) and Wilson (1993). The family is represented by many species in the Victorian fauna. The species and generic level classification need clarification and review. Habitats within the family are variable, and the biology is very poorly known (Wilson 1993). The PPBES–1 specimens of *Dentrimitrella* species (MoV 1729, 1730) were not located.

Family Conidae

Cone shells. This large family is represented by very few species in the Victorian fauna, being more common in tropical waters. All cone shells are predators; most eat worms. *Conus anemone* has direct development.

Family Dialidae

The validity of family rank for this group has been established by Ponder (1991). Species now included in this family were previously assigned to the Cerithiidae by authors. The generic and species definitions and nomenclature have not been documented and require review. *Diala magna* Tate 1891 was collected by PPBES–3. It has previously been reported from Port Phillip Bay by Macpherson and Gabriel (1962).

Family Fissurellidae

Keyhole or slit limpets. The taxonomy and biology of this quite large family are poorly known. Some genera are endemic to southern Australia. A number of genera are found in the intertidal and shallow sublittoral. Fissurellids graze on plant or animal tissue growing on hard substrates, and may be specialised predators (Wilson 1993). Approximately 20 species are recorded from Victoria, including many from Port Phillip Bay.

Family Iravadiidae

Species now included in this family was previously considered members of the Rissoidae. Genera of the family were reviewed by Ponder (1984). Species definitions are difficult and the unidentified species recorded in PPBES–1 and 2 has not been identified.

Family Marginellidae

This is considered one of the poorest known of the Australian prosobranch families (Wilson 1994). The large numbers of Victorian species are being studied by Dr D Hewish. Australia is one of the largest centres of marginellid distribution, with an estimated total number of species of approximately 200, including many from Victoria. The animals are probably carnivores (Wilson 1994).

Family Muricidae

This very large family is represented by many species in the Victorian fauna. All members of the family are carnivores. *Pterynotus triformis* (Reeve 1854) was not collected by PPBES–1. Macpherson and Gabriel (1962) reported the species from Western Port and there are a number of lots from Port Phillip Bay in the MoV collections.

Family Nassariidae

Dog whelks. This classification follows Vaught (1989), in assigning family status to this group rather than subfamily status as proposed by Ponder and Waren (1988) and Wilson (1993). These sand or mud dwelling snails are carnivores or scavengers, represented by several species in the Victorian fauna. Cernohorsky (1984) reviewed the generic and species level taxonomy. The PPBES–1 specimens should be re-examined to confirm identifications. *Nassarius pyrrhus* (Menke 1843) was not recorded by PPBES–1. Macpherson and Gabriel (1962) report the species as *Niotha pyrrhus* (Menke 1843) from several Port Phillip Bay localities.

Family Naticidae

Sand snails. Many species of this family are recorded in the Victorian fauna. They are found in coastal and estuarine habitats, feeding on bivalves (Wilson 1993). The classification and nomenclature of the group are confused and require review. PPBES–1 recorded *Glossaulax aulacoglossa* (Pilsbry and Vanatta 1902). The nomenclature of the species is confused and requires clarification. Macpherson and Gabriel (1962) record the species from Victoria, commenting that the species had been previously been known as *Polinices didymus* Chemnitz. Wilson (1993) recorded *Polinices didmya* Roding 1798 as a northern Australian species. *Polinices conicus* (Lamarck 1822) was not collected by PPBES–1. Macpherson and Gabriel (1962) reported the species as widespread in Port Phillip Bay.

Family Pyramidellidae

It was difficult to identify pyramidellids reliably in PPBES–1. Taxonomic knowledge of the southern Australian fauna of this group is still very limited.

These mainly ectoparasitic snails feed on a variety of invertebrates and are often host specific. The taxonomy of the family is very poorly known. The identifications are based on MoV collections and generic assignments follow Macpherson and Gabriel (1962).

Family Scissurellidae

Little slit shells. A small family of minute shells, with a single species recorded from PPBES–3. Five species have been recorded from Victoria, including one species, *Scissurella vincentiana* Cotton 1945 from Point Nepean. All are endemic to southern Australia. *Sinezona atkinsoni* (Tennison-Woods 1877) was not reported from PPBES-1. Macpherson and Gabriel (1962) reported it as *Schismope atkinsoni* from Portarlington, and MoV collections include specimens from Frankston and off Point Cook. Wilson (1993) assigned the species to *Sinezoma*, including as synonyms *tasmanica* Petterd 1879 and *carinata* Watson 1886.

Family Trochidae

Top shells. This very large family of mostly shallow water snails is represented in the Victorian fauna by many species. The major recent work on the family has been on the suprageneric classification (Hickman and McClean 1990). Most species live on hard substrates and may be herbivores, carnivores, or detritus feeders (Wilson 1993). The PPBES-3 record of *Clanculus* cf. *aloysii* Tennison-Woods 1877 is based on a single specimen which differs in some aspects of shell sculpture compared with identified specimens of *C. aloysii* in the MoV collections. The PPBES-3 record of *Clanculus sp.* (MoV 1581) is based on a single specimen, which cannot be identified to species, due to its small size and poor condition. PPBES–1 recorded *Ethminolia tasamanica* (Tennison-Woods 1877), a junior synonym of *E. vitilignea* (Menke 1843) (Wilson 1993).

Family Turbinidae

Turban shells. Most members of this large family live in shallow tropical and warm temperate seas. Recent work on the group is restricted to the suprageneric classification (Hickman and McClean 1990). PPBES-1 recorded *Micrastrea aureum* (Jonas 1845); the species was assigned to *Astralium* by Beu and Ponder (1979).

Family Turridae

The Turridae is the largest family in the Gastropoda (Wilson 1994).

Subclass Opisthobranchia

Most opisthobranchs are carnivores, feeding on sponges, cnidarians, bryozoa and other opisthobranchs, some are herbivores. Some species have specific diets and are always found near a food source. Opisthobranchs are hermaphroditic and are capable of reciprocal copulation.

Order Cephalaspisea

Families of this group of bubble shells found in Port Phillip Bay include Philinidae, Aglajidae, Haminoeidae, and Retusidae. Most are carnivores and feed on foraminiferans, sponges, polychaetes and molluscs.

Family Aglajidae

PPBES–1 recorded *Aglaja queritor* Burn 1957. Burn (1989) reassigned the species to *Melanochlamys* and included *A. henri,* Burn as a synonym. Burn (1989) reassigned *Aglaja taronga* Allan 1933 to the genus *Philinopsis.*

Family Haminoeidae

Liloa brevis (Quoy and Gaimard 1833) was not collected by PPBES–1. The species is reported as common in Port Phillip Bay and Western Port (Macpherson and Gabriel 1962).

Order Sacoglossa

These usually very small animals may or may not have a shell. The group includes the bivalve gastropods. Most feed on green algae. The families found in Port Phillip Bay include the Stiligeridae and the Costasiellidae.

Family Costasiellidae

Costasiella sp. (MoV 1571), known only from Port Phillip Bay is an undescribed species characterised by flattened cerata, which have dendritic, internal branching. Two other undescribed species of this genus are known from Victoria. The genus has a worldwide distribution in temperate and tropical waters and includes approximately 20 species.

Order Nudibranchia

The Australian nudibranch fauna includes hundreds of species, up to half of which may be undescribed (Burn 1989). The families found in Port Phillip Bay include the Okenidae, Dorididae and Aeolidiidae.

Family Okenidae

Okenia sp. MoV 1576 is known only from Port Phillip Bay and is an undescribed species. It is characterised by its small size, broad foot, high body and a few long slender papillae projecting from the pallial rim. The species is similar to, but distinct from, *Okenia plana* Baba 1960, a widespread Pacific species that has been recorded from eastern Victoria. *O. plana* has a flattened body and lacks the pallial rim of this species.

Family Dorididae

Doris sp. MoV 1736 is known from a single, poorly preserved specimen that is possibly a juvenile *Doris cameroni.*

Family Aeolidiidae

Aeolid sp. MoV 1573 is represented by minute specimens that cannot be identified without extensive analysis, including detailed dissections.

(iii) Chitons

Most chitons reproduce by spawning, but some, including southern Australian species of *Ischnochiton,* brood their young. There are no records of introduced chitons in Victoria.

Class Polyplacophora

Family Acanthochitonidae

Notoplax (Notoplax) wilsoni (Sykes 1896), whose type locality is Port Phillip, was not collected in PPBES–1. The generic assignment of this species follows Ludbrook and Gowlett-Holmes (1989).

Family Chitonidae

Chiton (Rhyssoplax) tricostalis Pilsbry 1894 was recorded as *Rhyssoplax tricostalis* by PPBES–1; generic assignment follows Ludbrook and Gowlett-Holmes (1989).

Family Ischnochitonidae

PPBES–1 recorded *Ischnochiton atkinsoni* Iredale and May 1916 and *I. variegatus* (Adams and Angas 1864). Both species were placed in the synonymy of *Ischnochiton carinulatus* (Reeve 1847) by Cochran (1993), who reviewed the southern Australian species of the subfamily Ischnochitoninae. *Subterenochiton* has been assigned to the subfamily Lepidochitoninae of the family Ischnochitonidae (Kaas and van Belle 1985a, 1985b).

Family Leptochitonidae

PPBES–1 recorded *Lepidopleurus mattewsianus* Bednall and Matthews 1906 in the family Lepidopleuridae. The species has been assigned to the genus *Lepidochiton,* family Leptochitonidae (Kaas and van Belle 1985a, 1985b).

9.3 INTRODUCED SPECIES IN PORT PHILLIP BAY

Class Bivalvia

Subclass Pteriomorphia

Family Mytilidae

Musculista senhousia **(Benson 1842)**
Figure 9.1

Synonymy and taxonomy

Modiola senhousia Benson 1842: 489;
Modiolus senhausii [sic] Reeve 1857: species 22;
Modiola bellardiana Tapparone-Canefri 1874: 144, pl. 4, Figures 1b, 4, 4a [fide Willan 1985];
Brachidontes aquarius Grabau and King 1928: 171 [fide Willan 1985];
Modiolus senhousei [sic] (Benson 1842). —Hanna 1966: 59, Figure 67;
Musculus senhausei: —Abbott 1974: 432, Figure;
Musculus (Musculista) senhausia: — Yamato and Habe 1958: 9, pl. 2, Figure 13 [fide Willan 1985]. — Kuroda et al. 1971: 349, pl. 73, Figure 16;
Musculista senhausia: — Morton 1974: 19. — Willan 1985: 85, Figures 1–3. — Willan 1987: 474. — Slack-Smith and Brearley 1987: 225. — Hoenslaar and Hoenslaar 1989: 73. — Bernard *et al.* 1993: 35. — Coleman 1993: 7. —Coleman and Sinclair (in prep.).

The nomenclature of this species is stable. The species was assigned to a number of genera in the early literature, but its generic status was resolved with the establishment of *Musculista* Yamato and Habe 1958 as a subgenus of *Musculus*, with *Modiola senhousia* as type species. *Musculista* was elevated to generic rank by Morton (1974) and later authors, including Vaught (1989). Two other northwestern Pacific species, *Musculista japonica* Dunker 1857 and *Musculista perfragilis* Dunker 1857, are included in the genus (Kira 1962; Kuroda *et al.* 1971; Bernard *et al.* 1993). Illustrations of these species indicate that they are both considerably more elongate than *M. senhousia*.

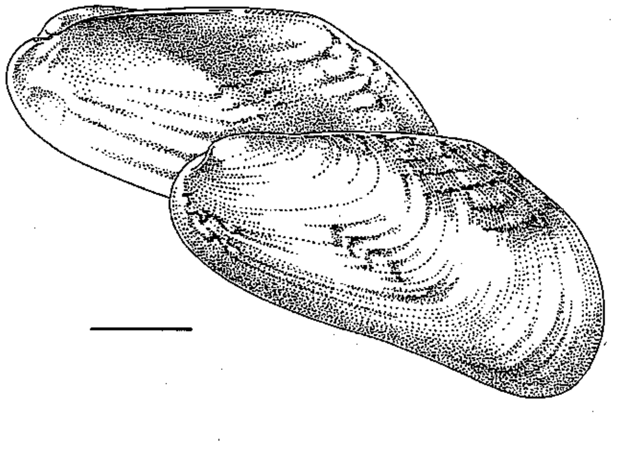

Figure 9.1. *Musculista senhousia*. Scale bar = 5mm.

This is the only species of the genus found in southern Australia. It could possibly be confused with juvenile specimens of some native species of Mytilidae.

Origin and existing distribution

The species is native to the north western Pacific, its type locality being Chusan and Canton Province, China. The natural distribution extends from Siberia and the Kuril Islands, Korea, Japan and China (Kuroda *et al.* 1971; Bernard *et al.* 1993).

The first record of the species outside its natural distribution was in the mid-1940's, when it was recorded from California, USA (Hanna 1966). It was later reported with a distribution extending to Washington (Abbott 1974). The species became established in the Mediterranean (France and Israel) by the early 1980's (Hoenselaar and Hoenselaar 1989).

Australian and Port Phillip Bay distribution

The first record of the species in the Southern Hemisphere was in New Zealand in the 1970's, when it became established in the Auckland and Whangarei Harbours (Willan 1985, 1987). The first Australian record was from the Swan Estuary, Western Australia, in the early 1980's (Slack-Smith and Brearley 1987). The species appears not to have become established in Victoria until the late 1980's, when it was recorded from Western Beach, Corio Bay and Point Wilson in Port Phillip Bay, and Grantville in Western Port (Coleman 1993). It also occurs in Portland Harbour.

Diagnosis

Shell small, thin, equivalve, inflated. Elongate trigonal in shape, rounded anteriorly, expanded posteriorly, with an almost angulate umbonal keel, posterior area compressed. Umbones anterior, subterminal. Shell surface smooth, with a few radial cords on the area anterior to umbos. Externally shell dull olive green to brown, with slightly darker radial rays on area behind keel; may be with zig-zag markings or have a mottled appearance; internally shell lustrous. Hinge without true teeth (edentulous). Ligament internal, elongate, set on weak nymphs. Dorsal margin with series of quite well defined, oblique, interlocking crenulations (dysodont teeth), more easily observed posteriorly. Thin, smooth, translucent periostracum. Well developed byssus present which may form nest or byssal mat.

Distinguishing features in Australia

Musculista senhousia could be confused with other Victorian mytilid species, particularly juvenile specimens. *Musculus cumingianus* (Reeve 1857) and *Musculus ulmus* Iredale 1936, although included in the same subfamily as *Musculista* can both be readily distinguished by shell shape (more inflated, less elongate) and shell sculpture (well defined radial ribs on large sections of shell). The less closely related *Xenostrobus inconstans* (Dunker 1857), which is recorded as widely distributed in shallow water mud habitats in Port Phillip Bay (Macpherson and Gabriel 1962), could be more easily confused. *X. inconstans* can be distinguished by differences in shape (umbones virtually terminal, umbonal keel rounded), the absence of any radial shell sculpture, the external colour being brown to black, without radial markings, and the absence of the interlocking crenulations on the dorsal margin.

Ecology

Ecological studies of this species have been undertaken mostly on the northwestern Pacific (Japanese) populations. Kikuchi and Tanaka (1978), Willan (1987) and Coleman and Sinclair (in prep.) provide comprehensive summaries of these works.

Musculista senhousia is reported from the intertidal and shallow subtidal (to depths of several metres), on hard and on or in soft substrates (Morton 1974; Willan 1985; Slack-Smith and Brearley 1987). The species has a well developed byssus, which may be woven into a nest or byssal bags, in which the animal can be completely enclosed (Morton 1974). The species is often found in dense aggregations, up to 3,000 m^{-2} (Morton 1974; Willan 1987). The sexes are separate and the species is highly fecund. Eggs and larvae are pelagic for 14–25 days; larvae have been reported all year except mid-winter. Development is rapid and adult size can be attained in 9 months (Morton 1974; Willan 1987) The species is tolerant of low oxygen concentrations and low salinities (Willan 1987).

Comments

Musculista senhousia is now abundant in Port Phillip Bay. The ecology of this species is well documented and it is known to form large byssal nests in mud and foul wharf pilings (Morton 1974; Hanna 1966; Willan 1985). Studies by Kulikova (1978) in Brusse Lagoon, Russia have recorded planktonic larvae of *M. senhousia* in the water column over the summer months in numbers as high as 17,000 specimens m^{-3}. As the larvae have been reported as being pelagic for up to 20 days (Kulikova 1978), the probability of being taken up in ballast water is high.

There have been multiple introductions of *M. senhousia* into North America. Introductions have been attributed to ballast water or ship fouling (Cohen and Carlton 1995) and as an incidental species with the Japanese oyster *Crassostrea gigas* (Kincaid 1947). *M. senhousia* has the potential to be translocated within Australia via a number of vectors including hull fouling, ballast water and the movement of mariculture species.

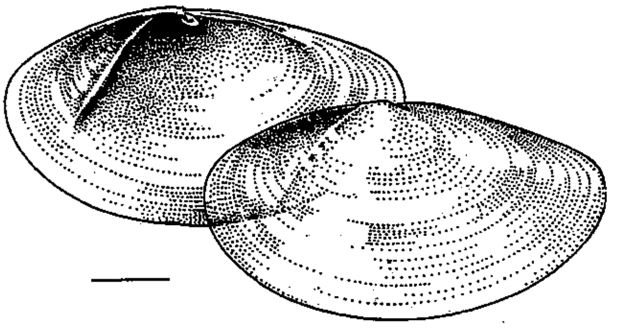

Figure 9.2. *Theora lubrica.* Scale bar = 2mm.

Subclass Heterodonta

Family Semelidae

Theora lubrica (Gould 1861)

Figure 9.2

Synonymy and taxonomy

Theora lubrica Gould 1861: 24. — Johnson 1964: 104, pl. 25, Figure 5. — Kuroda *et al.* 1971: 447, pl 21, Figure 2. —Bernard *et al.* 1993: 96. —Coleman 1993:7. — Coleman and Sinclair (in prep);

Theora (Endopleura) lubrica: — Adams 1864: 209. — Coan 1973: 325. — Seapy 1974: 385. — Powell 1976: 203. — Climo 1976: 11. — Chalmer *et al.* 1976: 397;

Theora fragilis. — Macpherson 1966: 236. — Poore *et al.* 1975: 26 (non Adams 1855).

The nomenclature of this species has been somewhat unstable in the past, and there has been confusion in the status and relationships of other species in the genus recorded from the Indo-west Pacific. A complete review of the genus is required to resolve the classification and document the taxa. Recognition of subgeneric groupings is not appropriate until the species are reviewed.

The species has commonly been confused with *Theora fragilis* Adams 1855 (type locality: Moreton Bay, Qld). This confusion was due, at least in part, to the absence of adequate illustrations of both species in the early literature. Recent work by Climo (1976) has confirmed that *T. fragilis* and *T. lubrica* are distinct species, and the types have now been well-illustrated (*T. lubrica* by Johnson (1964), *T. fragilis* by Climo (1976). Despite this, recent records continue to be inconsistent, Bernard *et al.* (1993) recording *T. fragilis* from China and including *T. lubrica* as a synonym. Semelids from the Museum–Fisheries and Wildlife survey (Macpherson 1966) and PPBES–1 (Poore and Rainer 1974) were misidentified as *T. fragilis*.

Other species in this genus include: *Theora lata* (Hinds 1843) and *T. nitida* Gould 1861, both possible synonyms of *T. fragilis* (Gould 1861; Smith 1885); *T. iridescens* (Hinds 1843), easily distinguished by its shape, is recorded from the Philippines, Indonesia, China and Japan (Smith 1885; Prashad 1932; Bernard *et al.* 1993); and *T. opalina* (Hinds 1843) described from the Philippines.

Origin and existing distribution

T. lubrica is endemic to the northwestern Pacific. The type locality is Hakodate Bay, Japan, but the confused nomenclature suggests that this distribution requires confirmation.

The species was introduced into California, USA, prior to the late 1960's and by 1974 was well established in southern parts of that state (Seapy 1974). In the early 1970's, the species became established in New Zealand, particularly in the North Island (Powell 1976; Climo 1976; Willan 1987).

Australian and Port Phillip Bay distribution

The first published record of this species in Australian waters was by Macpherson (1966) who recorded it (as *T. fragilis*) as being present in large numbers on sandy mud sediments in Port Phillip Bay as early as 1958. In 1969 it was the most common mollusc collected during PPBES–1 benthic sampling (MMBW and FWD 1973; Poore *et al.* 1975).

Chalmer *et al.* (1976) recorded this species in the Swan Estuary and Cockburn Sound, WA, in the early 1970's. The species has also been recorded from Botany Bay, NSW (Climo 1976) and upper Spencer Gulf, SA (South Australian Museum collections).

Diagnosis

Shell elongate, smooth, shiny, and white, without periostracum. Shell valves rounded anteriorly, with the posterior area slightly rostrate. Valves gape slightly anteriorly and posteriorly. The species is characterised by a fine, elongate rib extending obliquely across the internal surface of the shell, from the umbo towards the anteroventral margin. The rib is often evident through the almost transparent shell. The most prominent aspect of the hinge is the spoon-shaped chondrophore, to which the internal ligament (resilium) is attached. The hinge teeth are small, with a single slightly bifid cardinal in the left valve and two divergent cardinals in the right valve.

Distinguishing features in Australia

There have been no comparative morphological studies of populations of this species in its natural and introduced populations.

Theora lubrica can be distinguished from most other small bivalves in southern Australia by its smooth shell, elongate shape, distinctive rib on the internal shell surface, and the internal ligament and chondrophore. It has been confused with *T. fragilis*, a species recorded from Queensland, New South Wales and Victoria (Lamprell and Whitehead 1992).

Early literature records of *T. fragilis* from Victoria are based on specimens collected in 1911 off Point Cook, Port Phillip Bay (Gatliff and Gabriel 1911; Macpherson and Gabriel 1962). These specimens have been recently positively reidentified as *T. fragilis*, and together with a further lot collected on or prior to 1959, at the mouth of the Yarra River, are the only known Victorian records. The shell of *T. fragilis* does not have the internal rib which characterises *T. lubrica*, and is more tapered posteriorly.

Ecology

Ecological information on this species is based almost exclusively on studies undertaken on Japanese populations. Coleman and Sinclair (in prep) provide a comprehensive review of the literature.

In Japan, *T. lubrica* is found in bays, living in muddy sediments, from the low tide mark to 100 m (Kuroda *et al.* 1971). The species is well adapted for an opportunistic life style. Part of the population can spawn in any season and recruitment appears to be continuous. While most specimens die within a year, the life span may be up to 2 years, and juveniles of 1 mm can reach adult size in 1 to 3 months. Growth continues throughout the year, most rapidly at moderate water temperatures (20° C), slower in winter (14°–15° C) and at maximum summer temperatures (26°–27° C) (Kikuchi and Tanaka 1978, summary based on Coleman and Sinclair, in prep.). Population density of the species was reported as reduced in areas of reduced oxygen concentration (Imabayashi 1985). The species is considered a biological indicator species for anoxic conditions (Coleman and Sinclair in prep.).

In Port Phillip Bay, Poore and Rainer (1974) reported the species as a surface deposit feeder. The species has been found in the diets of demersal fish (green back flounder and red gurnard) in Port Phillip Bay (Parry *et al.* 1995).

In the PPBES–1 survey, *T. lubrica* was taken in large numbers from all regions. In PPBES–2, it was also collected in all regions, often in large numbers, at depths from 7 m to 24 m. Coleman and Sinclair (in prep.) consider that the conditions in Port Phillip Bay would favour rapid growth in this species for several months of the year.

Comments

There is a considerable body of research on the biology and ecology of *T. lubrica* (Imabayashi and Tsukuda 1984; Tanaka and Kikuchi 1979; Tanaka 1990). The presence of this species in Port Phillip Bay can be traced back to 1958, when large numbers were recorded from sandy mud sediments by Macpherson (1966). Within its native range in Japan, *T. lubrica* is capable of spawning almost all year round (Imabayashi 1985), which makes it susceptable to uptake and translocation in ballast water. Carlton *et al.* (1990) successfully reared bivalve veliger of *T. lubrica* sampled from the ballast tanks of Japanese cargo vessels arriving in Coos Bay, USA. Adults may also be transported in the sediments of anchor lockers or sea chests.

Family Mactridae

Raeta (Raetellops) pulchella (Adams and Reeve 1850)
Figure 9.3

Synonymy and taxonomy

Poromya pulchella Adams and Reeve 1850: 83;
Mactra rostralis Deshayes 1854: 69.— Reeve 1854: sp. 119;
Raeta pulchella: — Adams and Adams 1856: 386. — Smith 1885: 56;
Raeta yokohamensis Pilsbry 1895: 119 [*fide* Kuroda *et al.* 1971];
Labiosa (*Raeta*) *pulchella*: — Lamy 1917: 358;
Raeta elliptica Yokomya 1922: 131 [*fide* Kuroda *et al.* 1971];
Raetellops pulchella Habe 1951: 197 [*fide* Kuroda *et al.* 1971]. — Bernard *et al.* 1993: 106.

There is very little published information on the nomenclature and taxonomy of this group. There have been no major reviews since that of Lamy (1917). The type locality of the species is Borneo but most records are from Japan. There has been some confusion in the identification of this species. Lynge (1909) misidentified and illustrated a specimen of *Leptomya* from Siam (Thailand) as this species (Lamy 1917). The generic placement of the species follows Vaught (1989), who considered *Raetellops* to be of only subgeneric rank.

Origin and existing distribution

Raeta pulchella was described from Borneo and is recorded from various localities in China and Japan (Kuroda *et al.* 1971; Bernard *et al.* 1993).

Australian and Port Phillip Bay distribution

Australian records of this species are restricted to a few specimens from Port Phillip Bay, the first known specimens being collected in 1991 at Sandringham. It is also recorded from St Leonards and western sandy and deep muddy parts (7–25 m) of Port Phillip Bay.

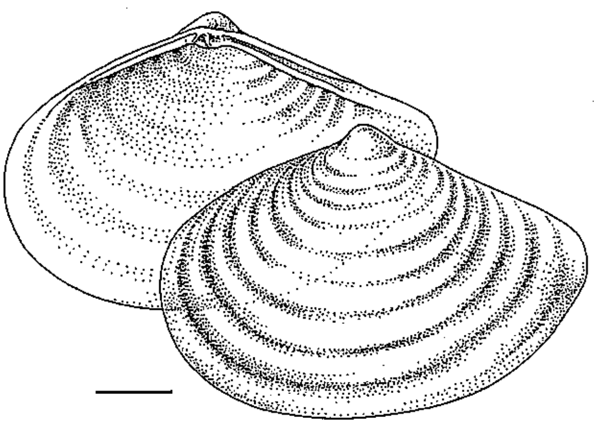

Figure 9.3. *Raeta (Raetellops) pulchella.* Scale bar = 2 mm.

There are no other records of this species being introduced to localities outside its presumed natural area of distribution.

Diagnosis

Shell small, delicate, thin, fragile, inflated, equivalve. Valves triangulate in outline, anterodorsal and ventrodorsal margins almost straight, ventral margin rounded; posterior area constricted, almost rostrate. Slightly gaping posteriorly. Umbones approximately central. Shell white, exterior with undulate, concentric ridges. Periostracum observed on some specimens, thin, papery, more evident near ventral and posterior margins. Hinge plate broad, thin, with two, dorsally joined cardinal teeth in each valve, giving the appearance of an inverted V. Lateral teeth present, two posterior and single anterior in each valve. Large internal ligament, chondrophore posterior to cardinal teeth.

Distinguishing features in Australia

Port Phillip Bay specimens of *Raeta* are not conspecific with other Australian species of the genus, which include *Raeta meridionalis* Tate 1889 from South Australia and New South Wales (Cotton 1961; Iredale and McMichael 1962) and *Raeta pellicula* (Reeve 1854) from Queensland and possibly northern Western Australia (Lamprell and Whitehead 1992). Their identification was based on comparison with Japanese specimens from the National Science Museum, Tokyo, and published and illustrated accounts (Kuroda *et al.* 1971).

Victorian specimens of *Raeta* (10–14 mm long) are more rounded, and less elongate than *Raeta meridionalis* and *Raeta pellicula,* both much larger at 40–45 mm.

Raeta pulchella can be distinguished from most other small bivalves in the Victorian fauna by its thin, fragile shell, inflated, triangulate shape, the undulate/ ridged exterior and the well developed internal ligament. In the Victorian fauna, it could possibly be confused with the thin shelled species, *Offadesma angasi* (Crosse and Fischer 1864), but this is a much larger species, is elongate with the valves gaping anteriorly and posteriorly, and has a very different hinge structure.

Ecology

There is very little published information on the ecology of this species. In Japan it is recorded from fine sandy and muddy bottoms, in sheltered waters, from lower tide mark to depths of 100 m (Kira 1962; Kuroda *et al.* 1971).

Comments

Very little is known on the biology of *R. pulchella.* As this species is from the family Mactridae, it is likely to have a planktonic larval stage that can potentially be intrained in ballast water.

Family Corbulidae

Corbula cf. *gibba* (Olivi 1792)

Figure 9.4

Synonymy and taxonomy[2]

Tellina gibba Olivi 1792**;
Mya inaequivalvis Montagu 1804**;
Corbula nucleus Lamarck 1818**;
Corbula olympica Costa 1829**;
Corbula rosea Brown 1844*;
Tellina naticuta Brusina 1870**;
Corbula curta Locard 1886**;
Corbula gibba maxima Bucquoy *et al.* 1896**;
Corbula gibba radiata Bucquoy *et al.* 1896**;
Corbula gibba fusca Bucquoy *et al.* 1896**;
Corbula gibba albida Bucquoy *et al.* 1896**;
Corbula gibba:—Lamy 1941: 211.—McMillan 1968: 97.—Jensen 1988: 357.—Jensen 1990: 101.—Sabelli *et al.* 1990: 333.— Coleman and Sinclair in prep.;
Aloidis (*Corbula*) *gibba*: — Yonge 1946: 358, Figures 1–14.
* applies to the Atlantic species *Corbula gibba* (Olivi).
** *fide* Lamy (1941).

The identification of the species remains uncertain and requires further study. The family has been the subject of only one major taxonomic study this century, that by Lamy (1941), a work based on the collections of the Muséum National d'Histoire Naturelle, Paris. Although useful, the work is far from comprehensive, and a number of decisions are not upheld in more recent regional works. The need for a revision of the family is well recognised (Morton 1988; Carlton *et al.* 1990). Recent estimates include approximately 100 species in the family worldwide.

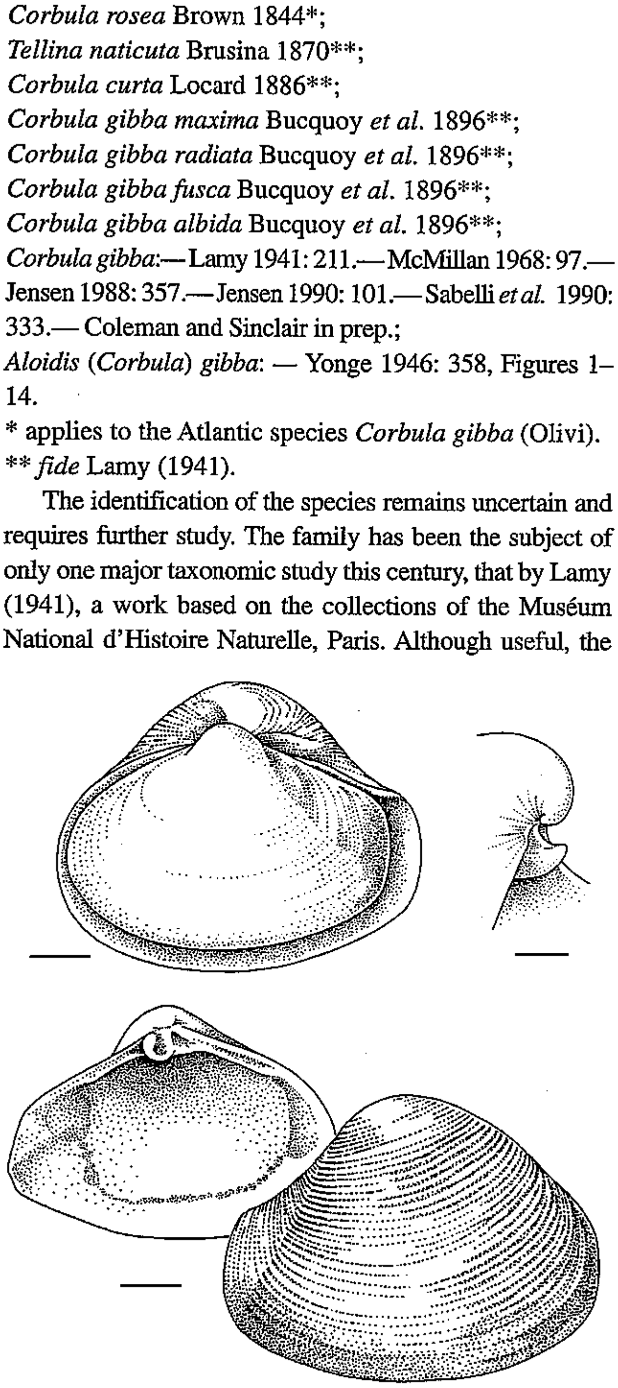

Figure 9.4. *Corbula* cf. *gibba*. Scale bar= 2mm (1mm on detail hinge).

[2]This synonymy of the Atlantic species *Corbula gibba* follows Lamy (1941) and Sabelli *et al.* (1990).

Victorian specimens are very similar in shell morphology to British and European material of *Corbula gibba*, and are probably conspecific. However, as there are similar species, it is considered that a complete review of the group is required to establish the status of nominal taxa. Such a review should be based on extensive collections and include diagnoses, descriptions and documentation of variation. It may also need to include a comparative electrophoretic analysis of European and Australian populations.

Lamy (1941) provided an extensive synonymy of the species, including a number of names as varieties, all of which were included as synonyms by Sabelli *et al.* (1990). Lamy (1941) included other species in a species-group with *C. gibba*. These included the western Atlantic species *C. disparilis* d'Orbigny 1846 (Florida and the Antilles) and *C. patagonica* d'Orbigny 1846 (Argentina). Abbott (1974) recorded *Varicorbula operculata* (Philippi 1847a), considered a junior synonym of *C. disparilis* by Lamy, from North Carolina to Florida and Texas, USA, the West Indies and Brazil. Rios (1994) recorded only *C. patagonica* from Brazil and Argentina. Also included in the group were *Corbula erythraensis* Adams 1870 (Red Sea) and *Corbula rotalis* Hinds1843 (Japan).

Compared to *C. gibba*, the western Atlantic and Red Sea specimens appear to differ in shell sculpture, whereas Japanese specimens are much smaller, but these observations are based on only a few specimens and illustrations in the literature (Oliver 1992; Kuroda *et al.* 1971).

The Victorian specimens are not *Potamocorbula amurensis* (Schrenck 1862), a northwestern Pacific species (China, Japan and Korea), reported as being introduced to San Francisco Bay, California, USA sometime prior to 1986 (Carlton *et al.* 1990). *P. amurensis* has a very elongate, slightly inequivalve shell, without well developed concentric sculpture.

Origins and existing distribution

Corbula gibba is native to the eastern Atlantic and the Mediterranean, with a distribution extending from Norway to the Canaries and Senegal (Lamy 1941).

Australian and Port Phillip Bay distribution

If the identification of the Victorian specimens is confirmed as *C. gibba* this will be the first documented record of the species outside its area of natural distribution. This species is now common in Port Phillip Bay and has also been recorded from the Port of Devonport and the D'Entrecasteaux Channel in Tasmania (Furlani 1996).

Diagnosis

Shell small, solid, elongate-ovate; anterior broadly rounded, posterior margin subtruncate. Species strongly inequivalve, left valve smaller, fitting into right valve, beaks (umbones) high, curved. Sculpture discrepant, right valve with many, narrow, regular, concentric ridges, left valve with weak concentric striae. Exterior of shell cream to buff coloured, right valve with brown patches which may be in radial bands; interior of right valve white with central area beneath umbos deep rose pink, interior of left valve purplish pink, colour deeper in areas inside pallial line. Hinge plate strong; single well defined cardinal tooth in each valve, right cardinal, large, peg-like, recurved, pointed; left cardinal rounded, spoon-shaped; laterals not obvious. Large, elastic, internal ligament attached to hollow area of left cardinal and to depression, posterior to right cardinal. Periostracum tufted, fibrous, if present in right valve restricted to area near margin; often nearly covers left valve and extends beyond shell margin; may be with radial lines. Pallial sinus absent.

Distinguishing features in Australia

The family is represented by many species in the Australian fauna. Approximately 15 have been described from southern Australia. Macpherson and Gabriel (1962) recognised three species in Victoria: *Corbula stolata* (Iredale 1930), *C. coxi* Pilsbry 1897 and *C. flindersi* Cotton 1930. Three species are also recorded from South Australia (Cotton 1961) and four from New South Wales (Iredale and McMichael 1962), with only three nominal species being recorded from more than one state. A review of the southern Australian species is required to establish the number of species present and their distributions. Northern Australian species have not been documented beyond records of distribution.

Corbula cf. *gibba* from Port Phillip Bay can be easily distinguished from the native species found in Victoria. It is most similar to *C. stolata*, but that species has a more elongate, only slightly inequivalve shell, with fewer, heavier, concentric ribs. The other species have almost equivalve, more elongate shells.

Ecology

There have not been any ecological studies of the Victorian populations of *C.* cf. *gibba*[3]. The only information available is on its distribution in Port Phillip Bay.

Coleman and Sinclair (in prep.) provide a comprehensive review of the ecology of Atlantic populations of *C. gibba*. The habitat of the species was reported as offshore, shallow water to great depths (McMillan 1968) but by Jensen (1990) as estuarine. It is a sedentary species, a shallow burrower, which inhabits thick muddy-sand, containing gravel and stones, attached by a single byssal thread (Yonge 1946). Populations of the species in Denmark are often in polluted areas; densities are variable and can be very high (up to 53,000 m^{-2} in 1 mm sieve samples), with animals capable of fast growth (Jensen 1990). Laboratory studies show the species is able to survive long periods in near-anoxic conditions (Jensen 1990). Life span is also shown to be variable through time, 1 to 2 years in recent studies compared with several years earlier in the century (Jensen 1990). Sexes are separate, and spawning appears to be in autumn in the Northern Hemisphere (Yonge 1946).

Comments

Healy and Lamprell (1996) recently confirmed specimens collected from Port Phillip Bay as being indistinguishable from typical European populations.

It has generally been considered that *C.* cf. *gibba* was introduced to Australian waters as larvae in ballast water, as seems to be the case for the introduction of the closely related Asian clam, *Potamocorbula amurensis,* to San Francisco Bay (Carlton *et al.* 1990). However, as mentioned earlier, adult specimens of *C.* cf. *gibba* have been found in the sea chests of an Australian ship suggesting another possible vector for translocation.

Class Gastropoda

Order Opisthobranchia

Family Zephyrindae

Janolus hyalinus (Alder and Hancock 1854)

Figure 9.5

Synonymy and taxonomy

Antiopa hyalina Alder and Hancock 1854: 105;

Janolus flagellatus Eliot 1906 [*fide* Miller and Willan 1986];

Janolus hyalinus Eliot 1906: 374 [*fide* Miller and Willan 1986]. — Burn 1958: 31.

The status and nomenclature of this species require clarification. The first record from Australia was by Burn (1958), and subsequent records were based on his identification. Miller and Willan (1986) document minor differences in the New Zealand and Australian specimens as compared with descriptions of the north-west Atlantic specimens of *J. hyalinus* (Alder and Hancock 1854). Burn (pers. comm.) suggests that the name may refer to a species complex, and that the Australian and New Zealand populations may represent a distinct species, and thus should not be considered an introduction. A comprehensive review of the group is required, including analysis of specimens from throughout its range to establish the relationships of the various populations now included in this species. Schmekel and Portmann (1982) and Thompson and Brown

[3]Editor's note: S Talman is currently studying the ecology of *C. gibba* in Port Phillip Bay; see discussion in Chapter 16.

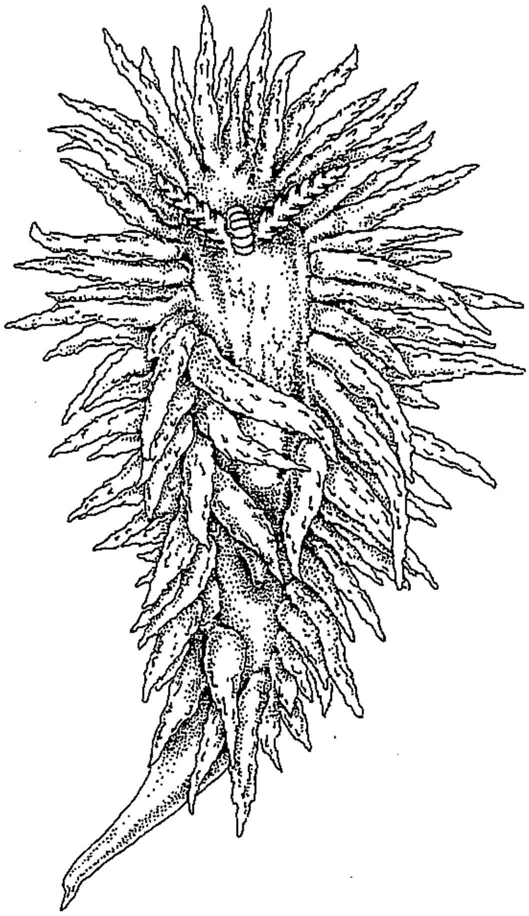

Figure 9.5. *Janolus hyalinus*: based on a figure in Picton and Morrow (1994).

(1984) did not include *J. flagellatus* in their synonymies of this species. Miller and Willan (1986) gave a well-argued case for its inclusion, and that decision is followed here.

Origin and existing distribution

J. hyalinus is native to the northwestern Atlantic and Mediterranean, with records from England, France, Italy and Morocco (Thompson and Brown 1984). It is reported as rare within at least part of this range (Thompson and Brown 1984).

Australian and Port Phillip Bay distribution

The only known Australian records of this species are from Victoria. The first were from Torquay, by Burn (1958), with subsequent records from Port Phillip Bay localities, Portarlington and Portsea (Miller and Willan 1986), San Remo, Western Port and Blanket Bay, Cape Otway (R Burn pers. comm.). The species is rare in New Zealand (Miller and Willan 1986). Hutchings *et al.* (1987) and Pollard and Hutchings (1990) accepted the Miller and Willan (1986) suggestion that the species may have been introduced as a fouling organism on ships' hulls. This must be considered to be open to question as the majority of records have not been from areas near to major ports.

Diagnosis

A slug of moderate size, elongate, tail tapered posteriorly. Anterior and latero-dorsal areas with series of numerous, thickly set cerata. Cerata are elongate, finger-like, surface with small, pointed, wart-like epidermal papillae or tubercles. Rhinophores lamellate with a lamellate caruncle or crest between their bases. Cerata are usually lost in the preservation process. Gonopore on right side in front half of body; anus dorsal at posterior end. Body colour is cream/fawn with brown blotches; a few white patches and orange specks dorsally. Tips of cerata and surface tubercles opaque white. Radular is rectangular, longer than broad, with a rachidian tooth present in every row.

Distinguishing features in Australia

The genus is represented in the southern Australian fauna by two or three other species, all undescribed. These species can easily be distinguished by the absence of tubercles on the cerata. A further species, *Caldukia affinis* (Burn 1958) could also possibly be confused with this, but it lacks the caruncle or crest at the base of the rhinophores found in *Janolus*. The species was figured by Picton and Morrow (1994).

Ecology

There have been no systematic studies of the ecology of this species; information on habitat, etc. is restricted to anecdotal comment. Species in the family feed on bryozoans. In the Northern Hemisphere, this species has been found on various species of *Bugula*, including *Bugula flabellata* (Thompson), a species which has also extended its distribution to Australia (see Chapter 13). In Victoria, *J. hyalinus* has been found under rocks in intertidal rock pools and on the bryozoan *Bicellariella ciliata* (Burn 1958; Thompson and Brown 1984; Miller and Willan 1986). The ectoparasitic copepod *Lichomolgus agilis* (Leydig) has been found on the skin of this species in Northern Hemisphere populations (Thompson and Brown 1984).

Family Hermaeidae

Aplysiopsis formosa Pruvot-Fol 1953

Figure 9.6

Synonymy and taxonomy

Aplysiopsis formosa Pruvot-Fol 1953: 47. — Ortea *et al.* 1990: 281. — Jensen 1995: 217;
Aplysiopsis zebra Clark 1982: 213.

Aplysiopsis formosa Pruvot-Fol 1953 was described from a single specimen collected in Morocco. Ortea *et al.* (1990) included *A. zebra* Clark 1982 (type locality, Fort Pierce Inlet, Florida) in the synonymy of this species and extended its distribution to the Canary Islands. Detailed descriptions and illustrations available in the literature were the basis of the identification. Australian specimens

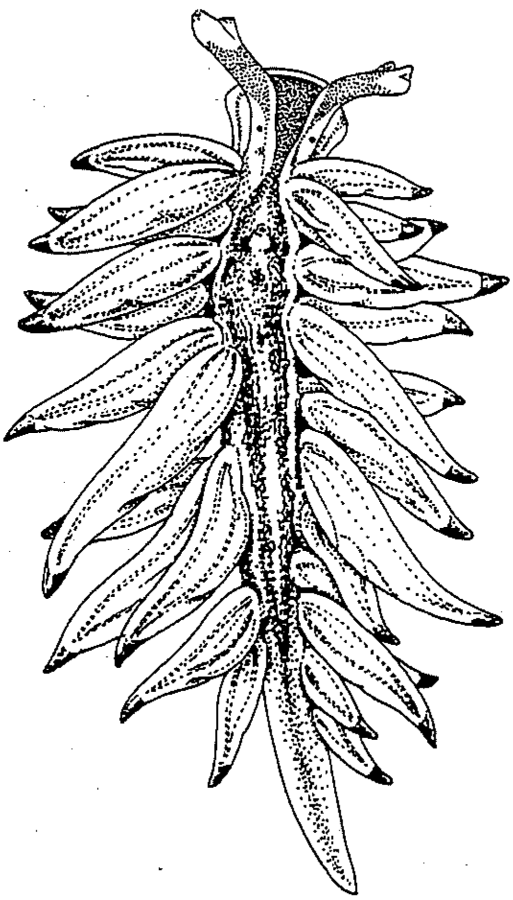

Figure 9.6. *Aplysiopsis formosa*: based on figures in Clark (1982), Jensen (1995) and Ortea *et al.* (1987).

agree with the species diagnosis, particularly in relation to body form and pigmentation.

Origin and existing distribution

The species was described from Morocco and has been recorded from both eastern and western Atlantic localities (Ortea *et al.* 1990). Jensen (1995) recorded the species from the Azores.

Australian and Port Phillip Bay distribution

Australian records are limited to two lots collected from Point Lonsdale, Port Phillip Heads, in 1994 and 1995. Specimens were not found at this locality in 1996.

Diagnosis

A slug of small to moderate size, elongate, slender, tail long and narrow. Sides of body with sparse series of cerata that are larger medially. Cerata elongate fusiform, smooth, and distinctively marked on medial surface with sparse network of branching vessels. Rhinophores anterior, deeply grooved along lower edge. Male genital pore below right eye, female pore on right side below anterior cerata, anus in front of pericardial hump. Body colour dark green with black mid-dorsal stripe from between the rhinophores to behind the pericardium, 2 or 3 slender black stripes on each side of body and 2 black stripes on foot sole. Cerata with black tips. Radula a single row of sabot-shaped teeth, with finely denticulate margins.

Distinguishing features in Australia

Aplysiopsis species are characterised by having a network of branching vessels on the medial face of the cerata. The genus is represented in south-eastern Australia by one or two other species, as yet unidentified. These species differ significantly in the pattern and /or pigmentation of the head, body and cerata, and lack the pair of broad dark bands on the foot sole.

Ecology

A. formosa lives in association with and feeds upon the green alga *Cladophora prolifera* (Roth) (Clark 1982; Ortea *et al.* 1990; Jensen 1995), which is a recent introduction to Australia (Fuhrer 1981; Womersley 1984). The first Australian record of *C. prolifera* (as *C. rugulosa* Martens) was from Rottnest Island WA, around 1950 and the species is now widespread across southern Australia to southern Queensland (Fuhrer 1981; Womersley 1984).

Clark (1982) recorded Florida populations of *A. formosa* in the lower intertidal zone in an area exposed to strong wave action, with highest densities in algae partially submerged in wet beach sand at low tide. The Australian specimens were collected in an area where *C. prolifera* was living on the sides of lower intertidal rock pools exposed to strong wave action. Higher densities of *A. formosa* occurred in pools where the algae is close to sand. The May 1995 sample of *A. formosa* included numerous specimens that were large and sexually mature; many eggs in egg-ribbons occurred entwined in the algae.

Comments

Hull fouling seems an unlikely vector for the introduction of either egg masses or adults. It is more likely that *A. formosa* was introduced to Australia via ballast water along with *C. prolifera*. Several species of *Cladophora* have been observed detached, forming loosely floating masses in shallow inshore waters (Collins and Harvey 1971) and may potentially be taken up in ballast water.

9.4 POTENTIAL INTRODUCTIONS TO PORT PHILLIP BAY

There are a number of mollusc species that are not currently known from Port Phillip Bay but which, on the basis of their invasive history or there occurrence in nearby areas, are likely to be introduced to the bay. Some of these are discussed below.

The New Zealand screw shell, *Maoricolpus roseus* (Turritellidae) was first recorded in Tasmanian in the late 1950's and has now spread across most of south-eastern Australia (Furlani 1996). It occurs from the intertidal zone down to 150 m and occupies a wide range of habitats. It has been suggested that this species was introduced to

Tasmania through the live oyster trade from New Zealand, although Garrard (1972) suggests ballast water as a possible vector. There are no records of *M. roseus* from Port Phillip Bay but it is common in Bass Strait where it is often taken in scallop dredges (R Martin pers. comm.). It has the potential to be introduced to Port Phillip Bay and become a dominant member of the benthic community as it has done in Tasmanian coastal and shelf waters.

The New Zealand green lipped mussel, *Perna canaliculus* (Mytillidae) has been reported from Bridport (specimens held at the Australian Museum) and Port Latta in northern Tasmania, Port Adelaide in South Australia and Cockburn Sound in Western Australia. Its current status at all four localities is uncertain. Freshly killed *P. canaliculus* are imported to Australian markets on a regular basis and it is not unexpected that dead shells from this source may find their way on to Australia shores.

The Asian clam, *Potamocorbula amurensis* (Corbulidae), which has successfully invaded San Francisco Bay (Carlton *et al.* 1990; Nichols *et al.* 1990; Duda 1994), has not yet been recorded in Australia, but there is considerable potential for it to be introduced through international shipping from Japan or the west coast of North America. This species is of considerable concern because of its ability to reach high densities (10,000 m^{-2}) within a few years (Carlton *et al.* 1990) and to impact on both benthic and planktonic community structure and trophic dynamics (Nichols *et al.* 1990).

The estuarine bivalve *Mytilopsis sallei* (Dreissinidae), native to the Gulf of Mexico and the Caribbean, has been introduced to many Northern Hemisphere harbours (Morton 1987). The presence of this highly invasive fouling mussel in Hong Kong, Japan and Taiwan significantly increases the risk that it will spread widely to Southern Hemisphere ports, including Port Phillip Bay. The recent incursion of this species in Darwin Harbour, via international yacht movements, highlights Australia's vulnerability to hull-fouling introductions (CRIMP unpub. data).

The bivalve *Mya arenaria* (Myidae), a native of the north west Atlantic, has been introduced to Europe and is now found on all British and Irish coasts (Eno *et al.* 1997), and in the Black Sea (Zolotarev 1996). *M. arenaria* has become the dominant species at some localities in the Black Sea, and can achieve a biomass in excess of 1 kg m^{-2} (Zolotarev 1996). Shipping is the likely mode of introduction for this species to the Black Sea. This species has the potential to thrive in the muddy sediments of Port Phillip Bay.

Several exotic opisthobranch species have been recorded from Australian waters over the last 60 years. The South American nudibranch *Thecacera pennigera* was first recorded in Australia from Sydney Harbour (Allan 1957) and has achieved a worldwide distribution in temperate waters in recent years. The South African *Polycera capensis* and North American *Polycera hedgpethi* have also both been introduced to Australian waters (Furlani 1996), with the latter species recorded from Mallacoota Inlet in eastern Victoria. Another South African nudibranch *Godiva quadricolor* has been recorded from Cockburn Sound (Willan 1987) where it has become well established. All these polycerid nudibranchs are associated with bryozoans that are mostly common fouling species, and thus have the potential to extend their distributions as a result of this association.

Wells and Kilburn (1986) reported on the discovery of three species of South African temperate water gastropods in south western Australia. These shells were dead when collected, and may never have been live within Australian waters, and the means of their transport is unknown. A live specimen of the Southern African abalone *Haliotis spadicea* was recorded near Cape Naturaliste in Western Australia (Macpherson 1953). The presence of these specimens, along with the nudibranchs discussed previously, serves to highlight the similarities between the temperate environments of Southern Africa and Australia and the potential for species to survive translocation between the two continents.

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10 SOFT SEDIMENT CRUSTACEA OF PORT PHILLIP BAY

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10.1 INTRODUCTION

The Crustacea is a diverse taxon whose morphology, ecology and reproductive biology are diverse. Some groups, such as the crabs, have a stable taxonomy and have been well known in southern Australia since late last century. Others, particularly the peracarids, were poorly known until recently while other abundant benthic taxa are still barely investigated taxonomically.

This review of introduced species is based principally on the results of several surveys of soft bottom benthos undertaken irregularly since the 1960's (Poore 1992; Currie and Parry 1996; Wilson *et al.* in press). Most of these surveys were part of the Port Phillip Bay Environmental Studies: phase 1 (PPBES-1, 1969–1973); phase 2 (PPBES-2, 1973); and phase 3 (PPBES-3, 1994–1995). These collections are now housed in Museum of Victoria (abbreviated as NMV in lists of material). Three species listed with the soft-bottom species (Appendix A, Table A4) are included on the basis of the survey of Corio Bay by MAFRI in 1996 and the survey of numerous habitats, including pile faunas, by CRIMP in 1995-1996. Native crustaceans on hard substrates (intertidal or fouling communities) are not listed and Table A4 is by no means a definitive list of all species of crustaceans in Port Phillip Bay.

The taxonomic composition and likelihood of introduction for the major groups of Crustacea are reviewed. These include all macrofaunal taxa and exclude meiofauna groups such as Copepoda and planktonic taxa. Since the 1960's seven crustacean species have been identified as introduced in Port Phillip Bay and are discussed in turn. Another, the portunid crab *Carcinus maenas*, introduced from UK or Europe late last century (Fulton and Grant 1900), is well reviewed in other literature. It is not discussed further here.

About a third of the 257 crustacean species listed in Table A4 (Appendix A) are not identified to species. Most of these are probably undescribed endemic taxa. The argument for this statement is that most (> 90% for many groups) of the known fauna is endemic (Wilson and Allen 1987; Poore 1995). But for some, and for others hastily identified as known widespread species, introduction to Australia is a possibility. Certain identification of any novel taxon, native or foreign, is possible only by careful comparison of local material with good literature descriptions of all the known similar species (usually those in the same genus). Many named species have not been well described and it becomes necessary to compare specimens from other localities. For some large genera, those with dozens of species, the task is extremely time-consuming. Multiply that by hundreds of species and it is impossible. Within Crustacea the problem is especially acute for the Amphipoda.

10.2 CRUSTACEA IN PORT PHILLIP BAY

The crustaceans of the PPBES-1 were identified using various sources and have been updated since as new names and revisions were published. Each major taxon is treated below separately.

Ostracoda

Of the two major groups of ostracods, the superorder Podocopida of Port Phillip Bay have been reported on by McKenzie (1967). The potential for introductions was not considered. They have not been reliably collected in any macrobenthic sampling program over the last three decades. Most species are less than 1 mm long and are not considered further in this report. Species of the other superorder, Myodocopida, are larger, diverse and regularly captured.

In PPBES-1 no species of ostracod was identified to species level. All of the 20 recognised were determined to genus or family level using the publications of McKenzie (1967) for two species of podocopidan, and Poulsen (1962, 1965) for myodocopidans. The only species of myodocopidan ostracod known from Port Phillip Bay at that time was *Vargula thielei* (Chapman 1906) and only 13 from shelf and slope waters of southeastern Australia (De Deckker and Jones 1978).

Expertise in the systematics of myodocopidan ostracods remains the domain of only a handful of systematists world wide. Knowledge of the southern Australian fauna has improved due to the work of Kornicker (1975, 1981, 1985, 1994 and 1995) and Kornicker and Poore (1996) but these studies are of Antarctic or deep-water faunas. No species from shallow waters has been recently described. However, Drs E Wallis and G Poore have been able to refine the identification of the Port Phillip Bay ostracod fauna. Four additional myodocopidan species have been recorded bringing the total to 16. The named species presently known from Port Phillip Bay were described originally from nearby Bass Strait.

Cirripedia

The two species of barnacles taken in the PPBES-1 survey were identified but other species are present in estuarine and hard substrates in Port Phillip Bay. Barnacles are rarely taken in soft substrate benthic surveys. Their systematics is relatively stable. Comments on the cirripedia are made in Chapter 13.

Leptostraca

The single species of leptostracan taken in the PPBES-1 survey was identified as *Nebalia longicornis* using the key in Hale (1929). Dahl (1985) revised the principles of leptostracan taxonomy and later examined the collections in Museum of Victoria. His work on them was never completed before the collections were returned. Nevertheless, he redescribed *N. longicornis* from lectotype material from New Zealand and concluded (in litt.) that the species did not occur in Australia and that all the Australian material at his disposal belonged to many endemic species. This opinion was confirmed by Walker-Smith (1993) in a thesis examining the taxonomy of some southern species.

Stomatopoda

The species of stomatopod taken in the PPBES-1 survey was identified using Hale (1927). Their identity has remained unchanged although the generic and family placement of one has been updated as a result of revisions by Manning (1966, 1980).

Mysidacea

The eight species of mysids taken in the PPBES-1 survey were identified largely using the keys in Hale (1929) and Dakin and Colefax (1940). No new species of mysidaceans have been recorded in Port Phillip Bay in recent surveys. Names of existing species have been updated using the works of Fenton (1985a, 1991). Her work (1985a) summarised the history of mysidacean taxonomy in Australia and listed all the species known: 94 species in 38 genera of Mysidae, Lophogastridae and Petalophthalmidae. The Lophogastridae are now considered to belong to a separate order of oceanic animals. Five of the 13 species listed as new in that thesis have now been described (Fenton 1985b, 1985c, 1991). A world-list of species and a key to genera of mysidaceans were given by Mauchline (1980).

Cumacea

The 12 species of cumaceans taken in the PPBES-1 survey were identified largely using the keys in Hale (1944, 1945 and 1946) and earlier papers in which the bulk of these species were described. Two species of *Gynodiastylis* could not be identified with Hale's species but this genus contains numerous undescribed species in Bass Strait. No additional species of cumaceans have been identified in recent surveys. These and the estuarine *Dimorphostylis colefaxi* Hale 1945 are the only species known from Port Phillip Bay.

Tanaidacea

The species of tanaidaceans taken in the PPBES-1 survey were identified using only the illustrations in Hale (1929) knowing that this covered only a few of the species found. There has been only slight additional taxonomic research on the Tanaidacea over recent years, none on the fauna of southern Australia. Identification of families was made easier by Sieg and Winn (1978) and a catalogue of species (Sieg 1983) provided an essential reference. Nevertheless, only a single species could be identified and the endemicity of the fauna was confirmed during discussions with the late Jürgen Sieg. The poor condition of much of the material in the PPBES collections made identification of genus difficult for some of the rare taxa.

Isopoda

The numerous species of isopods taken in the PPBES-1 survey were identified largely using the keys in Hale (1929) and descriptions in Naylor (1966). In the report by Poore *et al.* (1975) many species (21 of 37) were identified to family or genus level at best because they remained undescribed. Several similar species were confused with each other, these problems were solved for some families in later revisions. There has been considerable additional taxonomic research on the Isopoda of southern Australia over recent years, largely by G Poore, N L Bruce and L J Cookson. Many of the species from Port Phillip Bay are now described. Forty-six species are now recorded from benthic surveys in Port Phillip Bay and others have been collected in other habitats (Naylor 1966; Cookson 1991). The fauna of nearby Bass Strait is much larger.

Amphipoda

The species of amphipods taken in the PPBES-1 survey were identified largely using the keys to family and genus in Barnard (1969, 1973). Only a quarter of the 123 species recognised then could be identified to named species, almost all of these because they were covered in the first of Barnard's series on Australian marine amphipods (1972). There has been considerable additional taxonomic research on the Amphipoda of southern Australia over recent years, most by Barnard (1974), Barnard and Drummond (1978, 1979, 1982 and later smaller papers) and by Lowry and Poore (1985). All these authors incorporated material from PPBES-1 in their publications. Some families are therefore taxonomically well known while others are virtually unstudied in Australia. The species names of some that were listed by Poore *et al.* (1975) have since been corrected and the family allocation of others has been changed in Table A4 (Appendix A). The classification now follows that of Barnard and Barnard (1983) and Barnard and Karaman (1991).

Barnard brought his encyclopedic knowledge of amphipod taxonomy to Australia and described hundreds of new species here. He recognised the continent as a centre of amphipod radiation (Barnard and Karaman 1983). Apart from some species that he identified with the New Zealand fauna he found few (in the families studied) which he had seen in other parts of the world. He implied that the fauna was highly diverse and endemic.

Caridea

The species of caridean shrimps taken in the PPBES-1 survey were identified largely using the keys in Hale (1927). The names used in Poore *et al.* (1975) have since been corrected. The names of alpheid shrimps were updated using Banner and Banner (1982). Only one additional species of caridean has been added in recent sampling and it is a species common in Bass Strait. All the species known from these samples were described from southeastern Australia.

Thalassinidea

The species of thalassinideans taken in the PPBES-1 survey were quickly recognised as new endemic species and described (Poore 1975; Poore and Griffin 1979). A recent phylogenetic revision has placed members of the Callianassidae in new genera (Poore 1994) but otherwise the systematics of the order has not changed.

Anomura

The species of anomurans taken in the PPBES-1 survey were identified largely using the keys in Hale (1927). There has been considerable additional taxonomic research on the Anomura of southern Australia over recent years, largely by GJ Morgan and associates but none in Port Phillip Bay. The additional species collected since the first survey have been identified using his keys and diagnoses. All species were previously known from Bass Strait, described in 1905 or before, and none are suspected of being introduced.

Brachyura

The 12 species of brachyuran crabs taken in the PPBES-1 survey were identified largely using the keys in Hale (1927) and Griffin and Yaldwyn (1971). These last mentioned authors recorded many other species from the bay from earlier collections. Four additional species have been taken from recent benthic surveys. One, *Pyromaia tuberculata*, is definitely introduced from elsewhere and three are species previously known from Bass Strait or Western Port.

10.3 POTENTIAL FOR TRANSLOCATION

Each major crustacean taxon is discussed in turn with reference to the fauna of Port Phillip Bay.

Ostracoda Myodocopida

Myodocopidan ostracods are benthic scavengers or micropredators (Keable 1995). They are essentially benthic but males of some species may enter the plankton for short periods at night for mating. Ostracods have a fixed small number of instars and the females brood the eggs until they hatch. Life span may extend beyond one year (Fenwick 1984). Ostracods seem not to be well adapted for translocation by ship but Carlton (1985) summarised records of unnamed species in ballast water. There seems no record of identified species outside their natural range but this could be due to taxonomic difficulty with this group. There is no suggestion in the recent studies that any Australian species is introduced, rather that the fauna is diverse and endemic.

Cirripedia

Acorn barnacles (balanomorphs) are good candidates for artificial translocation. Of the two species of barnacles collected in these surveys, one has been introduced from Australia to Europe and the UK. None of the species recorded as introduced to Australia occurs in Port Phillip Bay (Pollard and Hutchings 1990)[1].

Leptostraca

Leptostracans are common inhabitants of muddy environments but fewer than 30 species have been described world-wide. Dahl's and Walker-Smith's research has shown that there are more than a dozen undescribed species in Victoria. One occurs in Port Phillip Bay and is widespread in southern Australia. Leptostracans, which brood their eggs and young, have not been recorded as being translocated.

Stomatopoda

Stomatopods are more common in tropical environments than in temperate latitudes like Port Phillip Bay. All have a characteristic alima larva which spends some time in the plankton so is likely to be entrained into ballast water and has been recorded there in Oregon (Carlton and Geller 1993). There are no records of stomatopods being introduced[2].

Mysidacea

Mysids are small epibenthic, free-swimming, swarming peracarid crustaceans whose biology is well studied (Mauchline 1980). Their habits make them liable to be taken up in ballast water and transported. Because they are brooders mysids can possibly reproduce in ballast

[1] Editor's note: Chapter 13 discusses this in depth.
[2] Editor's note: The stomatopod *Gonodactylis alohaensis* has been introduced to Hawaii (see Kinzie 1968 [as *G. falcatus*]; Coles *et al.* 1997).

water. So far only one introduced species has been recorded from Australia but not from Port Phillip Bay. *Neomysis japonica* Nakazawa 1910, a Japanese mysid has been found in the ballast water of a bulk cargo vessel in Tasmania (Williams *et al.* 1988) and introduced to the Hunter River, NSW some time about 1977 (Pollard and Hutchings 1990). Grab sampling is not an ideal method to catch mysids and a different sampling technique could discover more species in the Bay than are presently known. The fauna of Bass Strait is known to be more diverse.

Cumacea

Cumaceans are small benthic peracarid crustaceans and therefore brood their young. There is no free-swimming larval stage but the adults are attracted to lights at night and swim in the open water in shallow habitats (Hale 1953). Adults might therefore be drawn into ballast water but there are no records of cumaceans being introduced into foreign waters[3]. This may reflect the poor state of taxonomic knowledge of this group world-wide.

The order is taxonomically much better described in southern Australia than most other peracarid orders due to the excellent studies of Hale in the 1930's and 1940's. Nevertheless, there remain many undescribed species in Bass Strait.

Tanaidacea

Tanaidaceans are peracarid crustaceans and therefore brood their young rather than have pelagic larval stages. Translocation is therefore unlikely. One species, *Tanais dulongii* (Audouin), is alleged to have been introduced to Australia (Jones 1991) and be established in Spencer Gulf, SA. A similar species or complex of species is widespread in coastal habitats in Victoria, not in Port Phillip Bay, and may not be this European species (the late J Sieg pers. comm.). Introduction of tanaidaceans to Australia remains to be confirmed.

Isopoda

Isopods brood their eggs and young. This limits their dispersive powers but some species associate with sessile invertebrates and may be transported as fouling organisms. Six species were recorded as introduced to Australia by Pollard and Hutchings (1990). Two of these are now known from Port Phillip Bay: *Cirolana harfordi* and *Paracerceis sculpta*. Four families should be commented on:

Cirolanidae

Cirolanid isopods, commonly called sea-lice, are scavengers attracted to baits but seem unlikely candidates for transportation. Nevertheless, at least two species are suspected to be introduced to Australia.

Eurylana arcuata (Hale 1925) is thought to have been introduced to ports in NSW and SA before 1925 from New Zealand where it is common (Bowman *et al.* 1981). It is also common in Chile and has been found only in San Francisco Bay in the USA. Bruce (1986) notes some differences in the Australian populations from those in New Zealand. The species may be naturally distributed through the southern coasts and introduced to San Francisco Bay.

Another species, *Cirolana harfordi*, first recorded in Australia in 1972 (Bruce 1986) and has now been recorded from pile scrapings in Corio Bay (see below).

Idoteidae

It was suggested by Chapman and Carlton (1994) that the Japanese species *Synidotea laevidorsalis* (Miers 1881) had been introduced to coastal southeastern Australia and misidentified as two species described as endemic by Poore and Lew Ton (1993). Poore (1996) argued that this was not the case and the two species, *S. grisea* and *S. keablei*, are valid[4]. Neither species occurs in Port Phillip Bay. A related estuarine species, *S. laticauda* Benedict 1897, has however been introduced to France from San Francisco Bay (Poore 1996).

Limnoriidae

The family Limnoriidae includes the wood-boring isopods commonly called gribbles. These have been pests of wooden ships and are still a problem in wooden pilings. The economic costs associated with the prevention of boring by limnoriids is substantial and considerable research is carried out on the chemical treatment of timber structures in the sea. Other limnoriids burrow in macroalgae and seagrasses (Cookson 1991; Cookson and Poore 1994). The genus *Limnoria*, the largest of three and the only one to contain wood-boring species contains 50 species. The type species, *L. lignorum* (Rathke), was described from Europe in 1799 and it wasn't until 85 years later that a second species was recognised from the Northern Hemisphere. A third European species, *L. quadripunctata*, was described by Holthuis (1949). The genus however is concentrated in the Indo-west Pacific region (Cookson 1991). More than 20 species, many algal-borers of no economic significance, are known from Australia.

The ability of the wood-boring species of *Limnoria* to form and survive in extensive galleries in timber predisposes them to transport by wooden ships and circumstantial evidence exists for this.

Cookson (1991) listed over 30 papers citing the occurrence of *L. quadripunctata* which has now been recorded from widespread scattered localities on cool temperate coasts of both hemispheres. These include

[3] Editor's note: *Nippoleucon hinumensis* has been introduced from Japan to the North East Pacific (Washington, Oregon and California) (Posey 1986 as *H. comes*; Carlton unpub. ms).

[4] Editor's note: This is disputed by Chapman and Carlton (1997).

France, Italy, England, California, and New Zealand. It appears in all southern Australian states from Marks Point, NSW, to Bunbury, WA. The species has been recorded from wooden structures in most harbours and marinas in Port Phillip Bay. Many of these records have been obtained by placing timber baits in the water at depths shallower than 5 m. Being recognised as a separate species for such a short period inhibits knowledge of the natural distribution of the species. But human intervention seems likely to have played a part in its present distribution. The facts that:

- the species inhabits three widely separate regions not typically linked biogeographically (Europe, California and Australia/New Zealand);
- it was first recorded so late from Europe and may have escaped the eye of many competent taxonomists;
- many records of limnoriids in the first half of this century, including those from Australia, were ascribed to *L. lignorum*; and
- its distribution in Australia is typical of many southern endemics,

suggest that *L. quadripunctata* has been transported from Australia to Europe and California. Its presence in New Zealand and at The Snares could be artificial but the latter population differs morphologically from the Australian ones. Further, Cookson's (1989) provisional phylogenetic analysis of the genus places *L. quadripunctata* with a group of cool-temperate southern seagrass and algal borers and suggests a southern rather than northern origin.

Similar reasoning may apply to the distribution of a second Australian species reported from Port Phillip Bay. *Limnoria tripunctata* Menzies 1951 was described from southern California and has subsequently been recorded from numerous warm-temperate and tropical locations in the USA, central America, Argentina, Ghana, England, Mediterranean, India, Australia, New Zealand, Admiralty Is. and Hawaii. Cookson (1991) listed 45 papers citing the occurrence of this species and a further 100 dealing with biology and the role of the species as a pest in timber. Cookson (1989) placed this species in a group of tropical warm-temperate species of wood borers. Its original range, like that of many marine species from these environments, may be wider than that of *L. quadripunctata*. The question of whether or not Australia was within this range or not remains to be answered.

Sphaeromatidae

Four of about 200 species described from Australia are said to be introduced to Australia: *Paradella dianae* (Menzies) (Harrison and Holdich 1982b), *Sphaeroma serratum* (Fabricius) (Holdich and Harrison 1982a), *S. walkeri* Stebbing (Harrison and Holdich 1984) and *Paracerceis sculpta* (Holmes) (Pollard and Hutchings 1990). The two species of *Sphaeroma* are wood borers (or at least are associated with holes in wood) so are anticipated migrants that must compete in southern Australia with the endemic *S. quoianum* Milne Edwards. Only *P. sculpta* has now been reported from Port Phillip Bay (see below).

Amphipoda

All amphipods are brooders, the females carrying the eggs and juveniles in chambers formed from branches of the pereopods (oostegites). Importantly, there is no pelagic larval stage. There are some important differences in the ecology of the families that may influence the likelihood of artificial introduction. Taxonomic knowledge and the likelihood of introduction is covered for each of the 28 families in turn:

Caprellidae

Caprellids attach to algae, hydroids, bryozoans and other fouling epibiota and are therefore probable candidates for translocation on the outside of the hulls of ships. They are rare swimmers but may be taken into ballast water as tychoplankton. Although many species are apparently widespread there is no suggestion that these distributions are artificial rather than natural. The caprellid fauna of Port Phillip Bay comprises three species of *Caprella* and six local species. Most species of *Caprella* have a global widespread distribution but are morphologically variable (McCain 1968). Takeuchi identified caprellids from scallop aquaculture farms in Tasmania as *Caprella acanthogaster* Mayer 1890 (G Edgar pers. comm.). This species is endemic to northern Pacific but has not been recorded in Port Phillip Bay.

Caprella equilibra, first described from eastern USA, occurs on all continents and many islands from the intertidal down to perhaps 3,000 m depth. It was recorded in Port Jackson, NSW, Australia as *C. obesa* by Haswell (1879) and in Victoria by Haswell (1885). The latter is likely to have been from Port Phillip Bay. The complex synonymy, morphological differences between populations, and great depth range suggest that the species' distribution may be ancient and natural but this has never been tested.

Caprella penantis is similarly widespread and so variable that numerous named varieties have been proposed for it (McCain 1968). The former has been recorded from a coconut washed ashore on the Kermadec Islands, north of New Zealand, an observation supporting natural dispersal. Mayer (1903) first recorded the species from Australia as *C. acutifrons*, on the basis of a specimen from Port Jackson (Stebbing 1910). A subsequent record is from South Australia (Hale 1929). The single specimen from Port Phillip Bay reported by Poore *et al.* (1975) cannot now be found or therefore confirmed. The only Museum of Victoria specimens were collected in Western Port in the 1960's.

Caprella scaura has seven varieties and the Australian form resembles the original description from Mauritius and the subspecies *C. scaura* ssp. *typica* Mayer 1890 from Rio de Janeiro, Brazil, rather than the other two subspecies from Japan (I Takeuchi pers. comm.). It was first recorded in Australia at Port Jackson by Haswell (1885) as *C. attenuata* and in South Australia by Hale (1927). The earliest confirmed Port Phillip Bay record is in 1971 (PPBES-1 collections erroneously identified by Poore *et al.* 1975 as *C. septentrionalis*) but there is every reason to believe that it existed there much earlier. Biogeographic considerations suggest a natural distribution rather than an introduction. A new approach is needed to test the likelihood of artificial introductions in caprellids.

Phtisicidae

Phtisicid caprellideans have the same biology as members of the more diverse Caprellidae but the only species recorded from Port Phillip Bay is endemic.

Ampeliscidae

Lowry and Poore (1985) described or redescribed all the species known from southeastern Australia. Bellan-Santini and Dauvin (1993) considered the Australian species of *Byblis* a clade distinct from those of the rest of the world. None is introduced. Ampeliscids are tube builders in soft marine sediments.

Amphilochidae

The single unidentified species was rare in PPBES-1 and has not been subsequently identified. Other species occur as part of algal infauna in Port Phillip Bay one of which has been identified as *Stenothoes valida* Dana, this family by Poore and Lowry (1997) and Evans (1997) has discovered a diverse endemic fauna as yet only partly described. Ampithoids are tube builders that attach themselves to macroalgae and other fouling habitats, in clean estuarine or marine habitats. Among the 24 species recognised by them two were recorded from outside Australia.

Anamixidae

Only a single specimen (now lost) of *Anamixis* has ever been recorded.

Aoridae

Six of the 14 world species of *Aora* have been recorded from Australia (Myers and Moore 1983). One, *A. typica* Krøyer 1845 has a Gondwanan distribution, another, *A. maculata* (Thompson 1879) also occurs in New Zealand, and the remainder (including the one from Port Phillip Bay) are endemic. The four remaining genera of the subfamily Aorinae include 26 species in Australia, five of which have extrinsic distributions in the Indian Ocean or west Pacific Ocean (Myers 1988). None is considered introduced. Aorids generally live in soft sediments.

Colomastigidae

Species of the cosmopolitan genus *Colomastix* are associates of sponges and tunicates and often occur in low numbers in Australian collections of shallow-water benthos. Barnard and Karaman (1991: 133–135) listed 22 described species, including one from Australia but the genus has never been taxonomically studied here.

Corophiidae

Of the ten species now placed in this family, one is identified as a named native species, three as introduced species, and the remainder as undescribed species of widespread genera. *Xenocheira fasciata* was described last century from Sydney. Two of the three introduced species of *Corophium* are uncommon in PPBES-1 to -3 samples but extremely common on intertidal mudflats, particularly off drains from the Werribee Treatment Plant.

The representatives of other corophiid genera are almost certainly undescribed but only two have been thoroughly studied. The small genera *Cerapus* and *Rhinoecetes* are recently studied but others are not well understood in Australia. Two genera, *Photis* and *Gammaropsis*, are large with more than 50 and 100 species respectively but the relationships of the Port Phillip Bay material have never been examined. Many corophiids are tube builders, secreting silk that binds sediment into homes near the surface of sediment. Some favour estuarine environments. In combination these characteristics predispose corophiids to translocation but so far only *Corophium* is suspected to have introduced species.

Cyproideidae

The only species, newly recorded from Port Phillip Bay in 1994, is common in Western Port (from where it was first described) and Bass Strait. Cyproideids are algal dwellers.

Dexaminidae

The Port Phillip Bay species belong to a genus, *Paradexamine*, of more than 37 species, which is predominantly Australian so introduction is improbable (Barnard and Karaman 1991: 270–71). Dexaminids are algal and sediment dwellers.

Eusiridae

The species of *Harpinioides* is certainly a new endemic species common in Bass Strait. *Tethygeneia* has several species in southern Australia and this one seems close to *T. elanora* Barnard 1972 but is possibly new. Eusirids are common in shallow water algal communities but are also seen in sediments.

Hyalidae

Allorchestes compressa Dana 1853 is one of the earliest species of amphipods described from Australia and is confined to southern bays. It has been dubiously recorded from subantarctic islands of New Zealand (Barnard 1974: 43–49). Hyalids live in shallow marine habitats, often associated with drift weed.

Iphimediidae

Only three specimens of this mainly offshore family were taken in PPBES-1 and are not identifiable. Chances of their being introduced are negligible.

Isaeidae

The only recorded species belongs to a monotypic endemic genus moderately common in southeastern Australia.

Ischyroceridae

Jassa is a major fouling genus with 19 species often carried by ships to exotic ports (Barnard and Karaman 1991: 203). Most ischyrocerids build tubes in sediment so the likelihood of translocation is higher than in many other amphipod families.

Four species are known from southern Australian harbours, two probably introduced (Conlan 1990). *Jassa marmorata* Holmes 1903 and *J. slatteryi* Conlan 1990 are widespread in temperate and tropical harbours and both have been previously recorded from Port Jackson, NSW and Hobart, Tas. The first has now been recorded from Port Phillip Bay.

Other genera in this family may also contain transportable fouling species. Barnard and Karaman (1991: 188–189) listed 12 species of *Ericthonius* world-wide but the species from Port Phillip Bay is none of these.

Ischyrocerus is represented by a few incomplete specimens that cannot be identified to species. There are other species of the genus in Western Port and Bass Strait so an endemic fauna is probable. Barnard and Karaman (1991: 200–201) listed 39 species world-wide.

Leucothoidae

The three species are all endemic and described (Barnard 1974). Leucothoids are often commensal in the cavities of solitary tunicates and sponges and would be introduced only if the host were transported as part of ship fouling.

Liljeborgiidae

One of the two species was described from Australia last century and the other is new. Both are moderately common. Liljeborgiids live in soft sediments.

Lysianassidae

Some lysianassids could be identified as species that had previously been described from the region. Most were represented by so few specimens that generic identification was not possible; these are all now with Dr J K Lowry (Australian Museum) whose detailed work on this family has not discovered any introduced taxa. The family is diverse in soft sediments and in fouling communities but is rare in estuarine environments. Lysianassids are scavengers attracted to dead fishes and the like. Males which swim may be drawn in with ballast water.

Melitidae

The common family Melitidae (called Gammaridae in earlier publications) comprises several well-known species described from southeastern Australia (Barnard 1972). Melitids are common in many marine environments, some in harbours but there seems no particular reason why they should be more susceptible to translocation than other amphipods.

Melphidippidae

The four species (assigned to Gammaridae in earlier publications) were described from the local fauna or are new. One, *Maerella* sp. MoV1796, is very close to *M. tenuimana* (Bate 1862) from the Mediterranean and North Atlantic. It differs in setation of the epimera and gnathopods, and proportions of the limbs. It is widespread in Victorian marine bays and Bass Strait. Melphidippids live on the surface of sand and mud.

Oedicerotidae

Of the four species only one could reliably be identified to genus. The family is taxonomically diverse world-wide but the Victorian species, all moderately common since PPBES-1, appear endemic and undescribed. Oedicerotids live near the surface of soft sediments.

Paracalliopidae

Only a single specimen of an estuarine species, widely reported from southeastern Australia, was taken. Its genus is confined to the southwest Pacific.

Phoxocephalidae

Barnard and Drummond (1978) described 88 Australian species in 26 genera, comprising then about 40% of the known taxa in the family. They recognised the family as the largest so far discovered on the continent. They interpreted the southern Australian fauna as "primitive" and a centre of dispersal. Although vicariant processes are more likely to provide a better explanation for the present distribution of the family, their evidence and interpretation supports the existence of an endemic fauna in southern Australia. They found no introduced species. Many phoxocephalids are burrowers in the surface of sediments, some preferring fully marine environments and others more estuarine. The only genus with truly estuarine species in Australia, *Limnoporeia*, is endemic.

Platyischnopidae

Barnard and Drummond (1979) described five species from Australia. Species of *Platyischopus* are known from other continents but introduction is unlikely as the species are confined to coarse marine sediments.

Stenothoidae

A single male specimen of *Stenothoe* sp. MoV1671 was collected in 1995 but could not be assigned to any of the known described Australian species. It is not *S. valida* Dana 1853, a species described from Rio de Janiero and reported from several parts of the world including Port Jackson, NSW. Barnard (1974: 129) believed that the probability of this species occurring in Australia was high. There are 51 nominal species of this genus worldwide, some commensal (Barnard and Karaman 1991: 698–699).

Synopiidae

A species of *Metatiron*, rare in Port Phillip Bay, seems not to be either of the two from the Indian Ocean (Barnard and Karaman 1991: 714). *Synopia* is also rare and its taxonomy poorly known (Barnard and Karaman 1991: 7–16); the Port Phillip Bay species has not been checked against the nine known species. An undescribed species of *Tiron* is common in Port Phillip Bay and Bass Strait, and is certainly not any of the ten described world species. Synopiids are sediment dwellers.

Urohaustoriidae

Barnard and Drummond (1979) described 18 species from Australia and recognised the family as endemic. Introduction is therefore unlikely. Members of the family live in fully marine coarse sands.

Urothoidae

One new species was described from Port Phillip Bay material. Barnard and Drummond (1979) believed "...that the [eight] Australian species of *Urothoides* form a species cluster generically distinct from that represented by the type-species...". Introduction is therefore unlikely. Urothoids burrow in coarse sands.

Caridea

Caridean shrimps are decapod crustaceans with pelagic larval stages. This stage may be taken in with ballast water and transported. One species of Palaemonidae known from many coasts of the North Pacific, *Palaemon macrodactylus*, has been reported from NSW (Pollard and Hutchings 1990) but is so far not known from Port Phillip Bay.

Thalassinidea

Thalassinideans, ghost shrimps and mud shrimps, are burrowers in soft sediments. Most make permanent galleries down to a few centimetres depth. Callianassids are especially common in Port Phillip Bay and important nutrient recyclers. All have planktonic larval stages which hatch from the eggs incubated by the female. There seem to be no records of thalassinideans being introduced.

Anomura

Anomurans, hermit crabs and false crabs, are decapod crustaceans with pelagic larval stages. Like true crabs, this stage may be taken in with ballast water and transported. However, hermit crabs are unlikely to settle as adults unless they can find suitable shell homes in the holds of ships. This is not a problem for false crabs. *Petrolisthes elongatus* (Porcellanidae) is a confirmed late 19th century introduction to Tasmania from New Zealand (King 1997).

Brachyura

Brachyuran crabs are decapod crustaceans with pelagic larval stages. This stage may be taken in with ballast water and transported. Adults of species that cling to fouling algae may also be transported.

The introduced species *Pyromaia tuberculata* is the only one discovered in the course of recent surveys but others are reported from southeastern Australia.

Another introduced species of crab, the portunid *Carcinus maenas* (Linnaeus) occurs commonly in shallow rocky and seagrass habitats in Port Phillip Bay but is not taken in grab surveys in deeper water.

A cancrid crab common in New Zealand (McLay 1988), *Cancer novaezealandiae* (Jacquinot and Lucas 1853), occurs in shallow subtidal water on the coast of Victoria and in eastern Tasmania (Pollard and Hutchings 1990). The species was first identified in Australia on the basis of morphological similarity to the New Zealand form and confirmed on the basis of mitochondrial RNA by Michelle Harrison, Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada (pers. comm.). The species is common in eastern Tasmania where it has been for probably most of this century. It has been reliably reported elsewhere only from the Gippsland Lakes (1991) and Flinders, Vic., since 1995. An early report of this species from Beaumaris, Port Phillip Bay, by McNeill and Ward (1930) has not been repeated and material lodged in Museum of Victoria no longer exists. Its earliest appearance in Australia is uncertain.

The New Zealand hymenosomatid crab, *Halicarcinus innominatus* Richardson 1949 has been recorded from Tasmania since 1970 (Pollard and Hutchings 1990) and may be confused with other species of the genus in Port Phillip Bay. So far, it has not been recorded from the bay.

10.4 TAXONOMY AND SYSTEMATICS

Isopoda

Family Cirolanidae

Cirolana harfordi (Lockington 1877)

Figure 10.1

Synonymy and taxonomy

Aega harfordi Lockington 1877b: 46;

Cirolana californica Hansen 1890: 338, pl. 3 Figure 1;

Cirolana harfordi Richardson 1905: 109, Figures 91, 92 — Kussakin 1979: 194–196, Figures 73–75. — Bruce 1986: 146–147, Figure 98;

Cirolana harfordi japonica Theilemann 1910: 11, Figures

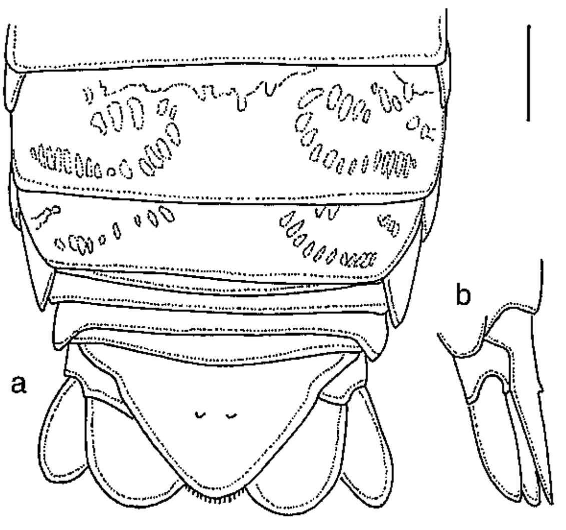

Figure 10.1. *Cirolana harfordi*: a) dorsal view; and b) lateral view of posterior region. Scale bar = 1 mm.

5–7. — Bruce and Jones 1981: 77–78, Figure 8a–f; *Cirolana theilemanni* Kussakin 1979: 196; *Cirolana japonica* Nunomura 1982: 23–30, Figures 1–4.

Bruce (1986) provides a more complete synonymy. Japanese representatives of this species have variously been regarded as subspecies (Theilemann 1910; Bruce and Jones 1981) or as separate species (Kussakin 1979; Nunomura 1982). There are minor differences between specimens from the two localities, those from the Californian type locality of the nominal subspecies being larger than those from Japan. The species bears no obvious phylogenetic relationship to any Australian species of *Cirolana*, and may be a sister species of *C. cranchii* or a similar species. The *C. cranchii* group has not been found outside the Atlantic. *C. harfordi* may have evolved as the result of a trans-Arctic dispersal/displacement event. A similar species has yet to be seen in the East Pacific or Indo-Pacific (N L Bruce pers. comm.).

Material

Victoria: Port Phillip Bay: Port Melbourne, pile scraping, 26 Mar 1996, CSIRO—CRIMP collection (6 specimens); Point Henry Pier, pile scraping, 0.5 m, D Crookes *et al.* 13 Oct 1997 (Victorian Marine and Freshwater Resources Institute, Geelong Port Exotic Species Survey), NMV J41570 (2 specimens); pile scraping, 3.0 m, MAFRI collection (6 specimens).

Origin and present Australian distribution

Cirolana harfordi was first described from California and is distributed in western North America from British Columbia to Baja California (Richardson 1905). The species has subsequently been recorded from Japan, eastern Russia and Malaysia. It was first found in Australia 1972 in scrapings from a boat on a slipway at Waverton, NSW. Subsequent records in 1980 are from Fremantle Bridge, Swan River, WA, and Lorne, Vic. It is now reported from Point Henry, Port Phillip Bay.

Distribution in Port Phillip Bay

Point Henry, Port Melbourne.

Diagnosis

Head with 2 interocular furrows, one running along anterior margin, second from dorsal surface of each eye. Frontal lamina pentagonal, broader anteriorly. Pleotelson with 2 submedian processes; posterior margin with about 10 robust setae. All pereopods with very few setae. Pleopod 2 appendix masculina extending beyond inner ramus by 0.2 of its length, apex with small process, minute scales on inner margin. Uropodal rami both rounded, extending beyond apex of pleoteson; margins densely setose, setae conscealing most robust setae; 1 robust seta on lateral margin of exopod. Dark even slate grey. Adult males to 18.0 mm.

Distinguishing features in Australia

The persistent slate grey colour with a pattern of regular rows of lighter well-defined dots immediately distinguishes this species. The pair of tubercles on the pleotelson on larger individuals is also characteristic. Most cirolanids in Australia are white or only mottled with dark pigment. It is the only ornamented species of *Cirolana* in southern Australia.

Ecology

The species occurs naturally intertidally and is concentrated at the lower intertidal levels (Johnson 1976). In USA and Japan very high densities have been recorded under stones and sandy beaches or protected in the dead valves of barnacles and serpulid polychaetes. Bruce and Jones (1981) recorded a density of 20 individuals cm^{-2}. This species is a scavenger and active predators on polychaetes and small crustaceans (Johnson 1976). In California females produce eggs throughout the year with one or two broods per year of 18–68 juveniles during their 2-year life span (Johnson 1976). Bruce and Jones (1981) suspected a single breeding season in southern Japan.

In Australia *Cirolana harfordi* is likely to compete with several other native species of cirolanids but the low densities recorded so far suggest that this has not happened yet.

Family Sphaeromatidae

Paracerceis sculpta (Holmes 1904)[5]

Figure 10.2

Synonymy and taxonomy

Dynamene sculpta Holmes 1904: 300–302, pl. 34 Figures 1–7;

[5] Editor's note: This species was not identified as a target introduction by MoV and was not incorporated into the target list in Chapters 2 and 15.

Cilicaea sculpta Richardson 1905: 318, 319. — Stebbing 1905: 35;
Parcerceis sculpta Richardson 1905: IX. — Menzies 1962: 340, 341, Figure 2. — Miller 1968: 9, 14. — Pires 1981: 219, 220. — Harrison and Holdich 1982: 440–441, Figure 10;
Sergiella angra Pires 1980: 212–*218*. — Pires 1981: 219, 220.

Females of this species in Brazil were described by Pires (1980) as a new genus and species. She realised her mistake a year later (1981) when the characteristic males were discovered. Harrison and Holdich (1982) listed a longer synonymy and described and figured the species in detail.

Material

Victoria: Port Phillip Bay. Williamstown, Anne Street Pier, pile scraping, CSIRO—CRIMP collection, 1995, NMV J41569 (2 males, 1 female).

Origin and present Australian distribution

Type material of *Paracerceis sculpta* was described from pieces of sponge dredged in shallow water from southern California. Its natural range is probably from central California (Miller 1968) to Mexico (Menzies 1962). It was first discovered in Hawaii in the very early 1940's by Miller (1968) who deduced that naval shipping was responsible for its presence there. Later records are from Townsville, Qld in 1975 (Harrison and Holdich 1982) and Rio de Janeiro, Brazil in 1978 (Pires 1980, 1981).

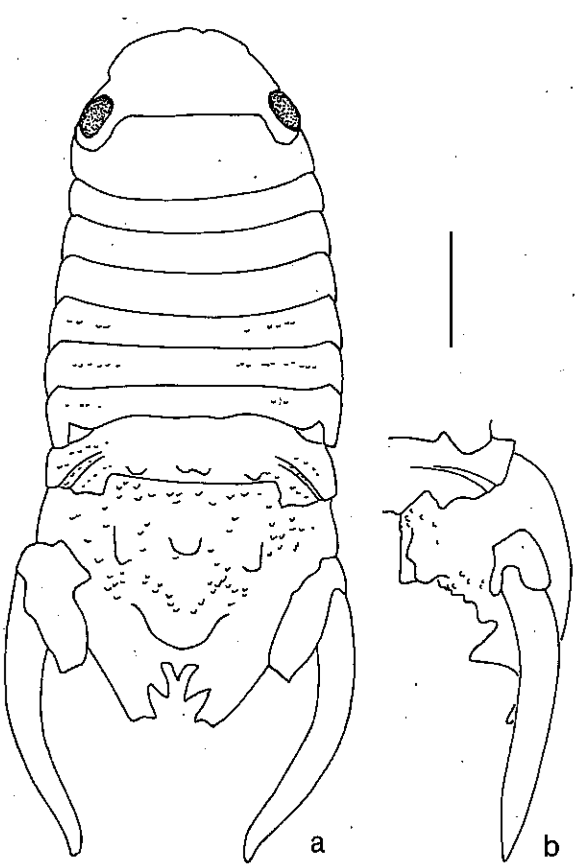

Figure 10.2. *Paracerceis sculpta*: a) dorsal view of male; and b) lateral view of uropodal endopod and exopod. Scale = 1 mm.

Distribution in Port Phillip Bay

Williamstown.

Diagnosis

Like most sphaeromatid isopods, *Paracerceis sculpta* is sexually dimorphic but in this case three male forms are known (Shuster 1987, 1992a):

Alpha-male. Pleon granulose with low bifid central tubercle and pair of simple lateral tubercles. Pleotelson with straight lateral margins; apical notch between concave distal margins with central anterior tooth and larger curved anterolateral tooth on each side (none reaching posterior margin); main dome granulose, with 3 pronounced short longitudinal ridges, the central one dorsally concave; posterior to dome bearing symmetrical arrangement of short setae surrounding prominent median conical tubercle. Pleopods 1 and 2 exopods with 2 and 10 marginal teeth. Pleopods 3–5 eubranchiate (both rami with transverse folds). Uropod with reduced endopod, with median dorsal tubercle, apex acute; exopod smooth, extended, curved, subcylindrical, with rounded apex. Red-brown. 8 mm maximum; 6.6 mm mean. Most males are of this form.

Beta-male. Similar to adult females, pleotelson with 3 low ridges. 4.8 mm maximum; 4.3 mm mean. 4% of males.

Gamma-male. Similar to immature individuals, pleotelson with 3 low ridges. 2.8 mm maximum.

Adult female. Pleotelson with 3 low smooth longitudinal ridges; apex acute, with simple ventral groove. Uropodal rami subequal. 5.3 mm maximum; 4.9 mm mean.

Distinguishing features in Australia

Like many sphaeromatids females and juveniles are almost impossible to identify without accompanying males. The alpha-male is unique in the shape of the apical notch, with a central and lateral teeth.

Ecology

The ecology and reproductive biology of *Paracerceis sculpta* in its native environment is exceptionally well studied.

In California the species is nocturnal. During its juvenile stages it lives in subtidal coralline algae. When mature adult alpha-males migrate to the midintertidal zone where they reside in the spongocoels (cavities) in the calcareous sponge *Leucetta losangelensis* (Shuster 1991b, 1992b). Alpha-males establish harems of up to 50 females but compete with smaller beta- and minute gamma-males for successful mating (Shuster 1987,1992a). All three males are equally successful in mating with females (Shuster and Wade 1991) and the genetic implications of this are understood (Shuster and Sassaman 1997). Courtship behaviour (Shuster 1990), changes in female anatomy (Shuster 1991a) and sexual selection are well documented (Shuster and Wade 1991). Females breed only once in their lifetime.

The species is so rarely recorded in Australia that nothing is known of its biology here. Although alpha-males have been found it is not certain that the species is established and breeding here. It is not known if the few specimens known were taken from sponges.

Isopoda

Family Corophiidae

Corophium spp.

Corophium is a widespread freshwater, estuarine and marine genus with about 60 described species in temperate and tropical latitudes (Barnard and Karaman 1991: 184–186). It is common in very shallow water but some species live down to 360 m depth.

Several species are said to have been introduced to harbours around the world. Five of the 12 species recorded from the UK have been noted outside this immediate area (Lincoln 1979) and presumably reached remote continents aided by shipping. Local mass invasions and range extensions are also reported. An example is *C. curvispinum*, a native of the Caspian Sea, which has invaded and become dominant in the lower and middle river Rhine since 1986 (den Hartog *et al.* 1992; van den Brink *et al.* 1993).

Undescribed native species exist in Australia but at least six species are alleged to have been introduced to Australia from Europe, UK or elsewhere in the Pacific. Three of the species in Port Phillip Bay are found in Europe but it is unclear whether Australia or Europe or both were the source of transported populations. It is probable that *C. acherusicum* and *C. insidiosum* came to Australia from Europe. The case for *C. sextonae* is less clear but the species is, nevertheless, included in this chapter. There are no early records of *Corophium* from Australia. Haswell (1882) did not list the genus. Chilton (1921) reported the first species of the genus from Australia. He identified *C. crassicorne* Bruzelius from Port Jackson, NSW, but this species does not occur there now and his record is almost certainly a misidentification of *C. acherusicum* (Hurley 1954). Hurley (1954) described three species, also known from Europe, in New Zealand and it is reasonable to assume that these were also in Australia at that time. One, *C. acutum*, was in New Zealand in 1880 and was identified in Australia in 1937.

Although there has been some research on the ecology of species of *Corophium*, particularly *C. volutator*, (e.g. Queiroga 1990; Essink *et al.* 1989; Jensen and Kristensen 1990; Pelegrí and Blackburn 1994; Pelegrí *et al.* 1994), the three local species have been poorly studied in their native habitat. Members of the genus are most commonly found in muddy environments or attached to dirty hard surfaces. All build fragile U-shaped tubes with silk which they secrete from glands and which incorporate mud and sand particles. They feed by grazing on bacteria on sediment particles or as suspension feeders (Miller 1984).

Diagnosis of genus

Corophioidea: Amphipoda usually with brown pigment, with fleshy short telson, posterior margin of coxa 4 not excavate.

Corophium: body flattened-cylindrical; head with small eyes on lateral lobes; antenna 2 markedly sexally dimorphic: male with robust article 4; gnathopod 1 slender, subchelate, setose; gnathopod 2 simple, with double row of long setae, carpus and propodus elongate and fused anteroposteriorly; pereopod 7 elongate; uropods 1 and 2 biramous, rami short; uropod 3 uniramous, flattened, ramus setose.

Species of *Corophium* are immediately recognisable by the presence of the two even rows of long setae on the second gnathopod (and separated from species of *Paracorophium* with which they co-occur by not having the scissors-like merus and carpus). Bousfield and Hoover (1997) divided *Corophium* into 13 genera based on a phyletic analysis. Their systematics needs careful appraisal and is not adopted here.

Corophium acherusicum Costa 1853

Figure 10.3

Synonymy and taxonomy

Audouinia acherusica Costa 1851: 24 (nomen nudum); *Corophium acherusicum* Costa 1853: 178. — Costa 1857: 232. — Hurley 1954: 442–445, Figures 35–39. — Fearn-Wannan 1968: 134–135. — Lincoln 1979: 532, Figures 255a–f. — Myers 1982: 186–187, Figure 124; *Corophium crassicorne* Chilton 1921: 229–233, Figure 5 (not Bruzelius);

Corophium sp. 1.: — Poore *et al.* 1975: 65.

Populations of *Corophium* from many localities have been ascribed to this species (see references in Myers 1982). A detailed comparison of material from Naples, Italy with Australian specimens confirmed the identity of the latter (Storey 1996).

Material

Victoria: Port Phillip Bay. Yarra River and Hobsons Bay, silty clay, 11 m, several samples, NMV collections. Northern section (37°55.3'S, 144°49.8'E), 9 m, sand, 7

Jun 1971 (stn PPBES 904), NMV J18365 (6 females). Western Treatment Plant, Werribee, Drain 145W 100m off shore (37°55'S, 144°40'E), 0.2 m, muddy sand, 22 May 1996, NMV J39212 (1 female). Western sandy region (38°04.70'S, 144°39.50'E), 13 m, 17 Oct 1995 (stn PPBES-5 113 1), NMV J44308 (1); (38°03.31'S, 144°41.67'E), 11 m, 17 Oct 1995 (stn PPBES-5 112 1), NMV J44309 (4). Off Werribee (37°57.7'S, 144°48.1'E), 9 m, sand, 8 Jun 1971 (stn PPBES 908), NMV J18362 (2 females; 5 juveniles); (37°57.7'S, 144°44.7'E), 5 m, sand, 3 Feb 1972 (stn PPBES 907), NMV J18364 (1 male; 3 females); (38°00.0'S, 144°42.9'E), 7 m, sand, 19 Nov 1971 (stn PPBES 912), NMV J18367 (1 female). Eastern side (38°04.7'S, 145°06.9'E), 6 m, sand, 18 Feb 1971 (stn PPBES 939), NMV J18361 (1 female; 2 juveniles). eastern side (38°00.0'S, 145°03.5'E), 8 m, sand, 23 Aug 1971 (stn PPBES 918), NMV J18363 (1 female; 1 juvenile). Off Portarlington (38°07.0'S, 144°44.7'E), 4 m, sand, 16 Nov 1971 (stn PPBES 945), NMV J18356 (5 females; 6 juvenile); (38°07.0'S, 144°41.3'E), 2 m, sand, 10 Jun 1971 (stn PPBES 944), NMV J18366 (1 female; 1 juvenile). Geelong Arm (38°09.3'S, 144°42.7'E), 3 m, sand, 11 Jun 1971 (stn PPBES 953), NMV J18357 (3 females; 1 juvenile); (38°09.3'S, 144°39.3'E), 9 m, sand, 11 Jun 1971 (stn PPBES 952), NMV J18359 (1 female; 1 male). Southern section (38°21.0'S, 144°51.5'E), 9 m, sand, Dec 1971 (stn PPBES 985), NMV J18358 (8 females; 10 juveniles); (38°02.3'S, 144°34.5'E), 6 m, silt sand, 18 Nov 1971 (stn PPBES 919), NMV J18360 (3 females). South Channel , pile bottom, NMV J18351 (1 female, 4 mm).

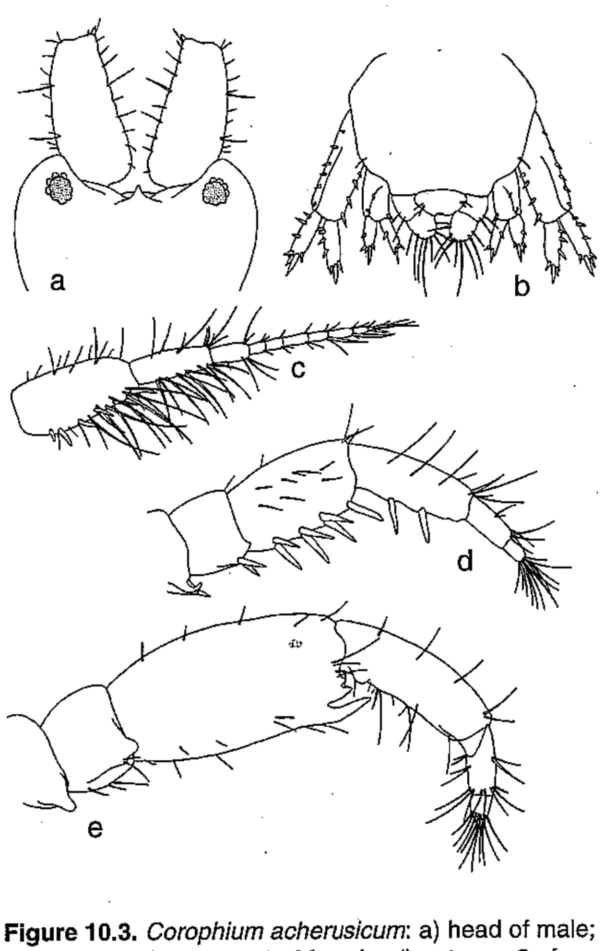

Figure 10.3. *Corophium acherusicum*: a) head of male; b) urosome; c) antenna 1 of female; d) antenna 2 of female; and e) antenna 2 of male. From Myers (1982).

Other NMV collections. Victoria: Western Port, Gippsland Lakes, Lake Victoria, Reeve Channel and Fraser Island. Tasmania: Tamar River, Lime Bay, Georges Bay, and Eggs and Bacon Bay. Western Australia: Swan River.

Brazil: Rio de Janeiro. Portugal: Ria de Aveiro, Canal de Ovar.

Origin and present Australian distribution

Corophium acherusicum was described from the Mediterranean (Bay of Naples) and has been widely reported from all coasts there and in the UK (Lincoln 1979; Myers 1982). It has also been reported from both sides of the North Atlantic, western South Atlantic, North Sea, Black Sea, south and east Africa, Sri Lanka, North Pacific, Australia, and New Zealand (Hurley 1954).

Its presence in New Zealand in 1881 is the earliest record of the species in the Southern Hemisphere (Thomson 1881; Chilton 1921; Hurley 1954). The first published report of the species from Australia is from Port Jackson, NSW (Chilton 1921 as *C. crassicorne*). Subsequent records from Bunbury and Swan River (WA), Port Kembla, Botany Bay (NSW), Mallacoota, Gippsland Lakes, Western Port and Port Phillip Bay (Vic.) (Fearn-Wannan 1968) and from eastern Tasmania are based on collections in museums in Sydney and Melbourne (Storey 1996).

Distribution in Port Phillip Bay

Within Port Phillip Bay, dense populations have been recorded only at 3 m depth in Hobsons Bay but it has also been taken down to about 9 m depth in other marginal environments. The only published report is by Fearn-Wannan (1968) who identified specimens from the Gippsland Lakes and Port Phillip Bay. Victorian Museum records are all post-1970 and sporadic. The species seems never to have become dominant over a wide range.

Diagnosis

Antenna 1 peduncular article 1 medial margin without processes, without robust setae (5 in female); posterior margin with 1 robust seta (6 in female). Antenna 2 peduncular article 3 without robust setae (2 in female); peduncular article 4, length 3.29 x height (length 2.52 x height in female), posterior margin without robust setae (with 3 pairs and 1 single robust seta in female), with 1 large and 2 small posterodistal spines (absent in female); peduncular article 5 posterior margin without robust setae

(2 in female), with a proximal and a distal blunt process (absent in female). Gnathopod 2 dactylus posterior margin with 2 spines. Pereopod 7 carpus medially protuberant. Urosomites 1–3 fused, lacking distinct dorsolateral ridge; lateral margin with notch at insertion of uropod 1. Uropod 1 with 4 robust setae on medial margin and 6–8 robust setae on lateral margin. Uropod 2 with lateral robust setae.

Distinguishing features in Australia

The diagnostic characters serve to recognise the species. It is found together with *C. insidiosum* in Port Phillip Bay but differs in the shorter rostrum and absence of a medial projection on the male antenna 1 peduncle.

Ecology

Corophium acherusicum is euryhaline, occurring subtidally on mud sediments or among algae and bryozoans (Bousfield 1973; Lincoln 1979; Myers 1982). The species seems never to have been studied quantitatively in its natural habitat. Bousfield (1973) reported it breeding in the summer in New England, USA.

Corophium insidiosum Crawford 1937

Figure 10.4

Synonymy and taxonomy

Corophium insidiosum Crawford 1937: 615. — Lincoln 1979: 530, Figures 254d–h. — Myers 1982: 191, Figure 128;

Corophium sp. 1.: — Poore and Kudenov 1978a: 146. — Poore and Kudenov 1978b: 161–165.

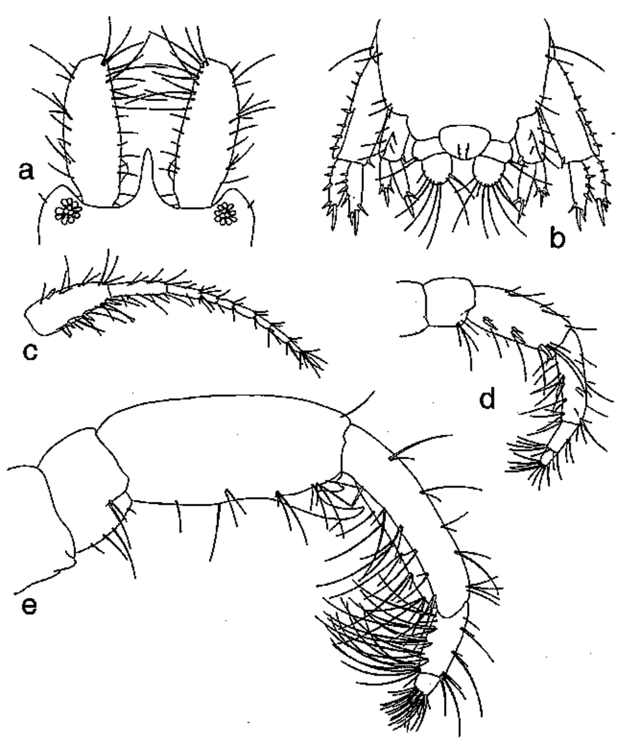

Figure 10.4. *Corophium insidiosum*: a) head of male; b) urosome; c) antenna 1 of female; d) antenna 2 of female; and e) antenna 2 of male. From Myers (1982).

Populations of *Corophium* from many localities have been ascribed to this species (see references in Myers 1982). A careful morphological comparison of material from Werribee, Port Phillip Bay, with the female holotype (Storey 1996) established the identity of the Australian species.

Material

Victoria: Port Phillip Bay. Yarra River, 2 km downstream from Fishermens Bend (37°50'S, 144°53'E), 10.3-11.3 m, silty clay, NMV J18334 (1). NMV J39209 (1 male). Western Treatment Plant, Werribee, Drain 145W, 45m off shore (37°55'S, 144°40'E), 0.1 m, muddy sand, 22 May 1996, several NMV collections (many males and females); NMV J39210 (1 female). Werribee beach (37°59'S, 144°38'E), 0 m, A. Hirst, May 1993, NMV J39211 (4 males; 4 females; 1 juvenile).

Other NMV collections. Victoria: Western Port, Boags Rocks. New South Wales: Port Kembla. South Australia: Port Macdonnell Pier. Tasmania: Eggs and Bacon Bay. Western Australia: Swan River.

Portugal: Ria de Aveiro, Canal de Ovar.

Origin and present Australian distribution

Corophium insidiosum was described from Plymouth, UK and, in England, inhabits only the southern coast. It has also been reported from both sides of the North Atlantic, and from the eastern Pacific (Lincoln 1979; Myers 1982).

This very common species was first recorded in Australia, from Port Phillip Bay in 1973 and 1975, as an unidentified species by Poore and Kudenov (1978a, 1978b). Subsequent records of the species from WA, Tasmania, SA, NSW and Victoria are based on collections in museums in Sydney and Melbourne (Storey 1996). Most are from harbours or estuaries. The exception is the artificially created estuarine environment off the outfall at Boags Rocks near the entrance to Port Phillip Bay in Bass Strait. All are recent, post-1970, so the date of introduction is uncertain.

Distribution in Port Phillip Bay

In Port Phillip Bay, the species is a dominant amphipod on the mud-flats near drains of the Werribee Treatment Plant. It also occurs in the mouth of the Yarra River.

Diagnosis

Antenna 1 peduncular article 1 medial margin with blunbt process (absent in female), without robust setae (3–4 in female); posterior margin with 1 robust seta (3–4 in female). Antenna 2 peduncular article 3 without robust setae (2 in female); peduncular article 4, length 3.3 x height (length 2.3 x height in female), posterior margin without robust setae (with 2 pairs and 1 single robust seta in female), with 1 large and 1 small posterodistal spine (absent in female); peduncular article 5 posterior margin without robust setae (1 in female), with 1 distal blunt process (without processes in female). Gnathopod 2 dactylus posterior margin with 3 spines (2 in female). Peraeopod 7 carpus not medially protuberant. Urosomites 1–3, fused, without distinct dorsolateral ridge; lateral margin with notch at insertion of uropod 1. Uropod 1 with 1 robust seta on medial margin (1 in female) and 7–8 robust setae on lateral margin (7–8 in female). Uropod 2 without lateral robust setae.

Distinguishing features in Australia

The diagnostic characters serve to recognise the species. It is found together with *C. acherusicum* in Port Phillip Bay but differs in the longer rostrum (male only) and presence of a medial projection on the male antenna 1 peduncle.

Ecology

Corophium insidiosum is estuarine, occurring intertidally and subtidally on mud sediments or among algae or seagrasses (Bousfield 1973; Lincoln 1979; Myers 1982). The only quantitative study of the biology of this species is in the UK (Sheader 1978). He found the species to be most common in areas of high turbidity and lowered salinity. Two main generations are possible: one produced in autumn, overwintering in an immature state, maturing from early summer onwards and disappearing in autumn; and a second generation produced in early summer, maturing and breeding in autumn, overwintering in a resting stage and maturing and breeding for a second time from late winter onwards.

Bousfield (1973) reported it breeding in spring and summer in New England, USA, with several broods per year. He also reported it migrating into deeper water in winter, a phenomenon not noted in Australia.

Corophium sextonae Crawford 1937

Figure 10.5

Synonymy and taxonomy

Corophium sextoni Crawford 1937: 620–623, Figures 3, 4; *Corophium sextonae*: — Hurley 1954: 433–439, Figures 1–21. — Lincoln 1979: 532, Figures 255g–k. — Myers 1982: 199, Figure 135.

A careful morphological comparison of the holotype and other specimens from Plymouth with collections from Tasmania, southern New South Wales and Queenscliff, Port Phillip Bay (Storey 1996) established the identity of the Australian species.

Material

Victoria: Port Phillip Bay. Point Henry, Pile 3, 2 m, 21 Sep 1995, CSIRO—CRIMP collection; Clarence Wreck, Queenscliff, 30 Oct 1996, 30 Oct 1986, NMV J42885 (1 female, 6 mm).

Other collections. Victoria: Western Port, off Crib Point. Tasmania: Georges Bay. New South Wales: Jervis Bay. Western Australia: Bunbury Harbour.

England: Plymouth (holotype and other material).

Origin and present Australian distribution

Corophium sextonae was described in 1937 from Plymouth on the south coast of England and subsequently reported from the Atlantic coast of France and The Netherlands, the Mediterranean and New Zealand (see references in Myers 1982).

Crawford (1937) implied that the species was introduced to England. He was surprised to have found so many individuals where there were previously none in rich collections from the same area made in 1895–1911. Hurley (1954) suggested that *C. sextonae* had possibly been introduced to Europe from New Zealand as there were specimens present in Chilton's (1921) material. It has not been previously reported from Australia but its natural distribution is uncertain. It may be naturally shared by Australia and New Zealand (like many other amphipod species; Barnard 1972), or introduced by shipping from either one to the other.

In Australia, records of the species from Georges Bay, Tas., Jervis Bay, NSW, and Queenscliff and Point Henry, Vic., are based on collections in museums in Sydney and Melbourne (Storey 1996) and the CSIRO—CRIMP collection in Tasmania. Most are from harbours or estuaries. All are recent, post-1980, so the potential date of introduction is uncertain.

Distribution in Port Phillip Bay

In Port Phillip Bay, the species is rare with only two records in the southern region.

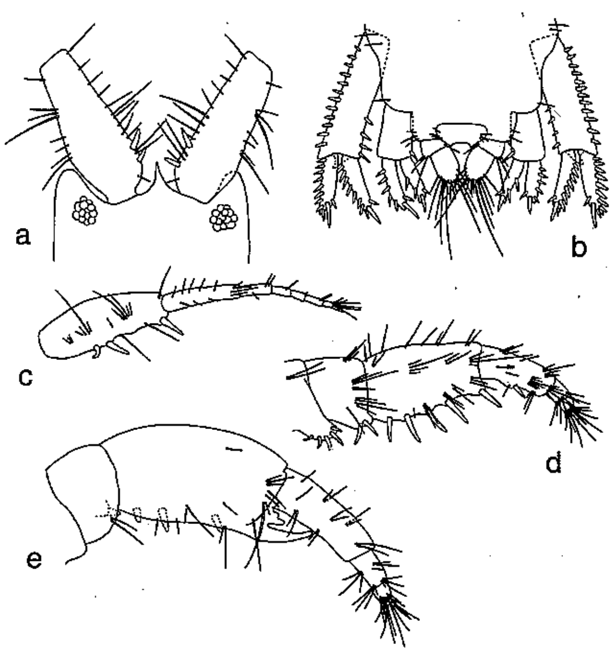

Figure 10.5. *Corophium sextonae*: a) head of male; b) urosome; c) antenna 1 of female; d) antenna 2 of female; and e) antenna 2 of male. From Myers (1982).

Diagnosis

Antenna 1 peduncular article 1 medial margin without processes, with 2 robust setae (2 in female); posterior margin with 3-6 robust seta (3–6 in female). Antenna 2 peduncular article 3 with 1 robust seta (2 in female); peduncular article 4, length 1.9 x height (length 2.1 x height in female), mesial face with 2–3 short robust setae (absent in female); posterior margin without robust setae (with 5 single robust setae in female), with 1 large and 2 small posterodistal spines (absent in female); peduncular article 5 posterior margin without robust setae (1 in female), with 1 distal blunt process (absent in female). Gnathopod 2 dactylus posterior margin with 2 spines. Peraeopod 7 carpus not medially protuberant. Urosomites 1–3 fused, without distinct dorsolateral ridge; lateral margin with notch at insertion of uropod 1. Uropod 1 with 4–5 robust setae on medial margin and 10–12 robust setae on lateral margin. Uropod 2 without lateral robust setae.

Distinguishing features in Australia

Characters that readily distinguish *C. sextonae* from other species include: antenna 1 with four to five flagellar articles, the short stout article 4 of antenna 2 of the male with two or three robust setae on the mesial face; five robust setae on the gland cone on antenna 2 of females; the single row of five robust setae on the lower margin of antenna 2, article 4 of females.

Ecology

Corophium sextonae occurs intertidally and subtidally on algae, hydroids and sponges (Crawford 1937; Hughes 1975). Hughes (1975) found the species to be common on hydroid holdfasts at Torbay, UK, indicating a tolerance to slow flowing water and large quantities of inorganic material. He reported two annual recruitment periods, a spring cohort and summer cohort, which breed approximately one year later (Hughes 1975, 1978). The population density was lowest during winter and reached a maximum after recruitment of the summer cohort.

Family Ischyroceridae

Jassa marmorata (Holmes 1903)

Figure 10.6

Synonymy and taxonomy

Jassa marmorata Holmes 1903: 289. — Lincoln 1979: 552–553, Figure 265a–j. — Conlan 1990: 2053–2055, Figures 2–6, 17;

?Podocerus australis Haswell 1879: 338–339, pl. 21 Figure 8.

Jassa is a major fouling genus with 19 species (Barnard and Karaman 1991: 203). *Jassa marmorata* has often been confused in the literature with *J. falcata* (Montagu 1808), a species found in Britain, the Atlantic coast of Spain and France, and Scandinavia (Conlan 1990). The latter name has also been used for many populations in other parts of the world that have subsequently proved to be specifically different from *J. marmorata*.

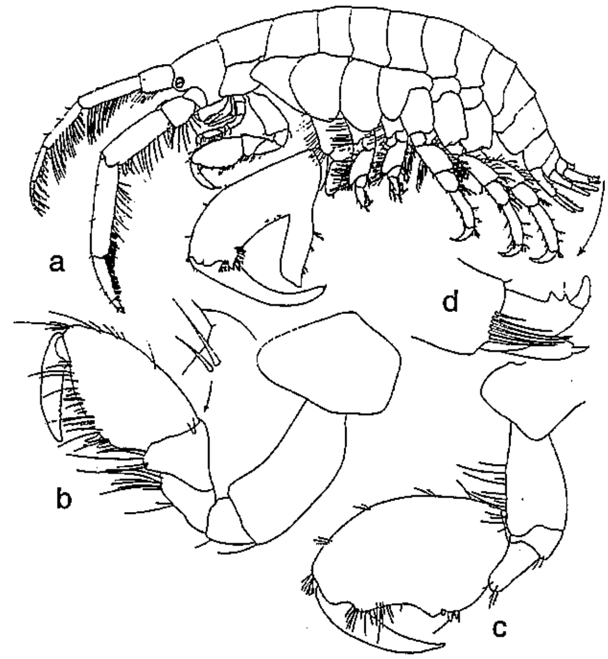

Figure 10.6. *Jassa marmorata*: a) adult male (major form); b) gnathopod 1 of female (with detail of setac on carapace); c) gnathopod 2 of female; and d) uropod 3 (a from Bonsfield 1973; and b-d original).

The type material of *Podocerus australis*, described by Haswell in 1879 from Port Jackson is missing from the Australian Museum but the illustration suggests a species of *Jassa*. Material in the Natural History Museum, London, labelled with this name but collected from Australia later than its description is in fact *J. marmorata* (Conlan 1990).

Material

Victoria: Port Phillip Bay. Pt Henry Pier, core and pile scraping samples, 0.5 m, 13 Oct 1997 (52 individuals); Corio Bay, grab sample, 28 Aug 1997 (1); Corio Quay, pile scraping, 22 Oct 1997 (3); Rippleside Pier, pile scrapings, 0.5 and 3 m, 14 Oct 1997 (20, 4); Point Wilson, pile scraping, 3 m, 23 Oct 1997 (80); Wheat Pier, pile scraping, 0.5 m, 15 Oct 1997 (150); Lascelles Wharf, pile scraping, 0.5 m, 16 Oct 1997 (1). MAFRI collections. Port Phillip Bay, western sandy region (37°56.28'S, 144°47.48'E), 7.5 m, Smith McIntyre grab sample, 4 Apr 1995 (stn PPBES-4 102 1), NMV J42623 (1); central muddy region (38°07.00'S, 144°55.00'E), 23 m (stn PPBES-4 313 1), NMV J42624 (2).

Other NMV collections. Victoria: Western Port, Crib Point.

Origin and present Australian distribution

Jassa marmorata inhabits bays and harbours along all coasts (cool-temperate to tropical) of the Atlantic Ocean, Mediterranean and North Pacific, eastern Africa, southern Australia, and New Zealand (Conlan 1990). Its type locality is New York Harbor but its wide present-day range makes deducing its natural distribution impossible.

In Australia the species is known only from Port Jackson and Hobart (Conlan 1990), Western Port and Port Phillip Bay. If Haswell's (1879) description of *Podocerus australis* is in fact of this species, it was introduced to Australia last century or earlier, or equally possible, transported from Australia to the rest of the world by sailing ships.

Distribution in Port Phillip Bay

Few specimens of this species exist in collections from Port Phillip Bay and Western Port. Adult males have been found only from wharf piles in and around Corio Bay but the species could be expected on hard substrates in most harbours.

Diagnosis

Amphipoda usually with brown pigment, with fleshy short telson, posterior margin of coxa 4 not excavate (Corophioidea); adult male dimorphic, major form with grossly produced thumb on propodus of gnathopod 2, minor form with less pronounced thumb, female and subadult males with 3 stout setae on palm of gnathopod 2, carpus of gnathopod 1 significantly shorter than propodus; uropod 3 with two short rami, exopod with 2 cuticular spines and apical curved strong seta, uropodal endopod simple, antenna 1 with 2+ articulate flagellum (*Jassa*); gnathopod 1 without row of long setae on anterolateral margin of basis, gnathopod 2 with row of long setae on anterolateral margin of basis and with 2 minute setae laterally on the anterolateral margin of carpus (*J. marmorata*).

Distinguishing features in Australia

Four species of *Jassa* have been recognised from Australian harbours: *J. justi* Conlan1990 from Pittwater, NSW (and Macquarie I., New Zealand and Chile); *J. gruneri* Conlan 1990 from Hobart, Tas.; *J. marmorata* from Hobart and Port Jackson (and many other temperate and tropical harbours throughout the world); and *J. slatteryi* Conlan 1990, also from Port Jackson and Hobart and temperate and tropical harbours throughout the world. Others as yet undescribed exist in museum collections.

A simple combination of characters, derived from Conlan's (1990), key serves to diagnose the species in Australia. Gnathopod 1 is without a row of long setae on the anterolateral margin of the basis, gnathopod 2 has a row of long setae on the anterolateral margin of the basis and has 2 minute setae displaced laterally on the anterolateral margin of carpus.

Ecology

Jassa marmorata is commonly found among algae, sponges, hydroids and bryozoans on high salinity rocky shores in mid- to high-latitudes. They inhabit silk tubes which they secrete themselves from glands in the third and fourth pereopods. The animal extends from the tube to feed on plankton and suspended material. They may be early settlers on artificial substrates and densities of up to 500,000 m^{-2} have been measured (Conlan 1989). Adult males and females bearing eggs can be found year round (Nair and Anger 1979, 1980). Females feed and brood their young with their tube and several broods may be produced. Males mate during the last instar when the second gnathopod becomes grossly thumbed (major male form) and it leaves its tube to fertilise a female. A minor male form, with a smaller thumbed second gnathopod is also able to fertilise females (Borowsky 1983, 1985).

The preference for hard surfaces explains why the species is not common in Port Phillip Bay soft benthos samples.

It is the ability to build tubes attached to clean hard surfaces that enables the species to be transported. This happens as part of fouling on a ship's hull rather than in ballast water.

Brachyura

Family Majidae

Pyromaia tuberculata (Lockington 1877)
Figure 10.7

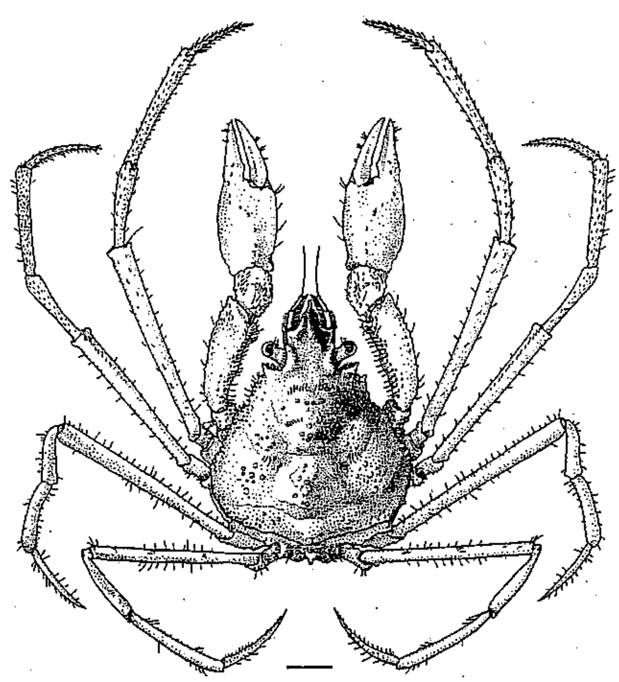

Figure 10.7. *Pyromaia tuberculata*: Scale bar = 2 mm.

Synonymy and taxonomy

Inachus tuberculatus Lockington 1877b: 30;
Pyromaia tuberculata: — Rathbun 1925: 133–137. — Garth 1958: 85–91 (more complete synonymy). — Sakai 1976: 168–170, Figure 92. — Webber and Wear 1981: 370—372, Figures 209–217 of zoea 1. — Wear and Fielder 1985: 28–30, Figures 71–81 of zoea 1. — McLay 1988: 112–114, Figure 24 (more complete synonymy). — Morgan 1990: 316–317. — Furota 1996a: 71–76. — Furota 1996b: 77–91.

Although the species was placed in several genera in the early American literature, its taxonomy is now stable. The species is relatively easy to distinguish from its two congenors (which occur only in the eastern USA). Identifications outside its native range have been made by reputable crab taxonomists and the species cannot be confused with native crabs in southern Australia.

Material

Victoria: Port Phillip Bay, central muddy region (38°16.30'S, 144°55.00'E), 21 m, 3 Apr 1995 (stn PPBES-4 317 2), NMV J41036 (1); (37°59.77'S, 144°57.43'E), 17 m, 3 Apr 1995 (stn PPBES-4 306 1), NMV J41037 (1); (38°02.30'S, 144°48.10'E), 18 m, 18 Oct 1994 (stn PPBES-3 304 1), NMV J43214 (1); 20 Oct 1994 (stn PPBES-3 317 2), NMV J43215 (2); (38°07.00'S, 144°55.00'E), 23 m, 3 Apr 1995 (stn PPBES-4 313 1), NMV J43443 (1); 3 Apr 1995 (stn PPBES-4 317 1), NMV J43444 (1); (38°04.70'S, 144°56.70'E), 21 m, 3 Apr 1995 (stn PPBES-4 312 1), NMV J43606 (1); (38°02.30'S, 144°48.10'E), 18 m, 3 Apr 1995 (stn PPBES-4 304 1), NMV J43607 (2); (38°14.85'S, 144°59.27'E), 18 m, 3 Apr 1995 (stn PPBES-4 309 1), NMV J43608 (2); (38°02.30'S, 144°48.10'E), 19 m, 17 Oct 1995 (stn PPBES-5 304 1), NMV J44050 (2); (38°07.00'S, 144°55.00'E), 23 m, 16 Oct 1995 (stn PPBES-5 313 5), NMV J44052 (1); (38°00.00'S, 144°49.80'E), 18 m, 17 Oct 1995 (stn PPBES-5 305 1), NMV J44053 (6); (38°07.00'S, 144°55.00'E), 23 m, 16 Oct 1995 (stn PPBES-5 313 4), NMV J44054 (1); eastern sandy region (37°55.29'S, 144°56.33'E), 10 m, 16 Oct 1995 (stn PPBES-5 208 1), NMV J44047 (2); (38°00.81'S, 145°02.40'E), 12 m, 16 Oct 1995 (stn PPBES-5 210 1), NMV J44049 (2); western sandy region (38°09.92'S, 144°44.65'E), 12 m, 18 Oct 1995 (stn PPBES-5 114 1), NMV J44048 (1); (38°09.92'S, 144°44.65'E), 12 m, 18 Oct 1995 (stn PPBES-5 114 2), NMV J44051 (2). All samples collected by Smith McIntyre Grab, by R S Wilson *et al.* Delray Beach (38°14'S, 147°22'E), J E Watson 1993, NMV J27670 (1).

Origin and present Australian distribution

Pyromaia tuberculata is a native of the west coast of the Americas ranging from San Francisco Bay, California (38°N) to Utria Bay, Columbia (5°N). Its type locality is San Diego Bay, USA.

The species has been distributed widely in the temperate and subtropical Pacific and South Atlantic since 1970. It was introduced to Japan before 1970 when it was first recorded in Tokyo (Sakai 1976). It is now established in large eutrophic polluted embayments between 34°N and 36°N: Tokyo Bay, Ise-Mikawa Bay and the eastern Seto Inland Sea, including Osaka Bay (Furota 1996a). There seem no records from more coastal habitats. The species was first recorded in the Auckland area, New Zealand (37°S) in 1978 (Webber and Wear 1981 relying on identification by J C Yaldwyn) but appears not to have spread (McLay 1988). The species has been reported too as an introduction from harbours in Brazil (Rio de Janiero, Sao Paulo and Rio Grande do Sul; 22°S–32°S; Melo and Veloso 1989).

The first Australian record was from Cockburn Sound, WA (33°S) in 1978 (Morgan1990). *P. tuberculata* is now known from Port Phillip Bay, Victoria, where it was first captured in 1990 (Parry *et al.* 1995). The species was not captured in the extensive 1969–1973 benthic survey of the bay. Later, in 1993, two specimens of the crab were taken off Delray Beach, Victoria (38°S, 147°E) by Marine Science and Ecology P/L, not having been captured there in surveys in 1990. The crab could have reached Port Phillip Bay and Delray Beach from any of the places from which it was previously recorded by attaching to ships' hulls or as larvae in ballast water.

Distribution in Port Phillip Bay

In Port Phillip Bay *P. tuberculata* has been taken by grab sampler from the central muddy region from 12 m depth down to the maximum depth of the Bay, 23 m (unpub. data). Typically, only one or two specimens are caught in a 0.1 m^2 sample but one sample contained six small specimens. The species also appears in the diets of demersal fish caught from depths greater than 7 m (Parry *et al.* 1995).

Diagnosis

Eyes without orbits, non-retractable (subfamily Inachinae). Body pear-shaped, with long pointed rostrum and 3 prominent dorsal median tubercles. Post-orbital tooth curved around end of eye. Chelipeds longer than carapace. No spine near middle of basal antennal article. First walking leg not much more than twice carapace length. Males with maximum carapace width of 21.5 mm; females smaller. Colour dirty yellow, finely hairy but not decorating as in other majids.

Distinguishing features in Australia

Pyromaia tuberculata can be distinguished from native southern Australian spider crabs (family Majidae) by its small size and exceptionally long and spindly walking legs. The species is unique in southern Australia in the possession of a simple pointed rostrum; all other majid crabs in the region have a bifid rostrum.

Ecology

In the USA, *Pyromaia tuberculata* is common on algal-covered wharf piles and rocky bottoms in harbours so is a prime candidate for translocation. The species also occurs on sandy and muddy bottoms down to a depth of 430 m (Garth 1958). Garth's records suggest continuous breeding with a summer peak.

The reproductive cycle of the crab in Tokyo Bay, which has a similar temperature range to that in Port Phillip Bay is well understood (Furota 1996a, 1996b). The environment in this bay fluctuates and the benthic fauna is subject to seasonal hypoxia and extinction. Like all majid crabs there are two zoeal stages and one megalopa before settlement. At 20° C incubation of the eggs takes 13 days and the three larval stages 17.5 days. At this temperature females reach maturity 60 days after settlement. Development is slower at lower temperatures but continues throughout the year. Eggs hatch only between 8° C and 26° C. Furota (1996b) has shown that two generations are possible each year, each older female being able to produce several thousand eggs. Colonisation of local habitats can therefore be rapid.

The crab is a significant part of the diet of sand flathead, sparsely spotted stingaree, globefish, snapper, banjo ray, red mullet, elephant shark and spiny gurnard. Very small specimens are found which indicate the species is breeding in Port Phillip Bay. The specimens from Delray Beach were taken near the Latrobe Valley Ocean Outfall.

Because sea temperatures in Port Phillip Bay are similar to those in Tokyo Bay its reproductive cycle could be expected to be similar with a potential for spread to Tasmania and a considerable distance along the eastern and western coasts of Australia.

10.5 ACKNOWLEDGEMENTS

We thank several individuals who contributed in many ways: Michelle Harrison, Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada, for sharing her results on *Cancer novaezelandiae*; Kate Thompson, Museum of Victoria, who prepared Figures 10.3, 10.4, 10.5 and 10.6, Ely Wallis, Museum of Victoria, for assisting with identification of ostracods, Dave Currie, Marine and Freshwater Resources Institute, for providing specimens. This study was funded in part by CSIRO, Centre for Research on Introduced Marine Pests, and we thank Ron Thresher, Chad Hewitt and Marnie Campbell for facilitating this and lending specimens. We thank I Takeuchi, N L Bruce, E Dahl, G Edgar, R King and the late J Sieg for sharing their views on introductions with us.

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11 ECHINODERMATA OF PORT PHILLIP BAY: INTRODUCED SPECIES

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11.1 INTRODUCTION

11.1.1 Background

Echinoderms are widespread in all marine waters from the poles to the tropics and from intertidal to hadal depths. Echinoderms of the southern Australian inshore areas are largely endemic. Many northern Australian echinoderms have widespread Indo-Pacific distributions. With some exceptions, the taxonomy of echinoderms is relatively stable and possibly over 80% of species have been described. The knowledge of the holothurian fauna of southern Australia remains incomplete. There are at least ten undescribed species, including several apodid holothurians from soft sediments (M O'Loughlin pers. comm.). Rowe and Gates (1995) give a checklist of described Australian echinoderms.

11.1.2 Echinoderms in Port Phillip Bay

The first comprehensive collection of echinoderms from Port Phillip Bay was that of J B Wilson who dredged extensively around Port Phillip Heads. Much of his material was sent to the British Museum where it was reported on by Bell (1888) and Clark (1966). Further previously unreported specimens are present in the collections of the Museum of Victoria.

The echinoderm fauna of the soft sediments was first investigated by Joshua (1912, 1914) who dredged several holothurian species from Corio Bay. The first bay wide study of invertebrates was conducted by the Museum of Victoria in 1957–1963. The echinoderms were reported by A M Clark (1966) one of the pre-eminent echinoderm taxonomists of the time. The nomenclature of the species listed by Clark (1966) is largely unchanged (Rowe and Gates 1995).

Only a few additional species have been identified from Port Phillip Bay since Clark (1966). The majority of those have been collected from the southern oceanic section of the bay (pers. obs.). A checklist of all echinoderms reported from Port Phillip Bay is given in Table A5 (Appendix A) along with the dates of the earliest known collection. This review focuses on the soft bottom echinoderms found in Port Phillip Bay.

11.1.3 Potential for introduction

Range extension and spread of echinoderms is a relatively rare occurrence. Opportunities exist for their transfer, however few introductions are known or have been reported. Historically, the possibility existed for such transfers via dry and semi-dry ballast and mariculture introductions. In recent years, ballast water has facilitated their transfer, although mariculture remains a potential vector.

All classes of echinoderms contain species with pelagic planktotrophic larvae that are theoretically capable of being transported in ballast water. Average larval periods range from a week to several months (Giese *et al.* 1991; O'Hara in press). Unidentified asteroid larvae have been found in ballast water samples (Jones 1991). Nevertheless, known introductions of echinoderms are few.

The habit of most echinoderms makes them unlikely candidates to become modern hull fouling animals. However, the wooden-hulled ships of previous centuries that carried significant fouling communities may have carried isolated animals. Hyman (1955) attributed the unusual distribution of certain asteroids to transportation on hulls of ships. Some epizoic species of ophiuroids may also have been transported in this manner.

Transportation in protected areas around ship hulls (e.g. sea chests) is more likely. Live individuals of *Asterias amurensis* have been found in the sea chest of a vessel originating from Tasmania (R Thresher pers. comm.).

Finally, the live transportation of seafood has been implicated in the introducation of two asteroids from New Zealand to Australia (see below). Modern fishing or aquaculture practices, such as the disposal of water from the transportation of live seafood or the transfer of mussel ropes from one lease to another, remain potential vectors for echinoderm introductions.

11.1.4 Records of introductions

Presently only three echinoderm introductions have been recognised worldwide. These incursions involve the species *Asterias amurensis*, *Astrostole scabra* and *Patiriella regularis*. Populations have become established within Australia (*A. amurensis*, *A. scabra* and *P. regularis*), Alaska (*A. amurensis*) and Canada (*A. amurensis*) (Turner 1992; McLoughin and Bax 1993; Johnson 1994; Ward and Andrew 1995; Furlani 1996; Byrne *et al.* 1997a, 1997b; also see Chapter 16). All introductions have come from the family Asteriidae and each introduction has been attributed to either ballast water release or translocation with mariculture species. Species in this family have a variety of reproductive strategies, with the larvae of the introduced species surviving for extended lengths of time within the water column.

11.1.5 Introductions to Australia

There have been three confirmed reports of introduced asteroids into Australia. *Patiriella regularis* and *Astrostole scabra* from New Zealand, and *Asterias amurensis* from the northwest Pacific.

Dartnall (1969) recorded *P. regularis* in large numbers from SE Tasmania. His hypothesis was that this species had been introduced from New Zealand in the early 1930's from transportation of live oysters. This species was also recorded from southern New South Wales in the 1930's (as *P. mimica*) but there are some doubts about the taxonomy of the species involved (Rowe and Gates 1995). Both New Zealand and Tasmanian populations of *P. regularis* exhibit polymorphism, possibly indicating the presence of several sibling species (M O'Loughlin pers. comm.). *P. regularis* has a planktotropic larvae that takes 9–10 weeks to develop to metamorphosis (Byrne 1991).

Dartnall (1969) reported *A. scabra* from north to south-eastern Tasmania, again implicating live oyster imports as the dispersal vector. It has a well-defined reproductive cycle, spawning once yearly during late winter-early spring (Town 1979). It is a scavenger and hence has the capability of impacting upon aquaculture (oyster, scallop and mussels) (Furlani 1996).

Town (1979) reported as possible introductions the New Zealand species *Astrostole insularis* and *A. multispina*, collected from around Sydney. However, Rowe and Gates (1995), after a morphological comparison of numerous specimens, synonymised these two forms with the native Australian *A. rodolphi*, recognizing a trans-Tasman species with an Australian distribution from southern Queensland to Sydney.

Rowe and Gates (1995) reported many other species from Australia for the first time. For example they record the South African ophiuroid *Ophionereis australis* from Sydney. I have recently examined this specimen in the Australian Museum. It dates from last century, is possibly a mislocation, and its occurrence near Sydney needs to be confirmed. However, other records could be investigated as possible introductions.

A. amurensis was first recorded from Tasmania in 1986 (Zeidler 1992) and from Port Phillip Bay in 1995 (O'Hara 1995). Its introduction into Australia could have been via larvae transportation in ballast water, or as adults in sea chests or other ship-based containers. This species is dealt with in more detail below.

11.2 REVIEW OF THE STATUS OF PORT PHILLIP BAY ECHINODERMS

Asteroidea

Three species have been identified from Port Phillip Bay in addition to those listed by Clark (1966) (unpub. data). These species have been recorded from the southern oceanic end of the bay or from shore rock platforms. Only three species were recorded by the recent Port Phillip Bay study and these are juveniles.

The nomenclature of the species listed by Clark (1966) is largely unchanged (see Rowe and Gates 1995).

Asteroids exhibit a variety of reproductive and dispersal strategies, including pelagic larvae, non-feeding (lecithotrophic) larvae, direct development (brooding or viviparity) and asexual fission (Giese *et al.* 1991).

Ophiuroidea

Four species have been identified from Port Phillip Bay in addition to those listed by Clark (1966) including *Conocladus australis*, *Ophiacantha shepherdi*, *Amphistigma minuta* and *Ophioplocus bispinosus* (unpub. data). These species have been recorded from only the southern oceanic end of Port Phillip Bay. The taxonomy of the fauna is largely unchanged since Clark (1966).

Ophiuroids exhibit a variety of reproductive and dispersal strategies, including pelagic larvae, short-lived non-feeding larvae, direct development (brooding or viviparity) and asexual fission (O'Hara in press). Pelagic larvae can live for up to three months making them a potential candidate for translocation via ballast water. The habit of most adult ophiuroids makes them unlikely to become fouling organisms. However, some species are epizoic on sessile invertebrates such as sponges. For example, the tropical epizoic species, *Ophiactis savignyi*, is occasionally reported from temperate waters, such as the Mediterranean (Guille 1968) or from near Cape Otway (unpub. data). This species predominantly reproduces by fission increasing the probability that these occurrences are not natural dispersal events.

Echinoidea

The nomenclature of the species listed by Clark (1966) is largely unchanged (Rowe and Gates 1995).

Echinoids exhibit a variety of reproductive and dispersal strategies, including pelagic larvae, non-feeding (lecithotrophic) larvae, and direct development (brooding or viviparity). Asexual reproduction is unknown (Giese *et al.* 1991).

Holothuroidea

Two species have been identified from Port Phillip Bay in addition to those listed by Clark (1966) (unpub. data). These species have been recorded from the southern oceanic end of Port Phillip Bay or from shore rock platforms. The nomenclature of the species listed by Clark (1966) is largely unchanged, except for *Pentacta ignava* (misidentified as *P. australis*).

Intensive collecting from southern Australian rock platforms and from subtidal surveys has doubled the number of known species since Clark (1966). O'Loughlin and O'Hara (1992) described twelve new species from shallow water oceanic localities. There are at least ten undescribed species, including several apodid holothurians from soft sediments.

Holothurians exhibit a variety of reproductive and dispersal strategies, including pelagic larvae, direct development (brooding or viviparity) and asexual fission (O'Hara in press). The habit of most adult holothurians makes them unlikely to become fouling organisms.

There have been no reports of holothurians introduced into Australia.

11.3 INTRODUCED SPECIES IN PORT PHILLIP BAY

Of the eight crinoid, 25 asteroid, 20 ophiuroid, 12 echinoid and 19 holothurian species recorded from the Bay, the majority are well characterised and clearly differentiated from other Australian and overseas species. The majority were recorded from Port Phillip Bay in the 1880's or at least before 1900.

11.3.1 Known introductions

Asterias amurensis Lütken 1871

Synonymy and Taxonomy

Asterias amurensis Lütken 1871: 296. — Fisher 1930: 6, pls 1–5, pl.6(2-8,10,11), pl. 7. — Hayashi 1973: 106, pl.1(3), 17(4). — Turner 1992: 18-19. — Zeidler 1992: 28–29. — Davenport and McLoughlin 1993: 1–38. — Buttermore *et al.* 1994: 21–25. — O'Hara 1995: 261. — Morrice 1995. — Ward and Andrew 1995: 99–109. — Bruce *et al.* 1995. — Byrne *et al.* 1997a: 235–239. — Byrne *et al.* 1997b: 673–685.

The genus *Asterias* consists of five similar species distributed around the northern hemisphere: *A. vulgaris* and *A. forbesi* in the North West Atlantic, *A. rubens* and *A. lincki* in the North East Atlantic, and *A. amurensis* in the North East Pacific (Byrne 1997b). *Asterias* species are conspicuous benthic predators with a tendency to aggregate into "outbreaks" under certain environmental conditions. *A. amurensis* is a variable species, with recognizable variations between geographical populations. Up to six sub-species have been recognized (Davenport and McLoughlin 1993).

A. amurensis was first identified from Tasmania by museum taxonomists in 1992 (Zeidler 1992). The first museum specimen (originally mis-identified as *Uniophora granifera*) dates back to 1986. Subsequent morphological and molecular research has confirmed the identification (Ward and Andrew 1995).

Origin and distribution

Northern Pacific between 33° and 49°N, from Japan to Alaska, 0–200 m.

Australian and Port Phillip Bay distribution

A. amurensis occurs on the southeast coast of Tasmania from Dover to Triabunna (Davenport and McLoughlin 1993; Byrne 1997a, 1997b), and in Port Phillip Bay, Victoria (O'Hara 1995). It was first collected in Port Phillip Bay in August 1995 and is now found from Dromana to Beaumaris along the east coast; Point Cook; Victoria Dock, Port of Melbourne (O'Hara unpub. data; N Hickman MAFRI pers. comm.).

Description

Large seastar, mottled yellow/purple/white, with five arms that are swollen at the base and tapering to a pointed tip. Spines on the dorsal (upper) surface are small and pointed, widely separated from each other. There is a single row of (adambulacral) spines running along the edge of the furrow.

Biology

A. amurensis is a very fecund species and its larvae dominate the zooplankton in the Derwent Estuary during winter (Bruce *et al.* 1995). It spawns from June to September, then remains in the water column for three months before settling during October, November and December (A Morris pers. comm.). It forms extensive aggregations and is a voracious predator of benthic invertebrates, with consequent adverse implications for rare endemic species and aquaculture (Morrice 1995). *A. amurensis* is an ABWMAC designated pest species.

Comments

Isolated adult specimens of *A. amurensis* have been recorded over the last few years from Port Phillip Bay. Between February and June 1998 over 100 juveniles were found at mussel farms near Dromana and 2 more on soft sediments near Beaumaris. This possibly indicates a local spawning event or discharge of infested ballast water.

Genetic studies (Andrew 1998; Murphy and Evans 1998) suggest that Tasmania is the most likely source for the Port Phillip Bay populations. Domestic shipping is implicated in this translocation. The discovery of a large specimen at Victoria Dock suggests the translocation of adults, possibly in sea chests or other hull-based cyptic habitats. A live individual has been found in a sea chest of a vessel originating from Tasmania (R Thresher pers. comm.). The original specimens from Japan may have been transported in this manner.

The recent discovery at a mussel farm off Dromana of large numbers of smaller seastars, forming a single settlement cohort, implies planktonic dispersal, possibly from a ballast water discharge. However, Japanese asteroid researchers regard the larvae of *A. amurensis* as feeble and unlikely to survive long periods in ballast water (M Komatsu pers. comm.).

11.3.2 Possible introductions

Amphipholis squamata (Della Chiaje 1828)

The ophiuroid *A. squamata* is a cosmopolitan species recorded from all regions except the Antarctic and subantarctic from 0 to 1,000 m. *A. squamata* is a viviparous hermaphrodite. There have been various unsuccessful attempts to split this taxon up into geographic species. The current consensus of echinoderm taxonomists is that *A. squamata* is a genuine cosmopolitan species. Different populations of this species are currently being compared using morphological and molecular techniques (P Mladenov pers. comm.). Until this is complete *A. squamata* is likely to remain a cosmopolitan species and can best be described as cryptogenic.

Amphiura (Ophiopeltis) parviscutata Clark 1966

The ophiuroid *A. parviscutata* was first described by Clark (1966) from Port Phillip Bay. The closest known relative of *A. parviscutata* is *A. securigera* from northern Europe. The other species in the subgenus are from the Indo-Pacific region or New Zealand and lack the axe-shaped middle arm spines characteristic of *A. parviscutata* and *A. securigera*.

A. securigera is very similar to *A. parviscutata* and the characters used by Clark (1966) to distinguish the two species (the relative size of the oral shields) do not hold in the current range of specimens. However, there do appear to be other distinguishing characters such as the number of arm spines (usually 3 in *A. securigera* and regularly 4 in *A. parviscutata*), the presence of incipient tentacle scales in *A. securigera* and its larger size (up to 8 mm compared to 5 mm).

Historically, *A. securigera* has been found rarely in coarse gravel on the western and southern western coasts of the British Isles, off the Shetland and Faroe Islands and along the Norwegian coast (Mortensen 1927; Picton 1993). More recently, it has been found in the Mediterranean off Spain in coarse biogenic sand (Guille 1972) and the Adriatic (Zavodnik 1972). In Australia *A. parviscutata* has been found in Port Phillip Bay (Clark 1966), near Albany and Fremantle in Western Australia (Marsh 1991) and off Delray beach in eastern Bass Strait (pers. obs.). Within Port Phillip, *A. parviscutata* occurs in sandy sediments to the west and east of the bay rather than the muddy central region (pers. obs.). The relatively large eggs that are present in this species in April suggests brooding or lecithotrophic (short lived, non-feeding) larvae (pers. obs.). Coarse, shallow substrates were used extensively for dry ballast around the world (Carlton 1989; Carlton 1992). Hence, the possibility of introduction in dry ballast transport cannot be refuted. Further distribution and molecular work is needed. Thus, at present *A. parviscutata* must be considered cryptogenic.

Taeniogyrus sp. MoV1643 (undescribed)

Synonymy and Taxonomy

Rowe (1976) who listed 14 species, including several from Australia, rediagnosed the genus *Taeniogyrus*. Museum of Victoria research into the fauna of southern Australia, eastern Antarctica and Macquarie Island have revealed several more undescribed holothurian species (M O'Loughlin pers. comm.; pers. obs.).

The Port Phillip species does not correspond exactly with any known species. It is similar to *T. diasema* and *T. japonica* from Japan. *T. diasema* differs in having numerous wheel ossicles in the skin and tentacle ossicles with side projections. *T. japonica* is a different colour (red) and has different shaped ossicles in the tentacles.

Origin and distribution

Unknown.

Australian and Port Phillip Bay distribution

Port Phillip Bay, on the Western sandy region, 38° 02.3'S 144° 37.8'E, 6–7 m, PPBES stn 104. It was first collected in October 1994.

Description

The specimens are small (to 10 mm length) and coloured white with bright orange eye spots around the oral rim. The ossicles in the body wall are sigmoid hooks, which are not aggregated into groups, a few wheels restricted to the region near the oral rim, and simple C-shaped ossicles in the tentacles.

Biology

Unknown.

Comments

An undescribed species of the holothurian genus *Taeniogyrus* collected during the PPBES-3 survey from one station (104) in the western side of the bay, where it is relatively abundant. It was taken in grab samples on 17/10/94, 3/4/95 and 17/10/95. The number of specimens retrieved from each grab sample varied from four to eleven.

This localised abundance in an area of the bay where ballast water is discharged makes it a candidate for introduction. However, taxonomic data is insufficient to determine whether this species is introduced at present.

11.3.3 Unlikely introductions

The status of several species was reviewed because they had some characteristics indicative of introduced species. These characteristics are: 1) a cosmopolitan distribution (*Amphipholis squamata*; *Echinocardium cordatum*); 2) a very similar species exist in the northern hemisphere (*Amphiura* (*Ophiopeltis*) *parviscutata*; *Leptosynapta dolabrifera*); 3) or they are currently abundant in Port Phillip Bay (*Trochodota allani*). On review, none of these species appear likely to be introduced.

Echinocardium cordatum (Pennant 1777)

The echinoid *E. cordatum* has a widespread, but discontinuous distribution, in temperate and sub-boreal regions, including the Northern Atlantic, Mediterranean, Southern Africa, Northern Pacific, Australia and New Zealand. *E. cordatum* is also known from fossil Oligocene deposits in England. There has been some debate whether the Australian and New Zealand populations are conspecific with those from Europe.

Gray (1851) was the first to describe Australasian specimens as separate species (*E. australe* and *E. zealandicum*). His one-line diagnoses are inadequate, however, and later taxonomists (e.g. Clark 1925; Mortensen 1951) could find no constant difference between specimens of the same size from England, Japan, Australia and New Zealand. Nevertheless, some New Zealand researchers persisted in using the name *E. australe* as late as 1968 (Higgins 1974). Higgins conducted a morphometric analysis between English, Australian and New Zealand specimens. He concluded that no reliable feature separated these populations, although he detected a morphological difference between specimens from sandy and muddy substrata from New Zealand. Higgins (1977) later compared specimens from South Africa, Japan, Brazil, Australia, New Zealand and Ireland and again concluded that only one species was involved.

Laurin *et al.* (1994) conducted both morphological and molecular (ribosomal RNA) analyses of specimens from the Atlantic (Brittany), Mediterranean (Banyuls), Japan (Asamushi), Australia (Port Phillip Bay) and New Zealand (Stewart Island) in an attempt to resolve the identity of intermediates between *E. cordatum* and *E. fenauxi*. The morphological data clustered New Zealand specimens with those from the Atlantic (Australian specimens were not morphologically measured). These two groups share a relatively long fasciole compared to those from the Mediterranean. The New Zealand and Atlantic specimens differed in their general shape.

The rRNA analysis produced an entirely different tree. The Atlantic specimens were isolated from a group that included specimens from New Zealand, Japan and Australia. Within this group New Zealand specimens clustered with those from Japan, more distantly with *E. fenauxi* material from the Mediterranean and only then to Australian specimens. Laurin *et al.* (1994) concluded a different molecular approach was required as there was not enough variation in the rRNA used. This lack of variation could be expected if the radiation of *E. cordatum* is relatively recent. They propose a future study using mitochondrial DNA or other more variable parts of the genome.

The possibility that *E. cordatum* is introduced is unlikely but cannot be rejected conclusively. The most recent opinion of the molecular taxonomists is that the Australasian populations of *E. cordatum* are distinct from those in Europe and Japan, and that its discontinuous distribution is attributable to vicariant events similar to those explaining the distribution of the seagrass genus *Posidonia* (J P Féral pers. comm.).

Leptosynapta dolabrifera (Stimpson 1855)

The holothurian *L. dolabrifera* has been recorded across southern Australia from Port Hedland, Western Australia to Mooloolabah, Queensland, including Tasmania. It is very similar to several other species including *L. inheres* from Europe and northern America and *L. latipatina* from northern Australia. The species are not well differentiated. The last revision of *Leptosynapta* was by Heding (1928) who listed 28 nominal species. Clark (1946) regarded at least a third of these invalid.

L. dolabrifera itself is a variable species. Several attempts have been made to separate out forms on the basis of colour or shape of the anchor plate ossicles in the body wall but all have been subsequently synonymised. A comprehensive review of the species is still required as several distinct colour forms appear to exist. Specimens from Port Phillip Bay and Port Hedland are purple flecked (pers. obs.), while those from the rocky shallows tend to be a uniform pinkish (Phillips *et al.* 1984).

Although *L. dolabrifera* is similar to *L. inhaerens*, there is no other reason to regard local populations as introduced. It was first discovered from Australia in the early 1850's and by 1914 had been collected throughout southern Australia. Although the close relationship has been noted on several occasions, no echinoderm taxonomist this century has proposed their synonymy.

Trochodota allani (Joshua 1912)

The holothurian *T. allani* is one of the most numerous invertebrates in the muddy areas of Port Phillip Bay. This species is often noted by divers who report being covered by a sticky holothurian. This abundance was noted by Joshua (1914) who wrote: "I have seen the dredge presenting the appearance of having been dragged through a mass of blood slime, from the thousands of this species adhering to it."

The genus *Trochodota* was revised by Rowe (1976) who recognised four species, three from southern Australia and one from the southern Ocean. Since then three more species have been described from the Kuril

Islands and from Madagascar. There is possibly another undescribed species from off East Gippsland (M O'Loughlin pers. comm.). *Trochodota allani* has a number of colour forms (orange/red; purple; grey) within Port Phillip Bay. These colour forms do not appear to differ morphologically (pers. obs.). There is no reason to assume this is an introduced species.

11.4 DISCUSSION AND CONCLUSIONS

Asterias amurensis remains the only echinoderm known to be introduced into Port Phillip Bay. The undescribed holothurian species (*Taeniogyrus* sp. MoV 1643) found in the west of the bay requires further study to establish its status.

There is potential for both *Patiriella regularis* and *Astrostole scabra* to move into the bay. Both species have a long lived planktonic larvae which theoretically could be transported in ballast. More likely is transportation of adults in sea chests or through the movement of live seafood or aquaculture equipment.

Control measures for these asteroids are limited. Hand removal by divers remaining the best option of small scale incursions. The recent deployment of baited seastar traps in Port Phillip Bay failed to capture *Asterias* (N Hickman MAFRI pers. comm.). The usefulness of the traps is possibly limited to medium to large aggregations. The possible introduction of the ciliate parasite *Orchitophyra stellarum*, which is known to castrate *Asterias*, is problematic, as it is not host specific and may result in infestation of native seastars (Byrne *et al.* 1997a).

11.5 ACKNOWLEDGEMENTS

I thank Mark O'Loughlin (Honorary Associate MoV), Dr G Poore (MoV), Dr Jean-Pierre Féral (Observatoire Océanologique, Banyuls/Mer, France), Dr M Komatsu (Toyama University, Japan), Dr R Thresher (CRIMP), Dr N Hickman (MAFRI) and Dr P Mladenov (Otago University) for offering information and advice relevant to this study.

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12 OCCURRENCE AND DISTRIBUTION OF EXOTIC FISHES IN PORT PHILLIP BAY

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12.1 INTRODUCTION

Current estimates of the number of species of fishes occurring in Australian waters well exceed 4,000. Of these, more than 700 are thought to occur in Victorian waters, 295 of which have been recorded in Port Phillip Bay (Gomon *et al.* 1994). Despite the great size of the Australian continent, its harsh climatological history has maintained its freshwater diversity at surprisingly low levels. Consequently, almost 95% of Australia's fish species are distributed in marine areas.

Of those known to occur in Australian waters, four marine species are currently recognised as having been accidentally translocated and subsequently established. All belong to taxonomically diverse families (i.e. Gobiidae and Tripterygiidae) having small cryptic species whose interrelationships are not fully understood and for which even less is known about their ecology. Invasive species established in other parts of the world also belong either to these families or to others (i.e. Blenniidae and Eleotridae) that could be similarly described.

The family Gobiidae with nearly 2,000 species (Nelson 1994) is the largest family of marine fishes, and the one generally accepted as still requiring the greatest effort taxonomically. Gobies are found in tropical and temperate regions throughout the world, and although primarily marine in distribution are represented in fully fresh waters as well. Many genera remain inadequately defined and, increasingly, recognised species are being revealed as constituting species complexes. Nearly ten percent of Australia's fish species are members of this family, or of very closely related families which have only recently been discovered as distinct.

Almost all gobies occur in coastal waters, with many featuring prominently in estuarine localities visited by commercial and recreational shipping. Their habitat requirements vary between species but when combined constitute virtually all sectors of the environment available to diminutive forms. It is thus not surprising that three out of the four recognised introduced fishes in Australia are gobies (Pollard and Hutchings 1990; Lockett and Gomon in prep.).

The Tripterygiidae is also a coastal distributed family of the world oceans, but one that is almost exclusively confined to tropical and temperate marine areas with hard substrates. It is currently recognised as comprising about 22 genera and slightly over a hundred species (Nelson 1994) with by far the greatest diversity existing in the Australasian region. A recent study by Fricke (1994) detailed 22 genera and 70 species from Australia, New Zealand and other southwestern Pacific waters, but did not resolve all taxonomic problems in the region. Two species primarily distributed in New Zealand waters are now recorded from southeastern Australia; one undoubtedly representing an introduction and the other regarded as cryptogenic (Furlani 1996; Lockett and Gomon in prep.).

With 53 genera and about 345 species (Nelson 1994), the family Blenniidae shares a close ancestry and many ecological parameters with the Tripterygiidae. Recent efforts by Springer and colleagues (e.g. Springer 1968; Smith-Vaniz and Springer 1971; Springer and Spreitzer 1978; Bath 1983, 1992; Springer 1988, 1991; Williams 1988) have shed a great deal of light on this previously difficult group.

Blennies are likewise found around the world in relatively shallow inshore waters, preferring tropical and subtropical climates. A number of genera populate estuaries and embayments, and are especially visible on wharves, jetties and breakwaters. Although yet to be identified as involved in Australian introductions, the high diversity of this family in tropical Australia, some 90 or more species, may cloud their status in northern ports. It is well documented that at least one species has been introduced from the Indo-Pacific into the Atlantic (Springer and Gomon 1975).

In contrast to the previous three families, the Eleotridae is primarily distributed in freshwater and estuarine regions of the world. A close relative of the Gobiidae, the family comprises about 35 genera and 150 species (Nelson 1994): at least 43 of these species occur in Australian waters. Like the gobies, further work is required not only to confirm species identities, but also to develop a better understanding of their inter-relationships. The rather lengthy and salinity tolerant nature of the larval stages of some species make them potential candidates for translocation. Although not yet implicated in Australian introductions, one species is documented as having been translocated from the Indo-Pacific to the Atlantic (Dawson 1973; Miller *et al.* 1989).

12.2 FISHES OF PORT PHILLIP BAY

Because Port Phillip Bay has supported several commercial fisheries in the past, and currently supports a large recreational fishery, the knowledge of fishes from the bay is generally sound. Previous surveys of large pelagic and demersal fishes have been conducted by the Marine and Freshwater Resources Institute (previously Victorian Fisheries Research Institute) however much of the data exists as unpublished species lists or internal publications (e.g. Parry *et al.* 1995). Parry *et al.* (1995) studied demersal fishes living over the soft sediments of Port Phillip Bay and collected a total of 74 species from four ecological regions, each characterised by a unique combination of sediment type, benthic community structure, depth and fish communities. Additional ecological studies of fishes in the bay include those by Coleman (1972) and more recently those by Jessop (1988), Henry and Jenkins (1995) and Jenkins *et al.* (1993, 1997). Jenkins (1986) studied the larval fishes of Port Phillip Bay and documented species-specific seasonal trends and distribution patterns. Neira and Tait (1996) and Cunningham (1998) have conducted further studies on larval fishes.

In addition, the Museum of Victoria holds a large collection of fishes from Victorian coastal waters, many of which were taken in Port Phillip Bay. However, fishes from the bay included in the collection represent the sum of haphazard sampling and accessions over the years without a specific collecting program having been undertaken to identify species occurring in the coastal regions of the bay. While sampling for this study was the first aimed at gathering information on the fish fauna of the coastal regions of the bay, the aforementioned studies combined with the collection held by the Museum document the fishes of Port Phillip Bay reasonably well. Even lesser known groups such as the Gobiidae and Tripterygiidae are well represented in the Museum's collections and taxonomic knowledge of species of these families in the bay is considered mostly complete (e.g. Gomon *et al.* 1994).

12.3 POTENTIAL FOR TRANSLOCATION

Currently it is thought that marine fishes are most probably transported to new environments in the ballast water of ships (Brittan *et al.* 1970; Hoese 1973; Springer and Gomon 1975; Haaker 1979; Chubb *et al.* 1979; Middleton 1982; Carlton 1985; Paxton and Hoese 1985; Bell *et al.* 1987; Pollard and Hutchings 1990). There are several reasons why ballast water is thought to be the primary vector for the transportation of these fishes to new regions. All of the known introduced species are robust cryptic fishes that commonly inhabit shallow coastal environments and are often abundant in port regions. They have long reproductive seasons and produce large numbers of free swimming pelagic larvae that have the potential for being taken up in ballast water. Support for this hypothesis is provided by the collection of live fishes from the ballast tanks of bulk carriers operating within Australia (Middleton 1982) and between Australia and Japan (Williams *et al.* 1988).

Introduced marine fishes are often found in greater abundance around commercial ports (Pollard and Hutchings 1990; this study) and those that have established self sustaining populations tend to be tolerant of the wide variations in temperature and salinity which may be encountered during translocation in ballast water or as hull fouling (Hoese 1973; Carlton 1985). This aspect of the biology of introduced fishes may also predispose them to successful invasion. Following introduction, their tolerance may enable them to persist in environments with physical parameters that do not exactly mirror those of their native habitat.

Acanthogobius flavimanus and *Tridentiger trigonocephalus* are two gobiids native to the North West Pacific and are the most broadly distributed of the exotic marine fishes, both having been introduced to Australian and USA waters. *Acanthogobius flavimanus* is recorded from San Francisco Bay, Los Angeles Harbor and San Diego Bay in California (Brittan *et al.* 1970; Haaker 1979), and the Sydney region NSW and Port Phillip Bay Victoria in south-east Australia (Gomon *et al.* 1994). *Tridentiger trigonocephalus* occurs in Los Angeles Harbour and San Francisco Bay (Hubbs and Miller 1965; Brittan *et al.* 1970), and has established populations in Sydney Harbour, Port Kembla NSW, and Port Phillip Bay Victoria in southeast Australia, and the Swan River estuary in WA (Gomon *et al.* 1994).

Another possible vector for the introduction of fishes involves the attachment of eggs either directly to vessel hulls (including sea chests and internal seawater pipe systems), or to other fouling organisms. Most known introduced fish species have demersal eggs that are attached to substrates. For most of these species the length of the prehatching development period exceeds the time required for vessels to move between ports (Dotu and Mito 1955; Hirose and Kubo 1983; Francis 1988). This method of introduction is considered unlikely as eggs on the hulls of vessels would be exposed to wide fluctuations in temperature (and in some case salinity) and those in sea water pipes to high current velocities. However, water temperature in some ballast tanks also fluctuates widely during a voyage and may approach that of the water the

Table 12.1. Accidentally introduced marine fishes that have established populations. * indicates Introduced species whose population status is not confirmed. Species expanding their ranges via passage through the Panama or Suez Canals are not included.

Family/species	Reference	Origin	Introduced populations
Gobiidae			
Acanthogobius flavimanus	Brittan *et al.* 1970; Pollard & Hutchings 1990	NW Pacific	SE Australia; California
Tridentiger trigonocephalus	Haaker 1979; Pollard & Hutchings 1990	NW Pacific	SE Australia; Western Australia; California
Tridentiger bifasciatus	Matern & Fleming 1995	NW Pacific	W coast of United States
Acentrogobius pflaumi	Lockett & Gomon in prep.	NW Pacific	Port Phillip Bay, Victoria
*Rhinogobius brunneus**	Al-Hassan & Miller 1987	NW Pacific	Arabian Gulf
Tripterygiidae			
Forsterygion lapillum	Lockett & Gomon in prep.	New Zealand	Port Phillip Bay
Blennidae			
Omobranchus punctatus	Springer & Gomon 1975	Indian Ocean	W Atlantic
*Lupinoblennius dispar**	Dawson 1970	Caribbean	Pacific Panama
Eleotridae			
Prionobutis koilomatodon	Dawson 1973; Miller *et al.* 1989	Indo-West Pacific	Panama Canal*, W Africa

ship is passing through (Carlton 1985). Furthermore, egg masses of cryptic species inhabiting shallow sub-tidal environments, including those that have been introduced, are often strongly anchored to the substratum to avoid being dislodged by wave action.

12.4 INTRODUCTION OF MARINE FISHES WORLD WIDE

To date nine species of marine fishes are known to have been accidentally translocated to regions widely separated from their natural ranges (Table 12.1). Four of these species, *Acanthogobius flavimanus*, *Tridentiger trigonocephalus* (both Gobiidae), *Prionobutis koilomatodon* (Eleotridae) and *Omobranchus punctatus* (Blennidae), have been introduced to several widely separate regions while the remaining five species are recorded from single locations outside their native ranges.

Following the recognition of *Tridentiger bifasciatus* and *T. trigonocephalus* as separate species (Akihito and Sakamoto 1989), both were reported in Californian waters (Matern and Fleming 1995). *Tridentiger bifasciatus* is also native to Japan and China and is very similar to *T. trigonocephalus*, but occurs at lower salinities. *Tridentiger bifasciatus* was first recorded in the upper reaches of the Sacramento-San Joaquin River delta (San Francisco) in 1985 and by 1990 it had become the most abundant fish both as adults and larvae in this region. It has also extended its range over 500 km south via an inland aquaduct (Matern and Fleming 1995). Matern and Fleming (1995) believed that *T. bifasciatus* would compete with the endangered tidewater goby (*Eucyclogobius newberryi*) because of an overlap in habitat preference and diet. During laboratory studies *T. bifasciatus* was observed to prey upon *Eucyclogobius newberryi*, disrupt its spawning and reduce its feeding (Matern and Fleming 1995).

Another gobiid native to the North West Pacific, *Rhinogobius brunneus*, has recently been recorded as an introduced species from the north-west corner of the Arabian Gulf (Al-Hassan and Miller 1987). Specimens were collected from a shallow estuarine inlet on the coast of Kuwait. While it is possible that a disjunct population may have arisen naturally, Al-Hassan and Miller (1987) felt that it was more likely that the species was introduced in the ballast tanks of oil tankers operating between Japan and Kuwait. The authors believed that electrophoretic work could conclusively demonstrate the origin of *R. brunneus* in this region.

Omobranchus punctatus (Bleniidae) is a shallow water species occurring in marine and brackish waters throughout the Indo-west Pacific region (Springer and Gomon 1975). In addition to its natural distribution two separate populations of this species have been recorded from the western Atlantic, a large and abundant population in Trinidad and a smaller population at the Atlantic entrance to the Panama Canal. Springer and Gomon (1975) presented a convincing case for the introduction of this species to these regions in ballast water. *Omobranchus punctatus* has been reported as the most common species around dock areas near Port of Spain in Trinidad (Lachner *et al.* 1970) and has also been reported from the coast of Venezuela (Springer and Gomon 1975).

Extensive sampling throughout the western Atlantic and the Pacific entrance of the Panama Canal has not yielded any further specimens of *O. punctatus* (Springer and Gomon 1975). However the origin of this species was more difficult to determine since it was first collected in Trinidad in 1930, much earlier than any of the other recognised introductions. While it is possible that collections of this species may represent a relic population, Springer and Gomon (1975) discounted this theory given that *O. punctatus* is the only tropical Indo-Pacific benthic shore fish that occurs in the western Atlantic, it appears to be absent from all but the western rim of the Pacific, and all other species of the tribe *Omobranchini* are restricted to the Indo-west Pacific. Furthermore, the authors believed that both populations had a common origin and that the Panama population was a derivative of the Trinidad population.

Prionobutis koilomatodon is an eleotrid naturally distributed throughout the tropical Indo-Pacific from Mozambique and the coast of India to the coastal waters of southern China. Dawson (1973) collected a single specimen of this species from Miraflores Lock on the Pacific coast of the Panama Canal and suggested ballast water as the most probable means of cross Pacific transport for this species. Additional collecting along the Pacific coast yielded no further specimens from this region and no other records of this species in Panama exist. Subsequently, Miller *et al.* (1989) collected many specimens of *Prionobutis koilomatodon* from Port Harcourt, Nigeria (West Africa) and believed that the presence of the species, given the sound knowledge of gobiids from this region, represented a recent introduction. Ballast water was suggested as the most probable transport method, a hypothesis supported by the abundance of *P. koilomatodon* in a commercial dock area. The species was also collected from nearby mangrove habitats and was found to occur over wide ranges of temperature (26.5°–32° C) and salinity (9.5‰–22‰) (Miller *et al.* 1989).

Many species of marine fishes have gained access to new habitats via passage through the Panama and Suez Canals (McCosker and Dawson 1975). The majority of fishes transiting the Panama Canal have moved from the Atlantic to the Pacific with the Miraflores Lock on the Pacific coast supporting a mixed biota of Atlantic and Pacific organisms (McCosker and Dawson 1975). For fishes to successfully pass through the Panama Canal naturally they must possess a high tolerance to fluctuating salinity because of the presence of freshwater lakes in the central region of the canal. However for stenohaline species known to have traversed the canal, passage via ballast water has been suggested as the most likely mechanism of transport.

Lupinoblennius dispar (Blennidae) is a marine species occurring naturally in the west Atlantic with a small population on the Pacific side of the Panama Canal discovered in 1967 (Dawson 1973). While this species can tolerate low salinity, Dawson (1973) suggested transport of eggs on the hull fouling of ships passing through the canal as a possible method by which this species became established on the Pacific side of the canal. Since the Suez Canal opened there has been a steady increase in the number of Red Sea fishes (and other organisms) found in the Mediterranean, the most recent account listing 48 species (Golani and Ben-Tuvia 1989; Baltz 1991). However only three species have moved southward from the Mediterranean to the Red Sea. Reasons suggested for this largely one-way movement include: (a) the higher diversity and abundance of Red Sea fishes compared to the Mediterranean assemblage; (b) high levels of competition in the Indo-west Pacific making species from that region better invaders; and (c) the prevailing currents in the Suez Canal favouring movement in this direction. Unlike the Panama Canal, there is no barrier to the movement of fishes through the Suez Canal (Ben-Tuvia 1971; Baltz 1991).

12.5 INTRODUCTION OF MARINE FISHES TO AUSTRALIA

Four species are currently known to have been accidentally introduced to Australian waters and have established viable populations (Table 12.1). Another species is classified as cryptogenic (Furlani 1996) and a further two are believed to have been introduced but do not appear to have established populations. The first recognised introduced marine fish in Australia was *Acanthogobius flavimanus* (yellowfin goby) which was collected in Sydney Harbour NSW on the southeast coast of Australia in 1971 (Hoese 1973). Subsequently, specimens have been collected from Botany Bay (south of Sydney Harbour), from the Hawkesbury River System (north of Sydney) NSW, and from Port Phillip Bay, Victoria (Middleton 1982; Bell *et al.* 1987; Gomon *et al.* 1994).

Tridentiger trigonocephalus (trident goby) was first taken in Australian waters in 1973, again in Sydney Harbour, New South Wales. The species also occurs in Port Kembla, New South Wales and Port Phillip Bay, Victoria, on the southeast coast of Australia, and in the Swan River estuary in the southwest of Western Australia (Chubb *et al.* 1979; Gomon *et al.* 1994).

Sampling conducted over the last three years by the Museum of Victoria's Ichthyology section has revealed a further two introduced species in south-eastern Australia, the gobiid *Acentrogobius pflaumi*, a native of the North West Pacific, and the tripterygiid *Forsterygion lapillum* otherwise restricted to New Zealand (Lockett and Gomon in prep.). Both of these species are currently believed to be restricted to Port Phillip Bay.

Another tripterygiid, *Forsterygion varium,* which is recorded from the south-east corner of Tasmania, is very similar to *F. lapillum* and is distributed throughout New Zealand. This species was first recorded in Australian waters in the early 1970's and while originally thought to be a native of Australia (Scott 1977; Last *et al.* 1983) is considered cryptogenic by Furlani (1996). This species occupies shallow rocky areas in large estuaries and bays and breeds from May to September/October in both New Zealand and Tasmania (Last *et al.* 1983; Thompson 1986; see also Ruck 1980; Thompson and Jones 1983).

A further two introduced species of fishes have been recorded from Australian waters but apparently neither has become established. The Japanese sea bass, *Lateolabrax japonicus* (Pisces: Percichthyidae) was recorded off the coast of Sydney in 1982 and again in 1983 from widely separated locations (Paxton and Hoese 1985), but there have been no subsequent records of this species in Australian waters. As this is a large and conspicuous species it is assumed that if a population had established in the Sydney region additional specimens would have been taken. *Lateolabrax japonicus* is native to the inshore coastal waters of Japan, Korea, Taiwan and China where it is a valuable food fish. It supports a commercial fishery in Japan and China and is raised artificially in ponds (Pollard and Hutchings 1990).

The sobaity sea bream, *Sparidentex hasta* (Sparidae), is native to the inshore waters of the north-western Indian Ocean and was collected from the Swan River in the early 1980's (Pollard and Hutchings 1990). There have been no subsequent records of this species in Australian waters.

12.6 INTRODUCED FISH SPECIES IN PORT PHILLIP BAY

The four introduced species currently known to occur in Port Phillip Bay, *A. flavimanus, T. trigonocephalus, A. pflaumi* and *F. lapillum* all appear to be restricted to this embayment in the Victorian region. *Tridentiger trigonocephalus* has been recorded in Port Phillip Bay since 1977 but of the four species, it shows the most restricted distribution within the estuary. *Acanthogobius flavimanus* prefers a different habitat and is generally more widely distributed throughout the bay with a population size that is believed to fluctuate significantly. *Forsterygion lapillum* appears to be restricted to Corio Bay in the western area of Port Phillip Bay but is abundant in this region. *Acentrogobius pflaumi* is the most recently recorded introduction but presently appears to be the most widely distributed with specimens having been collected from the lower reaches of the Yarra River and all regions of the bay except the mouth. A recent study into gobiid larvae in Port Phillip Bay by Cunningham (1998) has shown *A. pflaumi* larvae to be the most widespread and abundant of all three introduced gobies occurring in the bay.

12.6.1 Taxonomy and systematics

Acanthogobius flavimanus (Temminck and Schlegel)

Synonymy and Taxonomy

Gobius flavimanus Temminck and Schlegel 1881;
Acanthogobius flavimanus Jordan and Metz 1913;
Gobius stigmothonus Richardson 1844;
Acanthogobius stigmothonus Bleeker 1873;
Acanthogobius stigmothinus (error) Jordan and Starks 1905;
Acanthogobius jacoti Fowler 1930.

Common names

Mahaze (Japan), yellow fin goby, oriental goby and common goby.

Acanthogobius is widely recognised as comprising three species (*A. flavimanus, A. hasta* and *A. lactipes*) but may include up to ten (Hoese and Larson 1994).

Material

NMV A3717, NMV A10898, NMV A12203, NMV A13202, NMV A17494, NMV A17502, NMV A17509, NMV A17515, NMV A17516, NMV A17523, NMV A17524, NMV A17544, NMV A17548, NMV A17557, NMV A17558, NMV A17587, NMV A17596, NMV A17604, NMV A17608, NMV A17614, NMV A18331, NMV A18333, NMV A18334, NMV A18336, NMV A18338, NMV A18339, NMV A18340, NMV A18708,

NMV A19485, NMV A19493, NMV A19541, NMV A19551, NMV A19559.

Present Distribution

The yellowfin or common goby is a species that is native to the North West Pacific. Originally described from Nagasaki, Japan, it is recorded from Japan (Hokkaido to Kyushu), the far eastern USSR (Primorsk Kray, Sakhalin), the Korean peninsula and China (Macau, Guangzhou) (Pinchuk 1992; Masuda *et al.* 1984; Fowler 1961). *Acanthogobius flavimanus* was introduced to the west coast of the United States in the early 1960's. It is presently one of the most abundant fishes in San Francisco Bay and is also recorded from Los Angeles (Brittan *et al.* 1970; Haaker 1979). The species was introduced to the south-east coast of Australia in 1971.

Australian Distribution

The first Australian specimens of *A. flavimanus* were collected from Dawes Pt, Sydney Harbour in 1971 (Hoese 1973). Between 1977 and 1980, Middleton (1982) collected 108 specimens of *A. flavimanus* (45–237 mm T.L.) from widespread localities in Sydney Harbour and Botany Bay and from the Hunter River, Newcastle NSW. Sampling by Bell *et al.* (1987) in 1984 and 1985 revealed the presence of *A. flavimanus* in the Hawkesbury River System, an estuary approximately 30 km north of Sydney that is not a port of call for ocean going vessels. A total of 88 specimens (38–200 mm S.L.) were taken from the brackish water reaches tributaries Broken Bay (Hawkesbury River and Cowan Creek).

Port Phillip Bay Distribution

A. flavimanus was found to inhabit Port Phillip Bay in 1990. It was first identified from the gut content of a cormorant and was subsequently taken in the lower reaches of the Yarra River. Its present distribution includes most of the northern half of Port Phillip Bay with a continuous distribution from Pt Cook on the western side of the bay, through the commercial region of Hobsons Bay (extend Brighton on the east (Figure 12.1). It occurs over soft substrata including mud, sand and seagrass beds.

Although previously known from as far south as the Mornington Peninsula (NMV A13202) the south-eastern extent of this species' range appears to have contracted in recent years. In the west, two specimens of *A. flavimanus* were taken in the Geelong region, both at Cunningham Pier in Corio Bay. While not collected from Geelong Yacht Club during the course of a recent study, *A. flavimanus* was observed in this area and was also collected by Parry *et al.* (1995) elsewhere in Corio Bay. Despite extensive sampling around the perimeter of Corio Bay additional specimens have not been collected from this region. It appears that a disjunct population of this species has been established near the Geelong Yacht Club, perhaps the result of a translocation from the northern region of the bay.

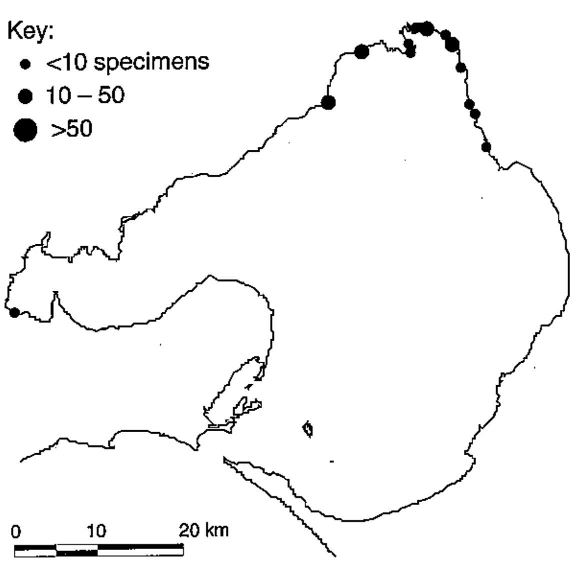

Figure 12.1. Distribution and abundance of *Acanthogobius flavimanus* in Port Phillip Bay.

Description

D. VIII–IX; I, 12–14. A. I, 11. C. (segmented) 17. P. 21. V. I, 5 LL. –.

Acanthogobius flavimanus is separable from other gobies of this region in having 8 or 9 spines in the first dorsal fin, 12–14 segmented rays in the second dorsal fin, the top of head with many(24–30 transverse rows) small scales, scaled cheeks, and a transverse line of sensory papillae on cheek (Hoese and Larson 1994; Masuda *et al.* 1984).

Body slender, head of moderate size (28–30% SL), triangular in cross section; interorbital space narrow, less than eye diameter; mouth oblique, rear end of jaws just in front and below middle of eye. Top of head with minute scales to just behind eyes, 24–30 transverse scale rows before D1 origin; scales mostly ctenoid, cycloid on belly and head, covering body in 52–53 vertical rows. Two dorsal fins; first originating above ventral fin insertions, second originating just behind first; anal fin origin below and just behind second dorsal origin; caudal and pectoral fins with rounded margins; ventral fins fused to form cup shaped disc, originating below pectoral fin insertions (Hoese and Larson 1994).

Body brown to grey in colour with dark brown mottling on back and six-eight irregularly shaped dark brown blotches on midside with larger round spot on each side at base of caudal fin; thin dark brown line extending from ventral margin of each eye forward and downward to near rear of jaws; dorsal fins with dark brown spots forming horizontal rows; caudal fin with six to eight wavy dark brown bands on upper two thirds of fin (Hoese and Larson 1994).

Potential Confusions

May be confused with juvenile whiting (*Sillago* spp.) but easily distinguished by fused ventral fins. Separable from all other gobiid species in southern Australia by its combination of eight or nine spines in the first dorsal fin and 12–14 segmented rays in the second dorsal fin. This species is often collected with, and is similar in appearance to, *Arenigobius bifrenatus* and *A. frenatus*, but lacks the horizontal black stripes on the head that are present in these species.

Ecology

In its natural range *Acanthogobius flavimanus* occurs over soft substrates across a temperature range of 0°–25° C. It lives in Y-shaped burrows dug in mud/sand bottoms along the shores of bays and estuaries and well into the freshwater reaches of some rivers (Masuda *et al.* 1984; Dotu and Mito 1955). In Japanese waters *Acanthogobius flavimanus* is sufficiently common to be used as a food source by local inhabitants.

Breeding in *A. flavimanus* appears to be temperature dependent; spawning takes place at the northern extent of its natural range between April and June (spring/summer) when water temperature ranges between 10° and 15° C (Hoshino *et al.* 1993). Towards the southern extent of its range, Dotu and Mito (1955) found *A. flavimanus* to spawn between January and March (winter) in water temperatures of 7.5°–9.7° C but were able to incubate eggs in experimental tanks at 13° C. Temperature effects on reproduction are likely to limit the southern extent of the natural range of *A. flavimanus.*

Larvae of *A. flavimanus* hatch after 28 days at a length of about 4.6 mm. The pelagic larvae range in size from 4.9–12.0 mm and feed on copepods. Settlement occurs when larve reach 15–20 mm (Dotu and Mito 1955). By aging individuals on the basis of scale annuli, Hoshino *et al.* (1993) were able to determine three age classes (0+, 1+, 2+). Male fish were found to mature at the end of their first year (0+) and females to mature at the end of their second year (1+).

Acanthogobius flavimanus was first recorded as an introduced species in San Francisco Bay in 1963 when two specimens were found in the Sacramento-San Joaquin River Delta (Brittan *et al.* 1970). It was estimated that the species was likely to have been introduced to the San Francisco area no earlier than 1959 (Brittan *et al.* 1970). Between 1993 and 1997 the numbers of *A. flavimanus* present in this region increased and the occurrence of small specimens (24–31 mm) indicated the presence of a breeding population. In 1967, large numbers of this species were found throughout the river delta and in areas outside and to the north of San Francisco Bay. Studies by Brittan *et al.* (1970) showed that between 1963 and 1967 the numbers of *A. flavimanus* increased only slowly as the goby spread rapidly through the area. However, around 1997 the species underwent a population explosion and occupied most of the suitable habitats in San Francisco Bay.

Between 1977 and 1980, Middleton (1982) collected 108 specimens of *A. flavimanus* (45–237 mm T.L.) from widespread localities in two Sydney estuaries, Sydney Harbour (16 sites) and Botany Bay (5 sites). Salinities at these sites ranged from 27.4‰–35.5‰ and temperatures between 12.3° and 27.0° C. Middleton classified the specimens collected in 1978 into age groups identified by Baker (1975) (0+ ≤ 101 mm, 1+ ≤ 140 mm, and 2+ ≤ 178 mm) and on the basis of the number of specimens in the 1+ age group, suggested that a successful recruitment had occurred in Sydney during 1977. As well as the specimens from Sydney, two specimens of *A. flavimanus* were collected from the Hunter River near Newcastle, approximately 120 km north of Sydney (Middleton 1982).

Bell *et al.* (1987) concluded that a breeding population of *A. flavimanus* was already established in the Hawkesbury River and suggested that this population may have resulted from the advection of larvae north from Sydney Harbour (the direction of prevailing currents) or from the translocation of mature adults by recreational vessels. The demersal nature of the eggs of *A. flavimanus* (Dotu and Mito 1955) and the winter flow regime of the rivers it inhabits were cited as reasons for the slow spread (approximately 13 years) of the species from Sydney up the coast to the Hawkesbury River System (Bell *et al.* 1987).

In the Sydney region, *A. flavimanus* is a typical opportunistic benthic carnivore consuming crustaceans (38%), detritus (22%), teleosts (13%) and polychaetes (7%). Juveniles (≤100 mm) feed predominantly on calanoid copepods and secondarily on polychaetes (Middleton 1982).

Comments

In Australian waters *A. flavimanus* appears not to have undergone a population increase comparable with that observed in San Francisco Bay. This may be the result of several factors including unsuitable temperature regime and competition with native species.

Middleton (1982) suggested that the water temperature in Sydney is too warm for *A. flavimanus* to breed beyond a point just sustaining its population. This species breeds in its natural habitat at temperatures of 7.5°–15° C and spawns in San Francisco during winter/spring when water temperature is at the lowest end of a 9°–24° C range. Water temperature in Sydney Harbour and Botany Bay ranges from 12.1°–26.7° C and 11.8°–27° C respectively. Female gonadosomatic index values for *A. flavimanus* in Sydney were highest during the late winter and early spring period, when water temperatures are lowest. While temperature may restrict reproduction in Sydney to some degree it seems unlikely that spawning is completely inhibited and that populations in the area are being maintained by continual re-introductions. This contention is supported by the collection of running ripe fish in Sydney Harbour during 1983 (Bell *et al.* 1987).

Another reason proposed by Middleton (1982) for the lack of an explosive spread of *A. flavimanus* is that of competition with native species. Hoese (1973) suggested that *A. flavimanus* might compete with *Arenigobius bifrenatus* or juvenile whiting, *Sillago* spp.

Tridentiger trigonocephalus (Gill)

Synonymy and Taxonomy

Triaenophorus trigonocephalus Gill 1858;
Triaenophorichthys trigonocephalus Gill 1859;
Tridentiger trigonocephalus Rendahl 1924;
Triaenophorichthys taeniatus Günther 1874;
Tridentiger taeniatus Reeves 1927;
Tridentiger bifasciatus Steindachner 1881;
Tridentiger bucco Jordan and Snyder 1901;
Tridentiger marmoratus Regan 1905;
Gobius fasciapectoralis Fowler 1938.

Common names

Shimahaze, trident goby, striped goby, tripletooth goby, chameleon goby.

The genus *Tridentiger* comprises seven species (*T. barbatus, T. bifasciatus, T. brevispinis, T. kuroiwae, T. obscurus, T. undicervicus*, and *T. trigonocephalus*), all characterised by trilobed teeth in the upper and lower jaws (Masuda *et al.* 1984).

Material

NMV A17540, NMV A17543, NMV A17552, NMV A17559, NMV A17578, NMV A17579, NMV A17583, NMV A17591, NMV A17605, NMV A17606, NMV A17618, NMV A17619, NMV A17948, NMV A17950, NMV A17952, NMV A17958, NMV A17959, NMV A18402, NMV A19510, NMV A19553.

Present Distribution

Tridentiger trigonocephalus is a native species of the North West Pacific. Originally described from China, it is recorded from Japan (Hokkaido to Kyushu), the Korean Peninsula and China (south to Hong Kong) (Masuda *et al.* 1984; Fowler 1961). This species generally inhabits areas with a hard substratum and is commonly found along the rocky coasts of Japanese bays (Masuda *et al.* 1984). The distribution of *T. trigonocephalus* was thought to extend into brackish water, but these reports may represent misidentifications of the brackish/freshwater *T. bifasciatus* (Akihito and Sakamoto 1989). *Tridentiger trigonocephalus* has also been introduced to the West Coast of the United States. It was first reported from Los Angeles Harbor in 1960 and subsequently, in 1966, from San Francisco Bay where it is now considered to be well established (Hubbs and Miller 1965; Brittan *et al.* 1970).

Australian Distribution

The first specimen of *T. trigonocephalus* collected in Australian waters was taken in 1973 from Sydney Harbour, NSW over seagrass (Hoese 1973). Specimens were later collected in 1976 in the Swan River estuary WA and then in 1977 in Port Phillip Bay, Vic (Paxton and Hoese 1985). The species is also abundant in Port Kembla NSW, south of Sydney (Pollard and Hutchings 1990). In all of these regions, *T. trigonocephalus* appears to maintain populations that have restricted distributions.

Port Phillip Bay Distribution

Tridentiger trigonocephalus is known to occur at sites from Altona on the western side of the bay continuously through Hobsons Bay and St Kilda in the north to Sandringham on the eastern bay (Figure 12.2). The species is found over hard substrates such as rocky reefs (e.g. Altona) and breakwaters (e.g. Sandringham, Breakwater Pier) as well as vertical and horizontal pier piles (e.g. Hobsons Bay). Specimens from Sandringham harbour may represent a disjunct population as specimens were not collected from sites between St. Kilda Pier and Sandringham.

Description

D. VI; I, 12-13. A. I, 10–11. C. (segmented) 17. P. 18–22. V. I, 5. LL.–.

Tridentiger trigonocephalus is separable from congeners by two black longitudinal stripes that run the length of the body (although sometimes not visible), the number of pectoral fin rays, the arrangement of head pores and the number of longitudinal scale rows.

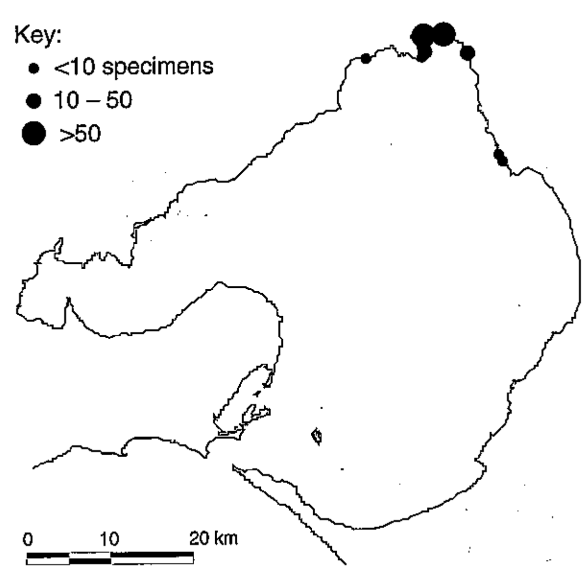

Figure 12.2. Distribution and abundance of *Tridentiger trigonocephalus* in Port Phillip Bay.

Body slender, head of moderate size, much broader than deep; interorbital space broad, about equal to or slightly less than eye diameter; mouth oblique, large, rear end of jaws just below middle to posterior quarter of eyes; teeth in jaws tricuspid; gill openings restricted to pectoral fin bases. Top of head scaled to behind eyes, 19–21 transverse rows of scales before first dorsal origin; body scales ctenoid (except on belly) in 45–55 vertical rows. Two dorsal fins; first dorsal low with rounded margin, originating above and just behind ventral fin insertions; second dorsal origin just behind first; anal fin origin below and just behind second dorsal origin. Pectoral fin with tips of upper two rays free from membrane. Ventral fins fused to form cup-shaped disc, originating below and just behind pectoral fin insertions (Hoese and Larson 1994).

Grey to brown, usually with black stripe from above and behind each eye along back to base of caudal fin; second black stripe from snout, through eye to upper portion of each pectoral fin base continuing along mid-side to base of caudal fin; stripes often absent in large fish being interrupted by banded pattern but often reappear after capture; fins clear to grey; dorsal fins often with brown horizontal stripes and scattered white spots; adults with broad yellow vertical bar at base of each ventral fin (Hoese and Larson 1994).

Potential Confusions

Tridentiger trigonocephalus can be distinguished from all other gobiid species in southern Australia by its unique tricuspid teeth. The two longitudinal stripes are also distinctive but the intensity of these stripes can be controlled by the fish in life. Larger specimens may be confused with *Bathygobius kreffti* in the field but the free upper rays of the pectoral fin in *B. kreffti* make it easy to recognise under the microscope. The species may also be confused with *Callogobius* spp. but lacks the distinctive raised flaps on the head that characterise fishes of that genus.

Ecology

Hirose and Kubo (1983) found the breeding season for populations of *T. trigonocephalus* near Tokyo to extend from May to August (summer) over a temperature range of 18° — 26° C. Specimens kept in experimental tanks were found to spawn up to 10 times during the breeding season with gonadosomal indices decreasing immediately after spawning, and then increasing over ten days to the next spawning. Larvae hatch from eggs 7–10 days after spawning at a length of about 3 mm (Hirose and Kubo 1983). Dotu (1958) found that spawning of *T. trigonocephalus* in Ariake Sound took place in April to June and incubation lasting 8.5 days at 20° C. Fish ages based on scale annuli indicated 35–50 mm fish to be in a 0+ age group and 55–75 mm individuals to be in a 1+ class, with few individuals reaching an age greater than this (Dotu 1958).

Little is known about any aspect of the biology of *T. trigonocephalus* populations in Australian waters. Sampling at a site near the commercial region of Sydney Harbour has shown this species to be abundant with densities estimated to be 2-3 m^{-2} and sampling of a similar habitat in Port Kembla revealed similar numbers (Pollard and Hutchings 1990). At both of these sites, *T. trigonocephalus* represented the highest biomass of fish collected (Pollard and Hutchings 1990). The species is presently one of the most common in disturbed habitats in Sydney Harbour (D Pollard pers. comm.). A similar trend was observed in Port Phillip Bay during sampling for a recent study, with *T. trigonocephalus* being the most abundant benthic species at disturbed sites (e.g. Ann Street Pier and Station Pier).

During the second period of sampling for this study (February) a substantial number of juveniles were taken from the commercial area of Hobsons Bay with very high numbers observed on all examined pier piles. This observation suggests that *T. trigonocephalus* had spawned shortly before this sampling trip, a hypothesis supported by the high level of gonad development of adults collected in earlier sampling (November/December) and results of studies in Japan which have shown this species to be a summer spawner. Cunningham (1998) found larvae of *T. trigonocephalus* only in December, February and March.

Comments

While *T. trigonocephalus* has been present in Australia for over twenty years it appears to have the most restricted distribution of the four introduced marine fishes in areas where it has become established. Masuda *et al.* (1984) state that *T. trigonocephalus* "inhabits rocky coasts along the shores of bay". Gill and Potter (1993) found that *T. trigonocephalus* was restricted to the only rocky area in the Swan River estuary and suggested that the lack of suitable habitat was a factor in the failure of *T. trigonocephalus* to successfully colonise the region. However the distribution of *T. trigonocephalus* in both Sydney and Melbourne estuaries is restricted despite the presence of what appear to be other suitable habitats close to areas that are heavily populated by this species. In Port Phillip Bay the species is most abundant in a small commercially developed area of Hobsons Bay. The density of individuals declines rapidly outside this region and only low numbers of individuals occur on rocky substratum along the nearby coasts at Altona and Williamstown.

Acentrogobius pflaumi (Bleeker)

Synonymy and Taxonomy

Gobius pflaumi Bleeker 1853;
Rhinogobius pflaumi Matsubara 1955;
Ctenobius virgatulus Jordan and Snyder 1901;
Coryphopterus virgatulus Jordan and Starks 1905;
Rhinogobius virgatulus Jordan *et al.* 1913;

Ctenogobius pflaumi Fowler 1961;
Acentrogobius pflaumi Prince Akihito, in Masuda *et al.* 1984.

Common names

Sujihaze (Japan).

Material

NMV A18398, NMV A18403, NMV A18461, NMV A18716, NMV A19500, NMV A19502, NMV A19503, NMV A19555, NMV A19558, NMV A19565.

Present Distribution

First described from Nagasaki, Japan, *Acentrogobius pflaumi* is native to the North West Pacific occurring naturally in Japan (from Honshu southward), the Korean Peninsula, Taiwan and the Philippines (Fowler 1961; Masuda *et al.* 1984).

Australian Distribution

In Australia, this species is only known to occur in Port Phillip Bay, Victoria.

Port Phillip Bay Distribution

The first specimen of *Acentrogobius pflaumi* was collected by the Marine and Freshwater Resources Institute (MAFRI) in November 1996 from the Melbourne docklands region adjacent to the mouth of the Yarra River. Further sampling conducted by the Museum of Victoria in late 1996 only recorded *Acentrogobius pflaumi* from soft sediments around pier piles in the Victoria Dock region in the lower reaches of the Yarra River. The species was absent from samples collected during an exotic species survey of Port Phillip Bay (Dec 1995 and Feb 1996, see methods section) which included sites near the mouth of the Yarra River (approximately 3 km downstream from Victoria Dock) and Corio Bay. In August, 1997 it was present in both benthic grab and sled samples taken in Corio during an exotic species survey of the Port of Geelong by MAFRI (D Currie MAFRI pers. comm.).

During a study of newly settled snapper (*Pagrus auratus*) in Port Phillip Bay, Hamer *et al.* (1997) sampled fishes from December 1996 to April 1997 using a small beam trawl. *Acentrogobius pflaumi* was the eighth most abundant species collected using this gear and was present in all regions of the bay except the entrance (Hamer *et al.* 1997). It is apparent that *A. pflaumi* presently inhabits soft substrata throughout Port Phillip Bay and the lower reaches of the Yarra River, and that it is relatively abundant in these regions.

Description

D. VI; I, 9–10. A. I, 10. C. (segmented) 17. P. 17–19. V. I, 5. LL.–.

Acentrogobius pflaumi is separable from other species of this large genus in having the following features: 10 segmented anal fin rays, 25–27 scales in a longitudinal series along each side, 8–10 predorsal scales, black band extending from front of eye downward to the posterior margin of the upper jaw, black blotch centrally on operculum, short black stripe immediately behind eye, black blotch at the rear of the head just above the upper end of the operculum, medial membrane on underside of lower jaw dark; series of five dark blotches mid-laterally on sides, the last persisting as prominent dark spot on base of caudal fin; series of thin longitudinal lines following scale rows and rows of small electric blue spots on each side in life.

Body slender, head of moderate size, about as broad as deep; interorbital space very narrow, eyes virtually adjacent to one another; mouth oblique, large, rear end of jaws below middle of eyes; teeth in jaws conical; gill openings restricted to pectoral fin bases. Scales covering top of head forward about 2/3 of way from dorsal fin origin to eyes, in about 8–10 rows; body scales cycloid, in 25–27 vertical rows. Two dorsal fins; first dorsal short with rounded margin, originating above and just behind ventral fin insertions; second dorsal origin just behind first; anal fin origin below second dorsal origin. Pectoral fin with tips of upper two rays free from membrane. Ventral fins fused to form cup-shaped disc, originating below and just behind pectoral fin insertions.

Pale grey to brown, with series of about 5 blotches of varying intensity in mid-lateral row on sides, the last usually large and distinctive, positioned at base of caudal fin; sides in life usually with narrow dusky horizontal lines following scale rows and electric blue spot at center of many scales laterally; head with black band extending from front of eye downward to upper jaw, short black stripe immediately behind eye, 3 fainter horizontal stripes below eye; black blotch centrally on operculum, and black blotch (blue in life) at rear of head just above upper end of operculum; membrane on isthmus of lower jaw blackish. Fins mostly transparent, anal and pelvics rather dusky, rays finely speckled.

Potential Confusions

Within Port Phillip Bay this species most closely resembles *Arenigobius bifrenatus* and *A. frenatus*; the genera *Acentrogobius* and *Arenigobius* considered to be quite closely related. Both species of *Arenigobius* lack scales on the head in advance of the dorsal fin, and differ in many aspects of coloration, having angled stripes or series of small blotches rather than the prominent mid-lateral blotches of *A. pflaumi*.

Ecology

In Japan *Acentrogobius pflaumi* inhabits brackish waters in the lower reaches of rivers (Masuda *et al.* 1984; H Larson pers. comm.). In southern Japan *A. pflaumi* occurs over seagrass beds (*Zostera* sp.) and sand flats between April and June, and then aggregates within the seagrass beds from July to March (Matsumiya *et al.* 1980).

The spawning season in this region extended from May to August (summer). Uchida and Dotsu (1980) reared larvae and juveniles of *Acentrogobius pflaumi* in sea water ranging between 26° and 28° C. Larvae hatched at 2.7 mm and developed to a length of 10 mm after approximately 30 days at which time they assumed a benthic juvenile life style (Uchida and Dotsu 1980). The diet of *A. pflaumi* consists of copepods during the early life stages and mainly gammaridean amphipods at around 50 mm TL.

At each of the three sites where *A. pflaumi* has been collected in Victoria Dock, it was the most abundant species present. In three collections a total of 36 specimens were taken, contrasting with 3 specimens each of the native *Callogobius mucosus* and the exotic *Acanthogobius flavimanus*, the next most abundant species collected.

Comments

Taxonomically, *Acentrogobius* and closely allied genera are in need of major revision. The limits of these genera are poorly defined and species within natural groups appear to be confused. As a result many of the species have been referred to a number of proposed genera and full synonymies for species like *A. pflaumi* are absent from the literature.

Although apparently the most recently introduced species, *A. pflaumi* appears to be abundant and widely distributed throughout Port Phillip Bay (Hamer *et al.* 1997) and may be the most successful of the four introduced marine fishes in the bay. In a recent study of larval gobiids, Cunningham (1998) found this species to be the most abundant and broadly distributed of the three introduced gobies.

Forsterygion lapillum (Hardy)

Synonymy and Taxonomy

Tripterygium nigripenne Gunther 1861;
Tripterygion capito Grace 1971;
Tripterygium capito Ayling and Cox 1982;
Forsterygion capito Anderson 1973;
Forsterygion sp. Francis 1988;
Forsterygion lapillum Hardy 1989.

Common names

Common triplefin

The genus *Forsterygion* contains six species (*F. bathytaton, F. flavonigrum, F. lapillum, F. malcolmi, F. profundum and F. varium*) distributed throughout New Zealand and south-eastern Australia. Most species occur in shallow, coastal waters but one, *F. bathytaton* is found offshore at depths to 550 m.

Material

NMV A17483, NMV A17484, NMV A17488, NMV A17489, NMV A17621, NMV A17790, NMV A18146, NMV A18148, NMV A18616, NMV A19695

Present Distribution

Initially described from Goose Bay, Kaikoura, *Forsterygion lapillum* is common and widely distributed in the rockpools and subtidal regions of New Zealand's North and South Islands. It is absent from the Three Kings, Snares and Chatham Islands (Hardy 1989).

Australian Distribution

Only recorded from Corio Bay in the south-western region of Port Phillip Bay.

Port Phillip Bay Distribution

Forsterygion lapillum was collected at 7 sites in Corio Bay in the south-western corner of Port Phillip Bay, the site of the commercial Port of Geelong. The species occurs on shallow rocky reefs and artificial structures such as breakwater walls and pier pilings. Although one specimen was collected from a pier at a depth of approximately 10 m, all others were taken in shallow (1–3 m) reef environments, just below the intertidal region. The population appears to be restricted in its distribution; sampling at adjacent localities has resulted in only one specimen being collected outside Corio Bay.

Description

D. V-VII, XIX–XXII, 9–10. A. II, 24–27. C. P. 17–19. V. I, 3. LL. 19–25 + 14–25.

Species of *Forsterygion* are distinguishable from other tripterygiids in having 5–8 spines (versus 3–4 in Port Phillip Bay species) in the first dorsal fin. *Forsterygion lapillum* differs from other tripterygiid species in lacking scales on its head and nape, and in having a lateral line with 19–25 tubular scales (anterior) and 14–24 notched scales (posterior). The species is very similar to *Grahamina* spp.

Body slender, head of moderate size; snout profile steep; interorbital space less than half eye diameter; mouth horizontal, large, rear end of jaws below middle of eyes; eye with trilobed fleshy supraorbital tentacle dorsally. Head and most of nape without scales or spines; two predorsal scales present immediately anterior to dorsal fin origin; body scales ctenoid, in 41–47 vertical rows, present on posterior sides of belly. Three dorsal fins; first dorsal low in both sexes, ascending to tip of first spine of second, originating above hind margin of preopercle; second dorsal origin immediately behind first, with longest base and tallest of the three fins; third dorsal arising immediately behind second, almost as tall as second anteriorly, decreasing rapidly to very short last ray posteriorly; anal fin long and low, originating below about 9th ray of second dorsal. Pectoral fin reaching beyond middle of second dorsal. Ventral fins each reduced to a spine and 2 rays, inserted below and in front of pectorals, beneath centre of opercula.

Mostly grey, males blackish, often developing a lattice-like pattern during breeding, sometimes with red dorsal fins; females with a longitudinal black streak running from post-temporal region of head above lateral line to caudal fin. Small specimens often whitish or yellowish, with dark reddish vertical fins; tips of anal fin rays bluish white (Fricke 1994).

Potential Confusions

In Port Phillip Bay *F. lapillum* occurs with the somewhat similar *Norfolkia clarkei* but can be distinguished from it by the lack of scales on the head, a greater number of spines in the first dorsal and a distinctly different colour pattern.

Ecology

Hardy (1989) described *F. lapillum* as "a ubiquitous inhabitant of tidal pools and sub-tidal rocky reefs around New Zealand" being most commonly found in shallow water (0–5 m) but reaching to depths of 30 m. The species is most abundant among cobbles or patches of small loose boulders. Willis and Roberts (1996) found this species to be the third most abundant species sampled from rock pools near Wellington on the North Island. In the subtidal regions, *F. lapillum* can reach densities of 2,700 fish per hectare (Fricke 1994).

The species is a benthic carnivore consuming small crustaceans and polychaetes but may also act as a cleaner fish, removing parasites from larger fishes. Adults reach an age of about three years and spawn between June and January. Eggs are attached to the underside of rocks and hatch in about 20 days. Newly hatched pelagic larvae average 4.9 mm in length and settle out into shallow regions from September to February. Juveniles mature in their first year at a length of about 45–55 mm (Fricke 1994).

With the exception of a single site immediately outside Corio Bay, *F. lapillum* was usually the most abundant species taken at rocky reef sites where it occurred (6 sites). Peak concentrations occurred in shallow sites as they do in its preferred habitat in New Zealand. A total of 156 specimens were collected in the course of sampling. The next most abundant species collected at these sites was the native tripterygiid *Norfolkia clarkei*, represented by 58 specimens. Sampling indicated that *F. lapillum* has not only occupied, but is also abundant in all areas where its preferred habitat exists in Corio Bay.

Comments

Its restricted distribution in an industrialised region of Port Phillip Bay and the fact that the species has not previously been recorded from anywhere in Australia suggests that *F. lapillum* is likely to have been introduced to Australia from New Zealand. While it is possible that this occurrence represents a natural range expansion, this is considered unlikely as the species is not recorded from the entrance to Port Phillip Bay or from coastal regions elsewhere in Victoria or Tasmania. Furthermore the species is absent from suitable habitats around islands close (approximately 100–800 km away) to New Zealand (Hardy 1989).

12.7 DISCUSSION

Little is known about the ecology of the introduced fishes in their native regions, and less so in the parts of Australia into which they have been introduced. The larger amount of information available on introduced species from the North West Pacific is a result of the higher emphasis placed on the study of these taxa in Japan. The numbers of fishes recognised as having been introduced will certainly increase as taxonomic and distributional knowledge of these poorly studied groups improves.

The introduction of these fishes is enhanced by aspects of their biology that predispose them to both the initial transport by ballast water and subsequent colonisation of new regions. Characteristics such as wide temperature and salinity tolerances mean native physical parameters only have to be approximated for individuals to thrive. Thus it seems likely that additional species will be introduced in the future unless concerted efforts are made to control their artificial movements.

12.7.1 Status and potential for spread

Together, *A. flavimanus* and *T. trigonocephalus* were two of the most abundant species of goby in Port Phillip Bay. *Tridentiger trigonocephalus* has been known from this locality since 1977 and while the species appears to be reasonably abundant in port areas, it occurs in low numbers outside these regions, suggesting the presence of biological factors limiting its dispersal. *Acanthogobius flavimanus* apparently colonised later (Gomon *et al.* 1994) but is distributed more widely throughout the estuary.

Middleton (1982) speculated that although water temperature in Sydney may be too high for *A. flavimanus* to greatly increase its numbers, temperatures in Port Phillip Bay which range from 10°–22° C, may make it a more favourable environment. It follows that water temperature in Tasmania would also provide a suitable habitat for the reproduction of *A. flavimanus*. This species has only been present in Port Phillip Bay for approximately eight years and although widely distributed, it may not have realised its full potential in this region. In San Francisco Bay *A. flavimanus* became one of the most abundant species approximately eight years after being introduced. Hirose and Kubo (1983) showed that *T. trigonocephalus* breeds at a higher temperature than *A. flavimanus* and as such may be more suited to colonising bays and estuaries in warmer regions of southern Australia. Of the two species, only *T. trigonocephalus* is currently known to occur in the Swan River Estuary, WA, where water temperature range from around 12° to 27° C (Gill *et al.* 1996).

Acentrogobius pflaumi has only been recorded from Port Phillip Bay for a short period of time yet it is already widely distributed. A recent study of the gobiid larvae of Port Phillip Bay has shown *A. pflaumi* to be the most widely distributed and abundant larval species of the three introduced gobiids. *Forsterygion lapillum* is also a recent introduction to the region and while not as widespread as *A. pflaumi* it is abundant in its preferred habitat throughout Corio Bay and may conceivably expand its range in the future. Unlike the three gobies, it seems to occur in high numbers in less disturbed hard substrate habitats and may be capable of colonising naturally occurring reefs. Of all the introduced species this one may be the most suited to physical conditions in Australian waters given its broad distribution throughout New Zealand.

12.7.2 Impacts

As few studies on the biology of these introduced species have been done in Australian waters, it is impossible to say what impact they have had, or may have, on Australian ecosystems. The most obvious impact may involve competition with native fauna. In addition to unfavourable physical parameters, it may be this factor that limits their abundance and distribution. As most gobies are benthic carnivores preying largely on small invertebrates (Hoese and Larson 1994) it is probable that introduced gobies will compete for food with other members of the family.

In this study *T. trigonocephalus* was collected with *Callogobius mucosus* and *Arenigobius bifrenatus*, while *A. flavimanus* occurred with *Nesogobius* sp., *Favonigobius lateralis, Arenigobius bifrenatus*, and others (Appendix A, Table A6). In addition, many species of other families are benthic carnivores (Parry *et al.* 1995) and may also be competitors. Since both *A. flavimanus* and *T. trigonocephalus* have specific habitat requirements it is possible that they will also enter into competition with species sharing their preferred habitats.

Acanthogobius flavimanus inhabits seagrass beds over soft substrates and may compete with gobies such as the variety of *Nesogobius* species occurring in these areas, as well as more distantly related species like *Ammotretis rostratus, Rhombosolea tapirina, Heteroclinus perspicillatus* and *Cristiceps australis*. As *T. trigonocephalus* occurs over rocky reefs and areas with similar complex substrates, it may compete with native reef dwelling species such as *Callogobius mucosus, Parablennius tasmanianus, Bovichtus angustifrons, Norfolkia clarkei, etc.* (Appendix A, Table A6).

Both *A. flavimanus* and *T. trigonocephalus* are known to carry several parasites, including one causing tumorous lesions on the skin of *A. flavimanus* (Kazuhiko *et al.* 1984; Shinkawa and Yamazaki 1987). This parasite is known to affect other species of fish in Japan and is believed to be present throughout most of the northern Pacific. Although the parasite doesn't seem to have a major impact on *A. flavimanus* in its natural range, its effect on Australian native species is unknown.

Further research is required on all of the introduced fishes mentioned above if any insight into their potential or present impacts is to be gained.

12.7.3 Translocation

Both *Acanthogobius flavimanus* and *Tridentiger trigonocephalus* occur in widely separated geographic regions in southern Australia. In addition to the possibility that these species have been separately introduced to each of these regions from Japan, they may have also been translocated by commercial shipping or recreational vessels. Since approximately 12% of ballast water entering Australian ports originates from ports within Australia (Jones 1991), it is possible that *A. flavimanus* and *T. trigonocephalus*, may have been introduced to different regions of Australia in this way and that *Acentrogobius pflaumi* and *Forsterygion lapillum* may be similarly translocated. Translocation by recreational vessels has been suggested for the spread of *A. flavimanus* from Sydney Harbour to the Hawkesbury River system, an estuary north of Sydney that is not a port for commercial shipping (Bell *et al.* 1987).

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13 INTRODUCED FOULING SPECIES IN PORT PHILLIP BAY

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13.1 INTRODUCTION

The term fouling has been used to describe the assemblage of sessile organisms that are found attached to hard substrata such as pier pilings, boat hulls, buoys, etc., as well as natural substrata. The term refers generally to these assemblages in ports and harbours, although hard substrata in more open environments are also covered by sessile organisms. In most cases, animals dominate these assemblages where they occur in either well-shaded environments or turbid water. Plants occur in the better-lit sections, but they have been relatively ignored in ecological studies.

We here focus on the fouling assemblages in Port Phillip Bay and identify components of that biota that are likely to be introduced, providing the possible dates, times and modes of those introductions. We also consider what is known of the current distribution of each species and indicate any information that exists to suggest the impact of these organisms on native species. Of the three major previous reviews of ballast-water introductions, Jones (1991) either did not find or did not report any fouling species considered to be introduced. Hutchings and colleagues (Hutchings *et al.* 1987; Pollard and Hutchings 1990) reported a substantial number of introduced species (some nudibranchs, three ascidians, two polychaetes, one hydroid and five species of bryozoans and a range of algae), although not all of these organisms have been reported from Victoria or Port Phillip Bay.

The current distribution of many species is poorly known and an accurate estimate of present ranges would require extensive field surveys.

13.1.1 Fouling organisms of Port Phillip Bay

Fouling organisms are drawn from a wide range of phyla, with wide variation in the extent of surveys and the amount of taxonomic knowledge of the group. The major groups, in terms of species richness, are ascidians, bryozoans, sponges and hydroids, then a few families of polychaetes, acorn barnacles and some molluscs. Numerically, or in terms of biomass, most fouling assemblages around Port Phillip Bay are dominated by a combination of ascidians, barnacles, bryozoans and sponges, with the dominant group varying around the bay. Below, we summarise the knowledge about each of these major groups.

Ascidians

Since the early 19th century, several collections of the class Ascidiacea from Australian waters have been compiled (e.g. Quoy and Gaimard 1834; Herdman 1899; Millar 1966). In assembling this review of fouling ascidians introduced to Australia, it became apparent that the paucity of studies would make an accurate determination of the time of introduction difficult. In particular, there was no major work devoted to the ascidian fauna of Victoria prior to the 1957–63 Port Phillip survey reported on by Millar (1966). In most cases, we have given the earliest collection record as the date of introduction. Where facts are available to accurately document the time of introduction, we have done so. These facts may include density of populations when first encountered or absence in collections in localities where the species was subsequently abundant.

It is also difficult to clearly identify species as introduced, as many of the ascidians that are likely to be introduced were recorded in the earliest surveys. Most authors consider these species to be introduced, because they have restricted local distributions and very short larval periods, yet are found in temperate ports and harbours around the world. The larval periods of ascidians generally range from a few minutes to hours for colonial species, to a few days for solitary ascidians.

In general, our knowledge of ascidian distributions is poor. The ascidian fauna of southern Australia is very diverse, so collections from a site potentially include a large number of species. A comprehensive assessment of the distribution of these species would require very extensive collections. It is not possible to map distributions of most species by simple field observations. With the exception of a few characteristic taxa (e.g. *Ciona*, *Pyura stolonifera*, *Podoclavella/Clavellina*, *Sycozoa cerebriformis*), they are difficult to identify in the field and for most species, diagnostic characters are internal and specimens must be dissected to identify them. Dissection is difficult for many of the colonial species, because the individual zooids are tiny. Australia has only one ascidian systematist (P Kott), so most of the information about ascidians in southern Australia is the result of her examination of collections in the Museum of Victoria, with those collections resulting disproportionately from the efforts of a few individuals.

Bryozoans

Bryozoans are ubiquitous members of fouling assemblages, occurring as either heavily calcified encrustations or bushy, arborescent growth forms. They have been surveyed in southern Australia since the latter parts of last century (MacGillivray 1879, 1887a, 1887b, 1889) followed by a large gap until the Port Phillip Bay surveys (Vigeland 1971). Almost all bryozoans reproduce via brooded larvae. These are fertilized within the parental zooid and retained there before being released as a short-lived, non-feeding stage. For most species that have been studied, larvae survive for hours to days, coupled with weak swimming abilities, means that they are unlikely to disperse over very long distances. Around major ports, they are generally restricted to areas of relatively high salinity and rarely extend into waters of reduced salinity.

As with the ascidians, the bryozoan fauna of southern Australia is very diverse (Bock 1982), but in contrast to ascidians, the diagnostic characters are mainly external skeletal features of individual zooids of the colony. However, these zooids are generally < 1 mm long, so there is a problem with potentially a large number of species in any field collection, many of which can only be distinguished after microscopic examination. Only a few species can be identified readily in the field (e.g. *Bugula dentata*, *B. neritina*, *Mucropetraliella* spp.). Bryozoans have received less extensive systematic examination than the ascidians in Australia, with the result that a substantial proportion of common shallow water families or genera are in desperate need of revision and/or clarification (e.g. *Celleporaria*, *Watersipora*). We have identified those species whose taxonomic status is uncertain but we emphasise that it is difficult to generate accurate distribution records for these species.

Sponges

It is generally difficult to identify sponges in the field and most ecological studies have provided only crude and often inconsistent, identifications. Wiedenmayer (1989) has given the most comprehensive account of the sponges of southern Australia. His account is, however, primarily systematic, with little information on distributions and based primarily on material collected in northern Bass Strait, rather than Port Phillip Bay. Wiedenmayer lists nine species with very broad or primarily Northern Hemisphere distributions (his "Tethyan" species of Table 5). Bergquist and Skinner (1982) provide a systematic guide to some of the more common southern Australian sponges. Bergquist (1996) described some additional species that she regarded as introduced, as well as lists of common sponges from a range of locations around Port Phillip Bay.

Overall, this group is very difficult to identify and the biogeography of local species is poorly known.

Hydroids

Hydroids are an important part of fouling assemblages: and are diverse in Port Phillip Bay, but they are often omitted in ecological studies. The hydroids of Port Phillip Bay are described elsewhere in this volume (Chapter 7) and are not presented in detail here.

Polychaetes

Three polychaete families are common members of fouling assemblages, the Sabellidae, which build sandy tubes and the Serpulidae and Spirorbidae, which build calcareous tubes. The latter two families are sometimes assigned sub-familial status and in the past have often been pooled into the Serpulidae. The Sabellidae have received some attention recently, with the arrival of *Sabella spallanzanii* in Port Phillip Bay, but not all of the common Australian species have been described. The Serpulidae and Spirorbidae have received only sporadic attention and in general, these families are in need of detailed examination. With few systematists and a great diversity of soft-sediment polychaetes, these families have been regarded as lower priorities for attention. Consequently, it is difficult to assess the geographic affinities of the Australian fauna.

Barnacles

Barnacles are often abundant in sheltered ports and harbours and as for the other groups, it is presumed that there is a substantial exotic component to the fauna of Australian harbours. They would benefit from close taxonomic inspection, as common genera, primarily *Balanus* and *Elminius*, have histories of substantial taxonomic revision, so that the distributional records of some species, particularly of *Balanus* and *Elminius*, present in Australian ports, are not clear.

Molluscs

Molluscs can be important parts of some fouling communities. The most abundant groups tend to be mussels and oysters. In Port Phillip Bay, mussels are common in sheltered harbour environments, but oysters are rare. Hutchings *et al.* (1987) list the Pacific oyster, *Crassostrea gigas*, as a possible introduction into Victoria in the early 1950's. These oysters are not found in fouling assemblages in Port Phillip Bay. We note that there have been plans to farm this species in eastern Victoria. The most notable species with respect to fouling communities are two predatory species of nudibranch, which prey on bryozoans. The nudibranch fauna of Victoria is well described, through a long history of collection by Burn

(1989 and references therein). Similarly, the molluscan fauna has a long history of systematic treatment, although nomenclature has changed frequently.

13.1.2 Potential for translocation

Fouling organisms can be readily transported as larval stages either in ballast water or as attached adults on hulls. Transport over longer distances as larvae is likely to be restricted to a relatively small number of species, as the majority of species discussed here possess short-lived, non-feeding larvae. These larvae are presumed to spend up to a few days in the plankton with many spending only a few hours before settling. They might therefore be expected to travel as larvae in ballast only on short trips, when the time between ballasting and de-ballasting is only a few days. The major exceptions are organisms such as barnacles, which go through a more prolonged planktonic development, lasting in many cases 2–4 weeks. These species could survive as larvae over longer voyages.

Fouling organisms can also be transported easily on hulls. The adults are often firmly attached and offer the potential for mature organisms to be transported to new areas. These animals could be dislodged as part of mooring procedures or hull cleaning activities. They could then continue growing and in some cases reattach if they encounter hard substrata. In addition to dislodgment, a potential problem is the release of larvae by these adults. Many of the colonial fouling species (colonial ascidians, most bryozoans, many sponges) brood their larvae, retaining eggs that are fertilized and develop in internal brooding structures. Development often takes weeks, so these animals would not rely on encountering suitable mates on arrival in a new port. The release of a brood of larvae, particularly brooded larvae, which are thought to have higher survival than larvae that have extensive planktonic development, could provide a significant initial inoculum to a new port.

A relatively neglected option for these species is dispersal by fragments. The colonial species are more correctly termed modular, with colonies composed of large numbers of physiologically independent units (polyps, zooids, etc.). This growth form means that pieces of a colony can be broken off and can survive and grow, in contrast to unitary (or solitary) animals, such as barnacles, where the removal of a large proportion of tissue is likely to be fatal. Broken fragments of colonies are often seen in the water column and could be taken up in ballast water and released on deballasting. The capacity to grow from these fragments will vary widely among fouling species, but it does offer another means of surviving longer voyages in ballast water and depositing reproductively capable colonies in a new port.

13.1.3 Introductions to Australia

Fouling organisms that are presumed to be exotic have a long history in most major ports. Many of the species described here are likely to be found in temperate harbours all over the world and many have been described in early surveys around the Sydney region and in Adelaide.

Details are provided for approximately 50 introduced or probably introduced species that occur in assemblages of fouling species in southeastern Australia. We have not considered a range of other sessile animals that may be introduced, but which are not part of fouling assemblages on hard substrata, nor have we considered species that are present in northern parts of Australia. Expansion of reviews to consider either of these categories would increase the list of introduced species substantially. For example, Kott, in her comprehensive review of the ascidian fauna of Australia (Kott 1985, 1990a, 1990b, 1997), describes a range of other species that, from their distributions, are likely to be introduced, but which are not recorded from Victoria.

It is impossible to determine confidently which species are introduced, because many species have been present since the earliest faunal surveys of this region. In many cases, however, the species are confined to ports and harbours in both hemispheres, yet have restricted larval dispersal. It seems very likely that such species dispersed via ships, rather than postulating trans-oceanic and trans-continental larval dispersal, with few described stepping-stones.

In most cases, it is not possible to identify the mode of introduction of these species, although the occurrence of many species predates the use of ballast water, so they most likely arrived attached to ships hulls. Only the recent arrivals have the potential to have been transported via ballast water, but even in those cases, it is feasible that transport occurred as established organisms attached to hulls. In the case of hull transport, larval release on arrival in port is the most likely means of final introduction.

13.1.4 Spread of introduced species

Many fouling species do not appear to have spread widely beyond sheltered ports and harbours, or to have colonized natural reefs extensively. The primary exceptions to this are the ascidians *Styela plicata*, *Botryllus schlosseri* and *Botrylloides*, the bryozoans *Tricellaria occidentalis*, *Cryptosula pallasiana* and *Watersipora subtorquata* and the polychaete *Sabella spallanzanii*. Of these, the compound ascidians, the bryozoan *Watersipora*, and the fanworm *Sabella* are capable of becoming numerically or competitively dominant and seem likely to have the greatest effect. We emphasize, however, that there are no studies of the impacts of *Watersipora* or *Sabella* and as mentioned before there is uncertainty about the identification and therefore distributions, of the botryllinid ascidians.

The rate of spread has varied widely. Some of the species that have remained uncommon or localised were introduced last century. Other species introduced at the same time have spread widely. Among the species known to be recent introductions, we also see contrasting rates of spread, exemplified by the two species of *Watersipora*. In this case, two closely related species have spread to very differing degrees and there is no ecological information that would allow us to understand why such a difference has occurred.

Gordon and Mawatari (1992) suggested that the successful expansion of this species, along with *Cryptosula pallasiana*, may be a result of their having little morphological specialisation. In contrast to many other bryozoans, these species do not have extensive spination, nor do they produce specialized structures, such as avicularia or sexually dimorphic zooids (e.g. *Celleporella hyalina*). The other successful bryozoan invader is *Bugula neritina* and it is interesting that it, too, has no spines or avicularia and is morphologically the simplest species of *Bugula*. If this suggestion is correct, the most likely mechanism may be that these species are habitat generalists. Alternatively, they may be good candidates for cryptogenic species, as most taxonomic work is based on external skeletal characters.

Around Port Phillip Bay, introduced fouling species do make up a major component of the sessile fauna. For example, at Breakwater Pier, Williamstown, the physical structure of the sessile assemblage is provided by dense mats of the solitary ascidian *Pyura stolonifera*, with a mixture of introduced solitary ascidians (*Styela* and *Ciona*) interspersed with them.

In isolated clearings and on ascidian tests there is a range of bryozoans, most of which are introduced: four species of *Bugula*, only one of which is native, *Tricellaria*, *Cryptosula* and the native *Celleporaria* and *Mucropetraliella ellerii*. A range of colonial ascidians, including the botryllinids, also grows over the ascidian tests. In very shallow subtidal areas, the dominant space occupiers are *Galeolaria*, *Watersipora* and *Elminius modestus*. This situation is also common in the Geelong Arm, with *Sabella spallanzanii* providing additional physical structure.

Limitations

Distributional records of most species are very poor, with no systematic surveys of the fauna and consequently little information about the rate of spread of various introduced species. The lack of surveys also prevented us from estimating the time of arrival of most species. This problem can not be remedied. It is not clear what value simple surveys of existing introduced species will have, when we can not identify the time scale over which range expansions have occurred. In addition, many of the earliest records do not have precise location details, so it is not possible to resurvey areas to identify distributional changes. As mentioned for *Bugula flabellata*, one can in many cases not distinguish between material attached to substrata at a locality and material washed up on the beach. In the latter case, the animals may have been transported a considerable distance.

13.2 TAXONOMY AND SYSTEMATICS

13.2.1 Ascidians

In covering the ascidians, we have not provided detailed synonymies. Unlike the other faunal groups discussed here, the ascidians are covered in a series of major publications, which provide exhaustive synonymies and full details of material available (Kott 1985, 1990a, 1990b). Identification of Australian material cannot be made without reference to these sources and the keys found in the more recent description of the southern Australian fauna (Kott 1997), so full synonymies will also be available to any researchers working on this group.

Similarly, detailed descriptions of individual species are not appropriate. With the exception of a few easily identified species, such as *Ciona intestinalis* and adult *Styela plicata* and *S. clava*, material can not be identified easily *in situ* and requires dissection. In the case of most presumed exotic species, there is a whole range of native species that could easily be confused with the exotic one. Sometimes, the native species may be congeners (e.g. *Botrylloides* spp.), but in other cases, it is animals from different sub-orders that may not be separable without some dissection. We have therefore only noted species that are easily recognized; for all other taxa, full working through taxonomic guides is necessary.

Phylum Chordata

Class Ascidacea

Suborder Aplousobranchia

Family Cionidae

Ciona intestinalis (Linnaeus 1767)

Synonymy and taxonomy

See Kott (1990a, p. 21).

Native range

C. intestinalis is a cosmopolitan species, recorded from harbours in all regions except the Antarctic and is assumed to have been distributed around the world on ships' hulls (Kott 1976a).

First recorded collection in Port Phillip Bay

This species has been known from Australian waters from at least the 1870's when Heller (1878) recorded it from Port Jackson NSW. This species was first recorded in Victorian waters in the Port Phillip Bay Survey in Corio Bay in 1958 (Miller 1966).

Subsequent distribution

Victoria: This ascidian has been recorded from Artificial Reef, Hobsons Bay, Yarra River, Portland Harbour, Port Melbourne and Beacon Point, Werribee (Kott 1976a; Russ 1977; Watson 1978; Spencer 1972; Holmes 1982; Kott 1990a). It also occurs at Point Wilson and in Corio Bay.

Distribution

The Australian records are all from harbours and port installations and several are from brackish locations well up river estuaries, indicating that its distribution is likely to be due to the movements of shipping. In South Australia, the species occurs through the Port River, but has also colonised some locations by larval dispersal. It was abundant in West Lakes (Keough 1983), an artificial sea water lake that drains into the Port River, but receives water from 5–10 km south of the Port River's mouth. It is not known whether substantial populations occur near the sea water intake, but the intake pipes are > 500 m long, so some dispersal has occurred.

Description

A solitary ascidian with a thin, transparent test and an elongated body. As an aplousobranch, the gut loop is behind the pharynx, in contrast to the other two sub-orders. Gonads are in the gut loop. This ascidian is figured in many zoological texts.

Potential for confusion with native species

None. This species is easily recognisable in the field. The aplousobranch nature of this ascidian can be seen in living material, because of its transparent test. The gut loop is clearly visible posterior to the pharynx. There are relatively few solitary aplousobranchs and the monotypic family Cionidae is distinguished by having a horizontal, rather than vertical, gut loop.

Ecology

Settlement can occur throughout the year, although high settlement rates are restricted to the warmer months of the year in Victoria and see Keough (1983) for descriptions of recruitment patterns from one location in South Australia. This solitary ascidian is widespread in ports and harbour areas in southern Australia, but is rarely seen in the more open waters of Port Phillip Bay and Bass Strait. It reaches high densities in local areas, but does vary in abundance from year to year. Sites in South Australia have had very high densities (> 50 individuals m^{-2}) of this ascidian in a particular year, but none the following year. Long-term dynamics of *Ciona* populations have also been described from Europe (Svane 1983, 1988; Svane and Havenhand 1993; Petersen and Svane 1995) and general growth rates reported for Japanese populations (Yamaguchi 1975).

The larval biology of these ascidians has also been described for a range of populations (Schmidt 1983; Havenhand and Svane 1991; Holmstrom *et al.* 1992) and settlement patterns in response to the presence of microbial films has been examined for populations in Port Phillip Bay (Todd and Keough 1994; Keough and Raimondi 1995).

This ascidian has not been shown to have a major impact on other species. At Williamstown and around Corio Bay, these ascidians do not reach sufficient densities to effect settlement rates, except on settlement plates.

Suborder Phlebobranchia

Family Ascidiidae

Ascidiella aspersa (Mueller 1776)

Synonymy and taxonomy

See Kott (1985, p. 22).

Native range

Known from the Mediterranean Sea, the English Channel, the Irish Sea and the West Coast of Ireland and Scotland.

First recorded collection in Port Phillip Bay

The time or mode of introduction is unknown.

Subsequent distribution

Known from Western Australia, Victoria, Tasmania, South Australia and New Zealand (Kott 1985). Kott (1985) reported the *A. aspersa* recorded from the Southern Hemisphere does not appear to be distinct from *A. aspersa* that is recorded from Europe. The presence of *A. aspersa* in the Southern Hemisphere may be the result of an introduction (Kott 1976a), though it is common in parts of southern Australia (J Havenhand pers. comm.).

Description

A small ascidian, with a transparent test and red markings around the openings to the siphons. Often attached along the left side and with a flattened body.

Potential for confusion with native species

Requires dissection to establish identity. It is distinguished from other genera in the family by the morphology of the neural duct (with secondary openings for *Phallusia*, without such openings for *Ascidia* and *Ascidiella*). Separation of *Ascidiella* and *Ascidia* requires examination of the branchial papillae, which are at junctions of longitudinal and transverse vessels in *Ascidia* and not at these junctions in *Ascidiella* (Kott 1997).

Ecology

Settlement patterns are not known in Australia. One recent study examined aspects of fertilization (Bolton and Havenhand 1996), but this information is not pertinent to the species as a potentially exotic fouling organism.

Suborder Stolidobranchia

Family Styelidae

Subfamily Botryllinae

The two putative introduced species in this subfamily are difficult to deal with. They are not easily distinguishable in the field and *Botrylloides leachi* may co-occur with the encrusting congener *B. perspicuus* and the more upright *B. magnicoecum*. Some systematic examination of this group of ascidians is needed (P Kott pers. comm.). Victorian records for the two possibly introduced species are reliable, as all material has been examined by Dr P Kott.

Botryllus schlosseri (Pallas 1766)

Synonymy and taxonomy

See Kott (1985, p. 267).

Native range

This species is mainly recorded from temperate waters; records from the Mediterranean and sub-tropical locations on the eastern and western coast of Australia are the only ones from warmer waters (Kott 1985).

First recorded collection in Port Phillip Bay

This species was first recorded in Australia by Hartmeyer and Michaelson (1928) in Western Australia in 1905. The earliest record of this species from Victorian waters is from Hobsons Bay (Russ 1977). More recently, Kott (1985) reported it in material collected from elsewhere in Port Phillip Bay.

Subsequent distribution

Presumably widespread, but as suggested above, many field records are unreliable.

Description

A colonial ascidian, with quite large zooids (c. 1 mm), which shows a large amount of colour polymorphism (see, e.g. Kott 1997). Colonies grow as sheets, with zooids in groups sharing exhalant apertures. Colour and size of zooid groups is highly variable.

Potential for confusion with native species

Primarily confused in field with other ascidians within the sub-family Botryllininae, especially when colonies are very small. The primary diagnostic feature is the location of developing ova, which protrude into the atrial cavity in *Botryllus* and from the size of the zooid in *Botrylloides*.

Ecology

B. schlosseri may settle throughout the year, especially through spring, summer and autumn. Some seasonal data is provided by Keough (1983), who also described year to year variation in recruitment rates. This ascidian is common and widespread in Port Phillip Bay but it has not been studied in much detail in southern Australia. Colonies generally do not cover large areas and there is a suggestion from overseas literature that colonies may use chemical defences against predators (Teo and Ryland 1994). Some aspects of its life history are well described (e.g. Chadwickfurman and Weisman 1995; Grosberg 1988; Yamaguchi 1975). These studies indicate considerable variation in life histories, including the recording by Grosberg (1988) of two forms of this species, one semelparous and one iteroparous, within the same small water body in Massachusetts, USA. One would, therefore, be reluctant to conclude that any of these studies could be extrapolated to Australia, without information about the source of Australian populations.

Botrylloides leachi (Savigny 1816)

Synonymy and taxonomy

See Kott (1985, p. 272).

Native range

This species appears to have a range from the north-eastern Atlantic Ocean to the Mediterranean and from the Red Sea to the tropical Indo-west Pacific and down into temperate waters across the southern coast of Australia (Kott 1985).

First recorded collection in Port Phillip Bay

This species has been known from Australian waters from at least the 1890's when Herdman (1899) reported it in a small Australian Museum collection from Port Jackson. The earliest record of this species from Victorian waters is in 1901 from Port Phillip Bay (see MoV[1] collection, from J Kershaw).

Subsequent distribution

Victoria: *B. leachi* has been recorded in Western Port Bay, Portland Harbour, Bass Strait, Lakes Entrance, Mallacoota, Portsea and Hobsons Bay; Tasmania: Flinders Island (Kott 1976; Russ 1977; Kott 1985; Russ 1980).

Description

Colonies form large sheets, which grow irregularly as they cover other organisms. Zooids tend to be in long rows, although crowding together of the rows may obscure this arrangement. Colony colour highly variable.

Potential for confusion with native species

See *Botryllus schlosseri*. *Botrylloides perspicuus* also occurs along the southern coast. The two *Botrylloides* are separated by the consistency of the test (soft in *leachi*, firm in *perspicuus*; Kott 1997) and by the arrangement of the cloacal canals (curved in *leachi*, not curved in *perspicuus*).

Ecology

This species is one of the most widespread introduced species, although distributional records should be viewed with considerable caution, given problems in identifying this species and distinguishing it from the similar and presumed native, congeners. Settlement occurs mostly in summer. Colonies reach a large size, covering up to 1 m^2 in South Australia. In South Australia, this ascidian is a dominant competitor, capable of overgrowing most other

[1] Museum of Victoria

species, but is highly seasonal (Kay and Keough 1981). Overseas, this ascidian has been claimed to deter settlement of other species (Grosberg 1981) and there are other overseas ecological studies (e.g. Myers 1990). *B. leachi* appears capable of influencing the structure of fouling assemblages, but definitive information will be difficult to obtain, as it has already spread widely, so any impacts have presumably occurred some time ago.

Subfamily Styelinae

This sub-family is composed of solitary ascidians. The genus *Styela* is represented by only two species in southern Australia, both of them introduced. It is distinguished from other members of this sub-family by the presence of a small number of long narrow gonads, in contrast to numerous, sac-like gonads of *Polycarpa*, and by having male follicles separate from the ovary, which separates the genus from *Asterocarpa* and *Cnemidocarpa*.

Styela plicata (Lesuer 1823)

Synonymy and taxonomy

See Kott (1985, p. 116).

Native range

It has been recorded from temperate waters of the Atlantic Ocean, the Mediterranean and the east coast of America. There are no records from the general Indo-west Pacific region to the north of Australia suggesting that it is not an indigenous species and may have been introduced by ships (Kott 1985).

First recorded collection in Port Phillip Bay

This species has been known from Australian waters from at least the 1870's[2] when Heller (1878) recorded it from Port Jackson and Port Hacking in NSW. It was first recorded in Victorian waters by Miller (1966) in the Port Phillip Bay Survey between 1957 and 1963.

Subsequent distribution

In Victoria, *S. plicata* is currently known from the Geelong Arm of Port Phillip Bay, Corio Bay and the northern end of Port Phillip Bay including Hobsons Bay (Millar 1966; Russ 1977; Watson 1978; Holmes 1982; Kott 1985).

Description

A mid-sized solitary ascidian, usually < 7 cm from base to siphon tips. In the field, they have conspicuous dark stripes running along the siphons, which separate them from some native species. The test is usually pale brown coloured, but may be fouled.

Potential for confusion with native species

The genus is readily identifiable on dissection and there are only two species within this genus in Australia. In the field, there are a large number of species that could be confused with *S. plicata*.

Ecology

Settlement occurs at any time of the year with a distinct summer peak. *S. plicata* occurs at high densities on piers in northern Port Phillip Bay and in the Geelong Arm. Most of these locations normally have high densities of *Pyura stolonifera*[3]. Little is known of the role of this species in fouling assemblages. It is potentially important if it settles into areas where it may prevent settlement of *P. stolonifera*.

The species dominates space in fouling assemblages on the east coast of North America, but in those waters, it is not long-lived, with large areas of ascidians sloughing off, to be replaced by other species (Sutherland 1974).

Styela clava Herdman 1881

Synonymy and taxonomy

See Kott (1985, p. 115).

Native range

Styela clava is a North Western Pacific species that has readily adapted to protected habitats in European temperate waters, Port Phillip Bay and in Sydney Harbour.

First recorded collection in Port Phillip Bay

This species was first recorded in Australia by Holmes (1976), from material collected in Port Phillip Bay in 1972.

Subsequent distribution

Records of this species in Australia are confined to Port Phillip Bay, Vic. (Holmes 1976) and Sydney Harbour, NSW (Russ 1977). In Victoria, it has only been recorded from Hobsons Bay in Port Phillip Bay (Holmes 1976; Watson 1978), although it is likely to be in the Geelong Arm, given its wide spread in other geographic areas.

Description

A mid-sized solitary ascidian, with a roughened test and generally growing on a short (usually < 7 cm) stalk. The stalk often appears as an elongation of the test, rather than the discrete, long, narrow stalk seen in species such as *Pyura spinifera* and *P. australis*. The test is usually a reddish brown in Port Phillip Bay specimens.

Potential for confusion with native species

The stalk narrows down the number of potentially confusing native species, but there are still many candidates; identification requires collection and dissection of specimens.

Ecology

Settlement occurs in late spring to early summer. Little is known of the ecology of this species. It does not reach very high densities in northern Port Phillip Bay.

[2] In a number of publications, particularly those in the late 19th century, the date of collection is unclear or not stated. In these cases we have given the decade that the paper was published as an approximate time of collection.

[3] *Pyura stolonifera* is a widely distributed solitary ascidian, reported from South Africa and Chile. However, it may be a complex species. Dalby (1995) has shown fixed genetic differences, morphological separation, and different endosymbionts, between populations of this ascidian in Port Phillip Bay and those on the Bass Strait coast. We use *P. stolonifera* in its older, broader sense.

Comments

The precise route of introduction to Australia is uncertain, as it may have been transported on ship's hulls either from Europe or from its endemic range in the north-west Pacific (Holmes 1976).

Family Molgulidae

Molgula manhattensis (De Kay 1843)

Synonymy and taxonomy

See Kott (1985, p. 379).

Native range

Atlantic coast of North America.

First recorded collection in Port Phillip Bay

This species was first recorded in Australia in 1967 in the Yarra River at the Newport Power station by Kott (1976b). The only other Australian record of this species is at the Port of Brisbane (Kott 1976b).

Subsequent distribution

Uncertain; there are few reliable records for this species around Port Phillip Bay.

Distribution

It is thought that this species has been transported by ship to Japan and to Australia. In Victoria, it has only been recorded from the Yarra River as reported above. Kott (1985) noted that *Molgula recumbens* Herdman (1899) superficially resembles *M. manhattensis* and may be evidence for an earlier introduction of the species to Port Jackson, NSW.

Description

A solitary ascidian with a soft, often sand-coloured test that is frequently globular. May occur in soft sediments, attached to small objects, as well as being part of a fouling assemblage.

Potential for confusion with native species

Many, although the Molgulidae are easily recognizable on dissection. There are two other species of *Molgula* known from Victorian waters.

Ecology

Little is known of the ecology of this species in Australia, although it has been studied in North America. This solitary ascidian occurs attached to hard surfaces, but, as with other ascidians in this genus, may be found clustered together on soft sediments. Settlement season is not known for Australia, although there is some overseas literature on this species.

13.2.2 Bryozoans

Phylum Bryozoa

Order Ctenostomata

The ctenostomes listed here all have chitinised, rather than calcified skeletons and the zooids are simple tubes, with the lophophore emerging from the distal end. We list two known introductions and two species that are very widely distributed and recorded from SA and NSW.

Family Nolellidae

Anguinella palmata van Beneden 1945

Synonymy and taxonomy

Anguinella palmata van Beneden 1845a, 1845b: 34. — Osburn 1914: 219. — Osburn 1944: 338. — Marcus 1937: 133. — Allen 1953. — Maturo 1957: 21. — Shier 1964: 649. — Winston 1982: 108).

Native range

A cosmopolitan species, with a large latitudinal range. In the western Atlantic, it extends from Brazil to Massachusetts, USA (Winston 1982).

First recorded collection in Port Phillip Bay

The occurrence of *A. palmata* in Australian waters was reported for the first time by Allen (1953) in NSW. This species is unlikely to have been overlooked by previous workers and, as it is a ship-fouling organism in other parts of the world, Allen (1953) concluded it had been introduced by ships. It is not definitively known from Port Phillip Bay, but is listed here as it is one of the species more likely to occur in the bay.

Subsequent distribution

N/A.

Description

Colonies are completely uncalcified and have large (length ~ 0.8 mm; Winston 1982), cylindrical zooids. The colonies are often covered with sediment and are described by Winston (1982), as resembling dirt-coated seaweed.

Potential for confusion with native species

Likely to be overlooked in field surveys.

Ecology

Settlement not reported in the literature. Ecology not known in Australia.

Family Vesiculariidae

Bowerbankia spp.

Synonymy and taxonomy

See comment below.

Native range

B. gracilis is thought to be cosmopolitan in shallow, warmer waters (Winston 1982).

First recorded collection in Port Phillip Bay

The earliest records of the genera *Bowerbankia* from Victorian waters are from Hobsons Bay in the 1970's (Watson 1978; Russ 1977). Russ considered that the material at Williamstown was *B. gracilis.*

Subsequent distribution

Recorded in 1973–4 at the old Williamstown Naval Dockyard by Russ (1977) and during PPBES-1 (Vigeland 1971).

Description
Colonies form tangled mats, with cylindrical zooids arising from a thin stolon that creeps over the substratum.

Potential for confusion with native species
Slight.

Ecology
Little is known of the ecology of this species.

Comments
Bock (1982) reported that *Bowerbankia* had apparently not been recorded from southern Australia before this time and may have been introduced by shipping. It seems likely that the specimens found in Victoria could be either *Bowerbankia gracilis* Leidy, recorded from South Australia (Brock 1979, 1985) and New Zealand (Gordon and Mawatari 1992) and/or *Bowerbankia imbricata* (Adams), recorded from New Zealand (Gordon and Mawatari 1992). Both *B. imbricata* and *B. gracilis* are included in Ryland's (1965) OECD catalogue of main marine fouling organisms.

Zoobotryon verticillatum (Delle Chiaje 1828)

Synonymy and taxonomy
Hydra vertillicata Delle Chiaje 1828: 203;
Zoobotryon pellucidum Ehrenberg 1831. — Marcus 1937: 139. — Osburn 1940: 341;
Zoobotryon verticillatum Osburn 1953: 742. — Maturo 1957: 25. — Cook 1968: 229. — Winston 1982: 113. — Bock 1982;
Zoobotryon verticillatum Prenant and Bobin 1956: 288.

Native range
A cosmopolitan fouling species of warmer waters.

First recorded collection in Port Phillip Bay
Not yet recorded in Victoria. A major fouler in New South Wales, South Australia and Western Australia (Russ and Wake 1975; Bock 1982; Brock 1985).

Subsequent distribution
N/A

Description
Colonies form tangled mats, with the stolons branching frequently.

Potential for confusion with native species
Easily recognisable.

Ecology
Settlement occurs during spring and summer in other states. Colonies can form large, tangled mats that may cover large areas.

Amathia distans Busk 1886

Synonymy and taxonomy
Amathia distans Busk 1886. — Marcus 1937: 134. — Osburn 1940: 339. — Maturo 1957: 23. — Cook 1968. — Winston 1982: 110. — Gordon and Mawatari 1992;
Amathia brasiliensis Busk 1886: 34. — Osburn 1940: 339;
?*Amathia goodei* Osburn 1914: 219.

Native range
Widely distributed throughout the world, occurring in France, the Mediterranean and Red Seas, the Atlantic coast of America from North California to Brazil and the Pacific coast from Puget Sound, Washington and Southern California, Australia (Victoria), Java, and Japan, (see Gordon and Mawatari 1992).

First recorded collection in Port Phillip Bay
Uncertain.

Subsequent distribution
Uncertain.

Description
Colonies are branched, with zooids arranged in groups and usually in paired rows within groups. The groups may run along branches, or may spiral around branches.

Potential for confusion with native species
Other, native species of *Amathia.*

Ecology
Settlement not reported in the literature. Nothing is known of the ecology of this species in southern Australia.

Order Cheilostomata
Suborder Anasca
Family Scrupariidae
Scruparia ambigua (d'Orbigny 1841)

Synonymy and taxonomy
Eucratea ambigua dÍOrbigny 1841;
Eucratea chelata var. *gracilis* Hincks 1880: 14;
Scruparia chelata MacGillivray 1887: 10; 1889: 287;
Scruparia ambigua Hastings 1941: 465. — Ryland 1965: 23. — Prenant and Bobin 1966:99.

Native range
Widely distributed around the world except in polar waters (Gordon and Mawatari 1992).

First recorded collection in Port Phillip Bay
The earliest known record of this species in Victorian waters is a specimen collected at Williamstown in 1881 and held at the Museum of Victoria.

Subsequent distribution
In southern Australia it is a minor component of the fouling community, growing on bushy fouling bryozoans, hydroids and leafy brown algae (Bock 1982). *S. ambigua* has been recorded throughout Port Phillip Bay (Vigeland 1971).

Description
Colonies grow as a uniserial chain of small, almost trumpet-shaped zooids and can be either encrusting or erect. Chains growing along the surface branch by lateral buds, whereas colonies that have grown upright grow by

budding off the frontal surface (Ryland and Hayward 1977).

Potential for confusion with native species

This is a small but easily identified species.

Ecology

Detected in spring and summer in Port Philip Bay, but it does not appear in many ecological studies. It grows as a small, arborescent colony, with branches formed from chains of single zooids. Colonies rarely exceed 1 cm in diameter and never attain a high percentage cover. It can be found most easily in clearings on hard surfaces, or growing on the surfaces of other animals. It almost certainly has no broader ecological effects.

Comments

Early records of this species may be suspect, as it was confused with *S. chelata* until the 1940's (Ryland and Hayward 1977). *S. ambigua* is an inconspicuous species, with very few external skeletal features; it is not clear if it is a single cosmopolitan species or a series of local ones.

Family Membraniporidae

This family, and in particular, the genus *Membranipora*, has been a repository for a wide range of anascan bryozoans characterised by little calcification over the frontal wall.

Membranipora membranacea (Linnaeus 1767)

Synonymy and taxonomy

Flustra membranacea Linnaeus 1767: 1301;
Membranipora membranacea Hincks 1880: 140. — MacGillivray 1887:20. — Prenant and Bobin 1966: 112.

Native range

A cosmopolitan fouling species.

First recorded collection in Port Phillip Bay

Known from Victorian waters since at least the 1870's; MacGillivray (1879) noted that it was widespread and common.

Subsequent distribution

Bock (1982) reported that it is often seen on the fronds of the kelp *Macrocystis*.

Description

Encrusting colonies, with little or no calcification of the frontal area, with a membrane as the only covering. The absence of calcification gives this species a lacy look. The zooids are rectangular and there may be tubercules at the corners.

Potential for confusion with native species

Electra, *Conopeum* and other weakly calcified encrusting species.

Ecology

Time of settlement has not been described for southern Australia. This species is an unusual bryozoan, with a feeding planktonic larva that takes 2–4 weeks to develop. It is widespread and has been studied extensively in North America (Yoshioka 1982a,1982b; Harvell *et al.* 1990; Harvell 1992), where it is highly seasonal and covers very large areas on fronds of giant kelp (*Macrocystis pyrifera*). On the west coast of North America, *Membranipora* colonies are abundant in summer[4]. In Port Phillip Bay, colonies encrust fronds of *Ecklonia radiata*, but only occasionally cover comparably large areas. Rapid growth and reproduction are typical of this species over its known range (Seed and Hughes 1992).

Conopeum reticulum (Linnaeus 1767)

Synonymy and taxonomy

Millepora reticulum Linnaeus 1767: 1284;
Membranipora lacroixii Hincks 1880: 129;
Conopeum reticulum Ryland 1965: 30. — Prenant and Bobin 1966: 124.

Native range

A cosmopolitan fouling species.

First recorded collection in Port Phillip Bay

Known from Victorian waters since at least the 1870's; recorded by MacGillivray (1879) at Point Cook, Brighton and Queenscliff.

Subsequent distribution

Not well known, but recorded near Heads region and from PPBES-1 areas 17, 29, 30, 59, 10, 7 and 58 (Vigeland 1971). It is likely to be widespread.

Description

A weakly calcified encrusting species, with little calcification over the frontal area of zooids. The main calcification is at the proximal end of zooids and the lateral walls (between zooids) are calcified to form a lip. One diagnostic feature of this species, as described by Ryland and Hayward (1977), is the presence of two small kenozooids (small, highly modified zooids, lacking a feeding polypide) at the distal end of each zooid (see Ryland and Hayward 1977, Figure 20). These kenozooids are most easily visible in young colonies and may become obscured as the calcification of the side walls increases.

Potential for confusion with native species

Can not be distinguished in the field from other weakly calcified encrusting species, such as *Membranipora* and *Electra.*

Ecology

Settlement is thought to occur throughout the year. The ecology of this species is not known locally. It is not an abundant member of the local fouling fauna. Ryland and Hayward (1977) and Cook (1964) provide some information about the general biology of this species in Britain.

[4] Editor's note: *Membranipora membranacea* has recently been introduced to the Gulf of Maine and is implicated in *Laminaria* kelp losses (Berman *et al.* 1992).

Family Electridae

Electra pilosa (Linnaeus 1761)

Synonymy and taxonomy

Flustra pilosa Linnaeus 1767: 1301;
Membranipora pilosa Hincks 1880: 137;
Electra pilosa MacGillivray 1887: 19. — Ryland 1965: 28. — Prenant and Bobin 1966: 140.

Native range

A cosmopolitan fouling species. Considered by Ryland and Hayward (1977) to be one of the world's most common bryozoans.

First recorded collection in Port Phillip Bay

Uncertain, but MacGillivray listed it in the 1860's.

Subsequent distribution

Bock (1982) reported that this species is widespread and that most local occurrences are on the stems and fronds of brown algae.

Description

Colonies are generally small (< 2 cm diameter), fast-growing and do not cover large areas of algal surfaces. Both colonies and zooids are often very irregular in shape. In this species, calcification extends over only the proximal half of the zooid wall.

Potential for confusion with native species

Requires laboratory examination to distinguish it from other weakly calcified encrusting genera, such as *Membranipora* and *Conopeum.*

Ecology

Time of settlement is not known locally. Settlement occurs in late summer in New Zealand (Gordon and Mawatari 1992). It is not often seen on hard substrata, but typically occurs as an algal epiphyte (Bock 1982). There are no ecological studies from southern Australia; this species seems unlikely to have had major ecological effects.

Family Aeteidae

Aetea anguina (Linnaeus 1758)

Synonymy and taxonomy

Sertularia anguina Linnaeus 1758: 816;
Aetea anguina Hincks 1880: 4.

Native range

A common but inconspicuous member of the fouling community, this species is cosmopolitan in distribution (Bock 1982), other than in polar waters (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Known from Victorian waters since at least the 1880's; recorded by MacGillivray (1887b) at Port Phillip Heads.

Subsequent distribution

Probably widespread, but overlooked in general surveys.

Description

A distinctive species, consisting of tubular zooids, with two parts. One part lies along the substratum, while the other, distal end, is erect. Colonies are generally uniserial chains of zooids. Most often seen encrusting algae or arborescent animals, such as hydroids and bryozoans.

Potential for confusion with native species

Easily recognized, but colonies are generally too small to see when in the field.

Ecology

Settlement may occur in spring and summer. This small species with its runner-like growth form never attains a high percentage cover in fouling communities. It can be found most easily in clearings on hard surfaces, or growing on the surfaces of other animals. It almost certainly has no major ecological effects.

Comments

This bryozoan is another species that lacks external skeletal modifications. It is therefore possible that it is not cosmopolitan, but a series of native species in different regions.

Family Bugulidae

This family of arborescent bryozoans includes native and presumed introduced species. They are common components of sessile assemblages and may sometimes play important ecological roles (e.g. the native *B. dentata*; Russ 1980). The genus is cosmopolitan in temperate seas and most continents now have mixtures of endemic species, and a suite of presumed introduced species (e.g. *B. neritina*, *B. stolonifera*, *B. avicularia* and *B. flabellata*). The original distribution of species such as *B. neritina* is not well known, because it has been present in most areas since earliest records. The larval period of < 1d makes natural transoceanic dispersal unlikely.

Species in this genus range from being characteristic and easily identifiable in the field (*B. neritina* and *B. dentata*) too cryptic and difficult to distinguish from congeners (*B. stolonifera* and *B. avicularia*).

The formal diagnosis of this family is as follows: colonies are upright and bushy, with branches composed of two or more series of zooids. The branches of the colony lack obvious joints. Most species (except for *B. neritina*) have acivularia on small stalks. Again, except for *B. neritina*, spines are often present on lateral parts of zooids. There is a group of similar arborescent bryozoans (*Scrupocellaria*, *Caberea*, *Tricellaria* and *Bugularia*) which can be hard to separate in the field. Members of this latter group all have a similar branching form, but can be separated using the key below (based on Ryland and Hayward 1977; Bock 1982; Gordon and Mawatari 1992). The two species of *Caberea* and *Bugularia* *dissimilis* are native, while the other genera in Port Phillip Bay contain primarily species presumed to be introduced.

Related genera of arborescent bryozoans can be separated using the following key:

1. Scutum (a modified lateral spine, curving over the front of zooids) generally present. Avicularia present, but sessile. Vibracula (a small, highly modified zooid, in which the operculum is modified to form a long setum, which is usually longer than a spine) often present...2
   Scutum and vibracula absent. Avicularia usually present and pedunculate (on short stalk). Colony lacking clear joints between branches............*Bugula*
2. Vibracula present on basal surface of zooids...........3
   Vibracula absent.......................................*Tricellaria*
3. Colony biserial to multiserial (i.e. zooids in 2 or > 2 rows). Chambers that are bases of vibracula are extensive and obscure much of the base of the zooids. Colonies have anchoring rhizoids (rootlets) that twine together down the basal area of the zooids to the substratum. In Port Phillip Bay, there are two species one biserial, one multiserial..........................*Caberea*
4. Colony biserial only. Chambers for vibracula are small and do not obscure the zooid surface. Anchoring rootlets tend to be individual.............*Scrupocellaria*

The species of *Bugula* recorded from Port Phillip Bay can be distinguished from each other with varying degrees of ease. The following guide is based in part on information provided by Ryland and Hayward (1977). We note that some species may be difficult to separate when they are small. It is possible that some records, such as the solitary record of *B. calathus,* could be a slightly abnormal specimen of the very common *B. flabellata.* Similarly, *B. simplex* and *B. flabellata* have been grouped together in other areas. It is quite likely that precise distributional records for these two species may not be accurate.

There are some additional species of this genus described from Victoria in the 19th century (*B. robusta* MacGillivray and *B. cucullata* Busk), but their precise status is uncertain.

Key to the species of *Bugula*:

1. Avicularia lacking; colony dark purple-brown
   ....*B. neritina*
   Avicularia present..2
2. Colony green...*B. dentata*
   Colony pale brown or straw coloured.....................3
3. Zooids in two rows along branches.........................4
   Zooids forming at least four rows along branches..5
4. Frontal wall of zooids extends along most of the length of the zooid. Avicularia large and classic "bird's beak" type (wider than zooids) ....*B. avicularia*
   Frontal wall extends less than 3/4 (and usually < 2/3) of the way along the zooid. The "bird's beak" avicularia are smaller, with their length much less than the width of a zooid.............................*B. stolonifera*
5. The zooids on the outer edge of branches have two spines on their inner corner and three on the outer distal corner...6
   Zooids on the outer edges of branches have one spine on their inner and outer distal corners.......*B. simplex*
6. Avicularia beaks are "rectangularly hooked" (Ryland and Hayward 1977), with a sharp bend. Marginal avicularia (i.e. on outer edges of branches) are small, with their length no greater than the width of a zooid
   ....*B. flabellata*
   Avicularia have beaks that are smoothly downcurved. The marginal avicularia are very large, their length equal to the width of two zooids..............*B. calathus*

Bugula flabellata (Thompson in Gray 1848)

Synonymy and taxonomy

Avicularia flabellata Thompson, MS, in Gray 1848: 106; *Bugula flabellata*: Hincks 1880. — Ryland 1960: 82. — Prenant and Bobin 1966: 503.

Native range

Widely distributed in warm and temperate waters of both hemispheres (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Allen and Wood (1950) recorded *B. flabellata* in Australia for the first time in 1946–47 in NSW. They suggested that it is most likely a recent arrival in Australia and was unlikely to have been overlooked by previous workers. However, a specimen from Torquay in Victoria was found at the Museum of Victoria in MacGillivray's collection from the late 19th century, which suggests it may have been present much earlier in Australia than reported by Allen and Wood (1950).

Subsequent distribution

B. flabellata is currently known from New South Wales, Victoria, South Australia and Western Australia (Russ and Wake 1975). In Victoria, it has been recorded from Hobsons Bay and Torquay (Holmes 1982). It also occurs in Corio Bay and at Point Wilson.

Description

An arborescent bryozoan that is distinguished from most other species in the genus by the arrangement of zooids down the arms of the colony. Branches made up of 4 zooid series, rather than the more typical 2 series of other species in the genus.

Potential for confusion with native species

Little potential for confusion with native species. It is more likely to be confused with other exotic species, such as those within the genera *Bugula*, *Scrupocellaria* or *Caberea*. In particular, *Bugula simplex* and *B. calathus* also have multiserial rows of zooids down the branches.

Ecology

Settlement occurs primarily in spring, summer and autumn in Port Phillip Bay. In the other southern states settlement occurs only in autumn. Little is known of the ecology of this species in Australia. The only published work describes settlement patterns in response to the presence of microbial films (Todd and Keough 1994; Keough and Raimondi 1995). Overseas, the larval biology, including settlement was described for eastern North America by Grave (1930) and reproductive patterns detailed for Britain by Dyrynda and Ryland (1982). Little is known of the potential impact of this species on other sessile organisms.

There is considerable variation in abundance of this species from year to year. At Breakwater Pier, Williamstown, this species has been present, though not abundant for 4–5 years, but in spring and summer of 1995, it was one of the most prominent bryozoans.

Comments

If MacGillivray's record is correct, this species must have arrived attached to hulls. If not, then there is no information about the mode, time, or initial point of introduction. The locality for this record is suspicious and the label on the specimen does not indicate the habitat from which it was taken. This species favours more sheltered water and Torquay, being semi-exposed ocean coast, is an unlikely site. The collection details do not distinguish between material collected live at that site and drift material found on the beach. The latter seems quite possible, with the material possibly being derived from a passing boat or having arrived as drift from a locality such as Corio Bay.

Bugula neritina (Linnaeus 1758)

Synonymy and taxonomy

Sertularia neritina Linnaeus 1758;

Bugula neritina Ryland 1960: 74; 1965: 45. — Prenant and Bobin 1966: 492.

Native range

This species is cosmopolitan except in cold polar and subarctic/subantarctic waters. Its wide distribution is probably in part due to the movements of shipping (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Known from most Australian ports and harbours. It has been present in Australian waters since at least the 1880's when it was recorded at Hobsons Bay, Queenscliff and Warrnambool in Victoria by MacGillivray (1881a)[5].

Subsequent distribution

Victoria: *B. neritina* has also been recorded from Wilson's Promontory, Bass Strait, Portsea, Torquay, Western Port Bay and the Port Phillip Bay Survey Areas 10(103–5), 12(196) (Vigeland 1971; Russ 1977; Watson 1978; Russ 1980; Holmes 1982; VIMS[6] WPNPA, MoV). In Port Phillip Bay, it is widely distributed but appears restricted to more sheltered waters. It is abundant in summer at piers in the northern half of the bay and in the Geelong Arm. The southerly limits appear to be at St Leonards in the Geelong Arm and at Portsea on the eastern side of Port Phillip Bay. It co-occurs with the native *B. dentata* in the northern part of the bay, but *B. dentata* extends throughout the bay and onto open coasts.

Elsewhere: in southern Australia it occurs in ports. It has apparently spread to some relatively isolated ports, such as Point Turton on Yorke Peninsula, South Australia, despite being absent from many nearby areas. Although this species has been present since the first surveys, given its global distribution patterns it is likely that it was introduced. Its early introduction suggests it probably arrived attached to hulls.

Description

An arborescent bryozoan showing no calcification and a very simple colony structure. Colonies are dark brown-purple and mature ovicells appear white.

Potential for confusion with native species

This species is easily identified in the field by its characteristic colour; there are no similar native species.

Ecology

Peak settlement occurs in summer in southern areas of Australia. In Port Phillip Bay, there is no settlement during winter and little settlement in spring until water temperatures rise. Reproductive individuals can be found earlier in the year in the Sydney region and in Gulf of St. Vincent, SA. In Victoria, this bryozoan occurs primarily on artificial substrata. In North America it also occurs on rocky reefs (Keough 1989a,1989b) and seagrass leaves (Keough 1986; Keough and Chernoff 1987).

The population dynamics of *B. neritina* from North America have been well reported and there is also extensive literature on larval biology, including laboratory studies of settlement behaviour and field studies of settlement. Little similar information is available for Australian populations.

Although this species has been studied extensively, it is not clear how useful overseas information is and *B. neritina* provides a cautionary lesson for other species. The behaviour of larvae, which is likely to be important for larval dispersal, shows great variation between populations (Raimondi and Keough 1990), with variation in swimming time and a range of taxis. The life history of this species is similarly variable, with growth rates and

[5] MacGillivray citations can be found in his monograph of the Victorian Bryozoa, published in McCoy's *Prodromus of Zoology* (1879-89), which is listed in an Appendix of Vigeland (1972).

[6] Victorian Institute of Marine Science.

the onset of sexual maturity varying with the kind of substratum (Keough 1989b), and between locations and times (Keough 1986). Settlement occurs primarily in spring and summer in most temperate areas, but is reversed, with winter growth and reproduction, in subtropical areas on the east coast of North America.

This result is not unexpected as most bryozoans have very short-lived larvae so isolated populations would be expected to diverge in response to spatially variable selective pressures. This suggests that studies of these organisms in their area of origin will not necessarily reflect their ecological properties in new environments.

In southern Australia, colonies regress in winter back to small rhizomes and are unlikely to be detected by field surveys. Colonies regenerate the following spring, reaching diameters of 15 cm. The time of regeneration and settlement varies from year to year and in some years colonies may only be prominent for a few months. The same phenomenon has been reported from Florida (Keough 1986).

Bugula simplex Hincks 1886

Synonymy and taxonomy

Bugula simplex Hincks 1886: 254. — Ryland 1960: 91; 1965: 49. — Prenant and Bobin 1966: 505;
Bugula sabatieri Calvet 1900: 19.

Native range

B. simplex is found on the east coast of North America (where it was for many years wrongly identified as *B. flabellata*), Britain, New Zealand and in the Mediterranean and Adriatic seas (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

The earliest known records of *B. simplex* in Australian waters are from the 1970's in South Australia (Brock 1985) and Victoria (Holmes 1982).

Subsequent distribution

Victoria: *B. simplex* has only been recorded from Hobsons Bay. There is no information about the mode of introduction.

Description

An arborescent species of *Bugula*, with zooids in multiserial rows. For diagnostic features, see discussion above.

Potential for confusion with native species

Most likely to be confused with *Bugula flabellata* and *B. calathus* (see above).

Ecology

Timing of settlement is not known locally. In Britain, settlement occurs from midsummer to late autumn (Ryland and Hayward 1977). Nothing is known about the species' ecology in Australia waters.

Bugula stolonifera Ryland 1960

Synonymy and taxonomy

Bugula stolonifera Ryland 1960: 78. — 1965: 50. — Prenant and Bobin 1966: 541.

Native range

Coastal waters of western Europe, northwards to the southern part of the British Isles; the Mediterranean and Adriatic Seas; New Zealand (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

In the Museum of Victoria collection, there are specimens from MacGillivray's 19th century collection from Port Phillip Bay, originally attributed to *B. avicularia*. The labels for these specimens have been annotated by Parker (presumably the late S Parker, of the South Australian Museum), to indicate that the records of *B. avicularia* from Hobsons Bay in fact refer to *B. stolonifera*. Therefore, it appears *B. stolonifera* has been present in Australian waters since at least the 1880's.

Subsequent distribution

Victoria: more recently, *B. stolonifera* has been recorded from Hobsons Bay, Portsea, Western Port Bay; and South Australia (Russ 1977; Watson 1978; Russ 1980; Holmes 1982; Brock 1985). It is widely distributed in the northern parts of Port Phillip Bay, but not common in southern areas or on open coasts. Its early introduction in Australian waters is consistent with its arrival attached to hulls.

Description

A small, pale coloured arborescent species, with colonies usually < 5 cm high. Zooids in two rows and highly mobile avicularia widely distributed over colony surface.

Potential for confusion with native species

This species is easily confused in the field with other fragile species of *Bugula*, and with *Tricellaria*, *Scrupocellaria* and possibly *Caberea*. Under a microscope, this species is similar to *Bugula avicularia* (see potentially introduced species, below).

Ecology

Settlement occurs in summer and autumn in the Northern Hemisphere. In northern Port Phillip Bay, settlement also occurs in spring. Keough (1983) described recruitment patterns over three years in SA. The only ecological work has been the studies of larval settlement in relation to the presence of microbial films (Todd and Keough 1994; Keough and Raimondi 1995). This species is unlikely to have a large influence on other organisms. Colonies rarely exceed 4 cm in diameter never attain a high surface cover. Colonies are generally found attached to other arborescent bryozoans, such as *B. neritina* and *B. dentata*.

Bugula calathus Norman 1868

Synonymy and taxonomy

Bugula calathus Norman 1868: 216. — Hincks 1880: 82;

Ryland 1960: 87. — Prenant and Bobin 1966: 500.

Native range

Recorded from the coasts of Britain, the Mediterranean and Africa (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Watson (1978) recorded *B. calathus* for the first time in Victoria in Hobsons Bay.

Subsequent distribution

Victoria: it is also known from other ports long the Victorian coastline (Watson 1978).

Description

A robust, pale coloured arborescent species, with colonies typically < 5 cm high. Zooids in rows of four along branches. The most characteristic feature of this species is the presence of giant avicularia (3–4 times larger than other avicularia) along the margins of branches of the colony.

Potential for confusion with native species

See earlier discussion.

Ecology

No information is available on the settlement or ecology of this species in Australia. The method of introduction is unknown.

Family Cabereidae

The main representative of this family in Australia, *Scrupocellaria*, is not well understood. A range of species have been recorded from Port Phillip Bay, including *S. cyclostoma, S. diadema, S. ornithorhyncus, S. scrupea, S. scruposa* and *S. bertholetti* (Vigeland 1971). Of these species, *S. scuposa, S. scrupea* and *S. bertholetti*, have been described elsewhere and may well be introduced to Port Phillip Bay. Of these records, *S. bertholetti* was listed by Bock (1982) and was a major member of the fouling assemblage in South Australia (Brock 1979). The systematics of this genus in Australia is in need of further examination.

Scrupocellaria bertholetti (Audouin)

Synonymy and taxonomy

Scrupocellaria bertholetti Hastings 1930: 733. — Osburn 1940: 386. — Osburn 1950: 133.

Native range

A cosmopolitan species of warmer waters.

First recorded collection in Port Phillip Bay

Uncertain.

Subsequent distribution

South Australia: *S. bertholetti* was recorded as a major fouler in Port Adelaide by Brock (1985); and Victoria: it is also present in Port Phillip Bay.

Description

A small, straw-coloured arborescent bryozoan, with colonies usually < 3 cm high. For general description of this genus, see above.

Potential for confusion with native species

See earlier comments on *Bugula*.

Ecology

Todd and Keough (1994) recorded settlement at Mornington in summer. In contrast to Brock's (1985) observations in SA, we have not seen this bryozoan in large numbers at piers in Port Phillip Bay where the larger arborescent bryozoans, principally *Bugula* and *Tricellaria*, are the major space occupiers. This suggests that this species has not had a major impact in Victoria.

Comments

The cosmopolitan distribution of this species is most likely the result of its movement by shipping.

Scrupocellaria scrupea Busk

Synonymy and taxonomy

Scruparia scrupea Busk 1852a, 1852b: 24. — MacGillivray 1887.

Native range

Regarded as a wide-ranging, warm-water species (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Recorded in MacGillivray's original collections from around the Heads.

Subsequent distribution

Probably widespread. Victoria: recorded during PPBES-1 by Vigeland (1971) from areas 11, 12, 335, 53, 55, 58, 59 and outside the heads at area 66.

Description

Forms small, robust colonies. Distinguished from other species of *Scrupocellaria* by the presence of vibracula and a scutum that is small and spade-shaped.

Potential for confusion with native species

Can be confused with other species of *Scrupocellaria.*

Ecology

Little is known of the ecology of this species from Australia.

Scrupocellaria scruposa (Linnaeus)

Synonymy and taxonomy

Sertularia scruposa Linnaeus 1758: 815;
Scrupocellaria scruposa Busk 1852a, 1852b: Pl. 22. — Hincks 1880: 45.

Native range

Wide distribution, mostly in warm waters (Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Uncertain. Not recorded in MacGillivray's early collections.

Subsequent distribution

Victoria: widely distributed in PPBES-1, recorded from areas 7, 11, 12, 21, 35, 55, 57, 58 and from areas outside the bay.

Description

Forms small, robust colonies. Distinguished from other species of *Scrupocellaria* by a combination of the absence of a scutum and the presence of spines at the distal edges of zooids.

Potential for confusion with native species

Similar to other species within the family.

Ecology

Little is known from Australia.

Comments

Little is known of this species from Australia.

Tricellaria occidentalis (Trask 1857)

Synonymy and taxonomy

Menipea porteri MacGillivray 1889;
Tricellaria porteri Bock 1982;
Tricellaria occidentalis Osburn 1950: 122 and synonymy within.

Native range

British Colombia to southern California, Baja California, China, Japan, Venice and New Zealand (regarded as introduced by Gordon and Mawatari 1992).

First recorded collection in Port Phillip Bay

Menipea porteri MacGillivray 1889, recorded in South Australia in the late 1800's, is a junior synonym of *T. occidentalis* (Gordon and Mawatari 1992).

Subsequent distribution

Victoria: Port Phillip Bay, (as *T. porteri*) from Hobsons Bay, Western Port Bay, Portsea and Queenscliff (Russ 1977; Russ 1980; Bock 1982; Holmes 1982); New South Wales: Sydney (Bock 1982); and South Australia: Port Adelaide (Brock 1979; Bock 1982). It is widely distributed around Port Phillip Bay and occurs on the outer coast.

Description

A fragile-looking, straw-coloured arborescent bryozoan, which attains a colony diameter of ~ 8 cm. Zooids occur in two series along branches. Avicularia common, but vary among colonies. They are most prominent along outside edges of zooids. Zooids have a scutum, which is variable in shape (Gordon and Mawatari 1992), which may account for confusion in identification. Zooids also have spines at their distal ends.

Potential for confusions with native species

See discussion for genus *Bugula*, above. This species in the past has been confused with *Scrupocellaria* (Gordon and Mawatari 1992).

Ecology

Settles throughout the year with a peak settlement period in summer/autumn (Russ 1980). In our records, settlement also occurs in large numbers in spring. This species occurs commonly in sessile assemblages dominated by native species and it is probably the most successful invader of the introduced bryozoans. There is, however, very little information on its impacts in those assemblages. It is common in Hobsons Bay and is also a prominent member of the sessile assemblage on Queenscliff pier.

Comments

It is difficult to determine if this species is introduced. It is considered to be introduced to New Zealand (Gordon and Mawatari 1992) and it seems likely that it is not native to Australia.

Suborder Ascophora

Family Cryptosulidae

Cryptosula pallasiana (von Moll 1803)

Synonymy and taxonomy

Eschara pallasiana von Moll 1903: 64;
Lepralia pallasiana Hincks 1880: 297;
Cryptosula pallasiana Marcus 1940: 253.

Native range

Widespread around the world, particularly in ports, harbours and estuarine situations. This wide distribution is probably in part due to its movement by shipping.

First recorded collection in Port Phillip Bay

The record of *Lepralia pallasiana* held in the Museum of Victoria is likely to be a junior synonym of *C. pallasiana*. This species was recorded from Hobsons Bay and Port Phillip Heads in the late 1800's.

Subsequent distribution

Victoria: Hobsons Bay, Western Port Bay, Portsea, Port Phillip Bay; New South Wales: Sydney Harbour; and South Australia: Port Adelaide (Russ 1977; Watson 1978; Russ 1980; Holmes 1982; Brock 1985). This bryozoan is widespread and often found well away from port environments.

Description

An encrusting species that forms flat, pale-coloured sheets. Zooids lack avicularia and are perforated all over their frontal surface. The aperture has a low, raised edge and is slightly longer than wide. Two small teeth, positioned laterally and near the proximal end of the aperture, give it a "bell-shaped" appearance (Hayward and Ryland 1979). Embryos are brooded internally, so colonies lack ovicells.

Potential for confusion with native species

As with many encrusting bryozoans, it is not possible to identify this species unambiguously in the field. Colonies may resemble other pale encrusting species, e.g. smittinids.

Ecology

Settlement occurs in spring, summer and autumn. Keough (1983) provides recruitment data for West Lakes, SA. Around Port Phillip Bay, this species is widespread and occurs away from piers and other artificial structures. It is found commonly in the very low intertidal zone of boulder fields. Colonies generally do not reach a large size or cover large areas of the substratum. This species is not reported in the literature as a strong competitor, so its impact is unlikely to be substantial.

Family Watersiporidae

Watersipora subtorquata (d'Orbigny 1852)

Synonymy and taxonomy

See Gordon (1989, p.40).

Gordon (1989) gives reason for referring to the species as *Watersipora subtorquata* rather than *W. subovoidea*, the name by which it has most often been cited in Australia.

Watersipora subtorquata – see Gordon 1989.

Native range

Exact distribution is uncertain because of taxonomic difficulties, but it certainly occurs in Brazil, the West Indies, Bermuda, Cape Verde Islands, Japan, Torres Strait and New Zealand (see Gordon and Mawatari 1992).

First recorded collection in Port Phillip Bay

First recorded in Hobsons Bay in Victoria, between 1973–76 (Holmes 1982).

Subsequent distribution

Victoria: *W. subtorquata* has also been recorded from Queenscliff, Mornington and Corio Bay. It is widespread through Port Phillip Bay and is found in the low intertidal zone, often associated with the polychaete *Galeolaria caespitosa*; South Australia: around Adelaide and on rocky shores at Port Lincoln.

Russ and Wake (1975) reported this species (as *W. subovoidea*) as a fouler in all Australian states except Tasmania. Overseas, Gordon and Mawatari (1992) considered that the species arrived relatively recently in New Zealand; the first report in 1982 being from an area from which it had been absent five years previously. They report it as now being widespread in New Zealand ports.

Description

An encrusting species most often found at the low-water mark. Colonies are dark red-brown, with the growing edge red or orange. Avicularia are absent and embryos are brooded internally, so no ovicells are present. Zooids have perforations over the entire frontal area. The aperture is rounded and slightly longer than wide. Two condyles (small, tooth-like projections) give the aperture the appearance of having a constriction close to the mid-point. The shape of the aperture allows *W. subtorquata* to be distinguished from *W. arcuata*.

Potential for confusion with native species

Watersipora colonies can be identified readily in the field. The colony colour and their occurrence in the lower intertidal and very shallow subtidal are characteristic. It is not, however, possible to distinguish between different species of *Watersipora* in the field. The only species with the potential for confusion is *Mucropetraliella*, colonies of which are bright red and occur in similar habitats.

Ecology

Settlement occurs throughout the year with a possible summer peak (as *Watersipora subovoidea*). In Port Phillip Bay we have recorded it as a common settler at Williamstown, Sandringham and Mornington, while it does not generally recruit at Sorrento Pier and colonises sparsely at Queenscliff Pier. Along with *Cryptosula* and *Tricellaria occidentalis*, this bryozoan has spread very widely, so it occurs far from port and harbour situations. It can reach high percentage cover, but appears restricted to the lower intertidal and the subtidal zone within about a meter of MLLW. In some locations, it is the most abundant organism in this depth zone. Few other animals or plants settle onto the surface of these bryozoans.

The only ecological work in Port Phillip Bay (and southern Australia) is by Stuart (1983), who described growth and reproduction of animals at Sandringham Yacht Club Marina. Some information about settlement preferences is provided by Todd and Keough (1994), Bathgate (1994), and Keough and Raimondi (1995).

The most interesting aspect of the distribution of this species is its apparent rapid spread since first records in northern Port Phillip Bay. Holmes (1982) was confident that the 1970's record represented a new arrival, rather than its detection as a result of more complete surveys. Most of the material that we have examined is this species, with *W. arcuata* being quite uncommon. It may be that it has followed the same sequence as in New Zealand, with *W. subtorquata* replacing *W. arcuata*.

Watersipora arcuata Banta 1969

Synonymy and taxonomy

See Gordon (1989, p.41).

The *Watersipora* species with an arcuate orifice studied by Wisely (1958) in Australia and the species encountered in eastern Australia in the 1940's by Allen and Wood (Skerman 1960) were both regarded as variations of the species *W. cucullata* Busk. However, it was subsequently appreciated that the arcuate form warranted recognition as a separate species and was named as such by Banta (1969a). The earliest records of the arcuate form, *Watersipora arcuata*, from Australia are in the collections of Allen and Wood (1950) from NSW in the 1940's.

Dakaria subovoidea Harmer 1957;

Watersipora subovoidea Russ and Wake 1975: 12;

As *Watersipora cucullata* Allen and Wood 1950.

Native range

Banta (1969b) concluded that *W. arcuata* was indigenous to the tropics and subtropics of the eastern Pacific and was transported via shipping to Australasia.

First recorded collection in Port Phillip Bay

It was recorded for the first time in Victoria in Hobsons Bay between 1973–76 by Holmes (1982) and has since been recorded at Portsea (Russ 1980).

Subsequent distribution

As *W. cucullata,* present in all states except Tasmania (Wood and Allen 1958).

Description

Same colony form as for *W. subtorquata,* from which it can be distinguished by the shape of the aperture. In *W. arcuata,* the aperture is roughly circular, with a broad sinus at the proximal end.

Potential for confusion with native species

Not likely to be confused with native species.

Ecology

Settlement has been reported as being greatest during summer months, but under favourable conditions this species will settle throughout the year. In New Zealand, *W. subtorquata* has expanded its range quite rapidly, and has taken over areas formerly occupied by *W. arcuata* (Gordon and Mawatari 1992). We have recently examined large amounts of *Watersipora* and all of this material corresponds to *W. subtorquata.*

Family Schizoporellidae

Schizoporella unicornis Johnston 1847

Synonymy and taxonomy

Lepralia unicornis Johnston in Wood 1944: 9;
Schizoporella unicornis Hincks 1880: 288. — Ryland 1965: 65. — Ryland 1968: 535;
Not *Schizoporella unicornis* Marcus 1940: 237.

Native range

Schizoporella unicornis has been recorded from almost all of the world's oceans, though often in error (OECD, Ryland and Hayward 1977).

First recorded collection in Port Phillip Bay

Uncertain.

Subsequent distribution

Russ and Wake (1975) reported this species as a fouler from Queensland, New South Wales, Victoria and South Australia. Allen (1953) reported this species as a common fouler in both Port Jackson, New South Wales and Fremantle Harbour, Western Australia. He indicated there is evidence that this species arrived in Sydney on two small Japanese vessels that were captured and anchored in Watson's Bay during World War II and that it subsequently spread through Port Jackson. Small encrusting zoaria of *Schizoporella unicornis* were recorded from the Great Barrier Reef in 1925 by Livingstone (1928) and may be evidence of an earlier introduction.

Potential for confusion with native species

This species cannot be identified in the field. There may be some difficulty with collected specimens because of taxonomic uncertainty.

Ecology

Settlement probably occurs during spring and summer. The local forms are not well known. At our primary study sites, colonies are never large, unlike, for example, those in North America, where this species can be a dominant component of the sessile fauna (Sutherland and Karlson 1977). It is unlikely that this species has had significant effects on local sessile animals and plants.

Comments

The distributional records for this bryozoan are not very reliable, because of taxonomic confusion. *S. errata* is very similar to *S. unicornis* and it is not clear if one or both species are present in Australia, or if there are similar native species. Bock (1982) questioned whether the Adelaide species is *S. unicornis,* noting that it looked more like *S. errata.* Gordon and Mawatari (1992) report S. *errata* from New Zealand, including material previously reported as *S. unicornis.* A similar situation exists in eastern North America, where a native form has at various times been a separate species, *S. floridana* and a subspecies of *S. unicornis* and *S. errata.*

Family Microporellidae

Microporella ciliata (Pallas 1766)

Synonymy and taxonomy

See Hayward and Ryland (1979, p. 222).
Eschara ciliata Pallas 1766: 38;
Lepralia ciliata MacGillivray (1879);
Microporella ciliata Hincks 1880: 206. — MacGillivray 1887. — Marcus 1940: 256.

Native range

M. ciliata has been ascribed an almost cosmopolitan distribution.

First recorded collection in Port Phillip Bay

This species has been known from Australian waters since at least the 1870's when MacGillivray (1879) recorded it (as *Lepralia ciliata*) from Queenscliff, Port Fairy and Warrnambool in Victoria.

Subsequent distribution

Victoria: Point Cook, Carrum, Port Phillip Heads, Sorrento, Dromana and Hobsons Bay (Vigeland 1971).

Description

An encrusting species, where colonies are unilaminar and rarely reach a size > 2 cm^2. Zooids are very distinct with clear borders. The aperture is D-shaped, with the proximal edge straight. Spines surround the curved part of the aperture; these may be broken or missing in older colonies, but are clear in young colonies. The ascopore is clearly visible and is crescent shaped. Most zooids have a single avicularium, which is proximal and lateral to the aperture. The frontal wall of the zooids has perforations over most of its surface.

Potential for confusion with native species

Species in this family can be readily identified in the laboratory based on the presence of an ascopore and the shape of the aperture.

Ecology

Settlement was recorded in summer at Mornington by Todd and Keough (1994), although they could not definitely identify the newly-settled bryozoans as *M. ciliata*, only as closely resembling that species. The small-scale distribution of this bryozoan is not known in Port Phillip Bay because it is impossible to identify in the field. Colonies never reach a large size (usually < 2 cm diameter) or a high density and are unlikely to have any great effect on local sessile biotas.

Comments

It is unclear whether *M. ciliata* is an endemic or introduced species. Maplestone (1904) found *M. ciliata* in the Victorian Tertiary deposits, suggesting that it is an endemic species. However, *M. ciliata* can be difficult to identify and in most areas there are presumed native species that can be quite similar and may have been wrongly identified by Maplestone (1904). *M. ciliata*, the type species of the genus, has the simplest external morphology, with other species differing primarily in the morphology of the avicularia. As a result, distributional records are unreliable.

Fenestrulina malusii (Audouin 1826)

Synonymy and taxonomy

See Hayward and Ryland (1979, p.224).
Cellepora malusii Audouin 1826: 239;
Microporella malusii Hincks 1880: 211. — MacGillivray 1887: 23;
Lepralia malusii MacGillivray (1879);
Fenestrulina malusii Marcus 1940: 260. — Gautier 1962: 170.

Native range

F. malusii has been reported from all the world's seas, with the exception of polar waters (Ryland and Hayward 1977). This species may also owe its wide distribution to the movement of shipping.

First recorded collection in Port Phillip Bay

It has been known from Australian waters from at least the 1870's when MacGillivray (1879) recorded it (as *Lepralia malusii*) at Queenscliff.

Subsequent distribution

Victoria: Hobsons Bay, Portsea and Port Phillip Heads (Vigeland 1971; Russ 1980).

Description

Usually forms small, encrusting colonies. Aperture D-shaped, with a few spines around the aperture in young colonies. Older colonies often lacking spines. The ascopore is crescent-shaped. No avicularia. Frontal wall has perforations but these may not be spread over the whole surface.

Potential for confusions with native species

It is hard to distinguish this from other small, encrusting species in the field. In the laboratory, this species is relatively easy to identify (as with *Microporella*) by the presence of the ascopore, the shape of aperture and the pattern of spination. It is most likely to be confused with *Microporella*, from which it can be distinguished by the absence of the avicularia, the weak pattern of spination and a difference in the shape of the ascopore

Ecology

Nothing known for southern Australia.

Family Hippothoidae

Celleporella hyalina (Linnaeus 1767)

Synonymy and taxonomy

Cellepora hyalina Linnaeus 1767: 1286;
Celleporella hyalina Gray 1848: 128;
Schizoporella hyalina Hincks 1880: 271. — MacGillivray (1889a);
Hippothoa hyalina Ryland and Gordon 1977: 38.

Native range

C. hyalina is widely distributed in both the Atlantic and Pacific Oceans. Ryland and Gordon have reported the Northern Hemisphere species *Celleporaria hyalina* in New Zealand, based on a single specimen from an unknown locality.

First recorded collection in Port Phillip Bay

MacGillivray (1889a) reported this species (as *Schizoporella hyalina*) as being common in Port Phillip Bay in the 1880's.

Subsequent distribution

Unknown, though the species is probably widespread.

Description

Colonies encrusting and rarely more than 30 mm in diameter. Zooids are small (< 0.4 mm), with smooth frontal walls. They are not strongly calcified and often have a glassy appearance. The orifice is rounded, with a weak sinus on the proximal edge. Colonies have male and female zooids (in contrast to most bryozoans), with male zooids much smaller.

Potential for confusion with native species

These small, fragile colonies are impossible to identify in the field. Other small, weakly calcified genera, such as *Electra* and occasionally *Membranipora*, may not be easy to separate in the field. *Hippothoa* spp. can be readily identified in the laboratory.

Ecology

This species has not been studied in southern Australia. R N Hughes and his students have completed extensive work on populations of this species in Great Britain (Cancino 1986; Hughes and Hughes 1986; Cancino and Hughes 1987; Hughes 1989; Hunter and Hughes 1995)

Comments

Hippothoid bryozoans commonly encrust algae, particularly *Ecklonia radiata* in Port Phillip Bay. It would be useful to examine the Victorian material in more detail, as they need some systematic attention (see below).

13.2.3 Sponges

Diagnosis of sponges is difficult and requires a combination of inspection of intact material and dissection of colonies. In general, these species cannot be identified reliably by more than a handful of biologists and the sponge fauna of Victoria probably contains many unidentified species. It is difficult, therefore, for non-specialists to classify sponge material as native or exotic. For this reason, only very simple descriptions are provided here and we have not listed potential confusions with native species for this group of fouling organisms.

Although some species may have been introduced, there are not reliable distributional records for them and no reliable information on seasonality of recruitment or ecological impacts. Wiedenmayer (1989) rejected the notion that some widely distributed species may have been introduced, even when the species are confined to harbours and have weakly dispersing larval stages. He disagreed with Scheltema (1986), who considered shipping to have been the prime cause of such disjunct distributions, preferring to invoke former widespread distributions that had collapsed and naturally occurring rafting. This argument is not well supported by much data, but nevertheless, it is hard to identify sponges that are clearly introduced, with the possible exception of *Aplysilla* and *Dysidea*[7]. The poor taxonomic state precludes any clear diagnosis.

Family Tedaniidae

Tedania anhelans (Lieberkühn)

Synonymy and taxonomy

This sponge has been classified into at least five genera and many species. The synonymy is complex and is discussed in some detail by Wiedenmayer (1989: 87ff).

Halichondria anhelans Lieberhühn 1859: 521;
Myxilla anhelans Schmidt 1862;
Tedania anhelans Hechtel 1965: 38;
Tedania nigrescens Burton and Rao 1932: 353;
Reniera digitata Schmidt 1862: 75;
Tedania digitata Carter 1886a-h: 52. — Dendy 1895: 258;
Suberites panis Selenka 1897: 570;
Tedania panis Thiele 1903a, 1903b: 946;
Reniera muggiana Schmidt 1868: 28;
Tedania rubicunda von Lendenfeld 1888: 190 (from Port Jackson NSW);
Tedania rubra von Lendenfeld 1888: 191. — Whitelegge 1889: 185, both from waters around Port Jackson;
Clathrissa elegans von Lendenfeld 1888: 218 (records from Port Jackson);
Tedania assabensis Keller 1891: 313.

Native range

Widely distributed in the Indian Ocean and the Mediterranean.

First recorded collection in Port Phillip Bay

The first Australian records date from the 1880's, as *Tedania digitata*, including records from southern Port Phillip Bay (Carter 1886a-h; Dendy 1895), at Sorrento and Queenscliff (Dendy 1895). Wiedenmayer (1989) refers to Australian Museum and British Museum records from von Lendenfeld of material from Port Phillip Bay, as *Clathrissa elegans*.

Subsequent distribution

Not known.

Description

A thinly encrusting species, with a very irregular shape. Colour varies from bright orange, through brown, dull green, bluish, to blackish (Wiedenmayer 1989).

Ecology

Nothing known from Australia.

Family Myxillidae

Lissodendoryx isodictyalis (Carter)

Synonymy and taxonomy

Wiedenmayer (1989: 98) provides a detailed synonymy for this species, which, again, has been listed under a range of generic and specific names;

Halichondria isodictyalis Carter 1882a, 1882b: 285. — Carter 1886a-h: 52, from Port Phillip Bay;
Myxilla isodictyalis Dendy 1896: 30, from Port Phillip Bay. — Whitelegge 1901: 79 from NSW;
Lissodendoryx isodictyalis Topsent 1897: 456. — Wiedenmayer 1989: 98;
Lissodendoryx similis Thiele 1899: 18;
Hamigera ternatensis Thiele 1903a, 1903b: 952;

[7] Editor's note: Note work by Coles *et al.* (1997) and Coles *et al.* (1999).

Lissodendoryx ternatensis Lundbeck 1905: 173. — Burton and Rao 1932: 331;
Lissodendoryx sinensis Brøndsted 1929: 228.

Native range
Atlantic and Pacific Oceans.

First recorded collection in Port Phillip Bay
First records for Port Phillip Bay are in the late 1800's.

Subsequent distribution
Not known.

Description
A thinly encrusting species with a highly variable growth form and colour.

Ecology
Unknown in Australia. Bergquist and Sinclair (1973) describe the larval biology of this species from the North Island of New Zealand.

Family Callyspongidae

Callyspongia pergamentacea (Ridley) (synonymy pp. 109–110)
Recorded in the earliest surveys from southern Australia, with distribution records from SA, southern Port Phillip Bay, Vic. and NSW. It is also recorded from northern Australia and Brazil.

Family Dysideidae

There is some uncertainty concerning this family. Wiedenmayer (1989) recorded *D. avara* from two stations in Bass Strait. Bergquist (1996) listed a specimen of *Dysidea,* which she thought close to *D. fragilis,* from St. Kilda Marina. She was of the opinion that many earlier records for *Dysidea*, particularly from tropical Australia, are highly suspect. We include both species here.

Dysidea avara (Schmidt)

Synonymy and taxonomy
Spongelia avara Schmidt 1862: 29. — von Lendenfeld 1889a, 1889b: 667. — Rutzler 1965: 42;
Spongelia pallescens Schmidt 1862: 30;
Dysidea pallescens Schulze 1878a, 1878b. — Vacelet 1959;
Dysidea avara de Laubenfels 1948. — Wiedenmayer 1989: 114.

Native range
Widely distributed through the Atlantic and tropical Pacific.

First recorded collection in Port Phillip Bay
Recorded from Port Phillip Heads by von Lendenfeld (1889a, 1889b).

Subsequent distribution
Not known.

Description
Encrusting sponge, often dark grey or purple in life.

Ecology
Not known from Australia.

Dysidea fragilis (Montagu)

Synonymy and taxonomy
Dysidea fragilis Montagu.

Native range
Widely distributed on the Atlantic coasts of Europe.

First recorded collection in Port Phillip Bay
In 1996 with CSIRO—CRIMP survey (Bergquist 1996).

Subsequent distribution
Not known.

Description
A variable-shaped colony that may occur in low sheets or lobed mounds. Colour is usually white-grey. Colonies are usually soft and spongy, with a slightly spiky surface.

Ecology
Little is known from Australia.

Comments
As mentioned earlier, Bergquist identified material from northern Port Phillip Bay as resembling *D. fragilis*. She mentions previous records of this sponge from Australian waters (Burton 1934) but considers that earlier misidentifications cause problems.

Family Darwinellidae

The family Darwinellidae includes *Aplysilla, Darwinella* and *Dendrilla.* It is likely that these species have been confused in ecological studies and even Wiedenmayer's account of *Aplysilla rosea* conflicts with Bergquist's (1980) opinion that two consistently different colour morphs represent the distinct species *A. rosea* (Barrois) and *A. sulphurea* (Schulze). We believe that, as Bergquist's decision was based on field ecological observations as well as morphology whereas Wiedenmayer's decisions are based solely on morphology, it is likely that these forms represent two species.

A. rosea may also be confused with *Dendrilla rosea,* which Wiedenmayer refers to *D. cactos* (Selenka); Wiedenmayer lists at least two popular guides that feature specimens labeled as *D. rosea* and *A. rosea.* Accepting Wiedenmayer's diagnosis, *Dendrilla cactos* (synonymy p. 152) is primarily an Australasian species that may also occur as far north as Indonesia. *Aplysilla rosea* (synonymy in Wiedenmayer 1989, p. 146) is widely distributed, being recorded from the Mediterranean, South Africa and Hawaii. It was recorded, as *A. rosea* and *A. sulphurea* from NSW last century. It is not clear whether this species is introduced, although the OECD (Sara 1974) lists it as a common, widespread fouling species. Of the remaining widely distributed species, *Darwinella australianensis* Carter (synonymy p. 147) is a Mediterranean species also known from Bermuda and *D. gardineri* Topsent (synonymy p. 149) represented the first record of a species known from the Indian Ocean.

Family Anchinoidea

Phorbas cf. tenacior Topsent (synonymy, p. 102)

A doubtful record of a Mediterranean species; Wiedenmayer believed that his new record may have been a distinct species.

Family Haliclonidae

Haliclona heterofibrosa

Synonymy and taxonomy

Reniera heterofibrosa Lundbeck 1905: 47. — Brøndsted 1923: 121;
Haliclona heterofibrosa Bergquist 1961a-c: 35;
Haliclona glabra Bergquist 1961a-c: 35;
Haliclona isodictyale Bergquist 1961a-c: 34.

Native range

H. heterofibrosa is a Northern Hemisphere species, common on cold water European Atlantic coasts. It is also established in northern New Zealand (Bergquist in press) where it has been known to occur for at least thirty years.

First recorded collection in Port Phillip Bay

In 1996 with CSIRO—CRIMP survey (Bergquist 1996).

Subsequent distribution

Not known.

Description

From Bergquist (1996): a fragile, pale brown to purple tinged sponge with tubular construction and prominent oscular turrets. The best published photograph and description is found in Bergquist and Warne (1980) (p.16; pl. 2, d–f; 3 a,b).

Ecology

Nothing known from Australia. On the North Island of New Zealand, *H. heterofibrosa* is present year round (Bergquist 1996).

Comments

Bergquist (in press) describes this species in New Zealand as occurring under intertidal boulders and on mussels in northern harbours. She considered that this species has no attributes that would indicate that it is a species easily transportable by ship and raises the possibility that Northern and Southern Hemisphere specimens belong to different species.

Family Halisarcidae

Halisarca dujardini Johnston

Synonymy and taxonomy

Halisarca dujardini Johnston 1842: 192. — von Lendenfeld 1889a, 1889b: 729. — Burton 1932: 169. — de Laubenfels 1948: 175. — Levi 1956: 184. — Bergquist and Sinclair 1973.

Native range

H. dujardini is a native of European Atlantic coasts (Bergquist 1996). It is a cosmopolitan species found in harbours, usually on mussels, in North America, New Zealand and South Africa. It has not been previously recorded from Australia, however, the species is very thin and inconspicuous and thus easily overlooked.

First recorded collection in Port Phillip Bay

In 1996 with CSIRO—CRIMP survey (Bergquist 1996).

Subsequent distribution

Not known.

Description

A sheet-like growth form, with a smooth surface. Colour ranges from yellow, to fawn, with a greyish or greenish tinge. There are no spicules.

Ecology

Bergquist (in press) describes this species in New Zealand as seasonal. It is present in spring and early summer and produces some dormant stages.

Comments

The sponge is a thin, beige-brown slimy plate, never more than 1.0 mm thick, with no mineral skeleton. It has no distinguishing surface features (Bergquist 1996). Bergquist refers to a useful photograph in Ackers *et al.* (1985, p.163). She considers that, given its habitat and life cycle, it could be a sponge easily transported by ships.

Family Pilakinidae

Corticulum candelabrum Schmidt.

A Mediterranean species, also known from the Great Barrier Reef. Wiedenmayer (1989, p. 13) was the first to report this species from southern Australia, but he also cites fossil material from New Zealand as closely resembling *C. candelabrum* and considers this species not to be introduced.

13.2.4 Hydroids

Class Hydrozoa

Hydroids have been well studied in Victoria, largely as a result of the extensive work by J E Watson. They appear in Chapter 7 and we have considered only the better known fouling species here. In general, they are difficult to identify in the field, with the exception of species with larger polyps, such as *Tubularia.*

Bougainvillia ramosa (van Benedon 1845)

Synonymy and taxonomy

See Chapter 7.

Native range

Northern Hemisphere. Watson (1982) reported that *B. ramosa* medusa are widely distributed in northern Atlantic and northern Pacific waters, the species apparently preferring generally cooler waters.

First recorded collection in Port Phillip Bay

Briggs (1931) first observed specimens of *B. ramosa* in Australian waters in May 1918 at Port Jackson. Prior to that date, no representatives had been encountered although the locality was visited frequently between 1912 and 1918. Its introduction may have occurred much earlier than this as von Lendenfeld (1885a, 1885b) (see Allen 1953) noted "I have found some *Bougainvillia* in Port Jackson, which are similar to *B. ramosa*. They are the only Hydroid polyps resembling that genus, which I have met in Australian waters". Allen (1953) suggests von Lendenfeld may have seen the individuals of an earlier but unsuccessful invasion of the species, while Briggs was fortunate to observe the beginning of a second, successful establishment.

This species was first recorded in 1963 at Sandringham in Victoria in the PPBES-1 (Southcott 1971) and no doubt has a much wider distribution in southern temperate waters than has so far been recorded (Watson 1982).

Subsequent distribution

Not well known.

Description

See Watson, Chapter 7.

Potential for confusion with native species

See Watson, Chapter 7.

Ecology

Settlement is thought to occur in spring and is more frequent during autumn (around May). Little ecological information is available for this species in southern Australia.

Comments

The sudden appearance of this typically Northern Hemisphere species in the coastal waters of eastern Australia suggests it was brought by ship to Port Jackson (Briggs 1931).

Tubularia crocea Agassiz

Synonymy and taxonomy

See Watson, Chapter 7.

Native range

Cosmopolitan.

First recorded collection in Port Phillip Bay

Recognised in Australia for the first time in November 1977 at Hobsons Bay, Victoria (Watson 1978).

Subsequent distribution

Not well known.

Description

See Watson, Chapter 7.

Potential for confusion with native species

See Watson, Chapter 7.

Ecology

Not well described in southern Australian fouling assemblages. Its impact has not been studied, nor has it been highlighted in ecological studies of southern Australian sessile assemblages.

Comments

A major fouling organism on ship hulls and port installations. It is distributed in ports from sub-tropical to cool-temperate regions in Australia and was probably brought to Australia on shipping from South Africa or North America.

13.2.5 Polychaetes

Phylum Annelida

Class Polychaeta

Family Serpulidae

Ficopomatus enigmaticus (Fauval 1923)

Synonymy and taxonomy

Mercierella enigmatica Fauvel 1923. — Allen 1953. — Russ and Wake 1975;

Ficopomatus enigmaticus ten Hove and Weerdenburg 1978: 114.

Distributional records for this species are unreliable. A detailed discussion is provided by ten Hove and Weerdenburg (1978), who note that some of the records from lower latitudes in Australia, referred to *F. enigmaticus*, represent other species in this genus.

Native range

Occurs in most oceans, although exact distribution is uncertain because of confused systematics (ten Hove and Weerdenburg 1978)[8].

First recorded collection in Port Phillip Bay

The first record in Port Phillip Bay is unclear; the first major record is in 1974 (Russ and Wake 1975).

Subsequent distribution

The earliest record of it in Australia is about 1932, in the Sydney area (Allen 1953). *F. enigmaticus* has been recorded in Western Australia, South Australia and Victoria (Allen 1953; Russ and Wake 1975). In Victoria, this species been recorded from Port Phillip Bay, particularly Hobsons Bay at the mouth of the Yarra River (Russ and Wake 1975; Holmes 1982) and Crib Point in Western Port Bay (Holmes 1982).

Description

A serpulid with a white tube, that may be covered by algae. The genus is separated from other serpulid genera by the shape of the collar setae (which have fine teeth). *F. enigmaticus* has a characteristic concave operculum, with a series of spines, which curve inwards. The spination on the operculum is rare in other serpulids.

[8] Editor's note: See Chapter 8 for further discussion.

Potential for confusion with native species

The family Serpulidae is not well studied in Australia and a number of native species can only be separated in the laboratory by dissection. This genus is primarily found in more estuarine waters.

Ecology

Settlement occurs in spring and summer. Little information is available for this species in southern Australia.

Comments

Described as a new species by Fauval (1923) in France, it was simultaneously discovered in London docks, then Brittany, Spain, Tunis, the Black Sea and California (Allen 1953). Fauval (1933) appeared convinced that the Madras area must be the region of origin (Allen 1953). However, there seems to be no record of the fact that it was also abundant and thriving in Australian waters at that time. As it is so widely distributed in Australia, this continent and not India may have been the source of the specimens introduced to European waters (Allen 1953). Allen (1953) noted that, whatever its country of origin, there can be little doubt that ships have played an important role in extending the distribution of this species.

Hydroides norvegica Gunnerus

Synonymy and taxonomy

Eupomatus elegant Haswell (1885).

Native range

H. norvegica has a world-wide distribution in warmer seas.

First recorded collection in Port Phillip Bay

First records for Port Phillip Bay are unclear. It has been recorded in all states except Tasmania (Russ and Wake 1975).

Subsequent distribution

Not well documented. Under the name of *Eupomatus elegant*, it was described from Port Jackson, NSW as a new species by Haswell (1885) (Allen 1953).

Description

A small, white serpulid.

Potential for confusion with native species

Not known.

Ecology

Can settle throughout the year; peak settlement in summer. There is little information on the ecology of this species in southern Australia.

Family Sabellidae

Sabella spallanzanii Viviani

The biology of this species is dealt with in more detail in Chapter 16, but we note here that it attaches to pier pilings, ascidian tests, etc. It's current distribution extends over piers up the west side of Port Phillip Bay to Port Melbourne and has recently been detected at Sandringham Marina on the eastern side (M Holloway pers. comm.). Individuals may also be seen in the shallow subtidal of rocky reefs in northern Port Phillip Bay.

Although no work has yet been done, hydrodynamic effects associated with high densities of *S. spallanzanii* on some piers around Corio Bay suggest that this introduced fouling species is likely to change the nature of local fouling assemblages[9].

13.2.6 Molluscs

Order Nudibranchia

Family Polyceridae

Polycerid nudibranchs that are easily recognisable having a long, slender body form and specialized radulae. They prey almost exclusively upon bryozoans.

Polycera hedgpethi Marcus 1964

Synonymy and taxonomy

Polycera hedgpethi Marcus 1964: 129.

Native range

P. hedgpethi has an almost cosmopolitan distribution. Originally described from California (Marcus 1964), it has been transported widely by shipping (Willan and Coleman 1984).

First recorded collection in Port Phillip Bay

Records for Port Phillip Bay are uncertain.

Subsequent distribution

First recorded in Victoria in 1973 at Malacoota (Willan and Coleman 1984; Hutchings *et al.* 1987).

Description

Californian specimens have a brown body, with yellow cerata. A specimen from South Africa is illustrated in Gosliner (1987, p. 97).

Potential for confusion with native species

Unless there is substantial colour variation, *P. hedgpethi* is easily distinguished from the endemic species in the family, such as *Tambja verconis*, which also feed on arborescent bryozoans. The small species *Polycera janjukia* was described by Burn from the outer coast to the west of Port Phillip Bay.

Ecology

Probably introduced by shipping; it feeds on arborescent bryozoans (such as *B. neritina* and *B. flabellata*) that typically occur as part of the fouling community on ships.

Kaloplocamus ramosus (Cantraine)

A species first described from the Mediterranean and subsequently from Africa and Japan (Burn 1989). Burn

[9]Editor's note: See Chapter 16 for further discussion.

lists the species as ranging over the south-eastern states, with a broad depth range. Little information is available about its distribution in Port Phillip Bay.

Family Okeniidae

Okenia plana **Baba 1960**

Synonymy and taxonomy

Okenia plana Baba 1960.

Native range

Cosmopolitan now, but originally described from Japan.

First recorded collection in Port Phillip Bay

Not known.

Subsequent distribution

Uncertain, though its host is widespread. First recorded in Australia in 1977 from Victoria, New South Wales and Queensland (see Hutchings *et al.* 1987).

Description

From Furlani (1996): dorid nudibranch; ground colour whitish with brownish spots, rhinophores yellow on upper half, 7–8 mm length, body flattened dorso-ventrally, head in process; 5 marginal processes on each side varying in length, oral tentacles present but not paired, rhinophores not simple, dorsal processes simple, 8–11 gills arranged in a semicircle, branchial plumes colourless, extra-branchial appendages absent.

Potential for confusion with native species

Burn (1967) has described *Okenia mija* from the coast outside Port Phillip Bay, and earlier (Burn 1966) recorded a specimen of *Okenia*, which he did not assign to a particular species, from the entrance to the Bay. *O. pellucida*, described from NSW, is morphologically similar to *O. plana*, and Burn (1967) used colour to distinguish these two specimens. The family was treated in some detail by Marcus (1957).

Ecology

Nothing is known of this species from Port Phillip Bay, or Victoria, in general. Species in this genus are often predators on arborescent bryozoans, and *O. pellucida* was recorded living and feeding on *Zoobotryon.*

Comments

Like *Polycera hedgpethi*, *O. plana* has now achieved a widespread but patchy distribution as a consequence of its intimate association with a cosmopolitan bryozoan (*M. membranacea*).

13.2.7 Barnacles

Phylum Crustacea

Class Cirrepedia

There are a few species of barnacles commonly found in the northern half of Port Phillip Bay that may be introduced. Their status remains unclear, in part because of taxonomic uncertainties.

Elminius modestus **Darwin**

Synonymy and taxonomy

Elminius modestus Darwin.

Native range

This small barnacle is endemic to New Zealand. It was introduced to Europe, where it has spread widely.

First recorded collection in Port Phillip Bay

It is not clear whether this species is native to Australia or an introduction from New Zealand.

Subsequent distribution

Common in Hobsons Bay and also found in the Geelong Arm of Port Phillip Bay. It is apparently confined to sheltered parts of Port Phillip Bay.

Description

A small barnacle, with four shell plates. The shell is white or grey, with an irregular outline in larger specimens. There are a few (usually < 8) strong ribs running down the shell from the aperture.

Potential for confusion with native species

In Port Phillip Bay, the genus *Elminius* is the only fouling barnacle with four shell plates. Care must be taken to distinguish *E. modestus* from congeners.

Ecology

Common in sheltered environments in southeastern Australia but not found on more exposed coasts. It settles in the intertidal and shallow subtidal, often in very large numbers.

Comments

Distributional records are unreliable because only a single species had been attributed in the genus prior to the 1980's. A number of other species have subsequently been recognized, including *E. covertus* Foster, *E. adelaidae* Bayliss, *E. flindersi* Bayliss, *E. placidus* Bayliss and *E. erubescens*. Some material previously included in *E. modestus* has now been referred to the genus *Hexaminius*. Existing museum material has not been re-examined, nor have published studies of settlement been revisited to determine the species of barnacle involved. In Victoria, *E. modestus* is the predominant species in Port Phillip Bay, whereas *E. covertus* is the primary barnacle in Western Port.

Balanus variegatus **Darwin and** ***Balanus amphitrite*** **Darwin**

These barnacles have also been subject to taxonomic confusion. *B. variegatus* was originally described as a variety of *B. amphitrite*. Species in this genus are widespread through temperate ports and harbours in both hemispheres and most ports have a mixture of native and exotic species. In southern Australia, *B. amphitrite* is considered exotic and *B. variegatus* native to Australia and New Zealand (Foster 1978). The two forms have not always been separated (see below) and some records listed as *B. amphitrite* may refer to *B. variegatus*.

According to Forster (1978) and Lewis (1981), a further species, *Balanus improvisus* Darwin, which also resembles *B. amphitrite*, has been reported from Australia, but it's status is uncertain. *B. improvisus* is an Atlantic species, which was thought to have spread to European waters in the latter part of the 1800's and to have reached the western Pacific some time later (Walford and Wicklund 1973). Bishop (1951) recorded it on the hull of a ship that had recently returned from Australia and he considered that settlement had occurred while the ship was in Australian waters. He provided few other details.

Balanus amphitrite Darwin

Synonymy and taxonomy

Balanus amphitrite Henry and McLauglin 1975: 30;
Balanus amphitrite var. communis Pope 1945. — Wood and Allen 1958;
Balanus variegatus var. *communis* Russ 1977.

Native range

Uncertain; distribution now cosmopolitan.

First recorded collection in Port Phillip Bay

Uncertain, because of taxonomic confusion.

Subsequent distribution

Probably widespread in sheltered parts of Port Phillip Bay, but confused identifications make the exact distribution unclear.

Description

A barnacle with 6 shell plates and fine ribs. Generally, pale white-brown, with longitudinal stripes, which may be purple.

Potential for confusion with native species

The genus *Balanus* is easy to diagnose. The main potential for confusion is with *B. variegatus*. As described by Lewis (1981), *B. amphitrite* can be distinguished from *B. variegatus*, by

- the presence of a weak or longitudinal striping on the shell, compared to cross-hatched colouration of the shell in *B. variegatus*;
- the morphology of the tergal plate (spur longer than wide in *B. variegatus*, versus wider than long in *B. amphitrite*); and
- the denticulation of the labrum (simple in *B. variegatus* versus. multidenticulate in *B. amphitrite*).

Ecology

B. amphitrite settle prolifically at times. Generally restricted to the shallow subtidal areas of ports and harbours; rare or absent on more open coastlines.

Comments

The origin of *B. amphitrite* is unclear, although its global distribution suggests a history of introduction. These barnacles do however have a larval period of a few weeks, so some long-distance dispersal is possible.

Because the two forms have not always been separated reliably, we also list a partial synonymy for *B. variegatus*, covering the major names by which it has been listed in Australia.

Balanus variegatus Darwin

Synonymy and taxonomy

Balanus variegatus Darwin 1854;
Balanus amphitrite var. *stutsburi* Kruger 1914;
Balanus amphitrite var. *cirratus* Pope 1945. — Wood and Allen 1958;
Balanus variegatus var. *cirratus* Russ and Wake 1975. — Russ 1977.

13.2.8 Algae

Introduced benthic algae have been covered in the two reviews by Hutchings *et al.* (1987), and Pollard and Hutchings (1990), and summarised by Lewis (Chapter 6). Lewis lists a number of species that can occur attached to pier pilings, including the red algae *Schottera nicaeensis*, *Polysiphonia pungens* and *P. brodiaei*, the brown alga *Stictyosiphon soriferus*, and the green algae *Ulva fasciata* and *Codium fragile*. Lewis (1983) has recorded *Schottera* and *Stictyosiphon* as common recruits onto pier pilings at a site in northern Port Phillip Bay.

Existing studies of fouling communities in Port Phillip Bay, apart from those of Lewis, provide little information about algae, for a number of reasons. In some cases, study areas were chosen to exclude algae, in other cases the systematics of the algae concerned have changed, so the introduced species in question may not have been distinguished from related species. This is particularly the case for *Ulva fasciata*.

13.3 POTENTIALLY INTRODUCED SPECIES

The faunal records from New Zealand included a number of other introduced bryozoans. It is possible, or even likely, that some of these occur in southeastern Australia and it is not clear that existing surveys would have detected them.

Electra tenella

Recorded by Gordon and Mawatari (1992), from material attached to dead bivalve shells, with further records from the Hauraki Gulf. It has not been recorded from Australia.

Membranipora savartii

Listed by Vigeland (1971) as being represented by 3 slides in the Museum of Victoria collection. Osburn (1950) and Winston (1982) describe this species as being cosmopolitan in warm water. The MoV records have not been checked.

Membranipora tuberculata

The MoV collection includes material labeled as *M. tuberculata*, a species with a trans-Pacific distribution (Osburn 1950). It occurs primarily as an algal epibiont and according to Osburn (1950), is often found attached to drifting *Sargassum*.

Conopeum seurati

An encrusting species from the northern Atlantic. Gordon and Mawatari (1992) reported it as occurring in a wide range of habitats over a relatively broad latitudinal range. They cite the first record as 1969, but suggest that it had been introduced far earlier. It is distinguished from *C. reticulum* primarily by the almost complete absence of a cryptocyst (the calcified shield that covers the frontal membrane), and the rarity of kenozooids (Ryland and Hayward 1977). This species is primarily estuarine.

Aeverrillia armata

Recorded from a single location in New Zealand by Morton and Miller (1968). Gordon and Mawatari were unable to locate specimens in 1977 and 1988.

Bugula avicularia

A widely distributed fouling species, which has often been confused with *B. stolonifera*. Russ and Wake (1975) recorded this species from Port Phillip Bay, but it is not clear from their figures whether their collections included both *B. stolonifera* and *B. avicularia*, or just *B. stolonifera*.

Celleporella and *Hippothoa* spp.

The family Hippothoidae includes these two genera, which are weakly calcified bryozoans that encrust algae, rocks and pier pilings. Bock (1982) recorded two species of *Hippothoa* as occurring commonly in Victorian waters, *H. distans*, a cosmopolitan species that encrusts solid objects and *H. aporosa* encrusts algae. He emphasised that the Australian species need revision. Vigeland (1971) also listed *H. divaricata* as present in Port Phillip Bay, but Hayward and Ryland (1979) regard this species as an Atlantic and Mediterranean species. Ryland and Gordon (1977) state that records outside this region should be viewed with suspicion because this species may have been confused with closely related ones.

Celleporaria albirostris

Vigeland (1971) recorded this bryozoan from the Port Phillip Bay survey and it is also known from the Gulf of Mexico (Shier 1964). The genus *Celleporaria* is long overdue for taxonomic revision.

Parasmittina trispinosa

This is another widely distributed bryozoan that shows great phenotypic variation and, as a consequence, distribution records must be viewed with suspicion (Osburn 1952; Vigeland 1971). It is premature to consider this species as introduced.

13.4 DISCUSSION & CONCLUSIONS

13.4.1 Impacts

As with most Australian marine habitats, there are relatively few ecological studies to provide guidance about the likely impact of introduced species on native fouling communities. With the exception of *Sabella spallanzanii*, there are no cases of ecological studies before and after a species introduction. The lack of ecological studies is a major handicap, as it inhibits our ability to explain the observed patterns (Keough and Butler 1995).

The species most likely to have an impact are the colonial ascidians, such as *Botrylloides*, which tend to be good competitors for space and capable of excluding other species (Kay and Keough 1981; Russ 1982; Keough 1984a, 1984b). The presence of these species predates any known ecological study of this fauna in Australia and there are no recorded recent introductions of colonial ascidians.

The group with the greatest diversity of introduced species, the bryozoa, tend to be weak competitors for space (Kay and Keough 1981; Russ 1982) and are less likely to have an impact. As with the ascidians, many species have been present for a long period and even in the case of the recently introduced *Watersipora* spp., the only information about the potential impacts comes from anecdotal reports of the replacement of one introduced species by its congener.

Of the remaining taxa, polychaetes and barnacles are even weaker competitors, although the barnacle *Elminius modestus* did spread to the Northern Hemisphere and become an abundant intertidal and shallow subtidal species around Britain. It is very unlikely that the polychaetes listed here (with the exception of *Sabella*) have had any major impact on native communities.

An understanding of the general biology of these species not only requires information about their competitive ability, but also their seasonality of reproduction. We have provided here indications of when recruitment has been observed, but have not indicated precise times or attempted to produce correlations with physical environmental variables. We caution that in general, information about timing of settlement and/or recruitment of various species is the result of short term studies, with data often collected for < 1 year. When recruitment has been followed for more years (e.g. Keough 1983), it is apparent that many species vary dramatically from year to year in the timing and scale of recruitment, with some species not even recruiting successfully in every year. Most of the studies of recruitment have also used sampling periods of 1–2 months, so it is not possible to provide precise statements of the recruitment period. The variation among years makes such a task pointless.

13.4.2 Controls

Fouling organisms are unusual in that there have been many attempts to prevent their attachment to hard surfaces through the use of a wide range of antifouling coatings. These coatings include toxic substances such as organotins and copper, a range of polymers and even antibiotics. All of these treatments are intended to prevent the settlement of larvae of fouling organisms. The coatings are generally only effective for short periods (1–2 years, depending on the location). The most effective coatings, such as organo-tins, have severe environmental impacts and have been largely discontinued as treatments for vessels < 30 m in length. The continued active search for new compounds is the best indication of the general failure of antifouling treatments to control sessile invertebrates, even on small scales.

There are documented predators for many of these species (see, for example, the review by Harris 1990), but little evidence that predators control populations. Fish may prey upon the species with the greatest potential for competitive dominance, the colonial ascidians. Russ (1980) showed that arborescent bryozoans provided protection for ascidian colonies in southern Port Phillip Bay, allowing them to escape attacks by schools of monacanthid fish. Keough (1984a) demonstrated, by excluding fish, that juvenile monacanthid fish could prevent recruitment of some colonial ascidians in South Australia. In both studies, the ascidians that were consumed were not the species listed in this report. We are not aware of empirical studies showing control of *Botryllus* or *Botrylloides* by predators on adult stages. There is similarly little evidence that the common solitary species, *Styela plicata* and *Ciona intestinalis*, are routinely controlled by predators elsewhere in the world.

In Port Phillip Bay, bryozoans in the genus *Bugula* are preyed upon by nudibranchs, *Tambja* spp., which will consume large amounts in the laboratory. They prey on both native and introduced *Bugula* and are most often found feeding on *B. dentata*. In other parts of the world, specialist nudibranch predators consume bryozoans. Yoshioka (1982a,1982b) and Harvell (1992) describe such a system for the cosmopolitan *Membranipora membranacea* and Klemke and Keough (1991) present an Australian example, the nudibranch *Madrella sanguinea* preying on the endemic bryozoan *Mucropetraliella ellerii*. While the fouling species may be the major or sole component of the diet of these predators, it is not clear that the predators are sufficiently abundant and/or voracious to limit populations of their prey. More general predators, such as sea stars and urchins, may consume sessile animals. In some locations, they may alter the composition of the fouling community (e.g. Day and Osman 1981), but in other cases, have only weak effects (Keough and Butler 1979). Echinoderms are not generally very specific predators.

Predators may also act on newly settled recruits or on larvae (or spores) of fouling organisms. Predation on larvae can sometimes be severe (e.g. Gaines and Roughgarden 1987) and at least one introduced fouling species, *Molgula manhattensis*, has been suggested as an important predator of larvae on the east coast of North America (Osman and Whitlach 1995a). Larval predation, however, is more often variable or weak and there is no widespread evidence that predators on larvae are major causes of mortality across a range of species (reviewed by Young 1990; Morgan 1995). Some recent experimental work demonstrates that predators on newly settled organisms can cause high mortality and even remove all settlers of some species. Osman and Whitlach (1995b) showed that two micro-gastropods could consume large numbers of ascidians. However, while these molluscs tended to be specific predators at a particular time, they readily changed to consuming alternative species. With such behaviour, they are unlikely to be able to limit target species without consumption of endemic fouling organisms.

One important consideration is that the majority of species discussed here are clonal (or modular) and such organisms, in contrast to unitary (also known as solitary, aclonal) organisms, are often not completely killed by predators. Instead, they suffer damage to the colony and can regenerate by asexual growth. Perhaps, as a consequence, there are relatively few accounts of control of populations of modular organisms by predators (see, for example, the papers by Jackson 1977, 1979, 1985; McKinney and Jackson 1989; Buss 1979). The arguments in those papers, plus those advanced for plants by Harper (1977; and see summaries in Begon *et al.* 1996), make it unlikely that any of these modular organisms will be controlled by predators.

The unitary or solitary organisms (solitary ascidians, barnacles and polychaetes) may have important predators, but we have argued that the polychaetes, except for *Sabella*, are not a major problem and it is not clear that the barnacles are exotic. The question of interest is the potential for control of the solitary ascidians. Specialist ascidian predators are known from some areas (e.g. the carnivorous snail *Cabestana spengleri* is a predator of the ascidian *Pyura stolonifera* in southeastern Australia) but, again, there are no documented cases of the control of individual species.

Parasites are not well known for fouling species, although some groups, such as ascidians, may harbour many endosymbionts. For example, Dalby (1995) found endosymbiotic nemerteans and amphipods in the two forms of *Pyura stolonifera*. These animals were common but, as they caused no clearly deleterious effects, they may be commensal, rather than parasitic.

Attention has been drawn recently to the possibility that some invertebrate species may experience low fertilization rates if their density is reduced (reviewed by Levitan 1995). This raises the potential for control of some invertebrate species by reduction in density, rather than complete removal. Unfortunately, many colonial fouling species appear capable of self-fertilization, often between different members of the colony. For example, in *Botryllus schlosseri* and *Celleporella hyalina*, selfing occurs and the level of selfing varies inversely with the supply of external sperm (Yund and McCarthy 1994). Thus, at high density, outcrossing occurs, but at lower densities the animals begin to self.

Gordon and Mawatari (1992) suggested some means of controlling the spread of already introduced bryozoans, e.g. mooring smaller vessels some distance from piers and other concentrated sources of larvae to take advantage of the limited larval periods of these species. They also mentioned the reduced osmotic tolerance of bryozoans in general, so that reduced salinity of ballast or passage of the vessels through waters of lowered salinity would kill bryozoans effectively. These methods would not however be useful for reducing established populations of these fouling organisms.

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14 EXOTIC MARINE PESTS IN THE PORT OF GEELONG, VICTORIA.[1]

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14.1 INTRODUCTION

The transport of species on the hulls and in the ballast water of international shipping, and the subsequent establishment of exotic organisms in foreign ports is not a new phenomenon (Byrne *et al.* 1997). The issue has only received attention in recent years as the magnitude of impacts caused by introductions on native species become more apparent. The devastating effects of introductions such as the zebra mussel, *Dreissena polymorpha,* into the Great Lakes (Griffiths *et al.* 1991; Strayer 1991), the ctenophore *Mnemiopsis leidyi* into the Black Sea (Vinogradov *et al.* 1989) and the clam *Potamocorbula amurensis* into San Francisco Bay (Carlton *et al.* 1990) have served to highlight the serious nature of this problem.

All exotic species alter natural interactions in the invaded ecosystems, but not all pose serious threats to these ecosystems. Unfortunately identifying species likely to establish in new ecosystems is difficult, as is predicting their likely impact (Hengeveld 1989). There are now over 180 exotic, cryptogenic and possibly introduced species in Port Phillip Bay, Victoria (M Campbell CRIMP pers. comm.). Not all of these species appear to be causing major disruptions but a number of species are cause for concern as they occur in large numbers.

Recognition that exotic species introduced into Victorian waters may be causing significant ecological effects resulted in the formation of the Victorian Ballast Water Working Group (VBWWG) in 1994. This group included representatives from Environment Protection Authority (EPA), Department of Natural Resources and Environment (DNRE), Port of Melbourne Authority (PMA) and the Australian Quarantine and Inspection Service (AQIS). VBWWG commissioned two studies in 1995. The first of these (Walters 1996) was a desk study to document patterns of ship visits and ballast water discharge in Victorian ports. The second study was to document the exotic species, which had established in each of Victoria's ports and is described, in part, in this report. This report describes the results of a field survey for exotic species in the Port of Geelong.

Concern about the impact of exotic species throughout all coastal regions of Australia and particularly near ports, resulted in the establishment of the Centre for Research on Introduced Marine Pests (CRIMP) within CSIRO Division of Fisheries, in 1994. One of the primary tasks of the Centre is to determine the diversity and distribution of introduced marine species in Australia by surveying a representative set of ports from all regions in Australia. CRIMP guidelines for the conduct of port surveys for exotic species (Hewitt and Martin 1996) were used as the basis for the design of earlier surveys of the Ports of Portland (Parry *et al.* 1997) and Hastings (Currie and Crookes 1997). This survey of the Port of Geelong employed the same methods outlined for the earlier surveys of Portland and Hastings.

A variety of sampling techniques were used to sample a large range of habitats for exotic species in the Port of Geelong. Potential 'pest' species in particular were targeted. Sampling strategies were designed to detect species listed on the Australian Ballast Water Management Advisory Council (ABWMAC) schedule of target introduced 'pest' species, including *Gymnodinium catenatum* and *Alexandrium* spp. (toxic dinoflagellates), *Undaria pinnatifida* (Japanese seaweed), *Asterias amurensis* (northern Pacific seastar), *Sabella spallanzanii* (giant fan worm) and *Carcinus maenas* (European shore crab), but not *Vibrio cholera* (cholera bacterium) or fish pathogens, although they are also on the ABWMAC schedule. In addition, recent research in Port Phillip Bay confirmed the presence of the exotic bivalve *Theora lubrica* and identified four newly established, abundant and potentially damaging pest species, the small sabellid polychaete worm *Euchone limnicola*, the bivalves *Corbula gibba* (Currie and Parry 1996) and *Musculista senhousia,* and the majid crab *Pyromaia tuberculata* (Parry *et al.* 1996). These five benthic species were also targeted in our survey.

14.2 DESCRIPTION OF THE PORT OF GEELONG

14.2.1 General features of the port

The Port of Geelong is located approximately 60 km south west of Melbourne in the Geelong Arm of Port Phillip

[1] This is an abridged version of the report of the survey of the Port of Geelong which is published as MAFRI Report No. 8 (Currie *et al.*1998).

Bay. Geelong is Victoria's second largest Port (after Melbourne) and is the States principal specialist bulk cargo port. Major imports include crude oil, petrochemicals, fertilizers and alumina. Major exports include refined petroleum products, bulk grain and woodchips. Geelong Port currently operates five commercial shipping terminals at Point Henry Pier, Bulk Grain Pier, Corio Quay, Lascelles Wharf and Refinery Pier, and one towage facility at Rippleside Pier. A seventh shipping facility located at Point Wilson is operated by the Commonwealth Government.

The port boundary extends west of a line from Little River to Portarlington, and encloses over 200 km^2 of water including Corio Bay and the Outer Harbour (Figure 14.1). Five shipping facilities in the Port of Geelong are located within 5 km of each other on the western shore of Corio Bay. Rippleside Pier, situated close to the Geelong central business district, is used primarily for mooring tugs and line tenders. To the north, the Bulk Grain Pier has two berths and handles grain cargoes including wheat, oats and barley. Nearby, Corio Quay has four berths and handles general cargo, steel and dry bulk cargo.

Lascelles Wharf has three berths and handles dry bulk and general cargoes including fertilizers and pine logs. While the Refinery Pier, situated at the northern end of the Corio Channel, has four berths dedicated to handling crude oil, refined petroleum products, chemicals and gasses. Two further shipping facilities are located in the Outer Harbour. Point Henry Pier on the southern shore has a single berth and handles petroleum coke and alumina to supply ALCOA's aluminium smelting plant. While Point Wilson Jetty on the northern shore has two berths and is used exclusively for handling explosives (PGA 1994).

The shallow waters of Corio Bay (< 9 m deep) and the Outer Harbour (< 12 m deep) are partially separated at low tide by a narrow sandbar that extends due north from Point Henry. This bar restricts water exchange between the two bodies of water and flushing rates for Corio Bay are estimated to be weeks rather than days (Holmes 1989). A large artificial channel (12 m deep, Figure 14.1) extending west through the Outer Harbour straddles the sand near Point Henry and provides shipping access to berths on the western shore of Corio Bay. Two smaller channels in the Outer Harbour (dredged to 12 m) provide ships free passage to berths at Point Henry and Point Wilson.

14.2.2 Port development and shipping movements

Geelong was first settled by Europeans in 1836, when the small vessel *Francis Freeling* discharged passengers and sheep from Tasmania near Point Henry. The sandbar at Point Henry precluded the entry of ocean going vessels to Corio Bay at that time, and cargo was discharged from ships at anchor here without the benefit of a pier for several years (PGA 1959). Shipping movements to the region increased dramatically in the early 1850's following the discovery of gold in nearby Ballarat. The Gold Rush focused attention on the need for better shipping access to Corio Bay, and led to the construction of a channel (4 m deep) through the northern reaches of the sand bar and the construction of several piers and jetties on south western shoreline of Corio Bay. Subsequent attempts to better improve shipping access into Corio Bay included the construction of a southern channel (5.5 m deep) in 1866 and the present Hopetoun Channel (7 m deep) in 1893.

Trade developed rapidly through the turn of the century as Victoria's pastoral industries developed. Wool, wheat and other primary produce dominated exports from Geelong to Europe during this period. Imports however were increasingly directed to the rapidly growing state capital, Melbourne. The establishment of large foreshore industries including a freezing works, a car manufacturing plant and a fertilizer plant, provided a stimulus for significant expansion of the port facilities in the early half of this century. The Hopetoun channel was redredged to 7 m and new berths were constructed at Corio Quay, Kings Wharf (later Lascelles Wharf) and the Grain Boards premises. Imports and exports were roughly equal in 1950 and totalled 1.2 million tonnes.

Port facilities were further expanded during the early 1950's and 1960's with the construction of two new shipping terminals built to service the Shell Oil Company refinery at Corio and ALCOA's aluminium smelter at Point Henry. Shipping channels and berthing pockets were deepened to 11 m during this same period to cater for an increasing number of large tankers and grain vessels visiting the port.

The total number of ships visiting the Port of Geelong peaked in 1970 (570 vessels). In that year, imports totalled 5.7 million tonnes and exports 2.9 million tonnes. Crude oil accounted for more than 80% of the import volume with a substantial quantity (more than 1 million tonnes) being transported from oil fields in Bass Strait. Exports in the same year were dominated by bulk grain (1.5 million tonnes) and refined petroleum products (1.3 million tonnes). However, the total volume of crude shipped to Geelong declined dramatically through the 1970's as oil began to enter the Shell Refinery via a new land based pipeline. By 1980, crude oil imports were below 0.8 million tonnes and total ship visits had dropped to 374.

Volume of trade and frequency of shipping for the Port of Geelong has fluctuated over the past two decades reflecting changing demands for commodities and

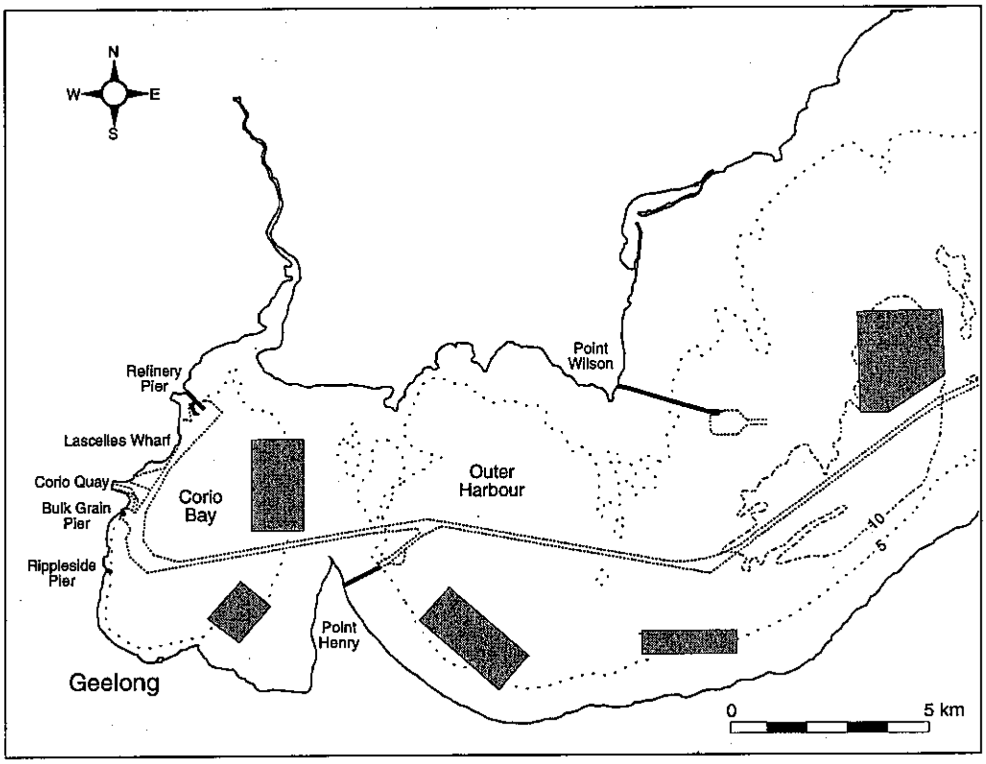

Figure 14.1. Map of the Port of Geelong showing the location of wharves surveyed for exotic marine species. Commercial shipping channels are outlined by fine broken lines and dredge spoil grounds are hatched.

increases in vessel size. In 1996/97, cargo throughput reached a record high (9.7 million tonnes) when 461 vessels visited the port. Exports during this financial year were dominated by petroleum products (2.4 million tonnes), bulk grain (1.9 million tonnes) and wood chips (0.6 million tonnes), most of which (approximately 70%) was shipped overseas. Foreign commodities including crude oil (2.4 million tonnes) and fertilizer products (0.5 million tonnes) dominated imports over the same period. Interstate imports by comparison accounted for less than 25% of the total trade during 1996/97 and included crude oil (0.6 million tonnes), alumina (0.3 million tonnes) and raw fertilizer (0.2 million tonnes) (D Kenwood Geelong Port pers. comm.)

14.2.3 Vessel ballasting patterns

The volume of ballast and the ballasting patterns of commercial shipping using Victoria's four major ports was recently documented by Walters (1996), and provides the source for the following summary.

During 1994/95, the Port of Geelong received the second highest number of ship visits for a Victorian port (342), but the least volume of ballast water. The estimated 1.1 million tonnes of ballast discharged at Geelong was marginally less than the 1.4 million tonnes discharged in Melbourne, even though Melbourne received nearly eight times more ship visits (2651 vessels). Differences between these two ports in the ratio of ballast discharged to vessel visits is accounted for by the relatively high volume of tankers and bulk carriers entering the Port of Geelong to load cargo. These vessels enter port in ballast with no cargo and the ballast is later discharged during loading. In the Port of Melbourne, most ships discharge minimal ballast as they both load and unload cargo.

Approximately 60% of the ballast water discharged at Geelong in 1994/95 came from vessels that had a domestic last port of call. In all, 213 vessels visiting Geelong had a domestic last port of call, while 129 had an international last port of call. The last ports of call for the majority of domestic vessels were Melbourne (44 ships), Sydney (33 ships), Newcastle (22 ships) and Hobart (21). Of these ports, most ballast discharged came from tankers operating out of Sydney. Much of the estimated 0.4 million tonnes of international ballast water entering the Port of Geelong in 1994/95 came from Japanese woodchip ships. Many vessels entering the Port of Geelong during the same year were classified as international/multiple visits and may have been carrying ballast from overseas ports as well as from their previous Australian port of call.

Although most trade statistics for the Port of Geelong have remained static since 1994/95, overseas exports of petroleum products, bulk grain and woodchips have more than doubled. Because the tankers and bulk carriers used to export these commodities enter port in ballast, total volumes discharged in the Port of Geelong during 1996/

97 probably exceed Walters' 1994/95 estimate of 1.1 million tonnes. The total volume of ballast water discharged in Port of Geelong is currently believed to be greater than that discharged in the ports of Melbourne and Portland, but is probably less than the 2.2 million tonnes estimated for the Port of Hastings.

14.2.4 Pile construction and cleaning

Wharf piles must be considered a primary site for establishment of exotic species introduced by vessels, and the principal point for the establishment of hull fouling species. The materials used in the construction of the piles may affect the available free space and therefore the susceptibility of the structure to colonisation by invasive species. Materials like corroding steel and rotting wood would seem the least desirable for settlement as the surfaces of these materials are constantly eroded.

A summary of wharf construction and subsequent development in the Port of Geelong is provided in Table 14.1. All piles at the Bulk Grain Pier, Refinery Pier and Corio Quay North (berths 1–3) are constructed from timber. Timber piles are also used at Rippleside Pier and Lascelles Wharf (berths 1 and 2), although some ageing pylons have now been replaced with reinforced concrete structures. The facilities at Corio Quay South (berth 1), Lascelles wharf (berth 3) and Point Henry Pier are constructed entirely from reinforced concrete. While all piles at Point Wilson Jetty are constructed from steel.

Geelong Port has no maintenance program to remove fouling organisms from the support piles and columns of its wharves. It does however periodically re-sleeve substandard wooden piles with concrete or epoxy resins. Several hundred timber piles in Corio Bay were coated with a 0.5 cm thick epoxy jacket during 1994/95. The jacket covers the full wetted length of the pile and is expected to prevent marine borer access over the life of the pile.

14.2.5 Channel dredging

More than 20 million m³ of seafloor are estimated to have been dredged from the Port of Geelong since 1854 to form and maintain shipping channels (PGA 1993). In recent years, most of the spoil from capital and maintenance dredging programs has been dumped at three spoil grounds located south of the main shipping access channel (Figure 14.1). However in 1997 two new spoil grounds north of the channel were opened to facilitate a major channel improvement program. This scheme was completed in April 1998 and involved the deepening of all shipping channels and berthing pockets in the Port of Geelong to 12 m. An estimated 5.1 million m³ of dredge cuttings were disposed of at the two spoil grounds during these operations.

14.3 EXISTING BIOLOGICAL INFORMATION

Although the need for a biological survey of Port Phillip Bay was recognised as early as 1888 (Macpherson and Lynch 1966), no systematic surveys of the bays' flora and fauna were conducted until the later half of this century. In 1957 the National Museum of Victoria and the Fisheries and Wildlife Department commenced a five year ecological survey of Port Phillip Bay. This study examined geology, geomorphology, bottom sediments, algae and the taxonomy of several invertebrate phyla. The results of this study were published in two volumes of the *Memoirs of the National Museum of Victoria* (No. 27, 1966 and No. 32, 1971). During the period 1967–1971, the Melbourne and Metropolitan Board of Works and the Fisheries and Wildlife Department of Victoria undertook a second more quantitative environmental survey of Port Phillip Bay (MMBW and FWD 1973). Biological considerations in this later study included surveys of phytoplankton, zooplankton, zoobenthos, fish and bacteria. Both of these bay-wide surveys include data directly relevant to the Port of Geelong, and salient information has been included in the following review.

14.3.1 Phytoplankton

Wood (1964) was the first to consider phytoplankton populations in Port Phillip Bay and document the dominant species. This early taxonomic research was the basis for a quantitative survey of phytoplankton distribution in Port Phillip Bay during 1970/71 (MMBW and FWD 1973). This study involved sampling at 3 stations in the Port of Geelong and a further 21 stations throughout the rest of Port Phillip Bay. A total of 114 taxa were identified in this survey, most of which were diatoms. Although no ABWMAC target introduced species (*Gymnodinium catenatum* and *Alexandrium* spp.) were detected during the survey, their presence in Port Phillip Bay at this time cannot be discounted as many dinoflagellate species, including *Gymnodinium catenatum* and *Alexandrium* spp., can encyst and lay dormant in sediments for several years.

The exotic dinoflagellate *Alexandrium catenella*, which is known to cause paralytic shellfish poisoning (PSP) in the northern hemisphere, was positively identified in Port Phillip Bay in April 1988 (Hallegraeff *et al.* 1988). Subsequent bay-wide monitoring programs (Arnott 1998) have identified several other species of introduced phytoplankton including *Alexandrium tamarense* in the Geelong Arm.

14.3.2 Benthic flora

Five research papers were found to contain data on benthic flora in the Port of Geelong. The earliest of these papers

Table 14.1. Summary of wharf development, Port of Geelong.

Berth	Pile construction	Year construction completed	Subsequent modifications	Depth (m)
Point Henry (1)	Reinforced concrete	1966	Concrete spall repairs during 1991	12.0
Rippleside	Timber/ reinforced concrete	1955		5.0
Bulk Grain (1)	Timber	1932		10.5
Bulk Grain (2)	Timber	1932		12.3
Corio Quay (1 south)	Solid faced concrete	1966		11.0
Corio Quay (1 north)	Timber	1958	Concrete berthing dolphins added 1993	11.0
Corio Quay (2 north)	Timber	1926	Concrete berthing dolphins added 1993	11.0
Corio Quay (3 north)	Timber	1938		11.0
Lascelles (1)	Timber/ reinforced concrete	1928	Pile/decking upgrade completed 1994	12.3
Lascelles (2)	Timber/ reinforced concrete	1928	Pile/decking upgrade completed 1994	12.3
Lascelles (3)*	Solid faced reinforced concrete	1953	Pile/decking upgrade completed 1994	12.3
Refinery Pier (1)	Timber	1954	New central berthing buffer 1992	12.3
Refinery Pier (2)	Timber	1954	New mooring dolphin 1992	12.3
Refinery Pier (3)	Timber	1961		12.3
Refinery Pier (4)	Timber	1961		12.3
Point Wilson (1&2)	Steel	1961		9.1

*Formerly known as Kings Wharf

(Womersley 1966) examined the distributions of subtidal algae collected throughout Port Phillip Bay between 1957/63. In this study, Womersley lists ten species as being confined largely to Corio Bay *Caulerpa geminata*, *Caulerpa longifolia* f. *crispata*, *Acetabularia peniculus*, *Dictyota dichotoma*, *Caulocystis uvifera*, *Rhabdonia coccinea*, *Rhodoglossum foliiferum*, *Botryocladia obovata*, *Lophothalia verticillata* and *Jeannerettia pedicellata*. Although none of these species are believed to be exotic, a later list of intertidal and shallow subtidal species for the same area (King *et al.* 1971) does include one exotic green algae *Ulva lactuca*. Three more recent publications consider the distribution of seagrasses *Heterozostera tasmanica* and *Halophila ovalis* in Corio Bay (Seedsman and Marsden 1980; Brown *et al.* 1980), and the occurrence of mangroves *Avicennia marina* and associated algal communities in Hovells Creek in northern Corio Bay (Davey and Woelkerling 1980). None of these floral studies document exotic species in Corio Bay, however recent research has confirmed the occurrence of at least two exotic algae, *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides*, within the Port of Geelong (T Burridge pers. comm.).

14.3.3 Benthic fauna

The first quantitative study of benthic fauna in Corio Bay and the Outer Harbour was conducted during 1971/72 as part of a larger bay-wide survey of Port Phillip Bay (Poore *et al.* 1975). Five replicate grab samples were taken at nine sites within the Port of Geelong harbour limits and the species composition examined. Many of the samples taken during this survey were dominated by the exotic bivalve *Theora lubrica*. Temporal trends in community composition at one of these sites in the center of Corio Bay were later examined over a three year period (1973–1975) by Poore and Rainer (1979). These workers collected 173 benthic species at the Corio Bay station during their study. The densities of most common species including *Theora lubrica* were found to fluctuate irregularly over the three year period. Similar fluctuations were also noted in the identities of minor species.

A more comprehensive survey of the macrobenthos of Corio Bay was undertaken in 1987 (Coleman 1993). This study was specifically designed to investigate the possible influence of known high concentrations of heavy metals and hydrocarbons in Corio Bay sediments on benthic community structure. Benthic grab samples were taken from 60 stations in 12 bay-wide strata and the fauna identified and counted. In total, 3,351 individuals belonging to 172 species were collected. These samples were dominated by polychaetes (45%), crustaceans (27%) and molluscs (17%). Most species were uncommon except for the exotic bivalve *Theora lubrica* and the polychaete *Tharyx* sp. that together accounted for nearly 30% of the total individuals. Coleman (1993) found that the species diversity in Corio Bay was similar in 1987 to that in the early 1970's but that the abundances of animals had decreased from 618-2304 individuals m^{-2} in 1973–75 to 140–420 individuals m^{-2} in 1987. It remains unclear if this reduction in species abundance represents the effects of pollution or other natural phenomenon. Small numbers of the introduced species: the ascidian *Ascidiella aspersa;* and the bivalves *Musculista senhousia* and *Corbula gibba*, were also collected during this survey. These are the earliest records of *Musculista senhousia* and *Corbula gibba* in Victorian waters.

A more recent survey sampled epibenthos and infauna at six sites in the Geelong Arm (Carey and Watson 1992). Most of the dominant epibenthic species found at the muddy sites were found to be typical of similar habitats in other regions of Port Phillip Bay. These included the seagrass *Halophila australis*, the green algae *Caulerpa remotifolia*, the ascidians *Pyura stolonifera* and *Sycozoa pedunculata*, the echinoderms *Stichopus mollis, Patiriella brevispina, Tosia australis*, the molluscs *Pecten lumatus* and *Electroma georgiana* and the hydroid *Obelia australis*. Large numbers of the introduced fan worm *Sabella spallanzanii* were also observed in this survey and appeared to be more abundant in Corio Bay (10 colonies 25 m^{-1} transect) than in the Outer Harbour (7 colonies 25 m^{-1} transect). Two additional exotic species, the bivalves *Theora lubrica* and *Musculista senhousia*, were common in infaunal samples collected near the centre of Corio Bay in this study.

A further 19 grab samples were taken from three stations in the Port of Geelong during 1994/95 (Wilson *et al.* 1996). All three stations were located at sites first quantitatively sampled during 1971/72 (Poore *et al.* 1975). Three exotic species were collected in this latter survey and included the European fan worm *Sabella spallanzanii*, the Asian bivalve *Theora lubrica* and the European clam *Corbula gibba*. Of these species, *Theora lubrica* was most abundant (2.8 individuals 0.1 m^{-2}) and occurred in more than 30% of all grabs. *Sabella spallanzanii* and *Corbula gibba* were neither abundant (0.6 and 0.2 individuals 0.1 m^{-2} respectively) nor widespread, and each species occurred in fewer than 16% of all grabs taken (R Wilson MoV[2] pers. comm.).

14.3.4 Demersal Fish

Demersal fish communities were intensively sampled at two sites in the Port of Geelong and a further 17 stations throughout Port Phillip Bay between 1969 and 1972 (MMBW and FWD 1973). All 68 fish species collected during this trawling program were found to be native to southern Australian waters. A 1982/83 survey of recreational fishing catches in Port Phillip Bay (MacDonald and Hall 1987) also failed to detect any introduced fish species, however the identities of many species collected in this survey could not be reliably confirmed.

Demersal fish populations in Port Phillip Bay have been surveyed annually since 1990 by researchers at the Marine Science Laboratories in Queenscliff. The autumn trawl program samples 22 stations bay-wide and includes one station in the centre of Corio Bay (7 m depth) and another in the Outer Harbour (12 m depth). In 1991, three Japanese yellow-fin gobies *Acanthogobius flavimanus* were collected from the Corio Bay station (Parry *et al.* 1995). *Acanthogobius flavimanus* has not been collected at any of the trawl stations since, nor have any other introduced fish species been collected in trawl samples subsequently.

Dietary studies of 35 fish species collected during the annual trawl surveys in Port Phillip Bay have revealed three further introduced species (Parry *et al.* 1995). The European clam *Corbula gibba* was present in the diets of nine indigenous fish species including sand flathead, eastern shovelnose stingaree, globefish, snapper, banjo ray, smooth stingray, elephant shark, spiny gurnard and angel shark. The incidence of *Corbula gibba* in the diets of most of these fish was low (< 5% by volume), but it was the most important item in the diets of globefish (58% by volume in fish collected from deeper stations), and a significant component in the diets of elephant shark (20% by volume in fish collected from intermediate depths). The introduced spider crab *Pyromaia tuberculata* was found to be a minor component in the diets of eight fish species including sand flathead, sparsely spotted-stingaree, globefish, snapper, banjo ray, red mullet, elephant shark and spiny gurnard. The Asian bivalve *Theora lubrica* was a minor component in the diets of greenback flounder and red gurnard.

14.4 SURVEY METHODS

The survey of the Port of Geelong took place between 28 August and 23 October 1997. The range of methods

[2] Museum of Victoria.

used in this survey are summarised in Table 14.2. The distribution of sampling sites and the sampling methods employed at each of the seven commercial shipping facilities (locations) in the Geelong Arm of Port Phillip Bay (Point Henry Pier, Rippleside Pier, Bulk Grain Pier, Corio Quay, Lascelles Wharf, Refinery Pier and Point Wilson Jetty) are shown in Currie *et al.* (1998).

14.4.1 Phytoplankton

Sediment sampling for cyst-forming species

Sediment cores were taken by divers using 20 cm long plastic tubes with a 25 mm internal diameter. Sediment tubes were capped with bungs and kept upright in a refrigerator or on ice until delivered to the Australian Government Analytical Laboratory on 24 October 1997. Three sediment cores were taken near the base of pylons at each location.

Water column sampling

Phytoplankton samples were collected using vertical tows of a small 20 µm plankton net. One sample was collected at each of the seven locations.

14.4.2 Trapping

Traps of three different sizes, intended to catch crabs, shrimp and scavenging organisms, were deployed at each location. The largest traps were oval-shaped "Opera-house" design crab/yabby traps (65 x 46 x 23 cm) covered in 2 cm mesh net. Shrimp traps were rectangular (43 x 25 x 25 cm) and covered in fine 2-5 mm mesh net. Scavenger traps were constructed of a 35 cm length of 10 cm diameter PVC pipe with a funnel at one end and a 1 mm plankton mesh covering the other. A set of three traps (crab, shrimp and scavenger) were deployed overnight at five different sites near each location.

14.4.3 Zooplankton

Zooplankton was collected using a 3 m long x 60 cm diameter, 300 µm mesh plankton net. A small vessel was used to take one 10 min plankton tow near each location. All samples were collected during daylight hours (between 1000 and 1300 hrs), were fixed in 10% formalin and have been archived.

14.4.4 Diver observations and collections on wharf piles

Semi-quantitative sampling was undertaken on six piles at each location. The six piles (sites) surveyed on each location were always separated by at least two piles. On each sampled pile a bungee cord was used to fix a weighted cord marked at 1 m intervals near the low water mark. A Panasonic NV MS95 SVHS video movie camera was used to record the marine fouling on each pile and care was taken to include the marked cord in the video to ensure depth was continuously recorded. At depths of 0.5, 3 and 7 m one photograph of fouling organisms (14–17 cm in area) was taken using a Nikonos Mark IVA underwater camera fitted with a 28 mm lens. An area 30 x 40 cm, that included the areas photographed, was then scraped with a dive knife and all attached fouling organisms collected in a mesh bag (5 mm) and subsequently fixed in 10% formalin. Sponges in all samples were preserved separately in 70% alcohol to prevent the loss of internal spicules (a critical taxonomic character). Fouling organisms scraped from three depths on two of the piles from each location were identified in the laboratory, while samples from the four other piles from each location were archived.

14.4.5 Visual searches

Diver observations and some additional qualitative samples were taken at one or two other sites in the vicinity of each location. The sites were specifically targeted for *Sabella* and *Undaria* during these surveys.

14.4.6 Epibenthos

Epibenthos was sampled with an Ockelmann sled at 19 sites (Currie *et al.* 1998). Most of these sled shots (13) were taken near commercial and recreational wharves in Corio Bay, while a further three sled shots were taken in waters adjacent to Point Henry Pier and Point Wilson Jetty in the Outer Harbour. The sled was fitted with a 1.0 cm mesh liner and towed for 5 min at each site. Samples were emptied into fish bins and a sub-sample (5% of bin) was retained and fixed in 10% formalin. All organisms present in the 19 sub-samples were later identified, enumerated and weighed.

14.4.7 Benthic infauna

Benthic infauna was sampled using 0.1 m^2 Smith-McIntyre grabs and diver cores. Grab samples were taken at 40 sites throughout the Geelong Arm (Currie *et al.* 1998). Most of these grabs (30) were taken within Corio Bay, while the remainder were taken around the wharf heads at Point Henry Pier (5) and Point Wilson Jetty (5). 20 of the Corio Bay grabs were located at sites sampled for infauna 10 years earlier (see Coleman 1993) so that changes in community structure over this period could be assessed. All 40 grab samples were drained of supernatant water before being weighed then rinsed on a 1 mm mesh sieve. Those animals retained on the sieve were preserved in 10% formalin and were later identified to species and counted under a dissecting microscope.

Three 86 mm diameter cores were collected by divers near the bases of two piles at each location. Processing of core samples was identical to that for grabs, but only two cores from each shipping facility were analysed and the remaining material was archived.

14.4.8 Seine netting

A 10 mm mesh seine net, 60 m long and 1.25 m high, was used to sample inshore fish. At each location the net was shot once during daylight (1300-1600 hrs) and once at night (2200-0300 hrs). Most fish caught in each shot were identified in the field to species before being counted and weighed. Small fish that could not be reliably identified *in situ* were fixed in 10% formalin and later examined under a dissecting microscope in the laboratory.

14.4.9 Sediment analysis

A 70 ml sub-sample of each benthic grab sample was taken in the field and frozen as soon as practical (< 6 h). These sediment samples were later analysed to determine percentage organic content and particle size composition. A 15–25 g sample of sediment from each grab was dried in an oven at 95° C for 24 h and then placed in a muffle furnace at 500° C for 24 h. The percentage organic content of the sediment was estimated from the loss of weight on ignition in the muffle furnace. A further 20–30 g sample was wet sieved through a 63 mm sieve and the fine fraction and coarse (sand) fraction were each dried at 95° C for 24 h and weighed. Fall velocities and equivalent grain sizes were measured for the sand fraction using a 2 m high automated settling tube controlled by a Macintosh computer with software from the University of Waikato (Greilach *et al.* 1995).

14.5 SURVEY RESULTS

14.5.1 Port environment

The Port of Geelong encloses more than 10% of the total water surface area of Port Phillip Bay (2,000 km^2). Tides in the port are predominantly semi-diurnal and range less than 1 m in height. There are no major freshwater inputs to the port; Hovells Creek in the north and Cowies Creek in the west of Corio Bay are the only two natural freshwater discharges and both creeks have restricted drainage basins. Salinity, recorded from 1980 to 1984 (Cowdell *et al.* 1984) ranged from 27.3‰ to 38.6‰, the lowest values being recorded close to the creek entrances. Mean seawater temperatures for Corio Bay during the period 1980/84 ranged from 9.2° C in the winter to 22.4° C in the summer (Cowdell *et al.* 1984).

Except for some patchy, low reef outcrops in the intertidal and shallow subtidal between Point Wilson and

Table 14.2. Summary of sampling methods, habitats sampled and target taxa, Port of Geelong survey, 28 August - 23 October 1997.

Sampling Methods	Habitat sampled	Target taxa
Non-targeted:		
Qualitative surveys:		
Diver searches	Piles, breakwaters, soft sediment	Algae, invertebrates, fish
Video/still photography	Piles, breakwaters, soft sediment	Algae, invertebrates, fish
Ockelmann sled	Soft sediment	Epifauna
Beach seine	Soft sediment, seagrass	Mobile epifauna, fish
Plankton net – 300 µm	Water column	Zooplankton
Quantitative surveys:		
Diver scrapings	Piles	Algae, invertebrates
Video/still photography	Piles	Algae, invertebrates
Smith-McIntyre grabs	Soft sediment	Infauna
Large cores	Soft sediment	Infauna
Targeted:		
Diver searches	Piles, breakwaters, soft sediment	*Asterias, Sabella, Carcinus*
Traps	Piles, breakwaters, soft sediment	*Carcinus*
Small cores	Soft sediment	Dinoflagellate cysts
Shore surveys	Intertidal wrack	*Undaria*
Plankton net - 20 µm	Water column	Dinoflagellates

Kirk Point (McShane *et al.* 1986), all bedforms in the Port of Geelong are composed of soft sediments. Sediments in Corio Bay and the Outer Harbour are predominantly silty–clay and clay, with some areas of sand being recorded along the shore and in the south east of Corio Bay (Beasley 1966). Sediment characteristics of stations sampled in the Port of Geelong are shown in Currie *et al.* (1998). Of note are the high levels of organic matter in sediments in the north east of Corio Bay. Previous studies have recorded elevated levels of petroleum hydrocarbons in the same area (Fabris *et al.* 1991) and it appears that the high organic load observed in this study is due to contaminated run-off from the nearby Refinery Pier. It is also of some note that the lowest organic component in the sediment samples taken in the Port of Geelong came from a station located over an operational dredge spoil ground in the center of Corio Bay.

14.5.2 Introduced species in port

All exotic species (19) found in the Port of Geelong are listed in Table 14.3. A summary of the mean number of all species found in the survey (except for dinoflagellates) by each sampling method and the percentage of samples containing each taxa for each sampling method is given in Currie *et al.* (1998).

ABWMAC target introduced species

***Gymnodinium* and *Alexandrium* spp.**

No cysts of the introduced toxic dinoflagellates *Alexandrium catenella* and *Gymnodinium catenatum* were found in sediment cores taken in the Port of Geelong (Currie *et al.* 1998), nor were live specimens of either species detected in phytoplankton samples taken from the Port of Geelong (Currie *et al.* 1998). Live specimens of the native non-toxic *Gymnodinium* spp. were however found along with the potentially toxic diatom *Pseudo-nitzschia pungens*. Species of the *Pseudo-nitzschia* genus are known to have caused amnesic shellfish poisoning (ASP) in humans.

Commercial shellfish populations near Clifton Springs and Grassy Point in the Geelong Arm of Port Phillip Bay have been monitored for paralytic shellfish poison (PSP) and domoic acid (the ASP toxin) on a monthly basis since September 1987. Mussels at these sites have periodically contained measurable levels of PSP toxins but concentrations have only exceeded the Victorian public health standard of 80 mg 100 g^{-1} on one occasion during the last 10 years. In 1993 shellfish harvesting was suspended at the Clifton Springs and Grassy Point aquaculture zones when concentrations of the exotic dinoflagellate *Alexandrium tamarense* reached 275 mg 100 g^{-1} (Arnott 1998). This species reappeared in the same area during the following winter of 1994, however no toxins were detected. Phytoplankton samples have also been taken at multiple sites in Port Phillip Bay over the same period and have contained at least six different dinoflagellate species in the genus *Alexandrium,* including the exotics *A. catenella*, *A. tamarense* and *A. minutum.*

Undaria pinnatifida

U. pinnatifida was observed by divers on three steel piles near the seaward end of the Point Wilson Jetty (see Currie *et al.* 1998). Between 5 and 10 adult stipes (< 40 cm length) were found growing at the low water mark at each of these three piles, but searches of more than 100 additional piles along the entire length of the Point Wilson Jetty failed to detect any additional plants. Beds of *U. pinnatifida* have been established in shallow reef areas off Point Wilson for at least two years, but the plant does not appear to be spreading rapidly. It was not observed at any other Port of Geelong commercial wharves during this survey and has yet to be found beyond the Geelong Arm in Port Phillip Bay[3] (T Burridge pers. comm.).

U. pinnatifida was first recorded in Australia at Rheban on the east coast of Tasmania in 1988 (Sanderson 1990). Subsequent surveys have indicated a gradual spread in distribution to more than 50 km of the Tasmanian coastline (AQIS 1994). The algae is thought to have been introduced to Tasmania in ballast water or on the hulls of woodchip ships, and a similar mode of introduction is suspected for Victoria.

Sabella spallanzanii

The large fan worm *S. spallanzanii* was found on all pier piles examined during the course of this study at all seven locations *S. spallanzanii* was rarely found close to the water surface and densities generally increased with increasing depth; the highest density (30 worms per 30 x 40 cm quadrat) being recorded from a depth of 7 m at the Refinery Pier. The Refinery Pier also supported the highest average density of *S. spallanzanii* (7 worms per 30 x 40 cm quadrat; n = 6, i.e. two scrapings at three depths) of all commercial wharves in the Port of Geelong. Average *S. spallanzanii* densities were slightly lower at the Bulk Grain Pier (6.8 worms per 30 x 40 cm quadrat) and Point Henry Pier (6.5 worms per 30 x 40 cm quadrat), but markedly lower at Lascelles Wharf (3.7 worms per 30 x 40 cm quadrat) and Corio Quay (3.5 worms per 30 x 40 cm quadrat). *S. spallanzanii* was least frequently encountered at Point Wilson Jetty (1.2 worms per 30 x 40 cm quadrat) and Rippleside Pier (0.8 worms per 30 x 40 cm quadrat).

S. spallanzanii was commonly found attached to artificial surfaces in the Port of Geelong, but it was also frequently collected in sled shots (~80% of tows; Currie *et al.* 1998) taken on the silty sediments of Corio Bay. A

[3] Editor's note: *Undaria* has recently been detected at St. Kilda Pier and Station Pier in the Port of Melbourne.

small number of animals were also collected from this soft benthic habitat by grabing (10% of grabs; Currie *et al.* 1998). Worms collected by these sampling methods were invariably anchored to dead oyster and scallop shells, and it seems likely that the reduced densities of *S. spallanzanii* observed in sleds (0.7 m^{-2}) and grabs (1.3 m^{-2}) reflects low availability of suitable hard substrates in the Corio Bay sediments.

S. spallanzanii is a native of the Mediterranean and Atlantic coasts of Europe, but is now present in a number of harbours along the southern coast of Australia (Clapin and Evans 1995). The worm is first thought to have become established in Victoria in Corio Bay during the late 1980's and has since spread to occupy much of Port Phillip Bay (Parry *et al.* 1996).

Data from annual dive surveys of soft sediments and pier piles in Port Phillip Bay since 1994 (Figure 14.2) show a general clockwise expansion of *S. spallanzanii* consistent with known water circulation patterns. In 1994 *S. spallanzanii* was largely restricted to the Geelong Arm, but by 1995 it was well established in regions off Werribee and Williamstown. Although worm densities apparently decreased during 1996 it had progressed to an area off Beaumaris on the eastern side of Port Phillip Bay. No further expansion in *S. spallanzanii* distribution was evident in 1997 however it had clearly become established inshore in the north east of the bay during the same year. Dive surveys conducted between February and April 1998 (Figure 14.2) show that *S. spallanzanii* has now invaded virtually all available subtidal habitats in Port Phillip Bay, however densities appear to have remained relatively low since 1995.

Carcinus maenas

Only four individuals of the European shore crab *C. maenas* were collected during the survey. One crab was captured in each of two baited traps set close inshore at Point Wilson Jetty, while the remaining specimens were taken in a baited trap and a seine net shot near the shoreline at Point Henry. Much larger numbers of *Carcinus* have been recovered from baited 'Starfish' traps deployed at other sites around Port Phillip Bay, particularly those in brackish water habitats including the lower reaches of the Yarra River and Mordialloc Creek (D Currie pers. obs.). Although *C. maenas* is known to display some preference for reduced salinity (McGaw and Naylor

Table 14.3. Exotic species found at each of the 7 commercial wharves in the Port of Geelong. Sites are: 1 = Corio Quay; 2 = Lascelles Wharf; 3 = Point Henry; 4 = Point Wilson; 5 = Rippleside Pier; 6 = Refinery Pier and; 7 = Grain Pier. * Indicates an ABWMAC target pest species. + indicates species present at location.

Taxa/species	Locations						
	1	2	3	4	5	6	7
Algae							
Ulva lactuca			+	+		+	+
*Undaria pinnatifida**				+			
Polychaeta							
Euchone limnicola		+				+	
Myxicola infundibulum	+						+
*Sabella spallanzanii**	+	+	+	+	+	+	+
Mollusca							
Corbula gibba	+			+		+	+
Musculista senhousia	+	+	+	+	+	+	+
Theora lubrica	+		+	+	+	+	+
Arthropoda							
*Carcinus maenas**			+	+			
Cirolana harfordi			+				
Jassa marmorata		+	+	+	+		+
Bryozoa							
Bugula dentata	+			+	+	+	+
Bugula neritina		+	+	+		+	+
Watersipora subtorquata	+	+			+	+	+
Ascidia							
Ascidiella aspersa	+	+	+	+	+	+	+
Ciona intestinalis		+		+		+	
Styela clava	+	+	+	+	+	+	+
Styela plicata		+			+	+	+
Pisces							
Amoya pflaumi	+			+		+	+

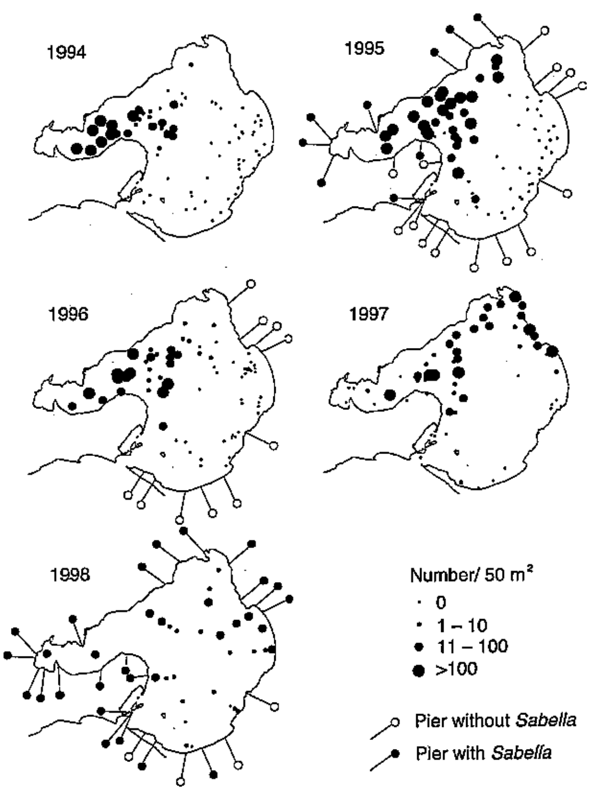

Figure 14.2. Distribution of *Sabella spallanzanii* from diver counts of 50 x 1 m transects sampled between 1994 and 1998 and piers examined between 1995 and 1998.

1992), it is unclear if the low capture rate in the Port of Geelong reflects a real differences in population size between sites or a difference in the efficiency of 'Starfish' and 'Opera-house' traps.

C. maenas is native to Europe but it has been reported from the Atlantic and Pacific coasts of North America (Welch 1968; Cohen *et al.* 1995), the Atlantic coast of South America (Chilton 1910), and the Indian Ocean (Joska and Branch 1986). The crab was first recorded in Australia at the turn of the century in Port Phillip Bay (Fulton and Grant 1900), but it may have been introduced to the bay even earlier on ships servicing the gold rushes of the 1850's (Walters 1996). *C. maenas* is now common in sheltered locations along most of the Victorian coast (MRGV 1984).

Other targeted species

One of the purposes of this and similar surveys of exotic species in Australian ports is to provide a better appreciation of those exotic species which are causing large impacts. Once further information becomes available it seems likely that there will be alterations to the ABWMAC schedule of marine pest species. Most of the pest species on the ABWMAC schedule occur in Port Phillip Bay (*Alexandrium, Asterias, Undaria, Sabella,* and *Carcinus*). However five additional species are considered as major threats to the ecology of Port Phillip Bay based on their apparent abundance and biomass; these are *Euchone limnicola, Corbula gibba, Theora lubrica, Musculista senhousia and Pyromaia tuberculata* (G Parry EPA pers. comm.). These five species were targeted in the Port of Geelong survey using Smith-McIntyre grabs and diver cores. *E. limnicola, C. gibba, T. lubrica* and *M. senhousia* were all detected using these sampling techniques.

Euchone limnicola

Euchone limnicola is a small (12 mm length) sabellid polychaete, originally described in California (Hartman 1965). It lives in muddy sediments and secretes mucous with which it builds a firm burrow wall. A total of seven *E. limnicola* were found in four grab samples taken within Corio Bay during the survey (see Currie *et al.* 1998). Densities of the worm in the Port of Geelong did not exceed 4 individuals 0.1 m^{-2}, and were relatively low compared with estimates obtained for other areas of Port Phillip Bay during an earlier survey in 1991–92 (> 100 individuals 0.1 m^{-2}; Currie and Parry 1996). *E. limnicola* was not found in Port Phillip Bay during 1970–74 (Poore *et al.* 1975), but small numbers have been recently identified in archived samples collected off Werribee in 1984 (M McArthur MAFRI pers. obs.). *E. limnicola* has also been found in Portland Harbour in western Victoria (density > 200 individuals 0.1 m^{-2}; Parry *et al.* 1997) and Botany Bay in New South Wales (R Wilson MoV pers. comm.).

Corbula gibba

Corbula gibba is a suspension feeding bivalve mollusc that grows to a maximum size of about 15 mm in shell length. It occurs at the surface of soft sediments between the shallow subtidal zone and depths of 150 m (Yonge 1946). *C. gibba* was collected in seven sled shots within Corio Bay, one diver core at Corio Quay, four grab samples in Corio Bay and one grab sample near Point Wilson in the Outer Harbour (see Currie *et al.* 1998). Densities of *C. gibba* in the Port of Geelong were relatively low during the present survey and did not exceed 6 individuals 0.1 m^{-2}. The mollusc is native to the North Atlantic and was first identified in Australia from samples taken during 1991 in Port Phillip Bay (Currie and Parry 1996). This species was not recorded in Port Phillip Bay during an extensive bay-wide survey conducted between 1969 and 1973 (Poore *et al.* 1975), but small numbers of *C. gibba* have been recently identified in archived samples collected in Corio Bay during 1987 (N Coleman pers. comm.). *C. gibba* is now abundant throughout Port Phillip Bay, attaining densities of 250 individuals 0.1 m^{-2}, and is a major component in the diets of nine species of demersal fish (Parry *et al.* 1995). Port Phillip Bay is probably the source for recent translocations of this species to Portland, Victoria (Parry *et al.* 1997) and Devonport, Tasmania (C Hewitt pers. comm.), particularly in view of the high volume of shipping movements between these Ports.

Theora lubrica

Theora lubrica is a deposit feeding bivalve that reaches a maximum length of about 14 mm. The mollusc was collected in three sled shots, 2 diver cores, 23 grab samples and one pylon scraping at Point Henry (see Currie *et al.* 1998). The mean density of *T. lubrica* in grabs from the Port of Geelong was more than 5 individuals 0.1 m^{-2} (Currie *et al.* 1998) although one replicate taken north of Lascelles Wharf contained nearly 10 times this number. *T. lubrica* was the most abundant and widespread organism collected during a survey of the Corio Bay macrobenthos in 1987 (Coleman 1993).

T. lubrica is native to the western Pacific region and is common in muddy sediments in bays throughout Japan where it can reach densities of more than 370 individuals 0.1 m^{-2} (Kikuchi and Tanaka 1979). Despite well documented inter-annual and seasonal fluctuations in population density overseas (Tanaka and Kikuchi 1979), the mollusc clearly remains a dominant organism in Corio Bay. *T. lubrica* was first identified in Australia from samples collected in the Swan Estuary in 1971 (Chalmer *et al.* 1976), however it has been present in Port Phillip Bay since at least 1969 (Poore *et al.* 1975; as *Theora fragilis*). The species is also known from Western Port Bay in Victoria (Currie and Crookes 1997), Botany Bay in New South Wales (Climo 1976) and Devonport in Tasmania (C Hewitt CRIMP pers. comm.). *T. lubrica* is thought to have been introduced into Australia via ballast water in commercial shipping (Hutchings *et al.* 1987).

Musculista senhousia

Musculista senhousia is a mussel (30 mm length) that occurs epifaunally on hard or soft substrates and may be found in great abundance (2,500 m^{-2}; Morton 1974). *M. senhousia* was the most abundant and widespread organism collected during the Port of Geelong Survey. It was found in 16 sled shots, one diver core at the Bulk Grain Pier and 17 grab samples. It was also collected in scrapings from two pylons at Point Henry Pier and Point Wilson Jetty, and was present in scrapings taken from one pile at Rippleside Pier, the Bulk Grain Pier, Lascelles Wharf and the Refinery Pier (see Currie *et al.* 1998).

M. senhousia is native to the western Pacific and has been recorded from the coasts of China and Japan (Morton 1974). The mussel is believed to have been introduced into Western Australia via shipping, either as a fouling organism or in ballast water (Slack-Smith and Brearley 1978). *M. senhousia* was first identified in Victorian waters from benthic samples taken during 1987 in Corio Bay (Coleman 1993), and has subsequently been recorded from Portland Harbour (Parry *et al.* 1997) and Western Port Bay (Currie and Crookes 1997).

M. senhousia was neither widespread nor abundant in this earlier survey being found in less than 15% of samples and at a maximum density of 3 individuals 0.1 m^{-2}. The population size of *M. senhousia* in Corio Bay has clearly increased over the last 10 years. One 0.1 m^{-2} grab sample (see Currie *et al.* 1998) taken in 3 m of water in the southern region of the bay contained 473 individuals. Interestingly, this same grab sample was also the most diverse collected during the course of the survey and contained 49 species. Increases in diversity with increasing density of *M. senhousia* have been observed on mud-flats in Mission Bay, San Diego (Crooks 1998) and are attributed to the structural modifications of the habitat facilitated by the deposition of *M. senhousia* shells. The observed increase in species richness at site 48 since 1987 may therefore be explained in part by the presence of *M. senhousia*. *M. senhousia* was not found in the diets of 35 fish species studied in Port Phillip Bay (Parry *et al.* 1995), but has subsequently been found in the diets of little rock whiting *Neoodax balteatus* (G Parry pers. comm.).

Additional exotic species detected

A further 12 species that were either exotic or probably exotic species were identified during the survey. These species included the algae *Ulva lactuca*, three bryozoans *Bugula dentata*[4], *Bugula neritina* and *Watersipora subtorquata*, the polychaete worm *Myxicola infundibulum*, the isopod *Cirolana harfordi*, the amphipod *Jassa marmorata*, four ascidians *Ascidiella aspersa*, *Ciona intestinalis*, *Styela clava* and *Styela plicata* and the goby *Amoya pflaumi*.

Ulva lactuca

Ulva lactuca is a cosmopolitan green alaga that is found in most of the world's oceans (Womersley 1984). *U. lactuca* occurred in three sled samples during the survey. It was also collected in diver scrapings from two piles at Lascelles Wharf and Point Wilson Jetty, and from one pile at Point Henry Pier and the Refinery Pier (see Currie *et al.* 1998).

U. lactuca is distinct from other *Ulva* spp. in that it forms only a single thallus from each holdfast (Womersley 1984). The majority of *Ulva* specimens from the southern Australian coast were once considered to be *Ulva lactuca* (Womersley 1956) but more recent work has shown that it is a rarely occurring species in a group of several from this genus (Womersley 1984).

Bugula dentata[4]

Bugula dentata is a small bushy green bryozoan that rarely exceeds 5 cm in height (Shepherd and Thomas 1982).

[4] Editor's note: Keough and Ross (Chapter 13) do not consider *Bugula dentata* to be an introduced species and therefore is not considered introduced in Chapter 18.

This fouling organism was collected exclusively in pile scrapings during this survey. Small colonies of were found on two piles at Rippleside Pier and Corio Quay and from one pile at the Bulk Grain Pier, the Refinery Pier and Point Wilson Jetty (see Currie *et al.* 1998).

B. dentata has a cosmopolitan distribution which is thought to have resulted from its transportation around the world on the hulls of ships (Parry *et al.* 1997). This species is known to occur in South Australia (Shepherd and Thomas 1982) and Victoria (Port Phillip Bay, Black 1971; Portland, Parry *et al.* 1997; Hastings, Currie and Crookes 1997).

Bugula neritina

Bugula neritina is a distinctive purple-brown bryozoan that forms erect flexible colonies up to 8 cm in height (Shepherd and Thomas 1982). This species was widely distributed on pier piles throughout the Port of Geelong, but like *B. dentata* it was never particularly abundant. *B. neritina* was found on two piles at the Bulk Grain Pier and Lascelles Wharf and from one pile at Point Henry Pier, the Refinery Pier and Point Wilson Jetty (see Currie *et al.* 1998).

B. neritina is also a cosmopolitan species and its current world-wide distribution probably results from its transportation on the hulls of ships. Its distribution in Australia includes coastal waters of South Australia (Shepherd and Thomas 1982), Victoria (Port Phillip Bay, Keough and Raimondi 1995; Portland, Parry *et al.* 1997; Hastings, Currie and Crookes 1997) and New South Wales (Port Kembla, Moran and Grant 1993).

Watersipora subtorquata

Watersipora subtorquata is a dark grey encrusting bryozoan which typically occurs in a narrow band on wharf piles near the low water mark (Gordon and Mawatari 1992). The bryozoan was found on two piles at Rippleside Pier, the Bulk Grain Pier and Lascelles Wharf and from one pile at Corio Quay and the Refinery Pier (see Currie *et al.* 1998). One crust of *W. subtorquata* was also collected from each of two diver cores taken from soft sediments beneath the Bulk Grain Pier (see Currie *et al.* 1998). These small colonies had probably been dislodged from adjacent pier piles and had fallen to the seafloor. *W. subtorquata* has a wide international distribution and has been recorded from Brazil, the West Indies and Japan. The type locality is given as Rio de Janeiro but its native range is currently unresolved (Gordon and Mawatari 1992). *W. subtorquata* is also widely distributed in Australian waters and has been recorded from Portland (Parry *et al.* 1997), Hastings (Currie and Crookes 1997), Townsville (Tzioumis 1994) and Torres Strait (Gordon and Mawatari 1992).

Myxicola infundibulum

Myxicola infundibulum is a medium sized (70 mm length) sabellid polychaete, first described from the Mediterranean Sea (Fitzhugh 1989). This species secretes a gelatinous mucous tube from which it filter feeds (Day 1967). Five specimens of *M. infundibulum* were collected in the Port of Geelong exotics survey. All of these worms were found in silty sediments in relatively deep water (> 10 m depth). Four *M. infundibulum* were taken from two sled shots in the central west of Corio Bay (see Currie *et al.* 1998). The other specimen was collected in a grab sample nearby (see Currie *et al.* 1998). *M. infundibulum* has been found in Cockburn Sound (Edgar 1997), Portland Harbour (Parry *et al.* 1997) and Port Phillip Bay (Poore *et al.* 1975).

Cirolana harfordi

Two specimens of the isopod *C. harfordi* were found in two pile scrapings from the Point Henry Pier (Currie *et al.* 1998). This is the first record of *C. harfordi* in Port Phillip Bay. *C. harfordi* is an isopod first described from California (Johnson 1976) and Australian material most closely resembles the Californian morphotype. It was first found in Australia (New South Wales) in 1972; isolated populations are found in Western Australia, New South Wales and Bass Strait (Bruce 1986).

Jassa marmorata

A total of 310 specimens of the gammarid amphipod *J. marmorata* were found in the Port of Geelong survey. One specimen was collected in a grab sample taken in the south of Corio Bay and two individuals were found in each of two diver cores beneath Point Henry Pier and Point Wilson Jetty (see Currie *et al.* 1998). The remainder were collected from pile scrapings at Point Henry Pier, Rippleside Pier, the Bulk Grain Pier, Lascelles Wharf and Point Wilson Jetty (see Currie *et al.* 1998). The Bulk Grain Pier scraping held 150 individuals. Only three *Jassa marmorata* had previously been found in Port Phillip Bay but this may be because hard substrates had not been sampled as intensively as sediments (Poore 1996). *J. marmorata* was first described from New York Harbor and is found on coasts in the Atlantic, Mediterranean Sea, North Pacific and Indian Ocean, but the native range of is not clearly defined (Poore 1996).

Ascidiella aspersa

A small (60 mm length) temperate water ascidian. It occurs in sheltered waters to 50 m depth and attaches to solid substrates, often forming dense colonies. A total of 150 *A. aspersa* were found in 38 samples from the Port of Geelong exotics survey. The greatest densities (maximum 18 per 30 x 40 cm quadrat) were found attached to pier piles. *A. aspersa* was collected from pile scrapings at Point Henry Pier, Rippleside Pier, the Bulk Grain Pier, Corio Quay, Lascelles Wharf, the

Refinery Pier and Point Wilson Jetty (see Currie *et al.* 1998). Smaller numbers were found attached to shell fragments in sled shots and grab samples (see Currie *et al.* 1998).

Australian populations of *A. aspersa* are found in isolated estuaries and embayments from Western Australia to Victoria and Tasmania. In the Northern Hemisphere it is found in the Mediterranean Sea, the English Channel and the Irish Sea (Kott 1985).

Ciona intestinalis

A medium sized (15 cm in length) ascidian which displays a preference for growth on the underside of artificial substrates (Kott 1990). A total of eight *C. intestinalis* were found in two sled shots and two pile scrapings taken at the Refinery Pier and Point Wilson Jetty (see Currie *et al.* 1998).

C. intestinalis is believed to have travelled as a fouling organism on ship hulls (Kott 1990). It is known from the Mediterranean Sea, the western seaboard of Europe, parts of North and South America, New Zealand and the Arctic (van Name 1945). Large populations existed in Australian ports in the 1950's and 1960's but Kott (1990) suggests numbers have declined in recent years.

Styela clava

Styela clava is a solitary ascidian with a cylindrical body up to 60 mm length. It is often attached to hard substrates by means of a narrow stalk (Kott 1985). Fifty-eight *S. clava* were found in the Port of Geelong exotics survey. Seven specimens were in three sled samples, the rest came from pile scrapings at Point Henry Pier, Rippleside Pier, the Bulk Grain Pier, Corio Quay, Lascelles Wharf, the Refinery Pier and Point Wilson Jetty (see Currie *et al.* 1998). This species was most abundant at a depth of 3 m on the wooden piles of the Bulk Grain Pier (10 individuals per 30 x 40 cm quadrat).

A native of the northern Pacific, *S. clava* has also been recorded from the English Channel, the Irish Sea and the Atlantic coast of North America (Carlisle 1954; Minchin and Duggan 1988; Berman *et al.* 1992). *S. clava* was first recorded in Australia from Hobsons Bay in the north of Port Phillip Bay (Holmes 1976).

Styela plicata

Styela plicata is a solitary ascidian that grows to 90 mm body length and attaches to solid substrates (Kott 1985). Five *S. plicata* were collected during this survey. All specimens were collected from pylon scrapings at Rippleside Pier, the Bulk Grain Pier, Lascelles Wharf and the Refinery Pier (see Currie *et al.* 1998).

S. plicata is known to occur in temperate areas of the Atlantic and Pacific oceans, excluding the western coast of North America (Kott 1985). It is widely distributed in sheltered waters along the southern Australian coast, but its absence from the Indo-west Pacific region led Kott (1985) to consider it an introduction.

Amoya pflaumi

Amoya pflaumi [4] is a goby (up to 80 mm length) first described as *Ctenogobius pflaumi* from a specimen in Nagasaki, Japan (Fowler 1972). A total of 11 *A. pflaumi* were found in six sled shots (see Currie *et al.* 1998) in the Port of Geelong. One further specimen was collected in a Smith-McIntyre grab near the Refinery Pier in the north of Corio Bay.

The species is also known to occur in Chinese, Korean and Philippine waters. *A. pflaumi* was first recorded in Port Phillip Bay in 1996 during a survey of the Melbourne docklands (Knuckey *et al.* 1997). The single specimen, then identified as *Acentrogobius* sp., was caught in a baited trap deployed near Webb Dock. The species was subsequently collected in beam trawl surveys of Corio Bay and northern Port Phillip Bay (P Hamer QMS pers. comm.).

14.5.3 Adequacy of survey intensity

The more samples that are taken in any biological survey the more species will be recorded. But as additional samples are taken additional species accumulate at a decreasing frequency, until an asymptote is approached where essentially all the species in all the habitats have been collected. To determine the likelihood that further species exist on wharf piles, benthos and the water column of the Port of Geelong cumulative species curves were calculated for each sampling technique (Figure 14.3a–f). In the Port of Geelong the total number of fish species collected (Figure 14.3f) had approached an asymptote after only eight seine net shots. Three subsequent nettings failed to collect any additional species and it is likely that most fish species present in this habitat and amenable to this sampling technique were recorded. Unfortunately cumulative curves for most other sampling techniques failed to approach an asymptote. Numbers of species collected in crab, shrimp and scavenger traps (Figure 14.3a) increased in a linear progression as more traps were deployed. Similar increases were observed for Ockelmann sled shots (Figure 14.3c) and Smith-McIntyre grab samples (Figure 14.3d). The number of species collected in cores (Figure 14.3e) was close to asymptotic after just eight samplings but subsequent cores contained several additional species. An inflection was also apparent in the plots of species numbers in pile scrapings from three different depths (Figure 14.3b). Most species occurring on pier pile in the Port of Geelong appeared to have been collected from only 11 scrapings, however subsequent scrapings contained at least 10 additional species within each depth zone. Although additional grabs, cores, sleds

[4] Editor's note: Recorded by Lockett and Gorman (Chapter 12) as *Acentrogobius pflaumi*.

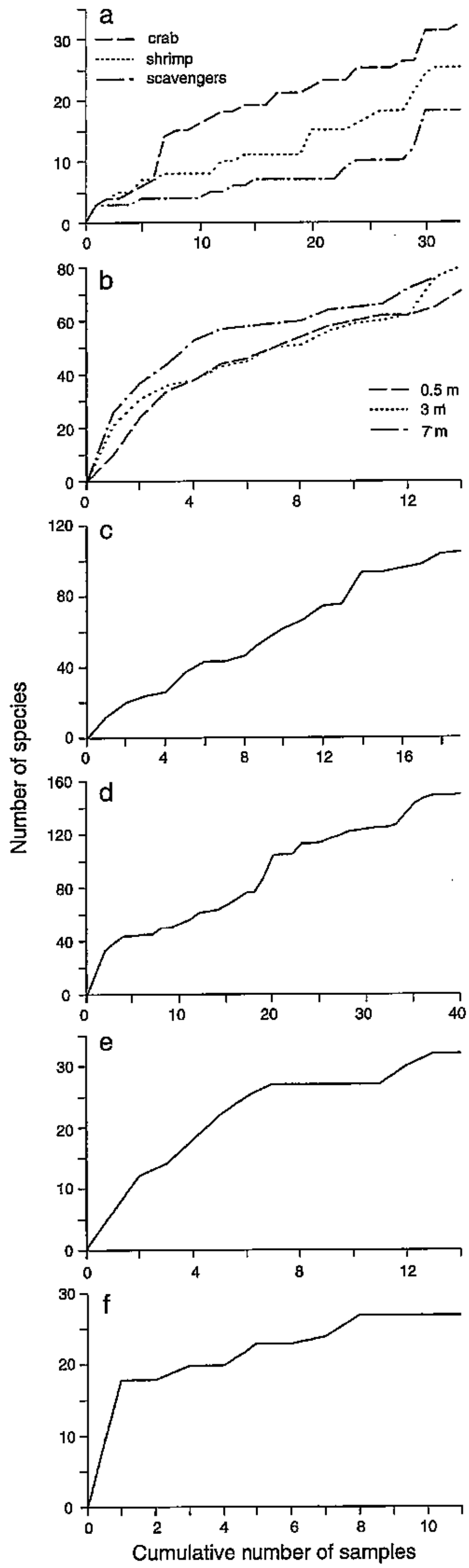

Figure 14.3. Cumulative species curves for: a) three different baited traps set in the Port of Geelong; b) diver scrapings taken at different depths (three) on piles (two) at each of the commercial shipping facilities (seven) in the Port of Geelong; c) Ocklemann sled tows (5 min. duration); d) benthic grab samples; e) infaunal cores; and f) beach seine nets.

scrapings and traps may have revealed several additional species, it is unlikely that any 'pest' species was not collected as such species must usually be abundant to be considered a 'pest'.

14.5.4 Changes in benthic community structure

Data collected during the present study were compared with that of a 1987 survey of macrobenthos in Corio Bay (Coleman 1993) in an effort to assess the significance of any recent changes in community structure. The locations of 20 stations were directly matched between studies and collection methods were essentially identical, although two grab samples were taken at each station in the earlier survey. As one of the stations sampled during the 1997 study was located on an operational dredge spoil ground (see Currie *et al.* 1998) data for this station were not included in all subsequent analysis. Considerable effort was made to ensure 'species' were recognised consistently across both studies and to update the taxonomic nomenclature of material from the 1987 survey with collections at the Museum of Victoria.

Differences in community structure between stations and surveys were examined using Bray-Curtis dissimilarity measures (Bray and Curtis 1957). Ordinations of triangular matrices of dissimilarities were obtained using non-metric multidimensional scaling (NMDS) options in the PRIMER program package (for further explanation see Clark 1993). The ordination presented in Figure 14.4 is plotted from double square-root transformed species abundance data. In this configuration stations sampled during 1997 form a relatively cohesive group and plot towards the bottom right of the page, while stations sampled during 1987 cluster towards the upper left of the page. These groupings differ significantly (ANOSIM, Global R 0.396, $p > 0.001$) and indicate a major change in benthic community structure between the two sampling periods. As NMDS plots obtained with square root and presence-absence transformed data were essentially identical to Figure 14.4 observed temporal differences are largely due to the presence of different suites of species in each sampling period and not changes in abundance.

Of the 140 species recorded from both sampling periods, only 42 species (30%) occurred during both surveys. 39 species were unique to the 1987 survey, while 59 were present only during the 1997 survey. Changes in community structure of this magnitude are not unusual in Port Phillip Bay (see Currie and Parry 1996), and appear to reflect interannual variations in species reproductive success and survival. Unfortunately, all four exotics species collected during the earlier survey *C. gibba*, *T. lubrica*, *A. aspersa* and *M. senhousia* still persist and were collected during 1997.

Table 14.4. Mean densities (± S.E.) and ratio of change in abundance of the ten most abundant infaunal species collected in Corio Bay during 1987 and 1997.

Species	Rank abundance	Mean density (per 0.1m²) 1987	Mean density (per 0.1m²) 1997	Ratio 1997/87	T - test
Musculista senhousia	1	0.08 ± 0.04	34.21 ± 24.79	427.63	P< 0.001
Theora lubrica	2	7.08 ± 1.43	5.53 ± 1.84	0.78	NS
Capitellid sp. 1	3	0.00	14.11 ± 8.16	∞	-
Tharyx sp. 1	4	3.40 ± 0.84	3.11 ± 1.54	0.91	NS
Neocallichirus limosus	5	0.26 ± 0.09	8.47 ± 1.56	32.58	P<0.001
Echinocardium cordatum	6	2.63 ± 0.58	1.00 ± 0.28	0.38	P <0.05
Electroma georgiana	7	2.05 ± 0.94	0.53 ± 0.28	0.26	NS
Tharyx sp. 3	8	0.26 ± 0.12	3.63 ± 2.05	13.96	P <0.05
Ascidiella aspersa	9	0.92 ± 0.36	0.26 ± 0.21	0.28	NS
Tharyx sp.	10	1.03 ± 1.00	0.00	0.00	-

Although the abundances of *C. gibba*, *T. lubrica* and *A. aspersa* have remained relatively static over the last 10 years, densities of *M. senhousia* have increased more than 400 fold (Table 14.4). This massive increase in population size appears to be coupled with an equally dramatic rate of spread. During 1987 it occurred at two shallow stations (see Currie *et al.* 1998) on the western side of Corio Bay, but in 1997 it was present in 18 stations throughout Corio Bay and the Outer Harbour.

14.6 IMPACT OF EXOTIC SPECIES

Non-native marine organisms have been found to exert a range of detrimental effects on their new environment including competition with and elimination of native species, habitat alterations, hybridisation, and trophic alterations (Kohler and Courtenay 1986). In high densities most non-native organisms will compete for food and space with native species. As the abundances of many exotic species detected during the survey of the Port of Geelong was high, it is likely that many of these introductions are currently having a major impact on the ecology of the port environment. *S. spallanzanii*, *A. aspersa*, *S. clava* and *M. senhousia* were the most abundant and widespread non-native organisms detected and therefore constitute the greatest threat to the ecology of the Port of Geelong. All four species are suspension-feeders and are likely to divert a significant proportion of particulate food in the ports' water column away from native filter-feeding organisms. As *S. spallanzanii*, *A. aspersa* and *S. clava* have no known predators in Port Phillip Bay (Parry *et al.* 1996), most of the primary productivity they assimilate will be directed to the benthos. Assuming this constitutes an alteration of established trophic pathways in the Port of Geelong changes in fish community structure can be expected. Other more direct effects of these exotics may be apparent in the survival, growth and competitive displacement of co-occurring species. The effects of *S. spallanzanii* on the recruitment success of native species is currently being investigated by M Holloway (University of Melbourne)[5].

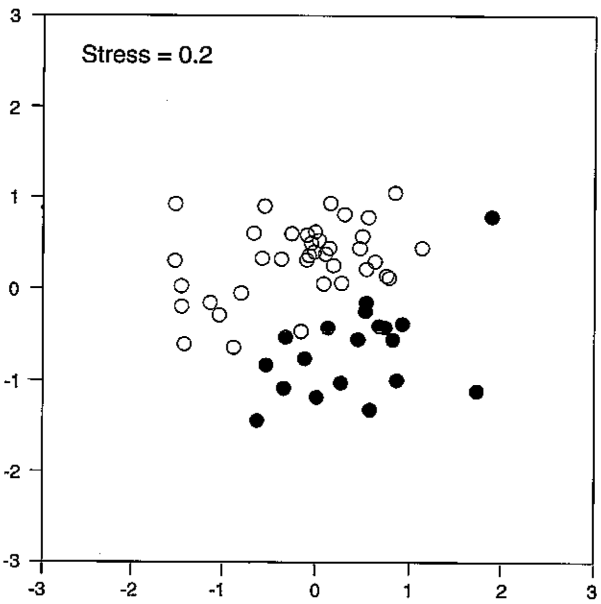

Figure 14.4. Non-metric multi-dimensional scaling ordination of Corio Bay Smith-McIntyre grab samples taken in 1987 (open circles) and 1997 (closed circles).

M. senhousia was found in virtually every habitat sampled in the Port of Geelong and current research shows that the population is increasing in size and distribution. *M. senhousia* has not been recorded from any other regions in Port Phillip Bay but its presence on both hard and soft substrates at depths to 12 m suggest it will, in time, invade a significant portion of the bay. *M. senhousia* forms dense mats in soft sediments in Corio Bay. A recent study in California (Crooks 1998) found that mats of

[5] Editor's note: See Chapter 16.

M. senhousia facilitate other organisms and species richness and density of individuals is typically higher in areas with mats than adjacent areas without mats. However in New Zealand, increases in the abundance of *M. senhousia* have apparently led to a reduction in the numbers of native mussels *Xenostrobus pulex* (Willan 1987). *X. pulex* is common in Victorian coastal waters and this mussel may be similarly impacted here. It is of some concern that the highest densities of *M. senhousia* in Corio Bay were recorded in seagrass beds. Although filter-feeding by mussels is known to improve light penetration and in some cases growth of aquatic macrophytes at depth (Lowe and Pillsbury 1995), competitive displacement of seagrass beds by *M. senhousia* may be significant and clearly warrants further research.

Another abundant species that is likely to be causing a significant impact on the ecology of the Port of Geelong is the Asian bivalve *T. lubrica*. This deposit-feeding mollusc has been a dominant component of muddy benthos in Port Phillip Bay for at least 30 years. In its native waters of Japan it can spawn throughout the year and recruits almost continuously. Its growth is rapid and juveniles (1 mm shell length) can attain maturity (6 mm shell length) in only two months (Kikuchi and Tanaka 1978). Similarities between the temperature regimes of Tamoe Cove, Japan and Port Phillip Bay have led Coleman (cited in Parry *et al.* 1996) to suggest that conditions in Port Phillip Bay are favourable for rapid growth of this species for several months of the year. Although *T. lubrica* is a minor component in the diets of two fish species in Port Phillip Bay (Parry *et al.* 1995) its impact on local marine communities is unknown.

In view of their low abundances, most other non-native species detected in the Port of Geelong are unlikely to be causing a significant ecological impact locally. However, two of these species (*C. gibba* and *E. limnicola*) occur elsewhere in Port Phillip Bay in significantly higher densities and are probably contributing to long-term and possibly irreversible ecological changes to Port Phillip Bay (Currie and Parry in press).

14.7 ORIGIN AND POSSIBLE VECTORS FOR THE INTRODUCTION OF EXOTIC SPECIES FOUND IN THE PORT

Expansion of a species' biogeographical range and shipping activities are widely cited as the two major mechanisms for introductions of marine organisms into new environments. Both processes initially require the physical transportation of the potential immigrant across an intervening space. This movement of larvae and or adult forms is mediated by wind and currents in natural systems, and by hull fouling and ballast water entrainment in shipping activities.

The large expanses of open coastline to the west of Port Phillip Bay present a significant barrier to the natural movement of non-native marine organisms towards Port Phillip Bay. Coastal water currents in Bass Strait move eastwards, but the slow net movement (100 km m^{-1}; G Jenkins pers. comm.) and absence of suitable sheltered habitat east of Portland Harbour (some 300 km distant) means that suitable exotic larvae have to survive several months in the water column to successfully reach Port Phillip Heads. Given that most exotic species detected in the Port of Geelong have a larval duration of less than one month, range expansions are not regarded as an important factor in the spread of exotics to the Port of Geelong. Therefore most exotic organisms found during the present survey were probably introduced by shipping activities, either directly from overseas ports or as secondary introductions from other Australian ports.

Hull fouling on shipping is identified as the most likely method for the introduction of the exotic bryozoan *B. neritina* into Geelong. Not only is this species extremely common on the hulls of boats it has a larval life of less than two hours when substrata are present and is unlikely to survive transportation within a ships ballast tanks. Two other exotic bryozoans found at Geelong (*W. subtorquata* and *B. dentata*) have similarly short larval lives and were probably introduced as fouling organisms on the hulls of ships. Other non-native fouling organisms that were probably introduced to Geelong on the hulls of ships or barges include the green algae *U. lactuca*, the isopod *C. harfordi*, the amphipod *J. marmorata*, and the ascidians *A. aspersa*, *C. intestinalis*, *S. clava* and *S. plicata*.

Some exotic species found in the Port of Geelong have the capacity to be translocated either as adults on the hulls of ships, or as larvae in ballast water. These include *U. pinnatifida*, *M. senhousia*, *S. spallanzanii* and *C. maenas*. Several other species detected are incapable of fouling hard substrates and have only been introduced to Geelong in the ballast tanks of ships. These include the bivalves *T. lubrica* and *C. gibba*[6], the polychaetes *E. limnicola* and *M. infundibulum* and the goby *A. pflaumi*.

Determining the proximal source of most exotic infestations in the Port of Geelong is difficult in view of our limited taxonomic and historical understanding of many other Australian temperate water ports. For example, many exotic species detected in the Port of Geelong are now known to occur in several other Australian ports, but the date of first infection for most of these ports cannot be accurately defined as their biological communities have not been regularly sampled over the last century. This

[6] Editor's note: See Chapter 9 for comments on the occurance of *C. gibba* in sea chests.

situation is further complicated by the fact that the ports of Geelong and Melbourne share the same body of water, and that exotic infections to one are invariably conferred on the other (e.g. *S. spallanzanii*). It is therefore not readily apparent if the 19 exotics detected in the Port of Geelong have been imported directly from overseas ports or if they have been translocated as secondary infections from other Australian ports including Melbourne.

14.8 INFLUENCES OF THE PORT ENVIRONMENT ON THE SURVIVAL OF INTRODUCED SPECIES

The total number of exotic marine species detected in the Port of Geelong during this survey (19) far exceeds that recorded in Victorias' other main provincial ports; Portland (nine species, Parry *et al.* 1997) and Hastings (seven species, Currie and Crookes 1998). While the high number of exotic species present in the Port of Geelong may simply reflect the relatively higher volume of shipping visits it receives, frequency of shipping visits does not necessarily imply success of introductions. With suitable environmental conditions, exotic species imported infrequently and in low numbers can be just as successful in their new habitat as those imported frequently and in large numbers (Walters 1996).

The risk of introductions of exotic species through ballast water would appear to be higher in the Port of Geelong than in other Victorian provincial ports because of its extremely sheltered location and low rate of water exchange. Larvae discharged in ballast water into Corio Bay are likely to reside in Corio Bay for several weeks and possibly months, increasing the probability of successful recruitment especially for species with longer-lived larval stages. Although flushing characteristics may in part explain the high diversity of exotic species within the Port of Geelong it does not readily explain their unparalleled success in this port.

Both primary habitats surveyed in the Port of Geelong (soft sediments and artificial surfaces) were dominated by exotic species. By comparison, most exotic organisms detected in similar habitats in the ports of Portland and Hastings were subordinate to native species and were never widespread nor abundant. As there are no significant differences in temperature and salinity regimes between the three ports it appears that biological factors rather than physical processes determine the post settlement success of introductions in these environments. The apparent lack of predators capable of feeding on *S. spallanzanii*, *A. aspersa* and *S. clava* in the Port of Geelong may well account for their success in this environment, although other biological parameters including availability of food are likely to be important.

14.9 ACKNOWLEDGEMENTS

We would like to thank Peter Lewry, John Falk, Andy Cowley, Jeff Rayner and Roger Gibb (harbourmasters) from the Port of Geelong for their assistance during field operations and for providing information on shipping movements and channel dredging.

The contribution of many staff members at the Marine and Freshwater Research Institute is gratefully acknowledged. In particular we would like to thank the following operations staff for their support in conducting the field work: Brett Abbot, John Barrie, Dave Beyer, Michael Callan, Mark Ferrier and Alan Kilpatrick. Thanks also to the many staff and students who, under the direction of Dianne Crookes, assisted in the laboratory analysis.

We would also like to thank the following staff from the Museum of Victoria for their assistance with the taxonomy of voucher reference material; Gary Poore (Crustaceans), Robin Wilson (Polychaetes) and Sue Boyd (Molluscs). Special thanks also to David Kenwood (Geelong Port), Chad Hewitt and Dick Martin (CRIMP), Noel Coleman (MAFRI), and Greg Parry and Colin Gibbs (EPA) for their valued advice and comments on earlier drafts of this manuscript.

This project was funded by the Victorian Fisheries Division, Victorian Environment Protection Authority, Port of Melbourne Authority and Geelong Port. It was commissioned by the Victorian Ballast Water Working Group, which is chaired by the Victorian Environment Protection Authority.

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15 A BAY-WIDE SURVEY FOR INTRODUCED SPECIES IN PORT PHILLIP BAY 1995–1996

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15.1 INTRODUCTION

Thirty-three years have passed since the last extensive (benthic and fouling) bay-wide survey of Port Phillip Bay (Port Phillip Bay Environmental Study, Phase One, 1968–1971) although additional work has been conducted by the Victorian Marine and Freshwater Resources Institute (MAFRI, formerly the Victorian Fisheries Research Institue: VFRI) and the Museum of Victoria (MoV). In the intervening period a number of introduced species have become abundant (e.g. *Asterias amurensis, Corbula gibba, Musculista senhousia, Sabella spallanzanii* and *Undaria pinnatifida*), in some cases experiencing increases of up to 400% (Wilson *et al.* 1996, 1998). These species have the potential to directly impact native flora and fauna or alter critical components of ecosystem function such as nutrient cycling (see Chapter 17).

All surveys in Port Phillip Bay have had intrinsic problems including limited spatial and habitat coverage, and unidentified and misidentified specimens due to either a poor knowledge of the phyla or a lack of experienced taxonomists (a situation that still exists for some groups). This has resulted in differential taxonomic resolution between phyla and an inability to obtain definite collection/identification dates, which in turn has hindered the deduction of accurate introduction dates (see Chapter 18). In addition, both collectors and researchers differentially sampled taxanomically, spatially and temporally. Thus, rare or hard to sample species were often missed and may not have been represented in records until later.

The recent results from partial re-surveys (Wilson *et al.* 1996, 1998) indicate that introduced species are more prevalent and potentially more widespread than 33 years ago. This may be due to an increase in shipping activity (and hence ballast water and hull-fouling) resulting in more introduced species inoculations into Port Phillip Bay. Alternately, the lack of comprehensive surveys targeting those regions and habitats most likely to have received introductions may have resulted in poor baseline resolution. As discussed in Chapter 1, the second phase of the CRIMP Port Phillip Bay study was to undertake a targeted field survey to rigorously sample the benthic fauna for introduced and cryptogenic species, and to place the results in the context of evaluations conducted by the taxonomic consultants (Chapters 6–13).

15.2 BASELINE BIOLOGICAL SURVEYS

Early biological surveys of Port Phillip Bay (in the 1800's) provided baseline information of the diverse taxa within this region. Studies by Harvey (1847, 1855, 1858–1863, 1869), Sonder (1852, 1853, 1880) and Wilson (1886, 1889, 1890, 1892, 1894, 1895) described the algae of the bay and helped provide the impetus for the formation of the Council of the Royal Society of Victoria. Similarly, knowledge of the fauna, specifically crinoids, sponges (Porifera), hydroids, algae and bryozoans was expanded via systematic biological surveys performed by Wilson, Agardh, Carpenter, Hickson, Spencer, Dendy and Pritchard among others (Anon 1890, 1892, 1894, 1895). The impetus for these collecting activities was bought to an end in 1895, with the death of J B Wilson.

Chapter 4 provides a summary of the surveys that have occurred since the mid-1950's. These surveys have recorded a number of introduced (Table 15.1) and cryptogenic (Table 15.2) species although most at the time were not recognised as introduced. For these surveys, complete species lists can be obtained from: Burn (1966), Clark (1966), Edmonds (1966), Macpherson (1966a, 1966b), Miller (1966), Naylor (1966), Pope (1966), Ralph (1966), Squires (1966), Womersley (1966), Cutress (1971), Griffith and Yaldwyn (1971), King *et al.* (1971), Knox and Cameron (1971), Southcott (1971), Utinomi (1966), Vigeland (1971), Watson and Utinomi (1971), Port of Melbourne Study (1979), PPES (1968–1971), Black (1971), Light and Woelkerling (1992), Poore (1992), Wood and Beardall (1992), Coleman (1993), Magro *et al.* (1996), Officer and Parry (1996), Wilson *et al.* (1996) and Chidgey and Edmunds (1997). Due to incomplete identifications and poor taxonomic resolution in specific taxa, additional introductions may have been present but remained undetected.

15.3 MATERIALS AND METHODS

The CRIMP survey was performed using methods outlined in Hewitt and Martin (1996; see Chapter 2). The sampling regime was designed to cover a variety of areas, concentrating on the shipping ports of Melbourne and

Table 15.1. Introduced species collected in previous surveys of Port Phillip Bay. Surveys listed are (1) Port Phillip Study (1957–1963); (2) Port Phillip Bay Environmental Study, Phase 1 (1968–1971); (3) Port Melbourne Study (1976–1977); (4) Corio Bay (1987) and (5) Port Phillip Bay Environmental Study (1991–1996). + denotes species collected during survey; ++ denotes species recognised as introduced at time of collection.

Taxa	Species	Previous surveys				
		1	2	3	4	5
Algae	*Antithamnionella spirographidis*					+
	Cladophora sp. (possibly C. prolifera)					+
	Deucalion levringii					++
	Medeiothamnion lyalli					++
	Polysiphonia brodiaei					+
	Polysiphonia pungens (senticulosa)					+
	Schottera nicaeensis					++
	Sorocarpus micromorus					+
	Stictysiphon soriferus					++
Dinoflagellate	*Alexandrium catenella*					++
	Gymnodinium mikimotoi					+
	Gymnodinium pulchellum					+
Cnidaria	*Amphisbetia operculata*	+				
	Ectopleura crocea	+				
	Halecium delicatulum	+				
	Obelia dichotoma (australis)	+				+
Annelida	*Boccardia proboscidea*					+
	Euchone sp.			+		+
	Myxicola infundibulum	+	+	+		
	Pseudopolydora paucibranchiata			+		+
	Sabella spallanzanii					++
Mollusca	*Corbula gibba*				+	++
	Janolus sp. (possibly *J. hyalinus*).	+				
	Musculista senhousia				+	+
	Okenia sp. (possible *O. plana*)	+				
	Theora lubrica	+	+	++	++	++
Arthropoda	*Carcinus maenas*	+		++		
	Pyromaia tuberculata					++
Bryozoa	*Aetea anguina*	+				
	Bowerbankia spp.	+				
	Bugula neritina	+				
	Celleporella hyalina	+				
	Conopeum reticulum	+				
	Fenestrulina malusii	+				
	Membranipora membranacea	+				
	Scruparia ambigua	+				
	Scrupocellaria scrupea	+				
	Scrupocellaria scruposa	+				
Ascidacea	*Ascidiella aspersa*	+			+	
	Botryllus schlosseri			++		
	Ciona intestinalis	+		++		
	Styela clava			++		++
	Styela plicata	+				

Geelong. For ease of discussion the bay was divided into five regions: 1) Port Melbourne; 2) Geelong Arm; 3) the Heads; 4) the Eastern Shore and; 5) the Middle Bay (Figure 15.1). Regions 1 and 2 are the main port areas, regions 3 and 4 are recreational and commercial fishing areas and region 5 is dominated by shipping channels and markers. Four surveys were conducted over spring 1995 and summer 1995/1996.

The consultants contracted to review known introductions within Port Phillip Bay (see Chapter 2) provided a target species list of introduced and cryptogenic species. (Chapter 2, Table 2.2). The CRIMP survey sampling efficiency was evaluated by comparing survey detection against the target list. Collected algae, dinoflagellates and phytoplankton were not identified or targeted in this survey, although the algae and dinoflagellates are listed on the target list.

Table 15.2. Cryptogenic and possibly introduced species collected in previous surveys of Port Phillip Bay. Surveys listed are as in Table 15.1; + denotes species collected during survey.

Taxa	Species	Previous surveys				
		1	2	3	4	5
Algae	*Acinetospora crinita*	+	+			+
	Bryopsis plumosa	+	+			+
	Centroceras clavulatum					+
	Ceramium flaccidum					+
	Ceramium rubrum					+
	Chaetomorpha aerea					+
	Chaetomorpha linum					+
	Colpomenia peregrina					+
	Colpomenia sinuosa	+	+			+
	Cutleria multifida	+	+			+
	Dictyota dichotoma		+			+
	Enteromorpha compressa		+			+
	Enteromorpha intestinalis		+			+
	Feldmania globifera	+				+
	Feldmania lebelii					+
	Gelidium pusillum					+
	Kuckuckia spinosa					+
	Leathesia difformis					+
	Nemalion helminthoides					+
	Petalonia fascia					+
	Petrospongium rugosum					+
	Pilayella littoralis					+
	Polysiphonia subtilissima					+
	Pterocladia capillacea	+				+
	Punctaria latifolia					+
	Scytosiphon lomentaria		+			+
	Sphacelaria fusca					+
	Ulva lactuca		+			+
	Ulva rigida					+
Arthropoda	*Caprella equilibra*			+		
	Elminius modestus	+	+			
Bryozoa	*Celleporaria albirostris*	+				
	Parasmittina trispinosa	+				

The numerous studies of Port Phillip Bay have resulted in considerable amounts of information being collected on the bay. However, the sampling strategies performed in each survey are not directly comparable due to different sampling intensities, site locations and habitats, sampling methodologies and because many taxonomic groups from previous surveys were not identified beyond taxa level. Because of this, no comparative statistical analyses with the CRIMP data is possible (K Haskard pers. comm.), although some descriptive statistics are used in section 15.6.2 below.

15.4 RESULTS

Based on historical information, bay-wide and the Port of Geelong (see Chapter 14; Currie *et al.* 1998) surveys there are at least 855 species currently in Port Phillip Bay, and potentially there are 191 are introduced, cryptogenic or possibly introduced species (Appendix A, Table A7).

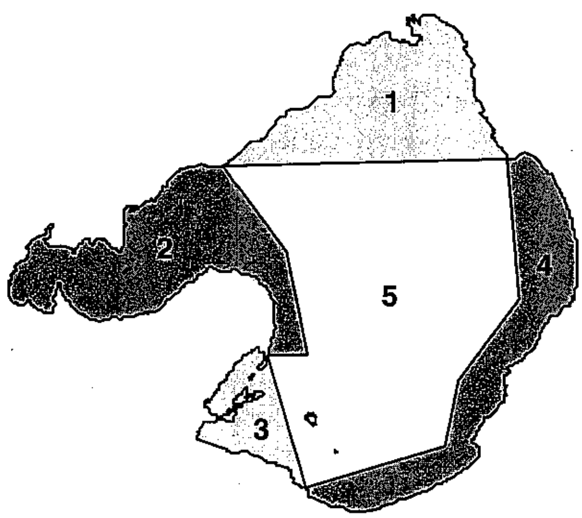

Figure 15.1. Port Phillip Bay regions: 1) Port Melbourne; 2) Geelong Arm; 3) the Heads; 4) the Eastern Shore and; 5) the Middle Bay.

Table 15.3. Total number of native species per phylum (n) and per region (1–5) that were collected on hard (H) and soft (S) substrates. Region 1) Port Melbourne; 2) Geelong Arm; 3) the Heads; 4) the Eastern Shore; and 5) the Middle Bay.

Phylum (n)	Substrate	Number of endemic species per region				
		1	2	3	4	5
Bryozoa (19)	H	7	6	9	7	4
Chordata (11)	H/S	4	8	2	0	0
Cnidaria (23)	H	9	8	5	15	10
Crustacea (140)	H/S	125	40	5	6	0
Echinodermata (10)	S	8	4	5	1	1
Mollusca (64)	H/S	24	12	1	6	2
Nemertea (7)	S	4	1	0	2	0
Polychaeta (132)	H/S	97	49	10	17	4
Porifera (27)	H	10	13	14	5	0
Urochordata (23)	H	16	6	8	3	3
Total number of species per region		304	147	59	62	24

15.4.1 Native species

The present survey collected and identified a total of 456 native species from 10 phyla. The numbers of native species per phylum collected by region is summarised in Table 15.3. Polychaetes were evenly distributed between the five regions, with other phyla being concentrated around the port regions of Melbourne and Geelong (region 1 and 2). Sixty percent of phyla appeared in all regions. The remaining 40% of phyla (chordates, nemerteans, crustaceans and sponges) were not collected at all sites due to the sampling effort for these organisms.

To summarise, the majority of native species were concentrated around the shipping regions of Port Melbourne (51.5%) and Geelong (25%), followed by fishing regions of the Eastern Shore (10.5%), the Heads (9%) and finally the shipping movement area in the Middle Bay (4%). This trend may be an artifact of sampling effort, which was concentrated around the Port of Melbourne and Geelong regions.

15.4.2 Introduced species

Fourty-nine introduced species were collected over the five sampling regions. Table 15.4 summarises the introduced species collected in this survey and their current distribution in Port Phillip Bay. The majority (76%) of introduced species were associated with hard substrates. Taxa with most introduced species were the Bryozoa (n = 12), Crustacea (n = 10), Cnidaria (n = 8), and Ascidiacea (n = 6). Three of these taxa (Ascidiacea, Bryozoa and Cnidaria) are common, dominant, hard substrate foulers (see Chapters 7 and 13).

Introduced species were concentrated around the shipping areas within the Port Melbourne (76%) and Geelong (64%) regions. The aquaculture area at Portarlington also had many introduced species, with the introduced hydroid *Ectopleura crocea* and the introduced fanworm *Sabella spallanzanii* commonly fouling aquaculture lines. In addition, a number of vessels moored at the nearby Portarlington marina were heavily fouled by *S. spallanzanii*. The fishing regions at the Eastern Shore (28%) and the Middle Bay (24%) had the next highest concentration of introduced species, followed by the Heads (14%).

15.5 INTRODUCTIONS NOT ON THE TARGET LIST

Cancer novaezelandiae was identified from Mentone in the region (McNeil and Ward 1930) but was not collected in the bay-wide survey or noted on the target list. *Cancer novaezelandiae* may be an historical introduction that has become locally extinct. One introduced species (*Paracerceis sculpta*) was collected, but was not detailed in the target list. The collection of *P. sculpta* represents the first record of this species in temperate Australian waters, although, *P. sculpta* has been collected from tropical Australian waters (Harrison and Holdich 1982). A brief taxonomic description of each species is provided below. A flat worm species, *Euplana gracilis*, native to the Atlantic coast of North America was identified previously (Prudhoe 1982) and is not treated herein.

15.5.1 Crustacea

Family Cancridae

Cancer novaezelandiae (Jacquinot and Lucas 1853)

Synonymy and taxonomy

Platycarcinus novae-zealandiaea, Jacquinot and Lucas 1853; *Cancer novae-zealandiae*, Milne Edwards 1865. — Miers 1874, 1876. — Filhol 1886. — Lenz 1901. — Chilton 1909, 1911. — Thomson 1912. — Thomson and Anderson 1921. — Stephensen 1927. — Chilton and Bennett 1929. — Young 1929. — McNeil and Ward 1930. — Richardson 1949; *Cancer novaezelandiae* Dell 1963, 1968, 1969. — Vermeij 1977. — Marsden and Fenwick 1978. — Probert *et al.* 1979. — Marsden 1981. — Knox 1983. — Wear and Fielder 1985. — McLay 1988. — Furlani 1996.

Table15.4. Introduced species collected (n) from regions 1–5 on hard (H) and soft (S) substrate during the bay-wide survey, 1995–1996. Regions are as in Table 15.3.

Taxa	Species	Substrate	Port Phillip Bay regions				
			1	2	3	4	5
Porifera	*Aplysilla rosea*	H			+	+	
	Dysidea fragilis	H	+				
	Haliclona heterofibrosa	H		+			
	Halisarca dujardini	H	+				
Cnidaria	*Bougainvillia muscus*	H	+	+			
	Clytia hemisphaerica	H	+	+			
	Clytia paulensis	H	+	+			+
	Ectopleura crocea	H		+			
	Obelia australis	H	+			+	
	Plumularia setacea	H	+	+			+
	Sarsia eximia (radiata)	H		+			+
	Turritopsis nutricula	H		+			
Polychaeta	*Sabella spallanzanii*	H/S	+	+			+
Mollusca	*Corbula gibba*	S	+	+			+
	Musculista senhousia	S	+	+			
	Raeta pulchella	S	+				
	Theora lubrica	S	+	+			
Crustacea	*Balanus amphitrite*	H	+	+		+	
	Balanus variegatus	H	+	+		+	+
	Carcinus maenas	S	+	+	+	+	
	Cirolana harfordi	H		+			
	Corophium acherusicum	S	+	+	+	+	
	Corophium insidiosum	S	+				
	Corophium sextonae	S			+		
	Elminius modestus	S	+			+	
	Paracerceis sculpta	H/S	+			+	+
	Pyromaia tuberculata	S	+				
Bryozoa	*Aetea anguina*	H	+				+
	Amathia distans	H	+	+			
	Bugula flabellata	H	+	+			+
	Bugula neritina	H	+	+			
	Bugula stolonifera	H	+	+			
	Conopeum reticulum	H	+	+			
	Cryptosula pallisiana	H	+	+		+	
	Electra pilosa	H				+	
	Membranipora membranacea	H			+		
	Schizoporella unicornis	H			+		
	Tricellaria occidentalis	H	+	+	+	+	+
	Watersipora subtorquata	H	+	+	+	+	
Ascidiacea	*Ascidiella aspersa*	H	+				+
	Botrylloides leachi	H	+	+			
	Botryllus schlosseri	H	+			+	
	Ciona intestinalis	H	+				
	Styela clava	H	+		+		
	Styela plicata	H	+				
Pisces	*Acanthogobius flavimanus*	H		+			
	Acentrogobius pflaumi	H	+	+		+	+
	Forsterygion lapillum	H	+	+			
	Tridentiger trigonocephalus	H	+				
Total number of introductions per region			38	31	7	14	12

Native distribution
Native to New Zealand.

Australian distribution
Tasmania: Hobart; New South Wales: Eden; and Victoria: Western Port, the central Victorian coastline and Port Phillip Bay.

Port Phillip Bay distribution and first records of collection
It was recorded from Mentone in 1930 (McNeil and Ward 1930) however, has not been collected since. This may represent a local extinction/failed invasion.

Description
A decapod crab. The carapace is domed, elliptical 28–112 mm wide, expanded sideways over short, slender legs. Its colour is grey to rust red above and cream below, often speckled with pinkish-brown. It holds its legs inert when uncovered making no attempt to escape.

Known or inferred impacts
Not known for Australia waters.

Comments
Cancer novaezelandiae is a nocturnal feeder that migrates into the littoral zone at night. Ovigerous females have been collected during summer/autumn in New Zealand and observed in winter in Tasmania (K Gowlett-Holmes pers. comm.). It lives in the subtidal zone in harbours, estuaries and rocky coastlines.

Family Sphaeromatidae
Paracerceis sculpta (Holmes 1904)

Synonymy and taxonomy
Dynamene sculpta Holmes 1904;
Cilicaea sculpta Richardson 1905;
Paracerceis sculpta Richardson 1905. — Menzies 1962. — Millar 1968. — Pires 1981. — Harrison and Holdich 1982. — Shuster 1987. — Rodriguez *et al.* 1992. —Furlani 1996; *Sergiella angra* Pires 1980, 1981.

Native distribution
North American Pacific coast, California to Mexico.

Australian distribution
Queensland: Townsville (Furlani 1996), Hay Point; New South Wales: Eden; and Western Australia: Swan River and Bunbury (CRIMP collection).

Port Phillip Bay distribution and first records of collection
Collected by CRIMP, at the Anne St. Pier, 19 September 1995. No other known records.

Description
See description in Chapter 10 of material provided to G Poore for verification.

Known or Inferred Impacts
Unknown for Australian waters.

Comments
Paracerceis sculpta breeds in intertidal sponges. It lives in the intertidal/infralittoral zone in macroalgae and under stones and is able to withstand strong wave action. Previously, it has only been recorded in North Queensland (Harrison and Holdich 1982). It is often associated with *Sphaeroma walkeri* and *Paradella dianae*.

15.6 DISCUSSION AND CONCLUSIONS

15.6.1 Sampling proficiency (target versus survey species)

Sampling proficiency for determining the presence of introduced species varied between regions and substrates (Table 15.5). Hard substrate sampling detected 47.5% of the total known target species (excluding the algae). Similarly, soft substrate sampling methods were 48% effective at detecting introductions (excluding algae and dinoflagellates). Detection of introduced species in the groups Chordata (100%), Ascidiacea (86%), Crustacea (80%), Porifera (66%), Cnidaria (60%), Mollusca (57%) and Bryozoa (52%) was high (Table 15.5). Conversely, few introductions were detected for the invertebrate groups Echinodermata (0%) and Polychaeta (12.5%; Table 15.5). Factors limiting detection include seasonality due to biphasic life histories (e.g. hydroids), recognised limited distribution (e.g. *Molgula manhattensis* and *Ectopleura crocea*) or habitat. Detection of cryptogenic and possibly introduced species (Bryozoa 0%, Crustacea 66%, Mollusca 0% and Porifera 0%) was also variable (Table 15.5).

15.6.2 Community and survey comparisons

Comparisons with previous surveys are restricted by a number factors. Many previous studies have concentrated on benthic substrates (Poore 1992; Currie and Parry 1996). Few hard substrate surveys in Port Phillip Bay are available, and those that are available are mostly historical descriptive papers (see MacGillivray 1883a, 1883b, 1883c, 1884, 1885, 1886, 1887a, 1887b, 1887c, 1890; Dendy 1895, 1896 and 1897). Two exceptions are the 1957–1963 surveys conducted by the Victorian Fisheries and Wildlife Department and the National Museum of Victoria (PPES 1968–1971) and the 1968–1971 survey conducted by the Melbourne and Metropolitan Board of Works, the Victorian Fisheries and Wildlife and the Port Phillip Authority (Port of Melbourne Environmental Study 1979) Comparisons of the bay-wide 1968–1971, 1957–1963 and present 1995–1997 surveys were made to note community changes. This comparison is for zoobenthos only.

The present and 1957–1963 surveys combined sampled 1,075 species with 89 species (8.3%) occurring in both; 568 species were unique to the 1957–1963 survey and 418 were unique to the 1995–1997 survey resulting in a Jaccard's Index of Similarity of 9.9%. This implies that the community structure has changed dramatically in the past 32 years. Introduced species in the 1957–1963 survey were few (18 species), with 83% being collected in the 1995–1997 survey.

Comparison with the 1968–1971 survey also shows changes in community structure, however the changes are less extreme. The present and the 1968–1971 surveys combined sampled slightly fewer species (928) with 125 (13.5%) species occurring in both surveys. The 1968–1971 survey had 421 species that were only collected in that survey while the present survey had 382 unique species resulting in a Jaccard's Index of 18.4%. Changes in community structure such as these in Port Phillip Bay are expected and have been briefly discussed in Chapter 14 and by Currie and Parry (1996, 1998), and Wilson *et al.* (1966, 1988).

The number of introduced species in the 1968–1971 survey decreased to three species. The drop in recorded introduced species is ascribed to the incomplete identifications of many of the 1968–1971 specimens. Large proportions (74.5%) of these species were only identified to family or genus level. The present survey collected 49 introduced species, representing a 3-fold increase from the 1957–1963 survey. Thus, as time progressed, and if we ignore the 1968–1971 results, more introduced species became established in the bay. This trend is discussed in more detail in Chapter 18.

15.6.3 Impact of introduced pests

There have been few comprehensive studies on the impacts of introduced species in Australia (see Chapter 16). International research on impacts is more advanced, with studies on a number of introduced species including the zebra mussel, *Dreissena polymorpha* (see Claudi and Mackie 1993; Madenjian 1995; Mellina *et al.* 1995; Klerks *et al.* 1997); the introduced seagrass *Zostera japonica* (Baldwin and Lovvorn 1993, 1994; Thom *et al.* 1995); the ctenophore *Mnemiopsis leidyi* (GESAMP 1997); the green crab *Carcinus maenas* (Grosholz and Ruiz 1995, 1996; Kuris and Lafferty 1996); and the introduced seaweeds *Undaria pinnatifida* (M Stuart 1998; pers. comm.) and *Caulerpa taxifolia* (Verlaque 1994; Verlaque and Fritayre 1994; Francour *et al.* 1995; Villele and Verlaque 1995; Bellan-Santini *et al.* 1996; Ribera *et al.* 1996; Ferrer *et al.* 1997). Generally, impacts studies are conducted for introduced species that pose obvious threats to native biodiversity or have an obvious economic impact. Consequently, species that cause little economic impact are often disregarded (e.g. the bryozoan *Membranipora membranacea*).

Recognising impacts is difficult if a species has been present in an area for many years. For example, at least 50% of the introduced bryozoans in Port Phillip Bay were first identified in the late 1800's and could easily have arrived in the early 1800's on wooden ships as hull foulers (see Chapter 18). The time between arrival and detection is sufficient for community structure to be altered through competition and displacement of native species. Yet this would be undetected because studies of the marine fauna in Port Phillip Bay did not begin until the mid–1800's with few quantitative evaluations of community structure until the late 1960's.

Numerous researchers (Smith and Carlton 1975; Simberloff 1986; Carlton *et al.* 1995; Shigesada and Kawasaki 1997) have discussed the potential impacts of introduced species. Potential impacts may include

- competition, displacement and extinction of native species;
- habitat alterations;
- introgression and hybridisation;
- ecosystem nutrient cycling modifications; and
- the vectoring of diseases.

Some of these impacts have occurred in Port Phillip Bay. For example, the introduced species *Sabella spallanzanii*, *Corbula gibba*, *Musculista senhousia*, *Theora lubrica*, *Euchone limnicola* and *Undaria pinnatifida*, have altered their habitats. These six species all occur in high densities and appear to have successfully out-competed native species. *S. spallanzanii* and *M. senhousia* can dominate both hard and soft substrates; the others dominate soft substrates. Other introduced species that have successfully competed for space include the introduced bryozoans, cnidarians and ascidians that are dominant on hard substrates.

The introduced alga *Codium fragile* ssp. *tomentosoides* is capable of interbreeding with the native *Codium fragile* subspecies (S Campbell pers. comm; also see Chapter 16). Furthermore, *Codium* can displace shellfish such as scallops, oysters and mussels, (Ramus 1971; Bleakney 1989) making it a potential pest. As discussed in Chapter 16, many introduced species can directly modify the substrate (e.g. *Corbula gibba*, *Corophium* sp., *Euchone limnicola* and *Musculista senhousia*) and alter nutrient cycling (e.g. *Corbula gibba*, *Codium fragile* ssp. *tomentosoides* and *Sabella spallanzanii*) (see Chapter 17; Harris *et al.* 1996).

As yet, the vectoring of diseases in introduced species has not been detected in Port Phillip Bay, but the potential for this to occur is significant due to the mariculture practices of importing spat and live adults. For example, in Tasmania, there have been concerns over the import of Atlantic salmon because of diseases they may bring into the Australian salmon mariculture industry.

In conclusion, few of the introduced species in Port Phillip Bay, or Australia have been extensively studied. Further research is required to fully comprehend the potential impacts that introduced species may have on our native species and habitats.

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Table 15.5. Introduced, cryptogenic and possibly introduced species on hard (H) and soft (S) substrates in the different regions of Port Phillip Bay. "Reported distribution" indicates known occurrence and distribution; "CRIMP survey" indicates occurrence and distribution as determined from the CRIMP bay-wide survey. Regions are as in Table 15.3; presence of species indicated by +; possible presence denoted by ?; [1] denotes species identified by taxonomic experts in this volume; [2] denotes species with a known limited distribution; [3] denotes species in a habitat unsampled by CRIMP survey; and [4] denotes species identified in Victoria but not in Port Phillip Bay.

Target species	Substrate	Port Phillip Bay regions									
		Reported distribution					CRIMP survey				
		1	2	3	4	5	1	2	3	4	5
Algae – introduced											
Antithamnionella spirographidis [1,2,3]	H	+									
Asperococcus compressus [1,2,3]	H	+									
Chondria arcuata [1,2,3]	H	+									
Cladophora prolifera [1,3]	S			+	+						
Codium fragile spp. *tomentosoides* [1,3]	S		+								
Deucalion levringii [1,3]	H	+		+							
Gymnogongrus crenulatus [1,3]	H	+	+								
Medeiothamnion lyallii [1,3]	H				+						
Polysiphonia brodiaei [1,3]	H	+		+							
Polysiphonia senticulosa (pungens) [1,3]	H	+	+		+						
Schottera nicaeensis [1,3]	H	+		+							
Solieria filiformis [1,2,3]	H	+									
Sorocarpus micromorus [1,2,3]	H				+						
Stictyosiphon soriferus [1,3]	H	+	+	+							
Ulva fasciata [1,2,3]	H	+									
Undaria pinnatifida [1,2]	H		+	+							
Algae – cryptogenic and possibly introduced											
Acinetospora crinita [1,3]	H		+	+	+	?					
Antithamnion cruciatum [1,4]	H	?	?	?	?	?					
Antithamnionella ternifolia [1,3]	H	+									
Arthrocladia villosa [1,4]	H	?	?	?	?	?					
Audouinella pacifica [1,2,3]	H	+									
Audouinella simplex [1,2,3]	H	+									
Bangia atropurpurea [1,3]	H	+	+	+							
Bryopsis plumosa [1,3]	H	+	+								
Caulerpa filiformis [1,4]	H	?	?	?	?	?					
Centroceras clavulatum [1,3]	H	+	+	+							
Ceramium flaccidum [1,2,3]	H	+									
Ceramium rubrum [1,2,3]	H	+									
Chaetomorpha aerea [1,3]	H	+	+	+	+	?					
Chaetomorpha capillaris [1,2,3]	H	+									
Chaetomorpha linum [1,2,3]	H	+									
Cladostephus spongiosus [1,3]	H	+	+	+							
Colpomenia peregrina [1,3]	H	+	+	+							
Colpomenia sinuosa [1,3]	H	+	+	+	+	?					
Cutleria multifida [1,3]	H	+	+		+						
Derbesia marina [1,2,3]	H	+									
Dictyota dichotoma [1,3]	H	+	+	+	+	?					
Discosporangium mesarthrocarpum [1,4]	H	?	?	?	?	?					
Ectocarpus fasciculatus [1,3]	H			+	+	?					
Ectocarpus siliculosus [1,3]	H	+		+	+	?					
Elachista orbicularis [1,4]	H	?	?	?	?	?					
Enteromorpha compressa [1,2,3]	H	+									
Enteromorpha intestinalis [1,2,3]	H	+									
Erythrotrichia carnea [1,2,3]	H		+	+							
Feldmannia globifera [1,3]	H	+		+	+						
Feldmannia irregularis [1,3]	H		+	+	+						
Feldmannia lebelii [1,2,3]	H			+							
Gelidium pusillum [1,3]	H	+	+	+	+						
Gymnothamnion elegans [1,3]	H			+							
Hildenbrandia occidentalis var. *yessoensis* [1,2,3]	H	+									

Table 15.5. continued.

Target species	Substrate	Port Phillip Bay regions									
		Target list					CRIMP survey				
		1	2	3	4	5	1	2	3	4	5
Hildenbrandia rubra [1,2,3]	H	+									
Hincksia granulosa [1,3]	H	+	+	+	+						
Hincksia mitchellae [1,3]	H	+		+	+						
Hincksia ovata [1,3]	H	+			+						
Hincksia sandriana [1,3]	H	+	+		+						
Kuckuckia spinosa [1,3]	H		+		+						
Leathesia difformis [1,2,3]	H			+							
Myrionema strangulans [1,3]	H		+	+							
Nemalion helminthoides [1,3]	H			+	+						
Petalonia fascia [1,3]	H	+	+		+						
Petrospongium rugosum [1,2,3]	H			+							
Peyssonnelia conchicola [1,2,3]	H	+									
Pilayella littoralis [1,3]	H		+		+						
Polysiphonia subtilissima [1,3]	H	+	+								
Pterocladia capillacea [1,3]	H	+		+							
Punctaria latifolia [1,3]	H	+	+		+						
Scytosiphon lomentaria [1,3]	H	+	+		+						
Sphacelaria fusca [1,2,3]	H	+									
Striaria attenuata [1,4]	H	?	?	?	?	?					
Stylonema alsidii [1,2,3]	H	+									
Ulva lactuca [1,2,3]	H	+									
Ulva rigida [1,2,3]	H	+									
Ulva stenophylla [1,3]	H	?	?	+	?	?					
Vaucheria piloboloides [1,4]	H	?	?	?	?	?					
Dinoflagellates - introduced											
Alexandrium catenella	S	?	?	?	?	?					
Dinoflagellates - cryptogenic and possibly introduced											
Alexandrium minutum	S	?	?	?	?	?					
Alexandrium tamarense	S	?	?	?	?	?					
Gymnodinium mikimotoi	S	?	?	?	?	?					
Gymnodinium pulchella	S	?	?	?	?	?					
Porifera – introduced											
Aplysilla rosea [1]	H			+					+	+	
Corticium candelabrum [1]	H			+							
Dysidea avara [1]	H			+							
Dysidea fragilis [1,2]	H	+					+				
Haliclona heterofibrosa [1,2]	H		+					+			
Halisarca dujardini [1,2]	H	+					+				
Porifera – cryptogenic and possibly introduced											
Callyspongia pergamentacea [1]	H			+							
Darwinella australianensis [1]	H			+							
Darwinella gardineri [1,4]	H	?	?	?	?	?					
Lissodendoryx isodictyalis [1]	H			+							
Phorbas cf. *tenacior* [1,4]	H	?	?	?	?	?					
Tedania anhelans [1]	H			+							
Cnidaria: Hydrozoa – introduced											
Amphisbetia operculata [1]	H			+							
Antennella secundaria [1]	H			+	+						
Bougainvillea muscus (ramosa) [1]	H	+	+				+	+			
Clytia hemisphaerica [1]	H	+	+	+	+	+	+	+			
Clytia paulensis [1]	H	+	+	+	+	+	+	+			+
Ectopleura crocea [1,2]	H		+				+	+		+	
Filellum serpens [1]	H			+	+						
Halecium delicatulum [1]	H			+	+	+					
Monotheca obliqua [1]	H			+	+	+					
Obelia dichotoma (australis) [1]	H	+	+	+	+	+	+	+		+	
Phialella quadrata [1]	H			+	+	+					

Table 15.5. continued.

Target species	Substrate	Port Phillip Bay regions: Target list 1	Target list 2	Target list 3	Target list 4	Target list 5	CRIMP survey 1	CRIMP survey 2	CRIMP survey 3	CRIMP survey 4	CRIMP survey 5
Plumularia setacea [1]	H			+	+	+	+				+
Sarsia eximia (radiata) [1]	H	+	+	+	+	+		+			+
Turritopsis nutricula [1,2]	H	+	+	+	+			+			
Platyhelminthes - introduced											
Euplana gracilis [4]	H/S	?	?	?	?	?					
Annelida: Polychaeta – introduced											
Boccardia proboscidea [1,2]	S	+									
Euchone limnicola [1]	S	+	+	+	+	+					
Hydroides norvegica [1,2]	S		+								
Mercierella enigmaticus [1,2]	H/S	+									
Myxicola infundibulum [4]	S		+								
Neanthes succinea [1]	S	+	+	+	+	+					
Pseudopolydora paucibranchiata [1]	S	+	+	+		+					
Sabella spallanzanii [1]	H/S	+	+		+	+	+	+			+
Mollusca – introduced											
Aplysiopsis formosa [1,2]	S			+							
Corbula gibba [1]	S		+			+	+	+			+
Janolus hyalinus [1]	S		+	+							
Musculista senhousia [1]	S		+				+	+			
Raeta pulchella [1]	S	+	+				+				
Theora lubrica (fragilis) [1]	S	+	+	+	+	+	+	+			
Mollusca – cryptogenic or possibly introduced											
Crassostrea gigas [1]	H/S		+								
Kaloplocamus ramosus [1,4]	H	?	?	?	?	?					
Okenia plana [1,4]	H	?	?	?	?	?					
Polycera hedgpethi [1,4]	H	?	?	?	?	?					
Arthropoda: Crustacea – introduced											
Balanus amphitrite [1]	H	+	+	+	+	+	+	+		+	
Cancer novaezelandiae [4]	S	+									
Carcinus maenus [1]	S	+	+	+	+		+	+	+	+	
Cirolana harfordi [1]	H/S		+					+			
Corophium acherusicum [1]	S	+	+	+	+		+	+	+	+	
Corophium insidiosum [1,2]	S	+					+				
Corophium sextonae [1]	S		+	+				+			
Jassa marmorata [1]	S	+				+					
Paracerceis sculpta [1,2]	S						+				
Pyromaia tuberculata [1]	S					+	+			+	
Arthropoda: Crustacea – cryptogenic and possibly introduced											
Balanus variegatus [1]	H	+	+	+	+	+	+	+		+	
Caprella acanthogaster [1,4]	S	?	?	?	?	?					
Caprella equilibra [1]	S	+	+				+	+			
Caprella penantis [1,4]	S	?	?	?	?	?					
Caprella scaura [1]	S	+	+	+			+	+	+		
Elminius modestus [1]	H	+	+		+		+			+	
Bryozoa – introduced											
Aetea anguina [1]	H			+			+				+
Amathia distans [1]	H	?	+	?	?	?	+	+			
Bowerbankia spp. [1,2]	H	+									
Bugula calathus [1,2]	H	+									
Bugula flabellata [1]	H	+					+	+			+
Bugula neritina [1]	H	+		+			+	+			
Bugula simplex [1,2]	H	+									
Bugula stolonifera [1]	H	+		+			+	+			
Celleporella hyalina [1]	H	+		+	+	+					
Conopeum reticulum [1]	H	+		+	+		+	+			

Table 15.5. continued.

Target species	Substrate	Port Phillip Bay regions									
		Target list					CRIMP survey				
		1	2	3	4	5	1	2	3	4	5
Cryptosula pallasiana[1]	H	+		+			+	+		+	
Electra pilosa[1]	H	+	+	+	+	+				+	
Fenestrulina malusii[1]	H	+		+							
Membranipora membranacea[1]	H	+	+	+	+	+		+			
Microporella ciliata[1]	H	+		+	+						
Schizoporella unicornis[1,2]	H	?	?	?	?	?		+			
Scruparia ambigua[1]	H	+		+							
Scrupocellaria bertholetti[1,2]	H				+						
Scrupocellaria scrupea[1]	H	+	+	+	+	+					
Scrupocellaria scruposa[1]	H	+	+	+	+	+					
Tricellaria occidentalis[1]	H	+		+			+	+	+	+	+
Watersipora arcuata[1,2]	H	+		+							
Watersipora subtorquata (subovoidea)[1]	H	+	+	+	+		+	+	+	+	
Bryozoa – cryptogenic and possibly introduced											
Aeverrillia armata[1,4]	H	?	?	?	?	?					
Anguinella palmata[1,4]	H	?	?	?	?	?					
Bugula avicularia[1,4]	H	?	?	?	?	?					
Celleporaria albirostris[1,4]	H	?	?	?	?	?					
Conopeum seurati[1,4]	H	?	?	?	?	?					
Electra tenella[1,4]	H	?	?	?	?	?					
Hippothoa aporosa[1,4]	H	?	?	?	?	?					
Hippothoa distans[1,4]	H	?	?	?	?	?					
Hippothoa divaricata[1,4]	H	?	?	?	?	?					
Membranipora savartii[1,4]	H	?	?	?	?	?					
Membranipora tuberculata[1,4]	H	?	?	?	?	?					
Parasmittina trispinosa[1,4]	H	?	?	?	?	?					
Zoobotryon verticellatum[1,4]	H	?	?	?	?	?					
Echinodermata – introduced											
Asterias amurensis[1,2]	H/S	+	+		+						
Echinodermata – cryptogenic and possibly introduced											
Amphipholis squamata[1,4]	H	?	?	?	?	?					
Amphiura parviscutata[1,4]	H		+	?	+						
Taeniogyrus sp.[1,4]	H	?	+	?	?	?					
Chordata: Pisces – introduced											
Acanthogobius flavimanus[1,2]	H	+	+				+	+			
Acentrogobius pflaumi[1]	H	+	+				+	+			
Forsterygion lapillum[1]	H	+	+				+	+			
Tridentiger trigonocephalus[1,2]	H	+					+				
Chordata: Ascidiacea – introduced											
Ascidiella aspersa[1]	H	+	+		+	+	+				+
Botrylloides leachi[1]	H	+	+	+	+		+	+			
Botryllus schlosseri[1]	H	+					+			+	
Ciona intestinalis[1]	H	+	+				+				
Molgula manhattensis[1,2,3]	H	+									
Styela clava[1]	H	+					+		+		
Styela plicata[1,2]	H	+	+			+	+				

16 IMPACTS OF SOME INTRODUCED MARINE SPECIES FOUND IN PORT PHILLIP BAY

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16.1 INTRODUCTION

The introduction of nonindigenous marine species is now recognised as a serious global environmental problem. Accidentally or deliberately introduced species potentially threaten human health, fishing and aquaculture industries, and the natural ecosystem of recipient environments. In some cases, the impact of the invader on the recipient environment may be catastrophic as exemplified by the establishment of the zebra mussels *Dreissena polymorpha* and *Dreissena* sp. in the Great Lakes system (May and Marsden 1992), the invasion of San Francisco Bay by the Asian clam *Potamocorbula amurensis* (Nichols *et al.* 1990) and the introduction of the comb jelly *Mnemiopsis leidyi* in the Black Sea (Shushkina and Musayeva 1990).

In Australia, approximately 175 introduced marine species have been recorded to date (C Hewitt pers. comm.). Of these, 12 have been identified by the Australian Ballast Water Management Advisory Council (ABWMAC) as 'pest' species with existing, known or potential economic and ecological impacts in Australia or overseas. Research on the ecology and potential impacts of a number of ABWMAC listed species found in Port Phillip Bay is currently being conducted, by Jeff Ross (*Asterias amurensis*), Sonia Talman (*Corbula gibba*), Michael Holloway (*Sabella spallanzanii*) and Stuart Campbell and Juanita Bité (*Undaria pinnatifida*). Other introduced species currently under investigation include *Codium fragile* spp. *tomentosoides* (Stuart Campbell), *Corophium* species (Melissa Storey) and *Euchone limnicola* (Matthew McArthur). The following section provides a short review of the biology, ecology and distribution of each species as well as information on the known or inferred impacts on recipient environments.

16.2 REVIEW OF THE BIOLOGY AND IMPACTS OF INTRODUCED SPECIES

16.2.1 *Asterias amurensis*

Biology, ecology and impacts

Asterias amurensis is a five-armed seastar, belonging to the Order Forcipulata and the Family Asteriidae. It is a native of the coasts of Japan, northern China, Korea and Russia extending as far north as the Bering Strait. It is also found in Alaskan and Canadian waters, however, Russian scientists believe this is the result of an introduction similar to that in Australia (McLoughin and Bax 1993). *A. amurensis* is most common in the shallow subtidal zones but is also found in the intertidal and has been reported to depths of around 200 m. This depth distribution appears to be mainly related to water temperature (McLoughin and Bax 1993). In some areas in Japan the species is characterised by periodic massive population outbreaks, during which it has caused extensive damage to both natural and cultured shellfish beds (Nojima *et al.* 1986).

A. amurensis can reach an arm length up to 78 mm in 12 months, which equates to an average growth rate of approximately 6 mm month^{-1} (Hatanaka and Kosaka 1959). The largest specimen recorded thus far is from Tasmania with a ray length of 203 mm (Buttermore *et al.* 1994)[1]. In Japan, the seastar has been reported to reach sexual maturity when around 4 cm in arm length, and is thus capable of spawning within one year of settlement if conditions are favorable (Nojima *et al.* 1986). Females can spawn up to 20 million eggs annually (Kasyanov

[1] Editor's note: The largest specimen recorded by CRIMP is 208 mm (L Goggin and N Murphy, unpub. data) and 224 mm by Morrice (1995).

1988). Gametes are released into the surrounding water and the resulting progeny develop into planktotrophic larvae. These larvae pass through a bipinnaria stage into a brachiolaria stage, before settling and metamorphosing into juveniles. Laboratory studies suggest that larval duration in the plankton can be anywhere between 50 and 120 days depending on temperature and feeding regime (Bruce *et al.* 1995). Given its high fecundity and dispersive life-history characteristics, this species, once established, has the ability to rapidly spread throughout a new biotically suitable environment.

No introduction in Australia has been more conspicuous than that of the northern Pacific seastar. Introduced to the waters of SE Tasmania (possibly in ballast water) in the early 1980's, this seastar has become the dominant benthic invertebrate predator in the Derwent River Estuary; its population size in the estuary was estimated recently at 28.1 million (Grannum *et al.* 1996). Densities of the seastar recorded within the estuary (up to 9.44 individuals m^{-2}) (Buttermore *et al.* 1994) are greater than any reported during outbreaks of this species in the Ariake Sea, Japan (Nojima *et al.* 1986). Larval densities recorded within the Derwent are the highest ever recorded for seastar larvae (Bruce *et al.* 1995).

Known or inferred impacts

The importance of asteroids in structuring benthic marine communities, their propensity for population outbreaks, and capacity to invade and significantly impact fishery and culture grounds is well documented (Hancock 1958; Paine 1966; Menge 1972, 1982; Sloan and Alderidge 1981; Dare 1982). In the Northern Hemisphere *A. amurensis* is known to be an opportunistic predator of a variety of epifaunal and infaunal species including molluscs, ascidians, bryozoans, sponges, crustaceans, polychaetes, fish and echinoderms (Hatanaka and Kosaka 1959; Fukuyama and Oliver 1985; Fukuyama 1994). The seastar has a profound effect on benthic communities and in Japan causes considerable damage to commercial shellfishes (e.g. oysters, cockles, scallops and other clams), and is a serious threat to the trawl fishing industry (Hatanaka and Kosaka 1959; Kim 1969; Nojima *et al.* 1986). On this evidence alone, it would be anticipated that the successful establishment of *A. amurensis* in southeast Tasmania has the potential to profoundly effect native benthic marine communities and commercial species.

In Tasmania, *A. amurensis* has been observed feeding on a wide variety of invertebrate and some vertebrate species including bivalve and gastropod molluscs, crustaceans, worms, ascidians, urchins, sea-cucumbers, other seastar species (including cannibalism) and fish carcasses (Buttermore *et al.* 1994; Morrice 1995). Indirect indications through observations of seastar foraging behavior, examination of gut contents, and estimates of feeding electivity (Buttermore *et al.* 1994; Morrice 1995; Grannum *et al.* 1996; S. Lockhart, unpub. data) suggest the potential for considerable impact on assemblages of native species in Tasmania.

Despite the strong rhetoric and publicity surrounding the establishment of *A. amurensis* in Tasmania (e.g. McLoughlin and Thresher 1994), the impact of the seastar on native assemblages had not been examined directly or quantitatively until recently. Preliminary results from field experiments indicate strong effects of the seastar on some species but not others (J Ross in prep.). More recently, a field experiment conducted within the Derwent River indicates the seastar dramatically limits the recruitment of a bivalve species in the estuary (J Ross in prep.). The complete analysis from these experiments will include data for the effect of the seastar on 40–50 infaunal species. To establish the generality of these effects, the experiment will be repeated at several sites and in several different benthic communities. These preliminary results suggest that the direct impact that the seastar has on native assemblages in the estuary is likely to produce indirect effects on all other marine communities that are associated with the estuary.

Although much attention has focused on the 'potential' effects of *A. amurensis* on the commercial shellfish industry, the seastar remains largely restricted to the Derwent River where there are currently no mariculture activities. The small numbers sighted outside the Derwent at marine farms have to date had negligible effect on commercial shellfish farming. This has been largely due to the low numbers present and the farming practices used that limit accessibility to shellfish by adult seastars. The most likely impact on shellfish farming is the consumption of shellfish spat following the direct settlement of seastar larvae from the plankton onto mussel lines and in commercial seed bags. Morrice (1995) collected both juvenile and small adult seastars from scallop spat bags in Mercury Passage on the Tasmanian east coast, and off Huon Island, in the south. In the Mercury Passage bags the seastars had caused mortality or damage to one-third of the scallops in each bag (Marsh 1993). To date, these sightings represent the only reported losses of shellfish spat to seastars however, juvenile seastars have recently been found on mussel lines in Port Phillip Bay (see below).

The method of seatar's introduction into Australia is not known. Ballast water introduction is considered the most likely vector of initial introduction of the species to southern Tasmania and the most likely means of spread from that area to mainland Australia (Sutton and Bruce 1996). *A. amurensis* larvae appear ideally suited for uptake and translocation in ballast water. *A. amurensis* has long lived pelagic larvae that are abundant within the upper 5 m of the

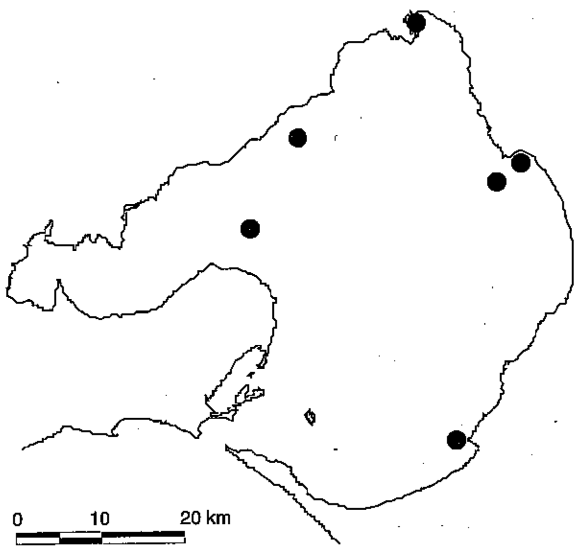

Figure 16.1. The current (1998) known distribution of the introduced seastar, *Asterias amurensis*, in Port Phillip Bay, Victoria.

water column. In the Derwent, larvae of *A. amurensis* are in the water column for around 6 months (July to at least January), and settle throughout this period (Morrice 1995). Larval concentrations within the Derwent are highest adjacent to wharf areas and are some of the highest reported for seastar larvae world-wide (Bruce *et al.* 1995).

Based on the temperature and salinity tolerances of its larvae, and given that *A. amurensis* in southern Tasmania have now aligned their spawning period with the austral winter, Sutton and Bruce (1996) classified Victorian ports in the high risk category for ballast mediated introduction from the Derwent River. The recent discovery of large numbers of seastars in Port Phillip Bay strongly suggests a ballast-mediated introduction from the Derwent River. This is further supported by genetic examination of seastars from Port Phillip Bay (Andrew 1998; Murphy and Evans 1998).[2]

Current status in Port Phillip Bay

A. amurensis was first recorded in Port Philip Bay in 1995 and, until recently, only four adult specimens had been collected from the bay. In early 1998, juvenile seastars were collected from mussel culture lines at Dromana and a single adult was later collected from Beaumaris. The more recent discovery of newly settled juveniles on mussel lines and the increasing number of adults suggests that the seastar may have successfully established a breeding population in Port Phillip Bay. The current (1998) distribution of *A. amurensis* in Port Phillip Bay is limited to Point Cook, off Portarlington, Port Melbourne, at Beaumaris and offshore from Beaumaris and off Dromana (Figure 16.1).

[2] Editor's note: Mature *Asterias* individuals have been collected from sea chests of vessels trading between Hobart and Geelong (K Murphy pers. comm.).

Currently, little is known about the densities, and hence, likely impact of the seastar on native communities in Port Phillip Bay. However, given the many similarities of the marine environment in Tasmania and Port Phillip Bay, the seastar has the potential to have comparable effects on native benthic marine communities in the bay.

A. amurensis is a serious threat to the mariculture operations and other commercial shellfish operations in Port Phillip Bay. The discovery of juvenile seastars on mussel lines at Dromana has major implications for mussel farming operations. Current farming practice involves the movement of mussel line from Port Phillip Bay to Western Port Bay prior to harvest. This practice has the potential to rapidly spread the seastar to Western Port.

16.2.2 *Corbula gibba*

Biology, ecology and distribution

Corbula gibba is a small bivalve mollusc belonging to the Corbulidae, the largest family of the Myoidea. It is native to the eastern Atlantic, the Mediterranean and the Black Sea and can occur in large numbers (53,000 individuals m^{-2}, Jensen 1990) in its preferred habitat of muddy sand. It is a shallow burrower and is relatively immobile once the single byssal thread has been attached to a piece of shell or rock (Yonge 1946). *C. gibba* has been recorded in water depths ranging from around 3 to 140 m (Jensen 1988; Yonge 1946).

In its native environment, *C. gibba* occurs at salinities of 28‰–34‰; at temperatures between -1°–16°C; and at oxygen concentrations of 7–11 mg L^{-1} (Jensen 1988, 1990). It is able to withstand almost anoxic conditions (0.18–0.37 mg oxygen L^{-1}) (Christensen 1970). This ability to tolerate low oxygen levels may stem from its unique shell structure (thick, tightly fitting unequal shell valves), its habit of parting shell valves only slightly when feeding and its ability to remain closed for long periods (Morton 1986). These same adaptations may confer a partial resistance to pollution as *C. gibba* is found in polluted areas where other species have been eliminated (Pearson and Rosenberg 1978; Zarkanellas 1979; Rygg 1985; Crema *et al.* 1991).

Investigations in the first and middle part of this century suggest that *C. gibba* is a long-lived (5–6 years) and slow-growing species (Jensen 1919 cit. in Jensen 1990; Jones 1956). However, more recent studies in the Limfjord, Denmark, indicate a decreased life span of only 1–2 years, a high growth rate, high production and one of the highest production to biomass ratios recorded for suspension feeding bivalves (Jensen 1990). These high values appear to be in response to increasing eutrophication of the Limfjord (Jensen 1990).

In the Northern Hemisphere, *C. gibba* reproduces and settles in late summer and autumn (Hrs-Brenko 1981) but larvae are also found in the plankton in winter (Muus 1973). Newly settled specimens can occur in densities of up to 67,000 individuals m^{-2} but mortality is very high following settlement, possibly due to high levels of predation (Jensen 1988).

C. gibba is a ciliary suspension feeder with short, fused, retractile siphons (Yonge 1946). The inhalant siphon, through which water is drawn into the mantle cavity, lies flush with the surface of the substratum so much inorganic bottom material enters with the inhalant current. *C. gibba* has a number of adaptations for disposing of the consequently large quantities of pseudo-faeces produced (Yonge 1946).

Known or inferred impacts

C. gibba has the potential to become a serious threat to the natural ecosystem of Port Phillip Bay because it is widespread throughout the bay and occurs in high densities at certain localities (Currie and Parry 1996; see Chapter 14; also Figure 16.2). It also possesses a number of characteristics which are likely to confer a competitive advantage over endemic species; the capacity for fast growth and high production, the ability to tolerate a wide range of environmental conditions including extreme pollution and the habit of occurring in high densities. *C. gibba* may compete with native infaunal species for space and/or with endemic suspension feeders, such as the economically important scallop (*Pecten fumatus*), by reducing planktonic food concentrations. *C. gibba* does not appear to be having the same impacts in Port Phillip Bay as those reported for the similar Asian clam *Potamocorbula amurensis* in San Francisco Bay (Nichols *et al.* 1990).

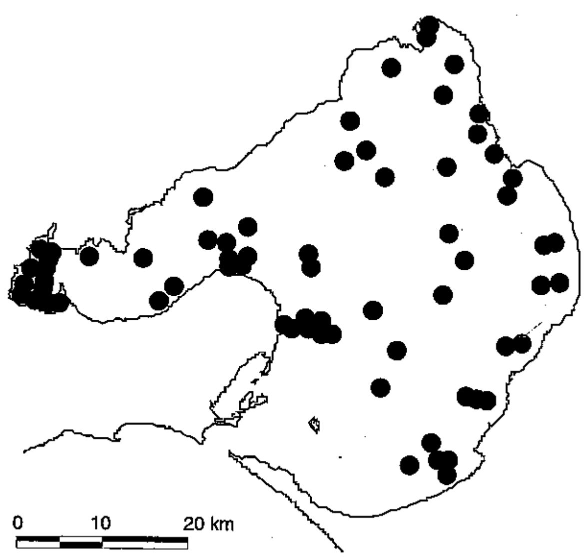

Figure 16.2. The current (1998) known distribution of the introduced bivalve, *Corbula gibba*, in Port Phillip Bay, Victoria based on historical data from 1987–1997

Current status in Port Phillip Bay

C. gibba was first discovered in the western arm of Port Phillip Bay, Victoria, in 1987 (Coleman 1993) but the specimens were misidentified. The first correct identification of this species in Port Phillip Bay was in 1991 (Currie and Parry 1996). This has become the first documented record of the species outside of its area of natural distribution. Recently, *C. gibba* has been recorded in Portland Harbour, Victoria (Parry *et al.* 1997), Devonport, Tasmania (C Hewitt pers. comm.) and a single shell valve was recovered from a sample taken in Western Port Bay, Victoria (Currie and Crookes 1997). It is probable that Port Phillip Bay was the source for these recent translocations (Currie and Crookes 1997).

Information on this species in Port Phillip Bay is limited to data on abundances from benthic samples collected over ten years (Coleman 1993; Currie and Parry 1996; Longmore *et al.* 1996; Wilson *et al.* 1996; Nicholson and Roob 1997) and to information on predators (Parry *et al.* 1995). *C. gibba* is consumed by at least nine species of fish in Port Phillip Bay (Parry *et al.* 1995) and potentially by predatory gastropods such as *Nassarius nigellus*, *Sinum zonale* and *Polinices sordidus* (D Currie pers. comm.).

Research currently being conducted in Port Phillip Bay is attempting to address this lack of information (S. Talman in prep.). This work will map the current distribution of *C. gibba* in Port Phillip Bay and investigate water depth and sediment grain size as factors influencing large-scale patterns of distribution. The research will also document growth, mortality, longevity and reproductive patterns of *C. gibba* in Port Phillip Bay and investigate interactions between *C. gibba* and endemic species.

16.2.3 *Sabella spallanzanii*

Biology, ecology and distribution

The marine fanworm *Sabella spallanzanii* is a polychaete in the family Sabellidae. It secretes a tough, flexible tube of muco-polysaccharide and fine sediment that is anchored to the substratum at the base and protrudes into the water column. It is among the largest members of its family, with tubes reaching around 0.4 m in length and 12 mm in diameter. Modified anterior tentacles form an asymmetrical spiralled fan, up to 15 cm across, which can be rapidly withdrawn into the tube, presumably as a defence mechanism. Fans vary in colour from a uniform dull white to brightly banded with stripes of orange, purple and white. The fan is used for suspension feeding, capturing fine particles from the surrounding water. Cilia on the fan produce water currents, but these are probably much less important for the movement of water through the fan than ambient water currents (Merz 1984).

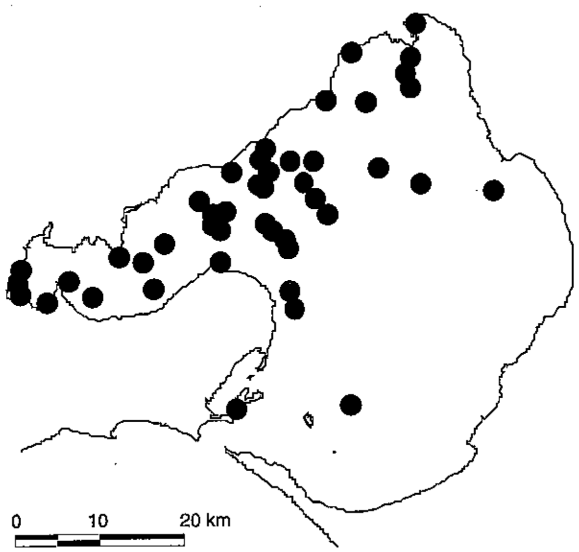

Figure 16.3. The current (1998) known distribution of the introduced polychaete *Sabella spallanzanii* in Port Phillip Bay, Victoria.

The European distribution of *S. spallanzanii* includes the Mediterranean Sea, the east Atlantic coast from Morocco to northern France and the Azores. Along the coast of Italy, it occurs in waters from 1–30 m depth, reaching densities of 300 individuals m^{-2} in harbours (Giangrande and Petraroli 1994).

S. spallanzanii is a broadcast spawner, releasing gametes into the water column (Gravier 1923, cited in Rouse and Fitzhugh 1994). In the Mediterranean, spawning occurs in February (Giangrande and Petraroli 1994). In the laboratory, the non-feeding larvae may swim for several days, after which they move to the bottom of the culture vessel. The period of swimming is variable and may last from three to more than eight days (Y Shiraki pers. comm.). Immature specimens collected on settlement panels are capable of crawling around the substratum before selecting a site and building a tube (M Holloway pers. obs.).

The species has a patchy world distribution, consistent with its probable translocation by ships. It is probably native to the Mediterranean and east Atlantic coast from NW France to Morocco. It is also found in the Azores where its status is uncertain (cryptogenic) and introduced populations have been found in Rio de Janeiro, Java and Australia (Knight-Jones and Perkins 1998).

Within Australia, *S. spallanzanii* is known from Port Phillip Bay in Victoria (Carey and Watson 1992), Albany, Bunbury, Fremantle, Cockburn Sound (Clapin and Evans 1995) and Esperance in Western Australia, Adelaide and Gulf of St. Vincent in South Australia, Devonport in Tasmania and Eden in New South Wales (C Hewitt pers. comm.). In Western Australia the highest densities are found in areas sheltered from wave action, including areas protected by depth (Clapin and Evans 1995).

Allozyme variation studies have indicated a probable Mediterranean origin for the Australian populations and suggest a single introduction to Australia, with subsequent translocation around the coast (Andrew and Ward 1997). Transport in ballast tanks or on ship's hulls is the most likely method of introduction (Clapin and Evans 1995; Walters 1996). *S. spallanzanii* could also be transported unintentionally via the movement of mariculture species. Small individuals could easily go undetected among commercial species such as mussels or oysters, and thus be transported to other locations.

Known or inferred impacts

The high densities achieved by *S. spallanzanii* and its rapid spread have raised concerns about its possible ecological impacts. It colonises both soft and hard substrata, yet in soft substrata it is often anchored to hard surfaces within the sediment (Clapin and Evans 1995; Parry *et al.* 1996). It also readily colonises artificial substrata such as jetty pilings, marinas and harbour walls (Koechlin 1977; Giangrande and Petraroli 1994).

S. spallanzanii appears to have no natural predators and is apparently not eaten by fish in Port Phillip Bay (Parry *et al.* 1996). Despite being introduced to several localities, little work has been done on the ecological impact of *S. spallanzanii*. Seagrass beds in Cockburn Sound, WA appear to have been replaced by beds of fanworms (Clapin and Evans 1995), however the loss of seagrass is attributed to increased nutrient inputs (Cambridge *et al.* 1986) and is probably not related to the introduction of *S. spallanzanii*. Clapin and Evans (1995) report no evidence of invasion by *S. spallanzanii* into existing seagrass beds, or displacement of other organisms. In fact, in Cockburn Sound fanworm tubes support a rich epifauna, comparable to that found on the blades of nearby seagrasses (Lemmens *et al.* 1996).

Concerns have also been raised over the effect of *S. spallanzanii* on the nitrogen cycle Port Phillip Bay's (Longmore *et al.* 1996). Most of the nitrogen inputs to Port Phillip Bay are taken up by phytoplankton, which then senesces and settles to the sea floor. Denitrification occurs in the sediments, and the nitrogen leaves the system in a biologically unavailable form as N_2 (Harris *et al.* 1996). There is some evidence that dense beds of *S. spallanzanii* may intercept settling organic material and excrete the nitrogen back into the water column as ammonia, bypassing the denitrification process, and possibly causing eutrophication (Longmore *et al.* 1996) (see Chapter 17 for a more detailed discussion of this issue).

S. spallanzanii has the capacity to filter large volumes of water (Lemmens *et al.* 1996), which could lead to depletion of suspended food particles in water passing through the fanworm canopy. Significantly depletion of food resources in the surrounding water has been reported for the large North American sabellid *Eudistilia vancouveri* (Merz 1984). Because of its ability to intercept food particles before they reach the substratum, *S. spallanzanii* may out-compete other benthic species. More information is needed on the feeding ecology of these species before this hypothesis can be evaluated.

Large structural elements of marine habitats, such as macroalgae and seagrass are known to influence physical (e.g. fluid and particle transport) and biological processes (e.g. recruitment and growth of other species) below their canopies (Eckman and Duggins 1991). Dense beds of fanworms are likely to have similar effects. Experiments showed that recruitment of some taxa to settlement panels is reduced under *S. spallanzanii* canopies, while other taxa increase, relative to worm free areas (M Holloway in prep.). No taxa were excluded altogether from areas with fanworms. Increased numbers in the presence of fanworm canopies was at least partly due to recruitment on fanworm tubes (M Holloway in prep.). In Corio Bay, in the west of Port Phillip Bay, worm tubes had a rich epifauna that would not otherwise occur in these areas, and *S. spallanzanii* did not appear to have displaced any native taxa (Carey and Watson 1992).

Although it has successfully invaded several locations in Australia and around the world, there is little evidence of any major ecological impact of *S. spallanzanii* on pre-existing benthic communities. Where it reaches high densities, *S. spallanzanii* could possibly compete for food with other benthic taxa, and influence community structure by physically altering the habitat, however, the available data do not indicate displacement of native species. In Port Phillip Bay, it is of particular concern because of possible effects on the bay's nitrogen cycle (Longmore *et al.* 1996), and the potential for competition with other suspension feeders. Overall, it is unclear whether the introduction of *S. spallanzanii* will have serious ecological consequences for Port Phillip Bay.

Current status in Port Phillip Bay

S. spallanzanii was positively identified in the western region of Port Phillip Bay in 1992 (Carey and Watson 1992). An extensive survey of Corio Bay in 1987 did not detect the species (Coleman 1993), but it was noticed by divers in the area in 1988 (A Stephens pers. comm. in Parry *et al.* 1996). Since its discovery, it has spread rapidly, and it now occurs in most parts of the bay, except for an area in the south east between Mornington and Queenscliff (Parry *et al.* 1996). Its subsequent distribution in Port Phillip Bay is illustrated in Figure 16.3. The highest densities are reached in sheltered habitats such as harbours and muddy bottoms. Patches of up to 300 individuals m^{-2} have been found on soft bottoms (Parry *et al.* 1996), while densities on jetty pilings exceed 1000 individuals m^{-2} (M Holloway unpub. data).

16.2.4 *Undaria pinnatifida*

Biology, ecology and distribution

Undaria pinnatifida is a native seaweed of Japan, Korea and parts of China (Akiyama and Kurogi 1982; Tseng 1984). It is an important cultivated sea vegetable known commonly as 'wakame' in Japan (Akiyama and Kurogi 1982; Tseng 1984). *U. pinnatifida* is a member of the Laminariales, which also includes the Australian native kelps *Ecklonia radiata* and *Macrocystis angustifolia.*

It is an annual seaweed with maximum growth and production in spring and early summer. In late summer, the large, golden-brown, diploid sporophyte (seaweed) dies back and simultaneously many spores are released from convoluted shaped structures called sporophylls. Individually these can release up to 10^8 zoospores (Saito 1975; Akiyama and Kurogi 1982) throughout the growing season (Sanderson and Barrett 1989; Hay and Villouta 1993). Release of zoospores from Port Phillip Bay plants occurs at temperatures between 10° and 20° C. The motile spores settle and attach to the substrate and germinate within hours of settling. A female or male gametophyte develops within three days of settlement. The egg in the female gametophyte is fertilized approximately nine days later, with spermatozoa produced by male gametophytes. These fertilized zygotes grow into a microscopic gametophyte which survives throughout summer (Floc'h *et al.* 1991). Increased light intensity promotes the maturation and fertilization of gametophytes, leading to the development of sporophytes, whereas low light intensity delays these events. Optimal conditions for sporophyte growth in Port Phillip Bay is from 15° to 20° C and at ≥ 30 µmol m^{-2} s^{-1} (Bité in prep.).

U. pinnatifida is also an invasive species in France, (Perez *et al.* 1981; Floc'h *et al.* 1991; Castric-Fey *et al.* 1993), the Mediterranean (Boudouresque *et al.* 1985), New Zealand (Hay and Luckens 1987; Hay 1990), on the south coast of England (Fletcher and Manfredi 1995), on the central Argentine coast (Casas and Piriz 1996) and intentionally introduced into Taiwan for mariculture (FAO database).

Known or inferred impacts

The fast growing nature of *U. pinnatifida,* confers a competitive advantage for this species over other native seaweeds. In Port Phillip Bay and Tasmania it has competed with and displaced dominant native macroalgal species (e.g. *Caulerpa remotifolia* and *Macrocystis angustifolia*) that provide habitat for faunal assemblages including the commercially important abalone (*Haliotis* spp.). It may also displace sea urchins (*Heliocidaris* spp.) by invading their barrens (Sanderson and Barrett 1989).

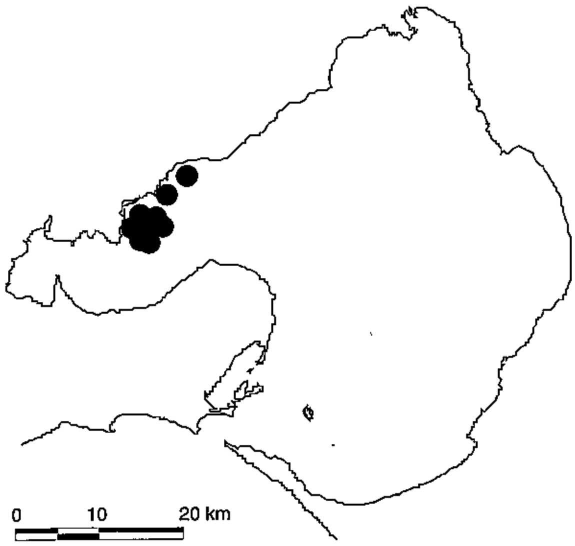

Figure 16.4. The current (1998) known distribution of the introduced alga, *Undaria pinnatifida*, in Port Phillip Bay, Victoria[3].

There is also potential for impact on other local invertebrate and fish populations. Recent studies have also shown that plants from Port Phillip Bay have a high capacity for uptake of inorganic nitrogen (Campbell *et al.* 1998). This may explain its capacity for excessive growth in shallow nutrient enriched areas of Port Phillip Bay (Campbell and Burridge 1998) and it has also been reported in the nutrient enriched Lagoon of Venice, Italy (Curiel *et al.* 1994). The conditions and requirements for its growth suggest that it has the potential to spread and establish itself along the southern Australian coast from Cape Leeuwin in WA to Woollongong in NSW (Sanderson and Barrett 1989; Sanderson 1990).

Current status in Port Phillip Bay

In 1988 *U. pinnatifida* was found at Rheban on the east coast of Tasmania at depths up to 12 m (Sanderson 1990). The alga was discovered in the Corio Arm of Port Phillip Bay on 8 July 1996 at a depth of 2–3 m (Campbell and Burridge 1998) (Figure 16.4). In Port Phillip Bay sporophyte recruitment first occurs in early autumn and plants can grow to lengths of 1–2 m by late spring. Plants are currently restricted to the northern part of the bay offshore the Western Sewage Treatment Plant. The population has also spread from its initial incursion site offshore Point Wilson to Kirk Point and Long Reef[3].

Preliminary investigations of the population structure in Port Phillip Bay suggest that possibly two recruitment phases occur, one in April and one in September. The population reaches a winter-spring density of up to 140 individuals m^{-2}, with sporophytes attaining a reproductive maturity at 400 mm. Spores continue to be released from senescent plants in early summer, but sporophytes are mostly absent throughout summer. In other countries populations of *U. pinnatifida* have several generations of sporophytes, with no obvious hiatus of sporophytes during late summer (Hay and Luckens 1987; Floc'h *et al.* 1991). By contrast, recruitment has only been recorded between autumn and winter in Argentina (Casas and Piriz 1996) and Korea (Koh and Shin 1990).

[3] Editor's note: *Undaria* has recently been detected at St. Kilda Pier and Station Pier in the Port of Melbourne.

16.2.5 *Codium fragile* ssp. *tomentosoides*

Biology, ecology and distribution

Codium fragile ssp. *tomentosoides* is a green macroalga thought to be native to South East Asia, presumably Japan. The most reliable features that distinguish the subspecies *tomentosoides* from native species are utricle shape, density of fronds, mode of reproduction and seasonality.

The utricles of subspecies *tomentosoides* have a median or submedian constriction about 2 cm below branch tips and a sharp apical point or mucron. These utricles have a long coating of dense hairs compared with native taxa, which have fewer utricle hairs (Trowbridge 1996). *C. fragile* ssp. *tomentosoides* have substantially fewer fronds arising from the holdfast but these are more branched than similar sized native species (Trowbridge 1996). Reproduction of the introduced form is exclusively asexual. Plants release flagellated parthenogenetic gametes that settle to hard substrata, germinate and form into microscopic thalli (Trowbridge 1996). In contrast, native subspecies of *C. fragile* have male and female gametes that fuse sexually (Dromgoole 1975). Fronds of *C. fragile* ssp. *tomentosoides* are annual and die back in autumn, whereas the basal holdfast is perennial (Fralick and Methieson 1973; Dromgoole 1975; Hanisak 1979a and 1979b). The fronds of native subspecies are generally perennial.

C. fragile ssp. *tomentosoides* has spread throughout the NE Atlantic and Mediterranean early this century (Silva 1955, 1957). The alga has also spread to the British Isles where it is reported to have displaced the native, morphologically similar congener *C. tomentosum* (Farnham 1980). In the 1950's the species spread to the NW Atlantic shores and now occurs from Nova Scotia to North Carolina. The subspecies prefers protected to semi exposed habitats whilst native Australian *Codium* species have been reported from moderate to rough wave exposed habitats (Silva and Womersley 1956).

The transport vector of *Codium fragile* ssp. *tomentosoides* is hull fouling (Dromgoole 1975; Carlton and Scanlon 1985). Although algae can be spread by ballast water or transported with mariculture spat, *C. fragile* ssp. *tomentosoides* has attributes that lend itself to hull fouling transport. As described by Lewis (see

Chapter 6), it has a tendency to grow on floating structures, needs little surface relief to settle and has a perennial basal holdfast, allowing it to survive transoceanic transport.

C. fragile ssp. *tomentosoides* exhibits rapid growth, high dispersal and broad physiological tolerance to environmental conditions. The extent to which biotic interactions influence the spread of the alga is not well known (Trowbridge 1995). Studies on the interaction between grazers and this exotic alga suggest that native herbivores exhibit little grazing pressure on *C. fragile* ssp. *tomentosoides* (Trowbridge 1995). Of eleven common species of grazers, tested in laboratory feeding trials, four gastropods and two echinoids readily consumed the introduced alga. In the field the major intertidal grazers on this alga were the snail *Turbo smaragdus* and the sea slugs *Placida dendrtica* and *Elysia maoria*. Trowbridge (1995) showed that the feeding preference by the grazers was not related to algal structural morphology such as utricle shape or branching. The presence of volatile secondary metabolites in the subspecies *tomentosoides* may influence the feeding preference such that grazers avoid fresh plant material (Trowbridge 1995).

C. fragile ssp. *tomentosoides* also has the ability to interbreed with native species. The hybrid forms can display invasive attributes with the propensity to grow on and displace native macroalgae and shellfish. Trowbridge (1995) concluded that the introduced alga will eventually successfully invade most of the protected to semi-exposed shores of New Zealand.

Culture studies have shown that optimal growth of filamentous gametophytes and mature thalli occur at 24°–25° C (Hanisak 1979a; Yang *et al.* 1997). If water temperatures rise above 10°–13° C during part of the year, the alga can grow (Hanisak 1979a). If water temperatures rise above 12°–15° C, the alga can produce viable gametes (Churchill and Moeller 1972; Fralick and Mathieson 1973; Hanisak 1979a; Carlton and Scanlon 1985). Gametophytes have a lower requirement for light, for optimal growth (~65 μmol m^{-2} s^{-1}, Yang *et al.* 1997), than that of mature thalli (150 μmol m^{-2} s^{-1}, Hanisak 1979a). A 16 h photoperiod is optimal for both growth of thalli and gametophyte sporelings but the effect of increasing daylength has been attributed to increased total daily irradiance rather than to a true photoperiodic effect (Hanisak 1979a).

Plants may be limited by nitrogen (N) in summer when ambient concentrations are low and a critical tissue N content of 1.90%, below which growth is reduced, has been determined (Hanisak 1979b). The species also has a relatively low capacity for N uptake compared to other fast growing and morphologically simple taxa (Wallentinus 1984). Such an uptake strategy is favoured by summer temperatures, which serve to enhance uptake rate. Its physiological suitability to summer, when light availability is high, is also reflected by a relatively low maximum rate of photosynthesis (P_{max}) and a relatively high irradiance at which photosynthesis is saturated (I_k ~140 μmol m^{-2} s^{-1}; unpubl. data).

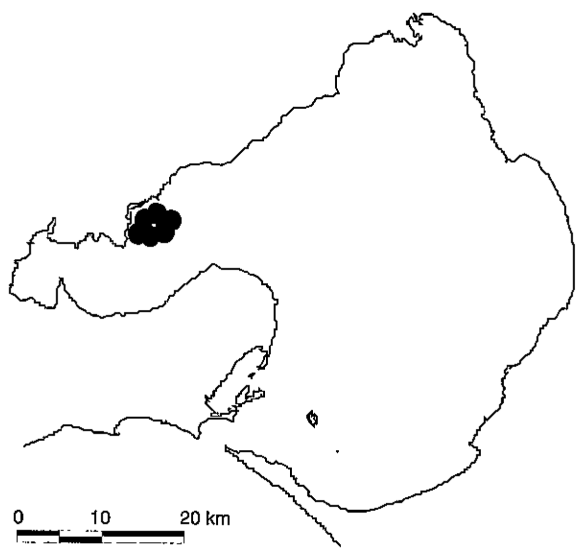

Figure 16.5. The current (1998) known distribution of the introduced alga, *Codium fragile* ssp. *tomentosoides*, in Port Phillip Bay, Victoria.

Known or inferred impacts

In Corner Inlet *C. fragile* ssp. *tomentosoides* has been reported to foul fishing nets. In Port Phillip Bay it was first found growing on populations of the mussel *Mytilus edulis* where it has the potential to attach and displace wild and commercial mussel species. In Western Port Bay the alga competes for space with, and grows epiphytically on, the dominant intertidal seaweed *Hormosira banksii*. Dromgoole (1975) reported that whilst growth of *C. fragile* ssp. *tomentosoides* was not capable of displacing other alga populations the plant does appear to exclude potential competitors such as *Hormosira banksii*.

C. fragile ssp. *tomentosoides* is reported to be a potential threat to shellfish industries as a result of its propensity to attach and remove oysters, scallops and mussels from natural substrata. Dense growths of the plant in North America have caused considerable damage to local shellfish industries (Ramus 1971). In addition to physical disturbance, dense growths of *C. fragile* ssp. *tomentosoides* may have ecological ramifications through changes to ecosystem nutrient uptake rates and sedimentation rates. It also can foul and exhibit nuisance growth on man-made structures such as wharf pilings and jetties.

Current status in Port Phillip Bay

The temperature, light and nutrient conditions, which are found in southern Australasian marine waters, appear optimal for growth of *C. fragile* ssp. *tomentosoides*. In 1973, *C. fragile* ssp. *tomentosoides* appeared in the Port of Auckland, New Zealand. The first report of the alga in Australia waters was in June 1996 in Corner Inlet, Victoria (J Lewis pers. comm.). In January 1997, the species was found subtidally (2–3 m depth) in Port Phillip Bay. Its subsequent distribution, in Port Phillip Bay, is disjunct (Figure 16.5). In March 1998 it was found in Western Port Bay inhabiting the intertidal zone. The alga has recently been reported from southern Tasmania (C Trowbridge pers. comm.)[4].

16.2.6 *Corophium* species

Biology, ecology and distribution

Amphipod crustaceans of the genus *Corophium* are benthic tube-dwellers in marine, estuarine and freshwater environments. Like other amphipods, they lack a planktonic dispersal phase of their life history. Eggs are brooded in a ventral marsupium (brood pouch) and soon after hatching, juveniles burrow directly into nearby sediments (Meadows and Reid 1966).

Species of *Corophium* construct U-shaped tubes or burrows by manipulating sediment using their pereopods and modified second antennae. The tube is cemented with silk secreted from the dactylus of pereopods 3 and 4 (Shillaker and Moore 1978). They construct tubes on muddy sand, algal holdfasts and hard substrates such as pier pilings and the hulls of ships (Barnard 1958; Shillaker and Moore 1978). Individuals have also been found in the ballast water of ships travelling between Japan and Australia (Williams *et al.* 1988).

Approximately 68 species comprise the genus *Corophium* and several species have global distributions that are unable to be explained by natural dispersal capabilities. One example is *Corophium acherusicum* which has been recorded from the Pacific Ocean, North Atlantic American coasts, the Indian Ocean, the North Sea, the Mediterranean and the Black Sea (Crawford 1937; Myers 1982; Hong 1983). Five other species, *C. insidiosum*, *C. acutum*, *C. baconi*, *C. sextonae* and *C. bonnellii* have similarly cosmopolitan distributions (Crawford 1937; Myers 1982; Hong 1983).

All six species are believed to be introduced to Australia (Storey 1996). *C. acherusicum* has been collected in the Gippsland Lakes, Shallow Inlet, Wingan Inlet, Tamboon Inlet Port Fairy and throughout Port Phillip Bay in Victoria and also in Tasmania, New South Wales and Queensland (J Moverley and J Hirst pers. comm.). *C. sextonae* has been found at Queenscliff in Port Phillip Bay and in Tasmania and New South Wales. *C. insidiosum* has been located in Victoria at Port Fairy, Western Port and at Werribee and Little River in Port Phillip Bay and also in New South Wales (J Moverley and J Hirst pers. comm.). *C. baconi* and *C. acutum* have both been recorded from New South Wales. *C. bonnellii* has been collected in Tasmania. Figure 16.6 illustrates their current distribution in Port Phillip Bay.

It is difficult to assess the timing of the introductions although the earliest published records of species of *Corophium* in Australia are *C. crassicorne* (probably *C. acherusicum* misidentified) in 1923 (Chilton 1923) and *C. acherusicum* in 1968 (Fearn-Wannan 1968). Some museum specimens of *C. acutum* were collected in 1937.

The origin of introduced species can be difficult to deduce if the time and mechanism of introduction are unknown however, studying evolutionary and biogeographic relationships is useful for inferring species origins. Little is known about evolutionary relationships within *Corophium* and the significant number of cosmopolitan species makes it difficult to analyse biogeographic patterns. Bousfield and Hoover (1997) analysed phenetic relationships between species of *Corophium* and created 13 genera based on this. As this phenetic analysis was not based on phylogenetic principles, their classification does not represent an evolutionary history of the group and is therefore not useful for inferring species origins. Chapman (1988) described a species from San Francisco Bay, California which he determined as exotic because of its relatedness to species from Asia, its tendency to be associated with other introduced species, its recent range expansion and the corroborating evidence of shipping

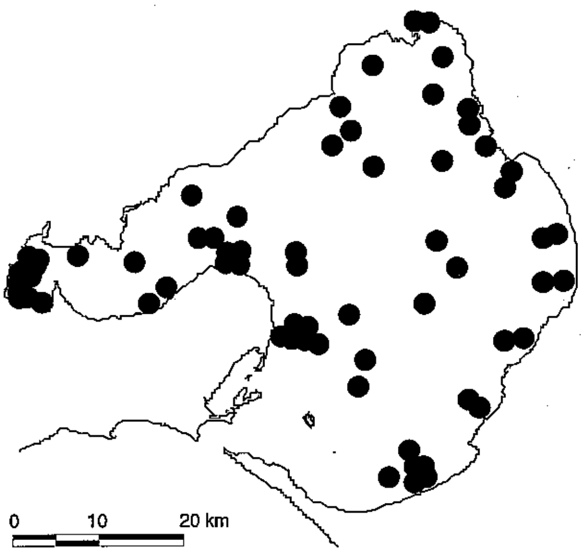

Figure 16.6. The current (1998) known distribution of the introduced crustaceans, *Corophium* species, in Port Phillip Bay, Victoria.

[4] Editor's note: The Tasmania introduction is likely to be old, either with oyster introductions or hull fouling.

routes between Vietnam and California at the end of the Vietnam War. Biogeographic and phylogenetic analysis of the genus *Corophium* could provide insight into the origin of Australian species.

In summary, several *Corophium* species have cosmopolitan distributions that may be the result of introduction by human activities. The prevalence of the introduction of some species around the world may be accounted for by their biology, being often found in harbours, where they are fouling organisms on artificial structures. The six introduced *Corophium* species in Australia have been recognised as introduced in other localities and are unlikely to have migrated naturally as they, like other amphipods, do not possess a planktonic dispersal stage in their life history. It is most likely that they were accidentally transported as fouling organisms or in the ballast water of ships. This is supported by evidence of *Corophium* in the ballast water of ships moving between Japan and Australia (Williams *et al.* 1988) and Japan and Oregon, USA (Carlton and Geller 1993). These animals may have been picked up while in the water column or may have been in sediment that is picked up incidentally with water when ships are ballasting.

Mariculture transfers may also introduce *Corophium* species to Australia. Hirayama (1984) has recorded *C. acherusicum* and *C. insidiosum* from Japan. The Pacific Oyster (*Crassostrea gigas*) grown in Japan and bought into Australia for mariculture, have associated faunal assemblages that can be accidentally introduced with the transport of these oysters from Japan to Australia. However, information on *Corophium* associations with *C. gigas* is lacking.[5]

The distinct possibility exists that *Corophium* spp. were transported via dry ballast (e.g. rock, cobble, shingle, or sand) used to provide trim and stability to wooden hulled sailing and steam vessels. Despite the term 'dry' ballast, this material was typically maintained in the bilge of a vessel and consequently collected large quantities of water, either drained from the deck or through leaky hulls. This material was generally collected from the littoral zone (low subtidal to supra-littoral) in the port of origin. Discharge was typically problematic, with dedicated de-ballasting regions identified in numerous ports and harbours as 'Ballast Head', though large quantities were discharged at dock or in nearby salt marshes. This mechanism of transport is implicated in the transfer of numerous organisms worldwide (Carlton 1989, 1992; Mills *et al.* 1993).

Known or inferred impacts

Little is known about densities or impact of *Corophium* in Port Phillip Bay, though Hirst (1994) found densities of 88,000 individuals m^{-2} during summer months at the mouth of the Werribee Treatment Complex and 224,000 individuals m^{-2} the mouth of Little River. These densities were attributed to the high primary productivity of the region, resulting from the input of nutrients from the Treatment Complex. In European estuaries, it has been found that the removal of *Corophium* from soft sediments is followed by an increase in microflora, a decrease in water content and an increase in sediment stability (Jones and Jago 1993; Gerdol and Hughes 1994). Therefore, the reduction of sediment stability caused by high densities of *Corophium* (up to 750,000 individuals m^{-2} in the river Rhine) may exacerbate erosion (van den Brink *et al.* 1993; Gerdol and Hughes 1994).

[5] Editor's note: *Corophium* spp. are commonly associated epifauna of *C. gigas* communities (Carlton 1979).

16.2.7 *Euchone limnicola*

Biology, ecology and distribution

The genus *Euchone* in the polychaete family Sabellidae, is one of twenty-eight genera currently placed in the sub-family Sabellinae (Fitzhugh 1989). Twenty-six species and one sub-species of *Euchone* have been described (Hartman 1965; Zhao *et al.* 1993). Members of this genus are small sabellids, rarely reaching 15 mm (Hutchings and Murray 1984; Zhao *et al.* 1993).

The distinctive arrangements of setae are usually the definitive way of determining the genus a sabellid worm belongs to (Fitzhugh 1989). The distinguishing feature between the genus *Euchone* and all other sabellids is the anal depression. All species of *Euchone* have posterior abdominal setigers that are flattened on the dorsal side. The size and number of radioles present in the crown is highly variable within the genus, yet this is not considered a consistent diagnostic feature of sabellids due to the fragility of these structures and the ability of most species to regenerate them. Distinguishing characters in the genus *Euchone* include the number of abdominal setigers before the start of the anal depression, the features in the peristomial collar and the presence or absence of radiolar eyes (Banse 1970, 1972; Ruff and Brown 1989; Zhao *et al.* 1993). *E. limnicola* is distinct from all other species of *Euchone* because it does not have a membranous flange surrounding the posterior depression. Specimens examined consistently have eight pre-depression setigers in the abdomen and unlike the specimens of the native species, *E. variabilis* lack readily visible eye spots on the crown (Hutchings and Murray 1984). Thus, *E. limnicola* is readily distinguished from the native *E. variabilis* by its lack of a depression membrane and crown eye-spots and its possession of only eight pre-depression abdominal setigers where *E. variabilis* generally has twelve to fourteen.

No literature is available on the habits of *E. limnicola*. Preliminary studies of its feeding biology suggest that it is an effective selective deposit feeder, ingesting particulate matter of a defined size range in the sediment/water interface. This is supported by anecdotal evidence of related species feeding by casting up sediment with the ventral radiolar appendages and ingesting the re-suspended matter (S Cochrane pers. comm.). No data is available on the rate at which *E. limnicola* feeds and the reproductive biology of this species is not known. Most species within the Sabellinae are considered to be broadcast spawners (Fitzhugh 1989).

A single bridled goby, *Arenigobius bifrenatus*, has been found to have eaten an *E. limnicola* (Parry *et al.* 1995). This was a chance discovery and no detailed study of *E. limnicola*'s palatability to local fish species has been undertaken.

Known or inferred impacts

Impacts are not known for this species in Australia, although impacts can be deduced. To date *E. limnicola* has been able to establish dense populations in soft sediments in Victorian ports. Once established in these high densities *E. limnicola* would be able to turnover large amounts of sediment and compete for space and food with native species.

Current status in Port Phillip Bay

The earliest known specimens of *E. limnicola* in Port Phillip Bay came from benthic samples taken at Werribee in 1984. Its subsequent distribution is shown in Figure 16.7. Currie and Parry (1996) and Poore (1992) later found large numbers, up to 75 individuals per Smith MacIntyre grab (0.1 m^2) making *E. limnicola* the sixth most abundant benthic invertebrate in Port Phillip Bay soft sediments. Small numbers were found in sandy sediments on the western side of the Bay but the highest densities were observed in the muddy habitats towards the centre of the Bay (Harris *et al.* 1996).

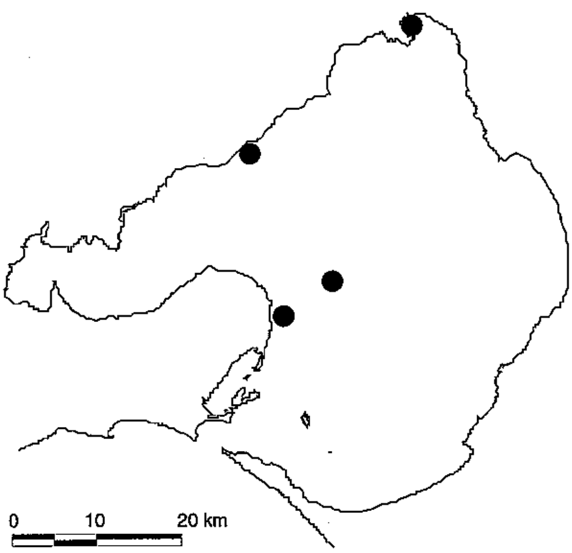

Figure 16.7. The current (1998) known distribution of the introduced polychaete, *Euchone limnicola*, in Port Phillip Bay, Victoria.

E. limnicola was also found in large numbers in Portland Harbour during an exotic species survey undertaken in 1996 (Parry *et al.* 1997), a survey of Botany Bay in 1996 and a survey of the Derwent Estuary.

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17 INTRODUCED MARINE SPECIES AND NITROGEN CYCLING IN PORT PHILLIP BAY

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17.1 INTRODUCTION

Nutrient loads to Port Phillip Bay have been a source of concern, and the subject of several major environmental studies, over the past three decades. Port Phillip Bay receives substantial loads of nutrients from the surrounding catchments, which is not surprising given a population of over three million people. Although the bay is relatively large, it is quite poorly flushed, and so there is potential for nutrient loads to lead to significant eutrophication. Successive studies have clearly demonstrated that nitrogen limits phytoplankton growth and biomass in Port Phillip Bay. However, it is only as a result of the recent Port Phillip Bay Environmental Study (PPBES), that a quantitative understanding has been established of the fate and impacts of nitrogen loads to the bay (Harris *et al.* 1996; Murray and Parslow 1997).

The interaction between introduced marine species and nitrogen cycling is of interest for two reasons. First, the nitrogen cycle underlies the spatial and temporal patterns of biological production, and water and sediment quality in the bay. These partly define the environment into which introductions occur, and affect the location, timing and subsequent evolution of successful invasions. Second, because of the long flushing time, the health of the bay depends critically on internal sinks of nitrogen, and changes in ecosystem structure and function following invasions could disrupt the biogeochemical/ecological processes controlling those sinks.

In this chapter, we address both of these issues. We first present a brief overview of the nitrogen (N) cycle in Port Phillip Bay, and the resulting spatial and temporal patterns in water and sediment quality. We then discuss the implications for colonisation. We analyse the mechanisms by which changes in benthic communities resulting from invasions might disrupt the N cycle in the bay, and present results from a model scenario run to address one such mechanism.

17.2 THE NITROGEN CYCLE IN PORT PHILLIP BAY

One way to think about the N cycle in the bay is in terms of average pools and annual fluxes (Figure 17.1). The bay receives an annual load of about 7,000 t N y^{-1}, of which about half is discharged into the western bay from the Western Treatment Plant (WTP, Werribee), which treats about half Melbourne's sewage. Other major sources are the Yarra estuary which discharges into Hobsons Bay in the north, and the Patterson-Mordialloc system which discharges into the eastern bay. Atmospheric inputs are thought to contribute about 1,000 t N y^{-1}. A large number of minor creeks and drains may contribute a further 5 to 10% of the total.

The majority of this annual load is in the form of dissolved inorganic nitrogen (DIN), and is readily available for uptake by phytoplankton or macrophytes.

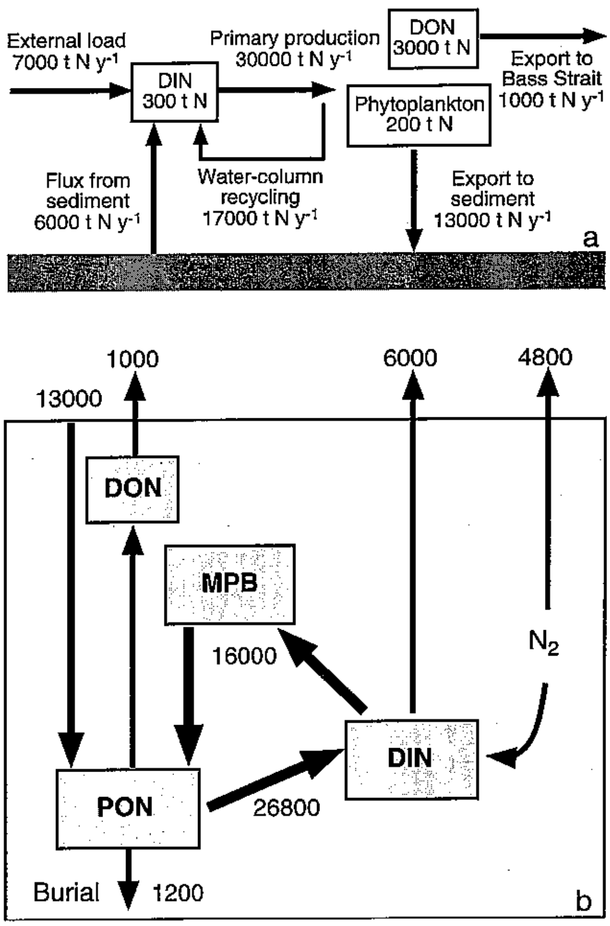

Figure 17.1. a) Annual bay-wide mean water column pools and fluxes in Port Phillip Bay water column; and b) Annual bay-wide mean nitrogen fluxes (t N y^{-1}) in Port Phillip Bay sediments.

Phytoplankton uptake results in a low mean DIN concentration and small DIN pool of about 300 t N, which turns over very rapidly. The estimated net phytoplankton production is equivalent to uptake of about 30,000 t N y^{-1}, which is much larger than the external load. This is possible because DIN is efficiently recycled within the bay. Despite this high production, average phytoplankton biomass is also fairly low within the bay, due to grazing by zooplankton and benthic filter-feeders, and the small pool of phytoplankton (about 200 t N) also turns over very rapidly, about once every two days.

Flushing of Port Phillip Bay is driven primarily by tidal mixing, but is very inefficient because of the flood tidal delta (the Sands) inside the Heads (Walker 1997). As a result, the effective flushing time is very long, on the order of one year.

Because the concentrations of DIN and particulate N in the water column are low, very little N is exported to Bass Strait. The largest pool of nitrogen in the water column is dissolved organic N (DON), with a Bay-wide pool of about 3,000 t N. However, the concentrations of DON in Bass Strait are also high, and the net export of DON is estimated to be only about 1,000 t N y^{-1}.

Export to Bass Strait can account for only a small proportion of the external nitrogen load. The fate of the remaining N is determined by sedimentary processes. Sediment studies as part of PPBES showed two surprising results (Figure 17.1b). First, production by benthic diatoms (also called microphytobenthos or MPB) is very high, amounting to about half of the phytoplankton production. Second, denitrification rates in the sediments are very high throughout most of the bay. Denitrification is a bacterial process which converts nitrate to N_2 gas, which is biologically unavailable and lost to the system. Measured denitrification efficiencies in the bay sediments during PPBES were very high, up to 90% in the Bay Centre, and about 50% on average.

Benthic flux measurements and mass balance suggest that denitrification is the principal sink for the external nitrogen load, accounting for about 5,000 t N y^{-1}. This sink allows Port Phillip Bay to remain in a mesotrophic condition, with generally low levels of DIN and chlorophyll, despite moderate nutrient loads and a very low flushing rate. If denitrification were to shut down, and the denitrification sink was replaced by export to Bass Strait, the concentrations of water column N would need to increase by a factor of 6, and the DIN and chlorophyll concentrations would likely increase by a much larger factor. The bay would then switch from mesotrophic to eutrophic status.

Observations in the bay, supported by modelling, suggest that denitrification efficiencies decrease as organic flux to the sediments, and sediment respiration rates, increase. Model analysis suggests that increases in external loads by a factor of two to three could increase primary production and sediment respiration to the point where denitrification would largely shut down, and the bay would undergo a transition to a eutrophic state (Murray and Parslow 1997). Once this transition had occurred, it would be difficult to reverse, as the bay would recycle N much more efficiently. Any other perturbation which shut down denitrification would also lead to eutrophication even at current N loads, and this would also be difficult to reverse for the same reasons.

Underlying this bay-wide annual average view of the N cycle are spatial and temporal patterns in DIN, phytoplankton biomass and production, and sediment respiration and denitrification. These patterns were resolved in PPBES through a combination of intensive monthly surveys and the development of a spatially-resolved biogeochemical model. The model has been calibrated against observations and shown to reproduce well the principal regional and seasonal patterns in water column and sediment properties.

The observed and modelled spatial and temporal patterns in nutrients and chlorophyll primarily reflect the patterns in nitrogen loads to the bay. The model describes Port Phillip Bay in terms of 59 polygonal cells, each a few kilometres across. For purposes of description and summary, these cells were aggregated into eight regions (Figure 17.2). There are seven fringing regions, and one central bay region, representing the area deeper than 15 m. Regions 1 and 2 correspond to the inner and outer Sands, dominated by tidal exchange and mixing between the bay

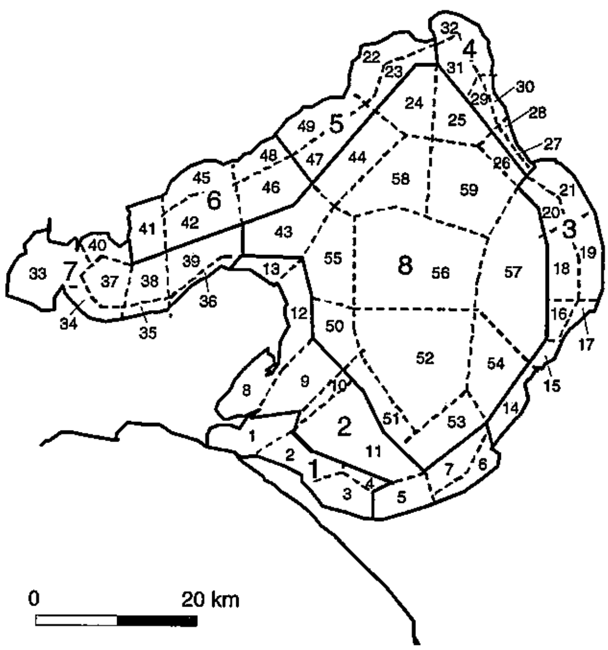

Figure 17.2. Spatial structure of the PPBES Integrated Model, showing boundaries of cells (dashed lines, small numbers) and regions (solid lines, large numbers).

centre and Bass Strait. Region 3 corresponds to the east coast, region 4 is dominated by Yarra loads, while region 5, the north-west, is influenced by both Yarra and WTP loads. Both region 6 (Werribee), and region 7 (Corio Bay) are dominated by WTP loads. Region 8 (the Bay Centre) represents about 50% of the surface area and 80% of the bay volume.

Regions 1 and 2 are characterised by low average values of DIN and chlorophyll. Region 3 is narrow (the bay shelves steeply in the east) so exchange with the Bay Centre is rapid, and DIN and chlorophyll values are generally low, although influenced at times by inputs from east coast rivers and large flood events from the Yarra River. The Yarra region (region 4) is subject to high inputs of nutrients from the Yarra catchment, which tend to be concentrated in major rainfall runoff events, with strong seasonal and interannual variability. These events result in prolonged phytoplankton blooms and the highest observed chlorophyll concentrations occur in Hobsons Bay. Sediment respiration rates are also highest in Hobsons Bay, and at times are sufficient to shut down sediment denitrification.

Nutrient loads from the WTP show a regular seasonal cycle, with most of the load occurring in winter, when nitrogen removal in the plant is least effective. This results in elevated levels of chlorophyll and DIN in the Werribee (region 6) and Corio Bay (region 7) regions in winter and early spring. Silicate limitation appears to limit phytoplankton utilisation of DIN in spring. DIN and chlorophyll levels in the north-west region are influenced by both WTP and Yarra loads, depending on the circulation.

The bay centre region is characterised by low and relatively constant levels of DIN and chlorophyll. Because of its large volume, it responds only weakly to load events, and also dominates bay-wide averages. Sediment respiration rates in the bay centre are relatively low, and denitrification efficiencies are very high.

Microphytobenthos (MPB) is distributed throughout the bay, but concentrated at intermediate depths on the western half of the bay. MPB are found at 20 m at very low bottom light intensities, but most of the production occurs shallower than 15 m. Macroalgal biomass in the bay appears to be limited by a lack of hard substrate. Most of the biomass is found at around 8 to 10 m in the west and northwest of the bay, in the form of loosely attached filamentous algae. This is associated with seasonally elevated DIN levels, but is presumably restricted to these depths, and low bottom light levels, by high bottom stress due to waves and currents at shallower depths. Light attenuation is quite high in the bay, and seagrass are restricted to shallow depths, less than 5 m, in the southwest of the bay.

17.3 ENVIRONMENTAL CONDITIONS AND INVASIONS

The introduced species discussed in previous chapters fall into one of four functional categories: filter feeders, deposit feeders, macroalgae and benthic predators. When considering future risks, one might wish to include introduced phytoplankton species, especially toxic dinoflagellates or diatoms.

The precise factors controlling establishment and subsequent population growth of any particular species are no doubt complex, and would require detailed ecological studies to unravel. Nonetheless, there are some useful generalizations we can make.

Filter feeders depend on suspended organic matter as a food source, and in Port Phillip Bay, phytoplankton production is the dominant source of organic matter. Invading filter-feeders such as *Corbula* and *Sabella*, which reach very high abundance, appear to be favoured by elevated phytoplankton biomass (Clapin 1996; Chapter 16).

Deposit feeders might be expected to be favoured by high rates of phytoplankton production and organic flux to the sediments. Observations suggest that diatoms are responsible for a considerable proportion of phytoplankton production, and are responsible for a large flux of labile organic matter to the sediment surface. The very high levels of benthic diatom production also create a highly favourable environment for surface deposit feeders.

We would expect macroalgae to be favoured by regions of elevated DIN, and moderate to high light intensity. As noted earlier, a lack of hard substrate limits macroalgal biomass in shallow areas of Port Phillip Bay, and the elevated DIN and high light environment along the western margins represent an opportunity for any species which is capable of establishing in soft substrate and resisting wave action. Species with low light requirements may be able to colonise deeper areas, away from wave action.

Phytoplankton should also be favoured by conditions of elevated DIN. Most phytoplankton in Port Phillip Bay appear to be subject to high grazing pressure, and any species which could avoid this might be expected to flourish. One might expect the silicate limitation in the western bay in spring to favour dinoflagellate blooms but these are not a dominant feature. Dinoflagellates are also favoured by stratified conditions, and the water column in Port Phillip Bay is generally well-mixed.

The conditions favouring predator invasions are not so clear. However, it seems plausible that elevated biomass of filter-feeders and deposit feeders, supported by elevated planktonic and benthic production, might encourage rapid population growth.

This (admittedly superficial) discussion suggests that water column concentrations of DIN and chlorophyll, bottom light levels, and benthic respiration, are likely to be useful in assessing the likely invasion success and population abundance of potential or past introductions within Port Phillip Bay. The median and 90%ile levels of these parameters, as predicted by the PPBES model for the years 1991–95, are shown in Figures 17.3 to 17.6.

Apart from local conditions controlling settlement, growth and survival, the evolution of spatial distributions within the bay are likely to be affected by physical transport of larvae (for those species with planktonic larvae). Physical circulation models show that, while the exchange with Bass Strait is poor, circulation within the bay is quite rapid, and larvae with residence times of 2 to 3 weeks are likely to reach most parts of the bay (Walker 1997).

17.4 IMPACTS OF INTRODUCED PESTS ON THE NITROGEN CYCLE

Denitrification in the sediments plays a critical role in the nitrogen cycle in Port Phillip Bay. Models predict that any substantial drop in denitrification efficiency in the sediments would lead to marked increases in phytoplankton production and biomass, and ultimately to a potentially catastrophic shift to a highly eutrophic state (Murray and Parslow 1997). Measured denitrification efficiencies, especially in the bay centre,

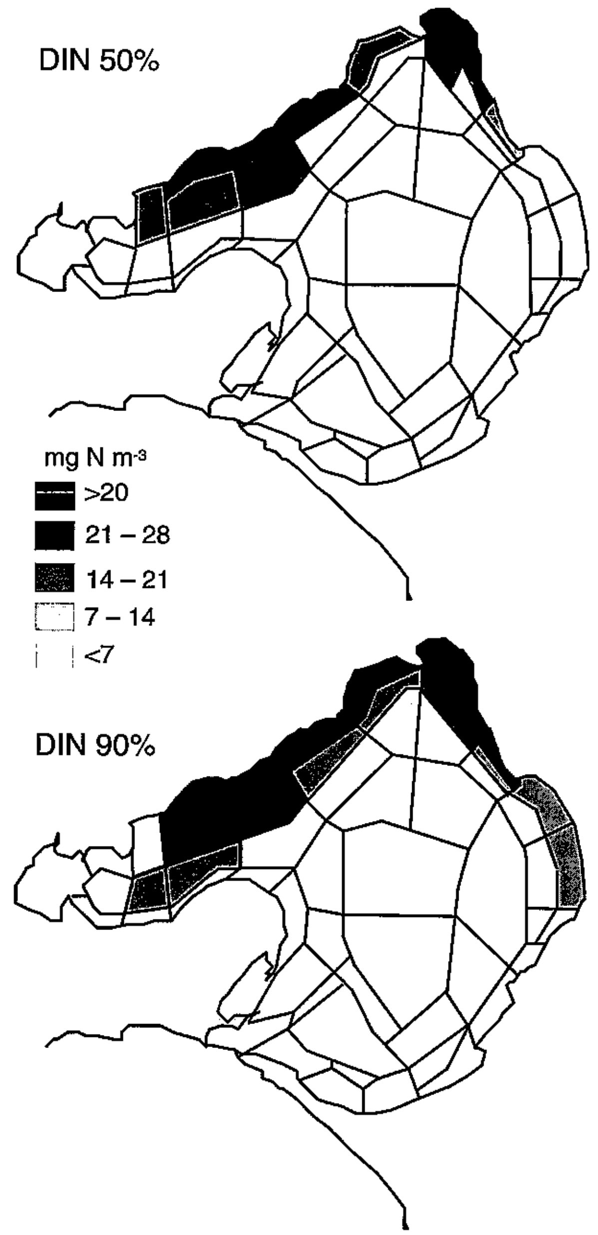

Figure 17.3. Spatial distribution of annual median and 90%ile DIN values predicted by PPBES Integrated model.

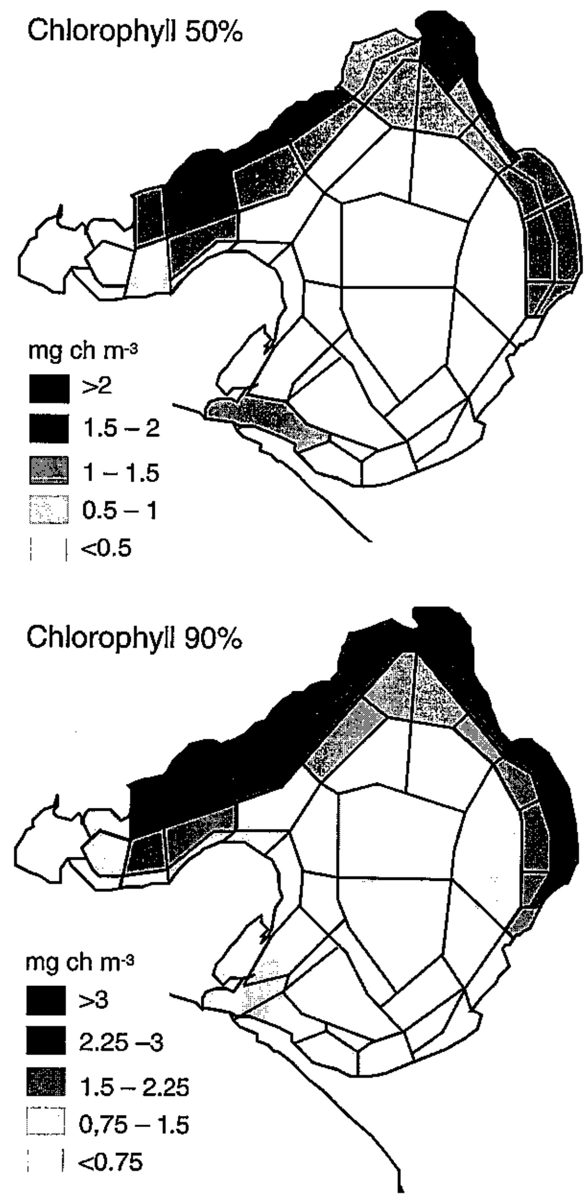

Figure 17.4. Spatial distribution of annual median and 90%ile Chl a values predicted by PPBES Integrated model. Note change in scale.

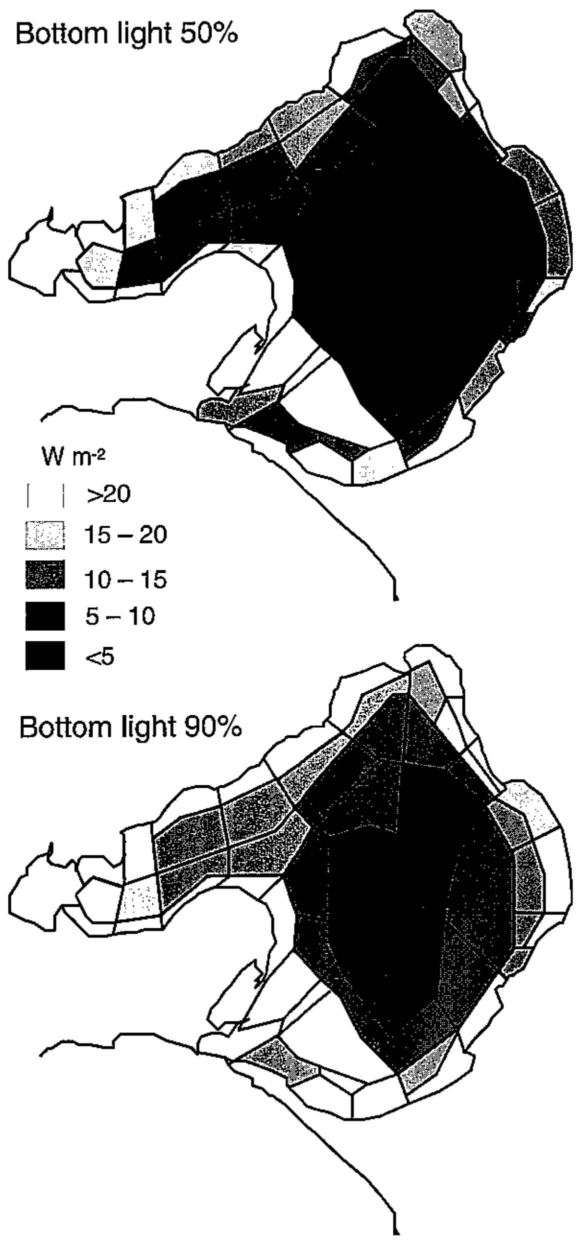

Figure 17.5. Spatial distribution of annual median and 90%ile bottom light intensities predicted by PPBES Integrated model.

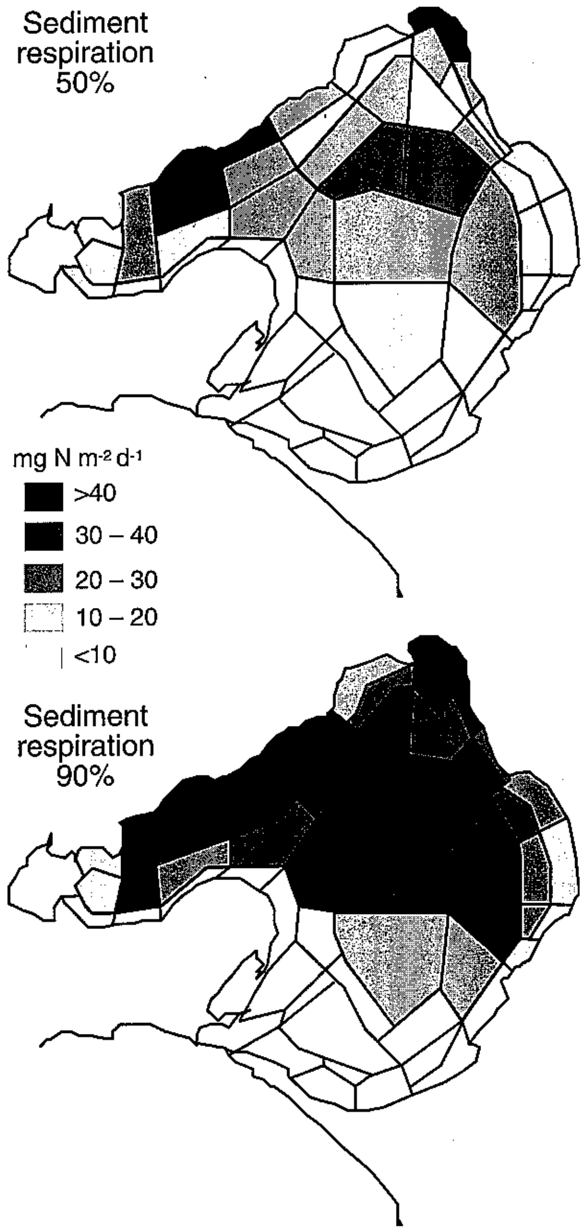

Figure 17.6. Spatial distribution of annual median and 90%ile sediment respiration rates (as equivalent N fluxes) predicted by PPBES Integrated model.

are unusually high, and the reasons for this are not well understood. Introduced species of benthic fauna or flora of the kind discussed in Chapters 6–16 have the potential to markedly change benthic ecosystem structure and function. There is a risk that these changes to benthic ecosystems could disrupt the conditions responsible for high denitrification efficiencies, and lead to a rapid and possibly irreversible deterioration in the health of the bay. This risk is difficult to quantify given our limited scientific understanding of the processes controlling denitrification efficiency in sediments, but current knowledge does permit some informed speculation about possible risk factors.

Sediments over most of Port Phillip Bay are subject to active bioturbation and bio-irrigation, to depths of 20 to 30 cm or more. Callianassid burrows are believed to contribute significantly to deep ventilation of sediments, although undoubtedly other infauna contribute (Bird *et al.* 1996). Over most of the bay, the oxic layer is quite thin, extending only 1 or 2 mm into the surface sediment (Burke 1995). Comparison of diffusion based estimates of oxygen flux with benthic chamber estimates suggest that roughly half the sediment respiration takes place in surface sediments, with the remainder occurring in the sediment interior, ventilated through bio-irrigation (Murray and Parslow 1997).

In the bay centre, where denitrification efficiencies are high, there is little evidence of sulphide production in the sediment interior. It appears that supply of oxygen through burrows is sufficient to match oxygen demand in the sediment interior. However, in Hobsons Bay, where denitrification efficiencies are low, there is evidence of sulphide production in the sediment interior. It is also notable that there is evidence of accumulation of labile or semi-labile organic matter in upper sediments in Hobsons Bay, but little evidence of this in the bay centre.

For denitrification to occur, the ammonia produced through remineralization of organic matter must first be oxidised to nitrate by nitrifying bacteria (in the presence of oxygen) and then denitrified to nitrogen gas (by denitrifying bacteria) in the presence of organic substrate and under anoxic conditions. Overall, denitrification is likely to be favoured by conditions which create strong local gradients in oxygen concentration. These conditions occur in surface sediments, along burrow walls, and in microniche environments around individual organic particles. Ammonia or nitrate in sediment pore water can either be released into overlying water, or captured by nitrifying/denitrifying bacteria. To achieve very high denitrification efficiencies, there must be a higher probability of nitrate molecules diffusing into low oxygen zones and being denitrified, then diffusing to the overlying water column. This is favoured if nitrifying and denitrifying bacteria are distributed in close proximity in a structured way along interfaces such as burrow walls, rather than distributed through the bulk sediment. It may also be favoured if oxygen concentrations in the sediment fluctuate over time e.g. driven by diel cycles in MPB photosynthesis.

While it seems plausible that high densities of burrowing infauna and high rates of bio-irrigation may be necessary for high denitrification efficiencies, measured bio-irrigation rates were high in Hobsons Bay, so the low denitrification efficiencies there are not due to a lack of burrows and bio-irrigation. There is evidence from other studies that nitrifying bacteria may be strongly inhibited by sulphide production, and this may explain the low denitrification efficiencies observed there.

This analysis suggests two kinds of mechanisms which could lead to loss of denitrification in sediments. Removal of deep-burrowing organisms such as callianassids, and their replacement by shallow filter and deposit feeders, could reduce the interface area suitable for nitrifying/denitrifying bacteria, and reduce the ventilation of the sediment interior. A reduction in ventilation and oxygen supply could in turn lead to sulphate reduction and sulphide production in the sediment interior, inhibiting nitrifying bacteria in surface sediments. Reductions in densities of deep-burrowing organisms could occur either through predation, or through competition, if dense beds of surface filter or deposit feeders intercept the flux of labile organic matter too effectively.

Nitrification in sediments depends on the presence of oxygen, which must come from the overlying water column. The broad, shallow morphology and relatively low freshwater input mean that stratification is infrequent in Port Phillip Bay and severe oxygen depletion in bottom waters has not been observed. However, it is possible that oxygen penetration to surface sediments could be affected by overlying communities. In eutrophic conditions, dense beds of filamentous algae can reduce diffusion and create an anoxic organic rich layer at the sediment surface. This will shut down nitrification in the underlying sediment, but may encourage nitrification in the algal bed itself. The net effect on denitrification efficiency is unclear.

The observations in Hobsons Bay already suggest that denitrification efficiency decreases when the organic matter flux to sediments is high. Bay-wide, this organic matter flux is strongly constrained by external nutrient loads. However, changes in function of either pelagic or benthic communities could lead to local or regional shifts in organic matter deposition and sediment respiration rates.

This discussion has focused on possible impacts of introduced species on denitrification efficiency because this carries the highest risk of severe consequences for the trophic state of the bay. However, introduced species certainly have the capacity to modify other aspects of the N cycle in the bay, especially at local or regional levels. Introduced filter-feeders such as *Corbula* and *Sabella* can reach very high local biomass, and have the potential to exert very high clearance rates on the overlying water column, especially in shallow areas (Clapin 1996). This can lead to a switch from a plankton-dominated to a benthic-dominated system, and/or to shifts in phytoplankton community composition. Introduced macroalgae can also potentially reduce phytoplankton production by competing for nutrients in shallow waters. Both filter-feeders and macroalgae are likely to lead to more efficient trapping and recycling of nutrients locally. This could lead to enrichment in the vicinity of nutrient inputs, and a reduction in nutrient supply and production in the bay interior.

17.5 MODELLING THE IMPACT OF INTRODUCED SPECIES: A CASE STUDY OF *SABELLA SPALLANZANII*

The integrated model developed as part of the PPBES represents the cycling of nitrogen, phosphorus, carbon and silicate through the water column and sediments of Port Phillip Bay (Murray and Parslow 1997). The model is essentially a biogeochemical model, describing the fluxes of nutrients among functional components. The model has a relatively crude representation of benthic ecosystems, but does explicitly represent seagrass, macroalgae and microphytobenthos, and a generic filter-feeder component. Deposit feeders are represented implicitly through the remineralization rate of organic matter in sediments.

The population of *Sabella* in Port Phillip Bay increased substantially through the period of the study. As the critical role played by denitrification became apparent, concerns were raised about the potential impacts of *Sabella* on denitrification and the N cycle in the bay. The model was consequently used to study the potential effects of increases in *Sabella* biomass. A full report is given in Murray and Parslow (1997). Here, we summarise the key findings.

After reviewing the literature on *Sabella spallanzanii*, including the study in Cockburn Sound by Clapin (1996), it was concluded that the clearance rates and growth rates achieved by *Sabella* were not remarkable or inconsistent with the generic filter-feeder parameters adopted in the model. *Sabella* is remarkable in its ability to achieve very high population densities. In the model, filter-feeder densities are controlled by a balance between growth and mortality, and the mortality rate had been chosen so that filter-feeder biomass and population clearance rates were consistent with broad estimates for the bay. Filter-feeder densities can be increased in the model to those achieved by *Sabella* simply by reducing the mortality rate. It seems likely that a similar mechanism may apply in nature; i.e. that the high densities achieved by *Sabella* are due to a lack of predation.

Far from resulting in a switch to a eutrophic state, increasing filter feeders in the model led to a more oligotrophic character for the bay. At maximum simulated filter-feeder biomass, bay-wide phytoplankton biomass and primary production decreased by 30%. The direct effect is quite straightforward: filter-feeders exert high clearance rates, and reduce phytoplankton concentrations, especially in shallow waters. There is also an indirect effect, in that filter feeders in the model are assumed to release DIN into the water column, but deposit faeces or pseudo-faeces on the sediment. Filter-feeders therefore transfer organic matter more efficiently to the sediment, reducing recycling of N in the water column by 50% at maximum biomass.

In the model, filter-feeders were assumed to feed on both small and large phytoplankton, and microzooplankton. This led to a strong predicted switch in phytoplankton composition: by removing microzooplankton, filter-feeders decreased grazing on small phytoplankton, and tilted the competition for nutrients between small and large phytoplankton strongly in favour of small phytoplankton (from approximately 1:1 to 10:1 in shallow waters).

By decreasing phytoplankton biomass overall, and removing suspended organic matter, the high biomass of filter-feeders led to an increase in DIN and a decrease in light attenuation in the water column. Both these effects favour benthic macrophytes such as seagrass and macroalgae. Increased light penetration also leads to increased MPB production in deep waters.

Other ecological consequences, not represented in the model, would be expected. The decrease in phytoplankton biomass and change in phytoplankton composition would be expected to lead to decreased growth rates in other filter-feeders, including cultured shellfish. To the extent that *Sabella* intercept the flux of labile organic matter to the sediment, one might expect deposit feeders to be adversely affected as well. However, this would depend on the nutritional quality of pseudofaeces deposited on the sediment.

In the model, the high biomass of filter-feeders had only minor effects on denitrification efficiency, primarily through increased trapping of nitrogen in coastal regions. However, there is no mechanism in the model for *Sabella* to modify sediment structure or biogeochemical processes. If *Sabella* does have an effect, it will be primarily an indirect one, through modification of the benthic community structure; e.g. exclusion of callianassids and other deep-burrowing organisms. This has yet to be demonstrated.

There have been attempts to measure nitrogen fluxes directly over *Sabella* beds, but there are still issues of size and scale of benthic chambers to be resolved (Longmore *et al.* 1996). Interestingly, laboratory studies suggest that *Sabella* colonies produce nitrate, presumably through nitrifying bacteria associated with the tube. If this is the case, *Sabella* may act to increase denitrification effciencies, as nitrification is generally regarded as the rate-limiting step.

This case study illustrates some of the potential interactions associated with changes in community structure following introductions. The Port Phillip Bay Integrated Model provides an ideal test bed for looking at direct and indirect impacts at regional and bay-wide scales. However, the case study also illustrates the need for carefully designed manipulative experiments and process studies, if local impacts of particular species are to be understood and modelled correctly.

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18 SYNTHESIS: INTRODUCED AND CRYPTOGENIC SPECIES IN PORT PHILLIP BAY

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18.1 INTRODUCTION

As the 20[th] century closes, the effects of human alterations on the marine environment are becoming increasingly apparent (Lubchenco *et al.* 1991; Vitousek *et al.* 1997). Perhaps the most insidious and persistent change is that associated with the transport, inoculation and establishment of species in regions far from their evolutionary origins (Elton 1958; Carlton 1989; Drake *et al.* 1989; Vitousek *et al.* 1997). The long distance transport and exchange of organisms between continents or oceans occurs as a result of both natural dispersal and human-mediated transport. The former is infrequent and occurs as a result of chance dispersal events or the breakdown of geographic or climatic barriers (e.g. MacArthur and Wilson 1967). Typically, these events involve the invasion of geographically proximate regions by single species undergoing range expansion. By contrast, human-mediated transport occurs at high frequency, over short transport times, and often between non-contiguous bioregions (Carlton 1985, 1989; Carlton *et al.* 1995). The short transport times (days to weeks) and the mechanisms involved in human-mediated transport often result in the inoculation of entire assemblages (including trophic partners, e.g. predators and their prey) of adult and larval organisms. These mechanisms are often, but far from exclusively, associated with shipping activities (e.g. hull fouling, hull boring, wet and dry ballast transport), and often result in port environments becoming major points of biotic invasion (see Chapter 5; Carlton 1985; Carlton *et al.* 1995; Cohen and Carlton 1995, 1998; Ruiz *et al.* 1997).

Despite an increased awareness over the last decade of the seriousness of this issue world-wide, detailed information on the scale of marine invasions or the mechanisms involved is sparse. Many studies have been anecdotal and suffered from a lack of rigorous quantitative evaluation. While terrestrial and freshwater invasions are well documented (e.g. Groves and Burdon 1986; Kitching 1986; MacDonald *et al.* 1986; Mooney and Drake 1986; Joenje *et al.* 1987; Kornberg and Williamson 1987; Drake *et al.* 1989; di Castri *et al.* 1990), there have been few similar studies in the marine environment. As first steps in documenting the scale of the problem, several broadly targeted evaluations of the introduced marine biota have been conducted in regional and local (port) areas around the world (see Table 18.3). These broad scale surveys typically indicate highly diverse introduced assemblages, but all suffer to some extent from uneven taxonomic or habitat coverage.

Australia is an island continent and its marine fauna and flora have experienced a high degree of geographic and evolutionary isolation; this has lead to high levels of endemicity (> 90% in some groups) in the southern temperate regions. Isolation and endemicity are thought to correlate with high invasibility (Moulton and Pimm 1986; Huston 1994) and, in terrestrial island communities at least, with disproportionately high invader impacts (Simberloff 1986, 1995). This suggests that Australian coastal communities are particularly susceptible to invasions. The combination of low biotic resistance and a high frequency of inoculation (a result of a dependence on shipping for international trade) could account for why Australia seems to face recurrent 'pest' invasions.

In 1995, CRIMP initiated two projects that were designed to evaluate the seriousness of the introduced species problem in Australian waters. These were (i) a nation-wide survey of Australian ports, and (ii) a detailed evaluation of introduced species in Port Phillip Bay. The national program uses standard survey protocols (Hewitt and Martin 1996) and is intended to provide both a regional perspective on marine introductions and the information needed to limit the domestic spread of introduced pests. The Port Phillip Bay project was focused at a much finer scale and was designed to provide information on the rate, mechanisms and historic pattern of invasions, to enable effective targeting of management responses.

As outlined in Chapter 1, Port Phillip Bay was chosen as a focal region for several reasons. These include a well-documented post-colonial maritime history, the availability of high quality background information (including detailed biological surveys in 1968–71, 1991–96 and several regional collections) and a concentration of taxonomic expertise with significant local knowledge. Port Phillip Bay was also of particular interest in the light of a previous analysis of the nutrient dynamics of the bay (Harris *et al.* 1996). Harris *et al.* (1996) noted the apparent health of the bay but also suggested that one of the main threats to this health was the uncertain impact of introduced species on the native biota and associated ecological processes (see Chapter 17).

18.2 INTRODUCED MARINE SPECIES OF PORT PHILLIP BAY: RICHNESS AND DIVERSITY

Reviews of the literature and museum collections, combined with additional field sampling during 1995–96, resulted in the identification of 165 introduced and cryptogenic species (99 and 66, respectively) in Port Phillip Bay (Table 18.1). In addition, one species had been introduced but had subsequently become locally extinct, while another 18 species were identified as 'potentially' introduced but their status could not be confirmed in Port Phillip Bay because of the absence of voucher specimens.

Depending upon the criteria used, therefore, we identified between 99 (definite introductions, with voucher specimens) and 178 (all reports) introduced species in Port Phillip Bay. Harris *et al.* (1996) reported that there are 713 zoobenthic and 478 benthic algal species in Port Phillip Bay. Of these, introduced species (introduced and cryptogenic) constitute 17.2% of the fauna (123 species) and 12.9% of the flora (62 species).

The numbers of introduced and cryptogenic species in Port Phillip Bay, though strikingly high by world standards (see below), are minimum estimates. The actual number of introduced species in Port Phillip Bay is likely to be much higher than documented in this study, for two reasons.

First, limited expertise and taxonomic uncertainties made it impossible to evaluate many taxa. A major gap in this study, for example, is the plankton. Ballast water provides a very effective mechanism for the transfer among bioregions of diverse planktonic organisms, ranging from protists to larger zooplankters (e.g. Carlton and Geller 1993; Galil and Hulsmann 1997). Nonetheless, examples of invasive plankton are sparse. Toxic dinoflagellates are one of the few groups examined in detail, mainly because of their impacts on human health and ability to form conspicuous 'red tides' (Hallegraeff and Bolch 1991). Other examples include a few diatoms (Carlton 1979) and a few large and conspicuous zooplankters, such as the ctenophore *Mnemiopsis leidyi* in the Black Sea (Harbison and Volovick 1994). The paucity of information on most other plankton is due largely to extreme taxonomic difficulties in resolving species identity and source location. Nonetheless, there is a very high probability that the planktonic communities in Port Phillip Bay (and in other Australian ports) are highly invaded. The same may also be true for other phyla for which we were unable to obtain specialist coverage. These groups include the flat and round worms (platyhelminthes, nemerteans and nematodes), annelids other than polychaetes, foraminiferans, sipunculids, echiuroids, most cnidarians, entoprocts, most brachiopods, and phoronids.

Second, for those groups that were covered, there was often a conspicuous bias in the coverage. An extreme example is the crustaceans coverage which, by design, focused entirely on those species inhabiting soft bottoms. The same habitat bias, again a consequence of the historical focus of sampling in the bay, is evident in a number of other phyla, and is reflected in museum collections and records. Coverage of molluscs does not, for example, include shipworms (Teredinidae) even though the family occurs in Port Phillip Bay and includes species with well documented invasive histories (*Teredo navalis* and *Lyrodus pedicellatus*). Although we sought to minimise these effects, such biases are common to all 'check-lists' of invasive marine species and reflect a global lack of taxonomic expertise in many marine phyla.

Taking these biases into account, we estimate that the 'true' number of introduced marine species in Port Phillip Bay is several times higher than that documented in this study. Conservatively, this 'true' number is likely to include at least 300–400 benthic species alone.

Every phyla examined in this study had at least one introduced species. However, the 165 introduced and cryptogenic species identified in this report are not evenly spread between phylogenetic groups (Figure 18.1). Four groups in particular (algae, bryozoans, crustaceans and cnidarians) dominate the reported introduced and cryptogenic species, jointly comprising more than 75% of the species. This dominance may be real (see below), but may also reflect the markedly different levels of taxonomic knowledge between groups. In some phyla, for example, a high degree of endemicity correlates with low specific resolution (i.e. few species described and named). In these groups, the identification of introduced species becomes problematic.

Differences between taxa could also reflect the assignation of species to native, introduced or cryptogenic status, which we left to the taxonomic experts. However, philosophical differences between various workers inevitably lend a subjective element to these decisions. In part to minimise this subjectivity, we recommended using the ten point criteria of Chapman and Carlton (1991, 1994) to aid the identification of introduced species and Carlton (1996a, 1996b) as a guide to identifying cryptogenic species. We recognise that these criteria are not definitive and can be mis-applied (Poore 1996; Hilliard *et al.* 1997; however see Cranfield *et al.* 1998). The extent to which these criteria were used by the taxonomists involved in the study was left up to the individual, and, based on our subsequent discussions with them, were clearly not uniformly applied.

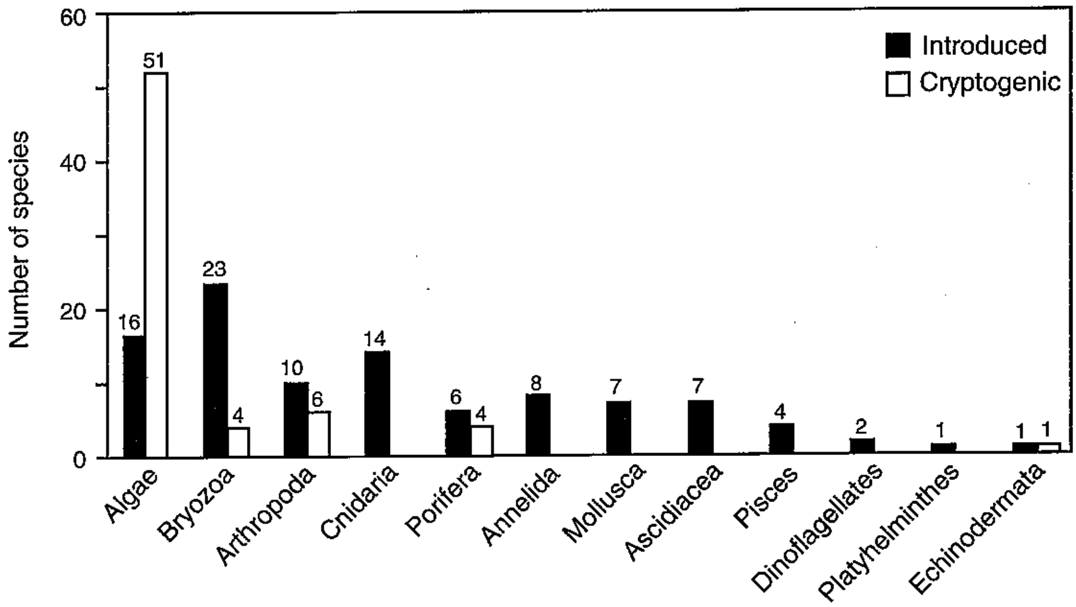

Figure 18.1. The number of introduced and cryptogenic species in Port Phillip Bay by taxonomic group.

Just as all phyla examined had introduced representatives, there are introduced and cryptogenic species in all regions of the bay. The richness of the invasive biota, however, varies widely across the bay (Table 18.1). There are three likely reasons for this uneven distribution: (i) habitats are not equally distributed between regions; (ii) inoculation frequency is higher in some areas than in others; and (iii) vectors have not been equally distributed between regions. Most of the reported introduced (72.7%) and cryptogenic (95%) species are found on hard substrate (i.e. pilings, breakwalls, natural and artificial reefs). These habitats are predominantly found in Regions 1 and 2, which is also where shipping activities are focused, where disturbances to native communities have historically been concentrated, and where most non-native species were reported (for example, 70.3% of the introduced and cryptogenic species were found in Region 1, the Port of Melbourne, as compared to 35.7% in Region 4, the eastern shore). Phyletic representation also differs significantly between regions ($G_{[36]} = 301.60$, $p < 0.005$), with algae

Table 18.1. Introduced, cryptogenic and possibly introduced species established in the different regions of Port Phillip Bay. See Chapter 2 for description of regions.

Taxonomic group	Port Phillip Bay Regions					
	All regions	Region 1	Region 2	Region 3	Region 4	Region 5
Algae	67	51	28	30	23	0
Dinoflagellates	2					
Porifera	10	2	1	7	1	0
Cnidaria	14	7	7	12	12	8
Platyhelminthes	1					
Annelida	8	6	6	3	3	4
Mollusca	7	5	6	2	1	1
Arthropoda	16	12	10	6	6	3
Bryozoa	27	21	13	16	11	9
Echinodermata	2	1	1	0	1	0
Pisces	4	4	3	0	0	0
Ascideacea	7	7	5	3	3	2
Total species	165	116	80	79	59	27

and chordates also concentrated in regions 1 and 2. Nonetheless, overall the distributions of hard and soft substrate-dwelling introduced species did not differ significantly among regions of the bay ($G_{[4]} = 4.90$, ns). We suspect this reflects the now wide distribution of older introductions that were often associated with hull fouling (difference in regional distribution between pre- and post-1940 introductions: $t_{[42]} = 2.70$, $p < 0.05$).

18.3 HISTORICAL PATTERNS, INVASION RATES, SOURCE REGIONS AND VECTORS

The first non-native species recorded from Port Phillip Bay was *Electra pilosa*, a cosmopolitan bryozoan noted as present in 1862 (MacGillivray 1869). Determining the subsequent invasion history of the bay is extremely difficult, given that most of the groups of interest are inconspicuous, subject to substantial taxonomic problems, and have been sampled sporadically.

One commonly used approach to recreating invasive history is to examine the dates at which each introduced and cryptogenic species was first noted (e.g. Cohen and Carlton 1995, 1998). For the Port Phillip Bay biota, dates were reliably available for 153 of the 165 species we identified. These dates are conspicuously bi-modal, with one peak of reports in the late 1800's and a second post 1960 (Figure 18.2). A superficial interpretation of this pattern is that there was a spate of introductions early in the development of Port Phillip Bay as a trading port, most likely as a result of hull fouling on wooden vessels from Europe (see discussion on source regions, below), followed by a long period of few new introductions (because the readily transported European species had already invaded?). This was followed by a modern resurgence of introductions associated with new vectors (e.g. ballast water), increased levels and rates of transport, and new source bioregions.

While this scenario is intuitively appealing and almost certainly contains a large element of truth, the gross pattern of apparent invasion dates in Port Phillip Bay provides little or no direct evidence to support or refute it. The main confounding factor is the differential collection, identification and reporting of species by taxa and habitat. As an example, all but a few of the many species of introduced algae in Port Phillip Bay have only been reported since 1950, which principally reflects a lack of critical examination prior to this time (see Chapter 6). Coles *et al.* (1997) and Coles *et al.* (1999) are the only studies to date that have attempted to adjust apparent invasion histories for differential sampling efforts. They did this by using the number of new native species reported each year as an index of sampling effort, and then used this index as a co-variate in the analysis of invasion rates over time. Unfortunately, we could not undertake a similar correction for Port Phillip Bay, as data on native species were not available.

The effect of taxonomic effort on this historical pattern is well illustrated by the bryozoans (Figure 18.3). The peak of reports in the late 1800's reflects research by MacGillivray (1869–1889), who was particularly interested in the group. After this, there was virtually no work on bryozoans (and consequently no reported invasions) until the recent post-1960 taxonomic surveys of Port Phillip Bay (see Chapter 13).

All four of the groups that dominate the records pre-1920 (bryozoans 12 of 28 species, cnidarians 6, porifera 5, and crustaceans 3) show similar strongly bi-model distributions of reporting years and, we suspect, reflect the same bi-modality in historical taxonomic interest. Of the three crustaceans reported pre-1920, it is noteworthy

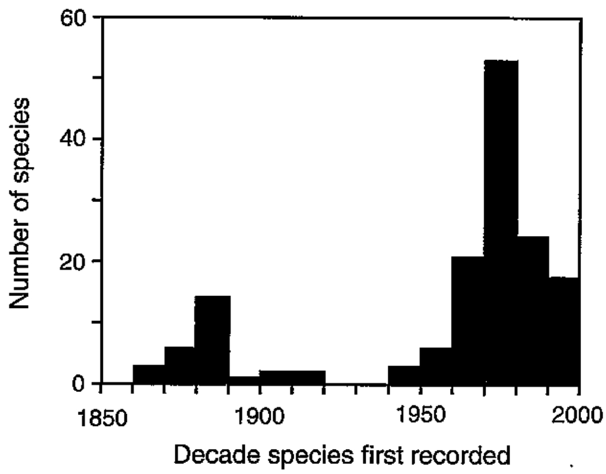

Figure 18.2. The distribution by decade of the first records of all introduced and cryptogenic species in Port Phillip Bay.

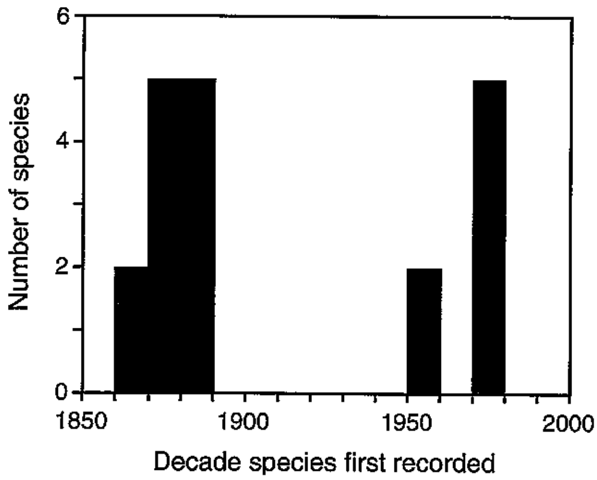

Figure 18.3. The distribution by decade of the first records of introduced and cryptogenic bryozoans in Port Phillip Bay.

that two (*Cancer novaezelandiae* and *Carcinus maenas*) are relatively large and conspicuous, and hence would be more likely than most other invaders to be noted by early naturalists.

If it is not possible to creditably reconstruct the invasion history for Port Phillip Bay, can we at least determine whether the rate of invasions has increased in recent decades? There are two ways we can address this question.

First, there are two groups for which sampling pre-1900 was reasonably comprehensive – the bryozoans, based on MacGillivray's work, and the hydroids, based on studies by Bale (see Chapters 7 and 13 respectively). On that basis, we can compare invasion rates for these taxa pre-1900, between 1900 and about 1970 (based on the Victorian surveys of Port Phillip Bay in the 1950's and 1960's), and post-1970 (as summarised in this study). The number of introduced bryozoan species first reported in those periods are 12, 2 and 5, respectively, which corresponds to mean invasion rates of 0.12, 0.03 and 0.13 species y^{-1}. The equivalent numbers for hydroids are 5, 2 and 6, corresponding to invasion rates of 0.05, 0.03 and 0.17 species y^{-1}.

Second, we can examine those phyla that are conspicuous and that have a high probability of being noted within a few years of an invasion, largely irrespective of specialist taxonomic interest in them. Three phyla fit this description: fishes, echinoderms and molluscs. Amateur interest in the last group, in particular, suggests that new invasions of medium to large species would be rapidly detected and reported. The invasion histories of these phyla are shown in Figure 18.4. In brief, the first introduced fish in Port Phillip Bay was first noted in 1977; the first echinoderm in 1995 (excluding several very early records of three common cryptogenic species, which may be native), and the first mollusc in 1953. This mollusc was the Pacific oyster (*Crassostrea gigas*), which was deliberately introduced to Australia; the first accidentally introduced mollusc was noted in 1956.

We draw two conclusions from these observations. First, the rate of invasions for the more cryptic, hull-fouling groups - bryozoans and hydroids as examples - is at least as high recently as it was when the bay was first invaded in the mid-1800's. In the intervening decades, the rate of invasion appears to have been very low. Second, invasions by the more prominent taxa only started after 1950. Both observations suggest that the rate of invasions has increased significantly in the last several decades, as has the diversity of the invasive taxa.

A current estimate of the overall rate of invasion is difficult to calculate. For the taxa we were able to assess, the historical mean rate of invasions (number of invasive species divided by years that Port Phillip Bay has been an international maritime destination) is one new species every 41 weeks, based on the 165 species identified in this report. For the prominent taxa, thirteen accidental introductions have occurred since 1956, that is, 1 new species every 2.3 years. The rate of invasion for these phyla has increased over time, however (Figure 18.5), so that the current (post-1990) rate for these phyla alone is about one new species every 1.3 years.

For other taxa, the confounding effects of taxonomic uncertainty and irregular effort make even crude estimates problematical. If the rate of invasion by bryozoans and hydroids (which are similar post-1970, at about one new species every eight years) is typical for fouling groups in

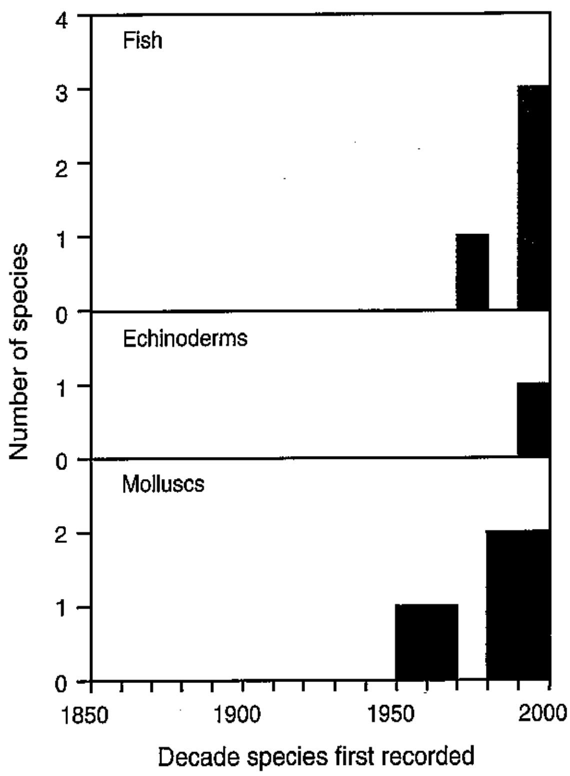

Figure 18.4. The distribution by decade of the first records of introduced fish, echinoderms and molluscs in Port Phillip Bay (*Crassostrea gigas* not included).

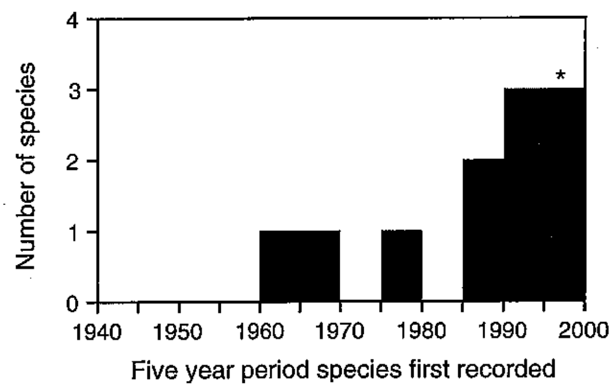

Figure 18.5. The distribution by half decade of the first records of all introduced species of fish, echinoderms and molluscs in Port Phillip Bay (*Crassostrea gigas* is not included in molluscs). * indicates incomplete period.

general, then an invasion rate of one or two fouling species per year is likely to be conservative. Summed across all groups, we suspect Port Phillip Bay is now being successfully invaded by three or more benthic species every year.

These species come from all over the world (Figure 18.6). Historically, the majority originated from the North East Atlantic (53) and the Mediterranean (24) bioregions, while another 21 species are Cosmopolitan, that is, globally distributed and of uncertain original source location. Not surprisingly given the shipping history of Port Phillip Bay (Chapter 5), the source regions for the first set of invaders to be reported focus on the Atlantic (Figure 18.7). Beyond this, three generalities are evident in the long-term pattern.

First, the Atlantic has been a consistent, major source of introductions. The persistence of this source region, however, is likely to largely reflect the lag between invasion and discovery. Most of the invasive macro-algae, for example, are of North Atlantic origin and probably have been in the bay since the turn of the century, although they were not reported until after 1950. Second, there has been a constant 'trickle' of Southern Hemisphere species into Port Phillip Bay, most from New Zealand. Third, there has been a striking increase in the rate of invasions from the North Pacific over the last 4 decades. There were no North Pacific species reported in Port Phillip Bay prior to 1950, but since 1990, it has been the single largest source of new introductions.

This prominence, however, does not necessarily reflect frequent invasions directly from the North Pacific. For example, three recently invading North Pacific species are all likely to be secondary invasions from other infested Southern Hemisphere sites. Genetic data indicate that *Asterias amurensis* in Port Phillip Bay originated from Tasmania (see papers in Goggin 1998). The algae *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides* are common in New Zealand and Tasmania and could have entered Port Phillip Bay on vessels from either area.

Analysis of likely vectors is also problematical, in part because of distortions due to the taxonomic unevenness of the sampling (the phyla we examined are predominantly fouling organisms) and in part because of uncertainty about the vector involved in any given introduction. For example, we have allocated all fish introductions to ballast water on the basis that the 'easiest' invasion route appears to be via the planktonic larval stage. However, at least one species is believed to have been originally introduced into Australia in oyster aggregates shipped live from New Zealand. All these species are small, cryptic and frequently occupy burrows and these characteristics, along with reports of similar kinds of fish in sea chests (Rainer 1995; K Murphy pers. comm.) suggests that other vectors may have been involved.

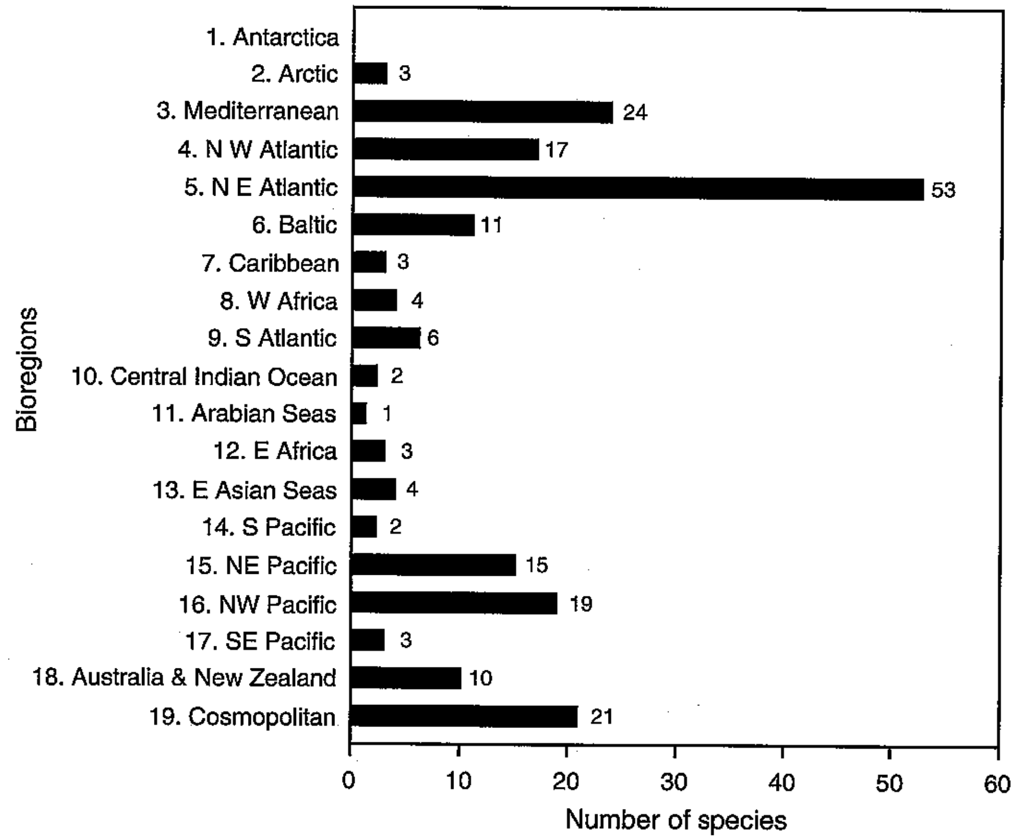

Figure 18.6. Native bioregions for introduced, cryptogenic and possible introduced species that have become established in Port Phillip Bay.

Similarly, the bivalve *Corbula gibba* is also considered a ballast water' species, but we have also collected it from sea chests (K Moore pers. comm.).

Transport vectors can be summarised into 5 groups: hull fouling/boring, mariculture, dry and semi-dry ballast, water ballast, and intentional introduction (Carlton 1979, 1985; Hewitt 1993; Coles *et al.* 1997). To assess the role of each in Port Phillip Bay, we scored each species for most probable vector(s) based on its biology (e.g. planktonic larvae for ballast water, attached benthic phase for hull fouling) and the timing of invasions (e.g. before or after the use of ballast water). We attempted to be conservative in our allocation.

Based on these criteria, the majority of the biota recorded in this study was introduced by hull fouling (77%), while only 20% were likely to have been transported by ballast water. This bias is not surprising given the length of time over which hull fouling and boring have been potential transport vectors (196 years) relative to ballast water (40 years). Nonetheless, the prominence of hull fouling is not just historical; fouling not only accounts for the first introduced species reported in Port Phillip Bay, but also the most recent, e.g. *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides.*

The role of ballast water, however, has increased substantially over the last several decades (Figure 18.8). In the 1990's, ballast water became the dominant vector

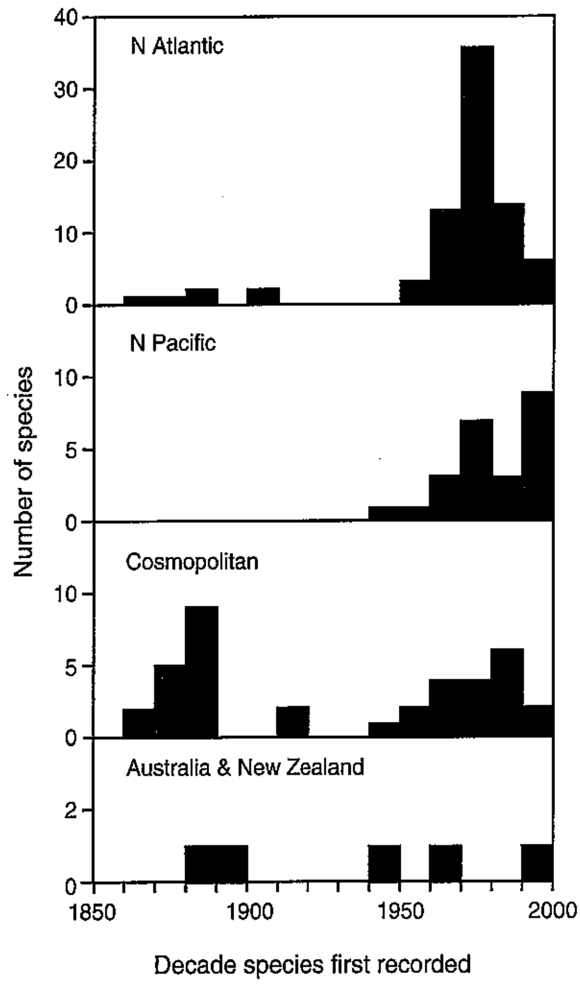

Figure 18.7. The distribution by decade of the first records from Port Phillip Bay of all introduced and cryptogenic species from four broad source regions.

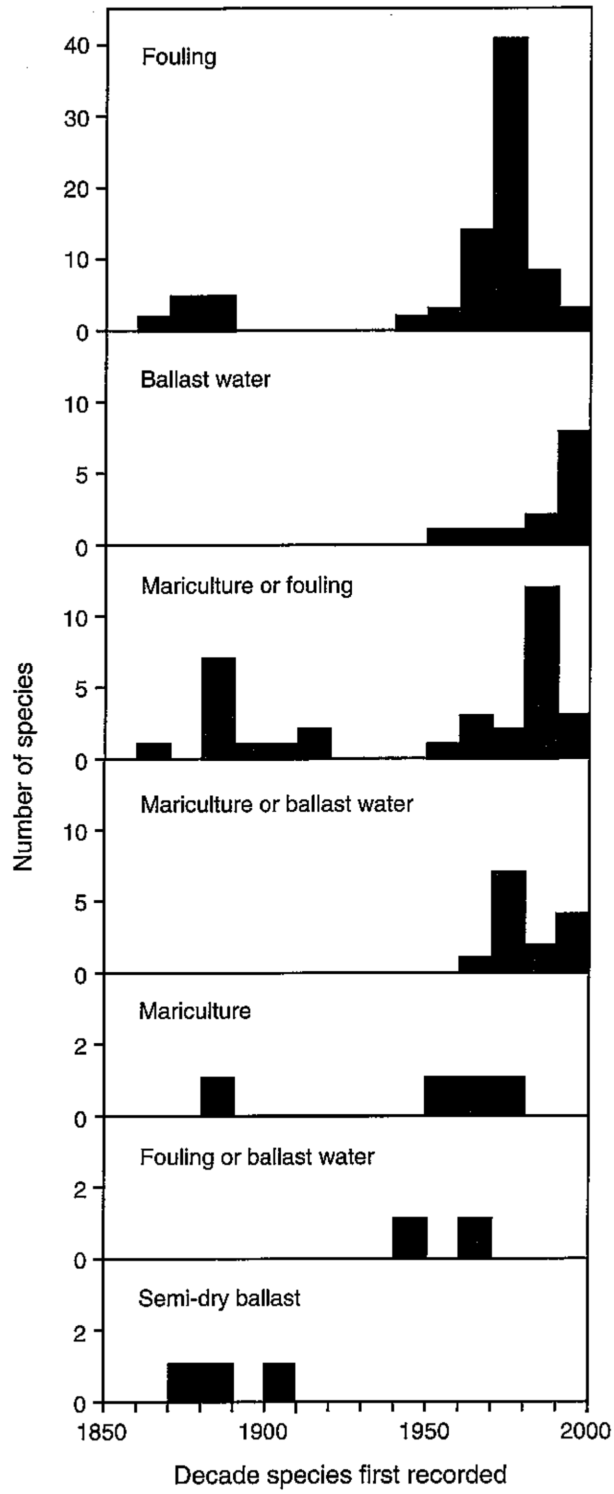

Figure 18.8. The distribution by decade of the first records of all introduced and cryptogenic species in Port Phillip Bay grouped by the likely vector for their introduction.

for newly reported introductions (eight out of 18 species, with another four that were equally likely to be introduced by either vector).

18.4 COMPARISON WITH OTHER AUSTRALIAN REGIONS

The richness of the introduced biota of Port Phillip Bay reflects at least in part the effort expended in documenting the problem. No other system in Australia, and few elsewhere in the world, has been as thoroughly investigated as Port Phillip Bay. However, detailed studies of other major Australian port environments are currently under way (Fremantle, Botany Bay and Darwin). Although only a small amount of data are available for these ports as yet, first indications are that they do not support as diverse an assemblage of introduced species as Port Phillip Bay. In contrast, we suspect that the Hobart marine environs (the Derwent Estuary and Storm Bay) is as least as heavily impacted by invasive species as Port Phillip Bay, on the basis of sharing many of the same pest species, but in an area of overall lower biodiversity.

Introduced species surveys have been conducted in many of the other Australian ports; most ports have only a subset of the species found in Port Phillip Bay, and many of these are broadly distributed (e.g. *Sabella spallanzanii* and *Carcinus maenas*). However, the protocols for these port surveys are targeted, quantitative and have much greater resolution but lack the literature and museum review approach taken in Port Phillip Bay (see Hewitt and Martin 1996); the Port Phillip Bay survey is not comparable to the national port surveys except for the large and conspicuous invasive species.

The total number of invasive species detected in this study in Port Phillip Bay (165) is similar to the total number reported in New Zealand (148) by Cranfield *et al.* (1998). As well, two other characteristics are shared between the Port Phillip Bay introduced marine biota and that elsewhere in the Australia/New Zealand region.

First, the prominence of several taxa (algae, bryozoans, crustaceans and cnidaria) in the introduced biota of Port Phillip Bay was noted above, and was suggested to derive, at least in part, from the unevenness of sampling and taxonomic effort. However, this pattern is also evident in the regional assessment of Australian introductions as whole (difference between Port Phillip Bay and Australia summed, $G_{[12]}$=16.04, ns) and in New Zealand ($G_{[12]}$=17.61, ns), based on Cranfield *et al.* (1998). The Port Phillip Bay and whole-of-Australia data sets are not independent, and similarities between Australian and New Zealand patterns of dominance could reflect similar suites of expertise and literature. Nonetheless, these similarities could indicate a distinctive pattern for the introduced regional biota.

The second point of similarity is the relative strength of the vectors. The prominence of hull fouling, and the relative unimportance of ballast water, is consistent with results for other ports in Australia. Our analysis of the introduced species in Australian waters (Table 18.2) suggests that the dominant mode of introduction to Australia historically is hull fouling, followed by accidental releases associated with mariculture and ballast water at about equal levels, and then dry ballast and intentional releases. Ballast water accounts for little more than 20% of introduced marine species identified so far from Australian coastal waters. The prominence of hull fouling and mariculture is true for all Australian states and territories except for the Northern Territory, for which we do not have enough data yet as to justify any conclusions. Again, it is striking that the New Zealand data appear to support the same conclusion. Cranfield *et al.* (1998) stated that 'most (69%) of the adventive species...arrived in New

Table 18.2. Introduced and cryptogenic marine species in Australia by state or territory and their likely mode of introduction (as of June 1999). Species are listed independently in each state where they occur; species that may be transported by more than one vector are scored for each vector.

State	Total species	Introduction vector				
		Hull fouling and boring	Mariculture	Semi-dry ballast	Ballast water	Intentional introductions
Western Australia	92	83	45	19	47	4
South Australia	98	91	53	24	45	3
Victoria	179	163	74	29	68	4
Tasmania	86	75	39	18	48	5
New South Wales	122	112	63	30	62	2
Queensland	67	62	29	9	39	3
Northern Territory	7	7	0	1	4	1

Table 18.3. Recent regional and local surveys for introduced marine and brackish water species.

Location	No. of Introduced species	Reference
Coos Bay, Oregon	78	Hewitt 1993; Carlton *et al.* unpub. data
Pearl Harbor, Hawaii	96	Coles *et al.* 1997
Ala Wai Yacht Harbor, Hawaii	57	Coles *et al.* 1999
Barbers Point, Hawaii	45	Coles *et al.* 1999
Honolulu, Hawaii	73	Coles *et al.* 1999
Keehi Lagoon, Hawaii	52	Coles *et al.* 1999
Kewalo Basin, Hawaii	49	Coles *et al.* 1999
San Francisco Bay, California	212[a]	Cohen & Carlton 1995
Hudson Bay	120[a]	Swanson 1995
Chesapeake Bay, Maryland	116[a]	Ruiz *et al.* 1997
Puget Sound, Washington	52	Cohen *et al.* 1998
Baltic Sea	96[a]	Gollasch & Leppakoski 1999
New Zealand	167[a]	Cranfield *et al.* 1998
United Kingdom	50[b]	Eno *et al.* 1997
Black Sea	35[a, b]	Zaitsev & Mamaev 1997
Mediterranean Sea	240[a,c]	Ruiz *et al.* 1997

[a] includes marine, brackish, freshwater and salt marsh species.
[b] partial listing of species.
[c] includes species reported, but not established.

Zealand as part of hull fouling communities', and only attribute 3% unambiguously to ballast water and another 21% to either fouling or ballast water.

18.5 COMPARISON WITH NORTHERN HEMISPHERE STUDIES

The number of introduced and cryptogenic species we report in Port Phillip Bay is higher than those reported anywhere else in the world (Table 18. 3). On paper, more introduced species are reported for the Mediterranean Sea, but this figure includes Lessepsian migrants (Red Sea to Mediterranean Sea via the Suez Canal) and a number of species detected only once, that have not apparently established. Cohen and Carlton's study of the San Francisco Bay and delta region (Cohen and Carlton 1995) also reports a greater richness of introduced species overall, but includes salt marsh and freshwater species, which we did not include in the Port Phillip Bay analysis. If the comparison is restricted to only those species in marine and brackish water habitats, Port Phillip Bay has nearly twice as many introduced species as San Francisco Bay (165 in Port Phillip Bay versus 95 in San Francisco Bay; Cohen *et al.* 1998).

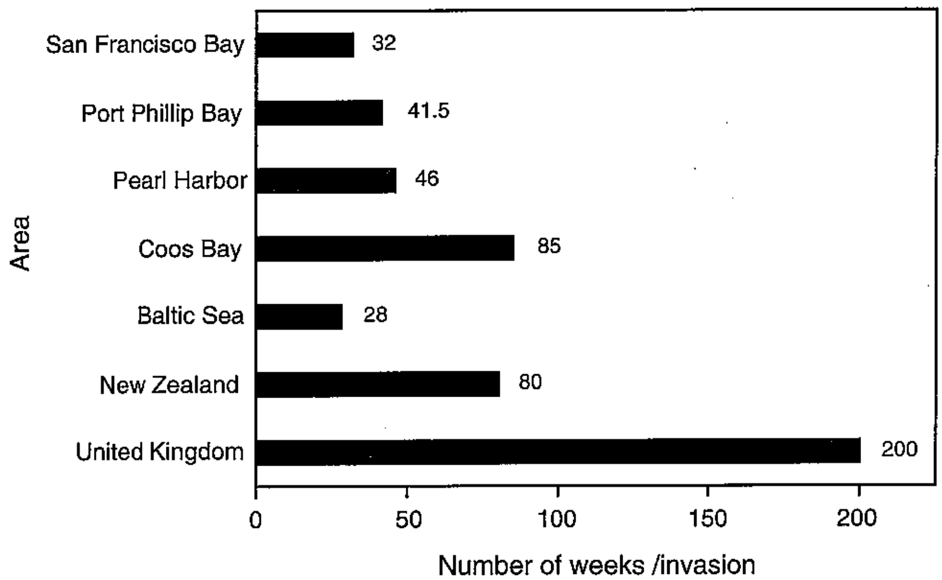

Figure 18.9. A comparison of historical mean invasion rates (weeks/invasion) for wholly marine species determined for local and regional areas (see Table 18.3 for references).

Comparisons of the total number of invasive species detected in an area, however, are largely uninformative. As noted above, our analysis of the biota of Port Phillip Bay excluded a range of phyla for which appropriate taxonomic expertise was not available. This is true for overseas studies as well, which also differ from Port Phillip Bay, and each other, in both sampling methodology and effort. In reality, the only conclusion that can be reached from these studies is that all the areas examined are heavily invaded. More meaningful comparisons between areas will only be possible when introduced species surveys are based on standard survey protocols. This is one of the core objectives of the CRIMP national port survey program, now under way.

The uncertain nature of the comparisons also limits the utility of calculated 'time to new invasion' rates (Cohen and Carlton 1995). For Port Phillip Bay as a whole, the historical mean rate of invasion is one new species establishing every 41.5 weeks. As indicated above, this rate is biased by sampling effort, but appears to have increased over the last several decades. We estimate the rate of new invasions in Port Phillip Bay is now around one new benthic species every 20 weeks. We cannot estimate the rate of invasion into the plankton.

This rate is low relative to that estimated from some Northern Hemisphere studies (Figure 18.9). In the San Francisco Bay and Delta region, one new species established itself every 55 weeks from 1851 to 1960, but every 14 weeks from 1961 to 1995; this increase is suggested to be the result of increased use of ballast water by shipping (Cohen and Carlton 1998). These estimates include estuarine and freshwater species and hence are not directly comparable with the Port Phillip Bay study. For marine species only, the historical mean invasion rate into San Francisco Bay has been one invasion every 32 weeks, which is similar to our estimate for Port Phillip Bay. Elsewhere, Coles *et al.* (1997) reported that for Pearl Harbor, Hawaii, a major military shipping port, a new species establishes every 66 weeks pre-1940 and every 38 weeks since then (overall a rate of 46 weeks). The historical maritime regions of the Baltic Sea and North Sea have recorded invasion rates of one new species every 28 weeks (Gollasch and Leppakoski 1999), however this is largely an artefact of the choice of starting point.

More meaningful between-area comparisons can be made in relation to invading taxa and introduction vectors. The similarity in phyletic dominance evident in Australian and New Zealand surveys was noted above. In contrast, the ranking of invasive phyla in Australia and New Zealand differs significantly from those observed in San Francisco Bay ($G_{[12]} = 49.58$, $p < 0.005$), Coos Bay ($G_{[12]} = 24.81$, $p < 0.05$) and Pearl Harbor ($G_{[12]} = 66.84$, $p < 0.005$). This difference is also significant for comparisons between the Northern and Southern Hemispheres ($G_{[12]} = 71.78$, $p < 0.005$) and is due principally to the dominance of arthropods and molluscs in the introduced biota of the Northern Hemisphere. In San Francisco Bay, arthropods were the richest introduced taxa (53 species), followed by molluscs and fish (30 and 28 species, respectively) (Cohen and Carlton 1995). Similarly, in Pearl Harbor, molluscs and arthropods comprised the two richest introduced groups (38, 35 species, respectively) (Coles *et al.* 1997). The consistency of these differences with Southern Hemisphere sites suggests that they are not the result of sampling artifacts.

The relative importance of the main groups of vectors also seems to differ between Port Phillip Bay and Northern Hemisphere sites. For example, the historical dominance of fouling as an introduction vector in Port Phillip Bay, and Australasia in general, contrasts with and differs significantly from the findings of Cohen and Carlton (1995) for San Francisco Bay ($G_{[4]} = 48.34$, $p < 0.005$; Figure 18.10). Cohen and Carlton estimate that fouling

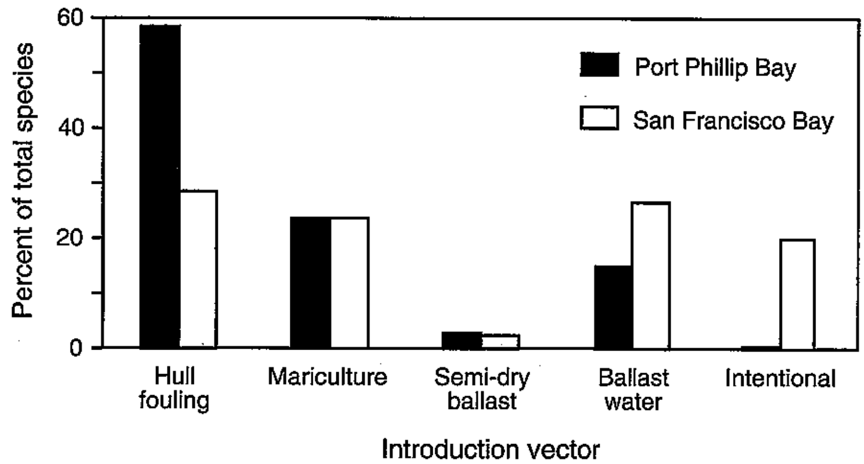

Figure 18.10. The proportion of the introduced and cryptogenic biota in Port Phillip Bay and San Francisco Bay attributable to each of five broad introduction vectors. Data for San Francisco Bay from Cohen and Carlton (1995).

was responsible for only 34% of introductions into San Francisco Bay, as compared to 30% due to ballast water (proportions calculated after removing terrestrial and aquatic introductions from their data set). In part, this difference may be due to the criteria used in determining the relative strengths of the vectors. Cohen and Carlton (1995) use 13 vector-categories, which we reduced to five for Port Phillip Bay.

The relative importance of the various vectors is different again for Britain. Eno *et al.* (1997) suggested that accidental introductions associated with mariculture was the largest single identifiable transport mechanism for introduced marine species (31% of the species). Fouling accounted for about 26% and ballast water for another 18%, with an additional 12% of species equally likely to have been introduced by either of these shipping-related vectors. Deliberate introductions accounted for a further 8% of the introduced species.

18.6 MANAGEMENT IMPLICATIONS

The results of this study provide further evidence that the problem of introduced marine species is global, significant and increasing. The state of the science involved in invasion biology is still rudimentary, to the extent that we still need to invest considerable effort in just documenting the scale of the problem rather than solving it. Even documentation is difficult, given taxonomic difficulties (and often sparse, poorly supported taxonomic expertise) and differences in sampling methods that suggest caution in comparing survey results among sites. Nonetheless, there are several robust conclusions that can be drawn from our analyses.

First, the problem of introduced marine species in the Southern Hemisphere is comparable in magnitude to that in the Northern Hemisphere. The need to cross the equator, and the presumed thermal stresses that temperate species are subjected to while making this crossing, has not protected Southern Hemisphere sites from invasions by North Atlantic and North Pacific species. In many instances, these are the same species that have been successful invaders in the Northern Hemisphere (e.g. *Carcinus maenas*, *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides*).

Second, the problem is an old one. European species were detected in Port Phillip Bay within a few decades of the port developing, and have likely been present almost since the first European ships arrived. The biota of Port Phillip Bay has not been fully 'natural' since at least that time, irrespective of the effects of other modifications such as port development, urban pollutants and fishing.

Third, the nature of the problem has changed in recent decades, because of new vectors (notably ballast water) and new source bioregions (notably the North Pacific). However, no single vector accounts for all, or even a majority of the problem. Hull fouling, broadly defined, accounts for most introduced species in Port Phillip Bay and Australasia in general, but the mix and importance of different vectors varies with locality and over time.

Specifically in relation to Port Phillip Bay there are three further conclusions we can draw. First, even given the uncertainties associated with uneven sampling and taxonomic coverage, it is evident that the bay's marine communities are highly invaded by introduced species. Around 10–15% of the biota in any given phyla is likely to be introduced, and in some habitats (e.g. inshore fouling communities), almost all of the conspicuous biota is introduced. Harris *et al.* (1996) noted that three of the six most abundant benthic species in Port Phillip Bay were introduced. This statement predates the invasions by *Asterias amurensis* and *Undaria pinnatifida*, both of which are likely to become major components of the bay's biota.

Second, introduced marine species, and presumably their impacts, are not uniformly distributed throughout the bay. Areas such as the Port of Melbourne are much more heavily invaded than more pristine areas further from industrial development. Nonetheless, the data are consistent with the spread of species from their introduction points, and no area in the bay is either entirely free of invaders or safe from further invasions.

Third, Port Phillip Bay is threatened by both international and domestic translocation of introduced species. Even though the original source regions for invaders may be overseas, several of the introduced species now found in Port Phillip Bay are likely to be secondary introductions from other areas within Australia (or New Zealand). Examples include *Asterias amurensis*, *Undaria pinnatifida* and *Codium fragile* ssp. *tomentosoides*.

The reasons for the presence of so many introduced species in Port Phillip Bay are complex and doubtless include the historical role of the bay in the colonisation of Australia, its status as a major shipping port, the size of the bay and the diversity of habitats within it, and its essentially clean environments (Harris *et al.* 1996). Solving or minimising the problems posed by these species will be equally complex.

The long history of biotic invasions into Port Phillip Bay and the diversity of the introduced species present are indicative of a system that is highly susceptible to invasions. As such, the bay will continue to be invaded, particularly given that the dominant vector and dominant source bioregions appear to be shifting, which will result in a new suite of potential invasive species. Early invasions of the bay altered its community dynamics at a time when such alterations would have gone largely unnoticed. For example, we have only a rough idea of shore line communities in Port Phillip Bay prior to invasion by *Carcinus maenas*, which appears to be a major structuring species as demonstrated in international and Australian work. The extent to which the bay is buffered from the impacts of these invaders is unknown, and is one of the key issues raised by Harris *et al.* (1996). But work overseas (e.g. *Potamocorbula amurensis* in San Francisco Bay and *Caulerpa taxifolia* in the Mediterranean Sea) unambiguously demonstrate the ability of a single invasive species to force a marine system into states that are stable, but significantly different. Management systems need to be robust to cater for a dynamic marine system that is not only changing over time, but also within which changes can be rapid and unpredictable in direction.

At least 165 known introduced and cryptogenic species of a suspected total of 300–400 among benthic species alone, a suspected invasion rate of 2–3 new invaders each year, and the presence of invasive species in essentially every biotic assemblage in Port Phillip Bay is an impossible problem to solve. Managers will need to set priorities. Most introduced species in Port Phillip Bay will be permanent immigrants, if for no other reason than that the costs of eradication would be difficult to justify. Priority setting is inevitably a political and social activity, only underpinned by science. Introduced species need to be fitted into existing frameworks of defined management objectives for the bay, and control targeted at those that pose the greatest threat to those objectives. Effective targeting requires that management adequately resources the assessment of known and likely impacts.

The history of Port Phillip Bay and the recent increase in the diversity of invasive species and rate of invasions suggest that it is only a matter of time before managers and the public face still more, high profile and potentially destructive pests. Current regional and national initiatives to manage high-risk vectors are an important step in reducing this threat. A key outcome of the present study, however, is that the current international and national focus on international shipping and ballast water, *per se*, is not only insufficient, but may be missing the main threat. While it is arguable that fouling as a threatening vector was more important in the past than it is today, there is little doubt that fouling brought Port Phillip Bay some of its most serious recent additions, including *Undaria pinnatifida*, *Sabella spallanzanii*, *Codium fragile* ssp. *tomentosoides* and, quite possibly, *Asterias amurensis*. Port Phillip Bay, because of its role as a domestic shipping port, a recreational site and site for mariculture operations, is not only a recipient of invasive species from elsewhere in the Australia/New Zealand bioregion, but also constitutes a significant threat to uninvaded regions. As a specific example, the risk of Botany Bay, Adelaide and other temperate ports being inoculated with *Asterias amurensis* is much higher since the species established in Port Phillip Bay, than it was when the pest was restricted to south east Tasmania. Managers need to identify all relevant vectors, respond to each on the basis of the risk posed, and do so in a nested structure, so that actions at the international level encompass and enhance defensive measures instituted for domestic threats. For the foreseeable future, measures that reduce the risks of domestic translocation are likely to be as needed as those that minimise the risks of new invasions from overseas.

Studies such as this provide managers with both a snapshot of the system and an indication of the scale and nature of the threatening processes involved. However, broad-scale monitoring of the distribution, abundance and richness of the introduced biota reaches a point of diminishing returns, and in some cases can even be contra-productive if it focuses remediation on sites that are well surveyed, rather than these of ecological or economic importance. Monitoring is still important, but perhaps would now be done best by targeting likely invasion sites (e.g. disturbed habitats, port areas, mariculture facilities) and high probability next pests, such as the Chinese mitten crab, *Eriochier sinensis*, as to provide options for rapid response and control. This implies that managers encourage the development of sufficient system understanding that these features can be identified.

The susceptibility of Port Phillip Bay to invasions also highlights the continuing threat to the bay and the need for management structures that reduce the frequency of new invaders, both directly from overseas or from domestic sources. The high rate of invasions into Port Phillip Bay means that we are involved in a form of biological roulette, that will inevitably lead to more pests and more alterations to Port Phillip Bay's marine communities and amenities.

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APPENDIX A

Table A1.1. Life form characteristics conducive to ship-borne introduction for macroalgae reported as likely adventives: FI – filamentous (* *Enteromorpha* and *Ulva* spp. have sheet-like thalli with a similar capacity for rapid growth to filamentous forms), CR – crustose habit, HA – heteromorphic life history, PR – perennation from prostrate stolons or discs, FO – known fouling species.

Taxa	Species	Life form				
		FI	CR	HA	PR	FO
Rhodophyta	*Schottera nicaeensis*				+	
	Gymnogongrus crenulatus				+	
	Solieria filiformis					
	Antithamnion cruciatum	+				
	Antithamnionella spirographidis	+				
	Deucalion levringii	+			+	
	Medeiothamnion lyalli	+			+	
	Polysiphonia brodiaei	+				+
	P. senticulosa	+				
	Chondria arcuata				+	
Phaeophyta	*Sorocarpus micromorus*	+				
	Elachista orbicularis		+			
	Discosporangium mesarthrocarpum	+				
	Arthrocladia villosa			+		
	Striaria attenuata			+		
	Stictyosiphon soriferus			+		
	Asperoccocus compressus			+		
	Undaria pinnatifida			+		+
Chrysophyta	*Vaucheria piloboloides*	+				
Chlorophyta	*Ulva fasciata*	+			+	
	Cladophora prolifera	+				
	Codium fragile				+	+
	Caulerpa filiformis				+	

Table A1.2. Life form characteristics conducive to ship-borne introduction for Port Phillip Bay macroalgae with exotic type localities. FI – filamentous (* *Enteromorpha* and *Ulva* spp. have sheet-like thalli with a similar capacity for rapid growth to filamentous forms), CR – crustose habit, HA – heteromorphic life history, PR – perennation from prostrate stolons or discs, FO – known fouling species.

Taxa	Species	Life form				
		FI	CR	HA	PR	FO
Rhodophyta	*Stylonema alsidii*	+				
	Erythrotrichia carnea	+				
	Bangia atropurpurea	+				+
	Audouinella simplex	+				
	A. pacifica	+				
	Nemalion helminthoides			+		
	Gelidium pusillum				+	
	Pterocladia capillacea				+	
	Hildenbrandia rubra	+				
	H. occidentalis	+				
	Peyssonnelia conchicola		+			
	Gymnothamnion elegans	+				
	Antithamnionella ternifolia	+				
	Centroceras clavulatum	+				
	Ceramium flaccidum	+				
	Ceramium rubrum	+				
	Polysiphonia subtilissima	+				

Table A1.2. continued.

Taxa	Species	Life form				
		FI	CR	HA	PR	FO
Phaeophyta	*Acinetospora crinita*	+				
	Ectocarpus siliculosus					+
	E. fasciculatus	+				+
	Feldmannia globifera	+				+
	F. irregularis	+				
	F. lebelii	+				
	Hincksia granulosa	+				+
	H. mitchellae	+				+
	H. ovata	+				
	H. sandriana	+				+
	Kuckuckia spinosa	+				
	Pilayella littoralis	+				+
	Myrionema strangulans	+			+	
	Petrospongium rugosum		+	+		
	Leathesia difformis			+		
	Sphacelaria fusca	+			+	
	Cladostephus spongiosus				+	
	Dictyota dichotoma				+	+
	Cutleria multifida			+		
	Petalonia fascia			+		+
	Scytosiphon lomentaria			+		+
	Colpomenia sinuosa			+		
	C. peregrina			+		
	Punctaria latifolia			+		
Chlorophyta	*Enteromorpha compressa*	+			+	
	E. intestinalis	+			+	+
	Ulva lactuca	+				+
	U. rigida	+				+
	U. stenophylla	+				
	Chaetomorpha aerea	+				
	C. capillaris	+				+
	C. linum	+				+
	Bryopsis plumosa			+		+
	Derbesia marina	+		+		+

Table A1.3. Distribution of southern Australian macroalgae reported as likely adventives. M – Mediterranean, NA – N Atlantic, SA – S Atlantic, NP – N Pacific, SP – S Pacific, I – Indian Ocean: + confirmed presence; ? = reported presence; T = type locality; i = likely introduction.

Taxa	Species	Distribution					
		M	NA	SA	NP	SP	I
Rhodophyta	*Schottera nicaeensis*	T	+				i
	Gymnogongrus crenulatus	+	T				
	Solieria filiformis	+	T	+			
	Antithamnion cruciatum	T	+				
	Antithamnionella spirographidis	T	+				
	Deucalion levringii					T	
	Polysiphonia brodiaei		T		+		
	P. senticulosa				T	i	
	Chondria arcuata				T		
Phaeophyta	*Sorocarpus micromorus*		T		+		
	Elachista orbicularis				T		
	Discosporangium mesarthrocarpum	T					
	Arthrocladia villosa	?	T				

Table A1.3. continued.

Taxa	Species	Distribution					
		M	NA	SA	NP	SP	I
	Striaria attenuata		T	+	+	i	
	Stictyosiphon soriferus	+	T				
	Asperococcus compressus	+	T	+			
	Undaria pinnatifida	i	i		T	i	
Chrysophyta	*Vaucheria piloboloides*	+	T	+	+		
Chlorophyta	*Ulva fasciata*	T	+	+	+		+
	Cladophora prolifera	T	+			i	
	Codium fragile subsp. tomentosoides		i T		+[1]	i	
	Caulerpa filiformis			T			
Total types per region		6	10	1	5	2	0
% of Total		25.0	41.7	4.2	20.8	8.3	0

Note [1] although the type locality for this subspecies is in Europe, it is considered to have been introduced to Europe from Japan.

Table A1.4. Region of original collection of Port Phillip Bay macroalgae with exotic type localities. M – Mediterranean, NA – N Atlantic, SA – S Atlantic, NP – N Pacific, SP – S Pacific, I – Indian Ocean.

Taxa	Species	Distribution					
		M	NA	SA	NP	SP	I
Rhodophyta	*Stylonema alsidii*	+					
	Erythrotrichia carnea		+				
	Bangia atropurpurea		+				
	Audouinella simplex				+		
	A. pacifica				+		
	Nemalion helminthoides		+				
	Gelidium pusillum		+				
	Pterocladia capillacea	+					
	Hildenbrandia rubra	+					
	H. occidentalis						
	Peyssonnelia conchicola						
	Gymnothamnion elegans		+				
	Antithamnionella ternifolia					+	
	Centroceras clavulatum					+	
	Ceramium flaccidum		+				
	Ceramium rubrum		+				
	Polysiphonia subtilissima	+					
Phaeophyta	*Acinetospora crinita*		+				
	Ectocarpus siliculosus		+				
	E. fasciculatus		+				
	Feldmannia globifera	+					
	F. irregularis	+					
	F. lebelii		+				
	Hincksia granulosa		+				
	H. mitchellae		+				
	H. ovata		+				
	H. sandriana	+					
	Kuckuckia spinosa	+					
	Pilayella littoralis		+				
	Myrionema strangulans		+				
	Petrospongium rugosum				+		
	Leathesia difformis		+				
	Sphacelaria fusca		+				
	Cladostephus spongiosus		+				
	Dictyota dichotoma		+				

Table A1.4. continued.

Taxa	Species	Distribution					
		M	NA	SA	NP	SP	I
	Cutleria multifida		+				
	Petalonia fascia		+				
	Scytosiphon lomentaria		+				
	Colpomenia sinuosa		+				
	C. peregrina		+				
	Punctaria latifolia		+				
Chlorophyta	*Enteromorpha compressa*		+				
	E. intestinalis		?				
	Ulva lactuca		+				
	U. rigida		+				
	U. stenophylla				+		
	Chaetomorpha aerea		+				
	C. capillaris	+					
	C. linum		+				
	Bryopsis plumosa		+				
	Derbesia marina		+				
Region totals		9	34	0	4	2	0
% of Total		18.4	69.4	0	8.2	4.1	0

Table A2. Polychaete species from Port Phillip Bay listed with Museum of Victoria (MoV) species numbers and equivalent Port Phillip Bay (PPB) species numbers. MoV equivalent numbers have not been given to all species.

Family	Genus Species	PPB and MoV numbers
Ampharetidae	*Ampharetid* sp1	PPB 182
	Isolda pulchella Müller 1858	PPB 240
	Neosabellides sp1	PPB 633
	Samythella sp1	PPB 356
Arenicolidae	*Branchiomaldane* sp1	PPB 514
Capitellidae	*Barantolla* sp1	PPB 162
	Capitella sp1	PPB 163
	Capitellethus dispar Ehlers 1907	PPB 017
	Capitellid sp2	PPB 706
	Dasybranchus sp1	PPB 290
	Heteromastides sp1	PPB 531
	Heteromastus sp1	PPB 161
	Leiochrides sp1	PPB 696
	Mediomastus sp1	PPB 018
	Notomastus sp1	PPB 093
	Notomastus sp3	PPB 398
	Pulliella sp1	PPB 489
	Scyphoproctus sp1	PPB 258
Chaetopteridae	*Chaetopterus variopedatus* (Renier 1804)	PPB 205; MoV 1718
	Phyllochaetopterus socialis Claparède 1870	PPB 097; MoV 640
Chrysopetalidae	*Paleanotus chrysolepis* Schmarda 1861	PPB 656
Cirratulidae	*Caulleriella bioculatus* (Keferstein 1862)	PPB 506
	Caulleriella sp1	PPB 152
	Caulleriella sp2	PPB 246
	Caulleriella sp3	PPB 497
	Caulleriella sp4	PPB 594
	Cirratulus chrysoderma Claparède 1868	PPB 174
	Chaetozone setosa Malmgren 1867	PPB 011; MoV 653
	Cirratulus cf. *chrysoderma nuchalis Day*	PPB 495
	Cirriformia filigera (Delle Chiaje 1825)	PPB 010
	Cirriformia sp2	PPB 151
	Cirriformia sp3	PPB 493
	Dodecaceria sp1	PPB 642
	Dodecaceria sp2	PPB 617
	Tharyx sp1	PPB 125
	Tharyx marionii sensu Kudenov 1976	PPB 203, 504, 505
Dorvilleidae	*Dorvillea australiensis* (McIntosh 1885)	PPB 150; MoV 316
	Schistomeringos loveni (Kinbergh 1864)	PPB 625; MoV 318
	Protodorvillea sp.	PPB 302; MoV 317
Eunicidae	*Eunice laticeps* Ehlers 1868	PPB 062
	Eunicid sp1	PPB 525
	Lysidice sp2	PPB 377
	Marphysa sp1	PPB 225
	Marphysa sp2	PPB 622
	Nematonereis sp1	PPB 534
	Palola siciliensis	PPB 666
Flabelligeridae	*Diplocirrus* sp1	PPB 149
	Flabelligera sp1	PPB 707
	Pherusa sp1	PPB 206
Glyceridae	*Glycera americana* Leidy 1855	PPB 092; MoV 675
	Glycera capitata Ørsted 1843	PPB 582; MoV 1387
Goniadidae	*Glycinde* sp1	PPB 153
	Goniada sp1	PPB 008; MoV 1403

Table A2. continued.

Family	Genus Species	PPB and MoV numbers
Hesionidae	*Gyptis* sp1	PPB 186
	Hesionid sp1	PPB 378
	Microphthalmus sp1	PPB 634
	Nerimyra sp1	PPB 005
	Nerimyra sp2	PPB 337
Lumbrineridae	*Lumbrineris latreilli* Audouin & Milne-Edwards 1843	PPB 009; MoV 322
Magelonidae	*Magelona dakini* Jones 1978	PPB 064; MoV 749
	Magelona sp2	PPB 254; MoV 1355
	Magelona sp3	PPB 313; MoV 747
	Magelona sp4	PPB 352; MoV 1356
	Asychis glabra Knox & Cameron 1971	PPB 118
Maldanidae	*Axiothella* sp1	PPB 286
	Axiothella sp2	PPB 250
	Petaloproctus terricola Quatrefages 1865	PPB 621
	Praxillella sp1	PPB 094
	Rhodine sp.	PPB 095; MoV 1465
Nephtyidae	*Nephtys inornata* Rainer & Hutchings 1977	PPB 006; MoV 399
	Nephtys australiensis Fauchald 1965	PPB 486; MoV 1163
Nereididae	*Australonereis ehlersi* (Augener 1913)	PPB 432; MoV 1064
	Olganereis edmondsi (Hartman 1954)	PPB 200; MoV 1090
	Simplisetia aequisetis (Augener 1913)	PPB 168; MoV 1061
	Ceratonereis australis Hartmann-Schröder 1980	PPB 662, 509; MoV 1093
	cf. *Eunereis* sp2	PPB 196
	Nereis maxillodentata Hutchings & Turvey 1982	PPB 511, 665; MoV 506
	Micronereis sp1	PPB 597
	Neanthes bassi Wilson 1984	PPB 471; MoV 1062
	Neanthes cricognatha Ehlers 1904	PPB 604; MoV 400
	Nereid sp1	PPB 091
	Nereid sp2	PPB 690
	Neanthes succinea (Leuckart 1847)	PPB 324, 575; MoV 1063
	Platynereis dumerili antipoda Hartman 1954	PPB 513; MoV 507
Oenidae	*Arabella* sp1	PPB 524
	Arabella iricolor iricolor (Montagu 1804)	PPB 334
	Drilonereis sp1	PPB 214
	Notocirrus sp1	PPB 460
Oenonidae	*Oenone* sp1	PPB 249
Onuphidae	*Nothria holobranchiata* Marenzeller 1879	PPB 510
	Onuphis sp1	PPB 430
Opheliidae	*Armandia* sp. (MoV 1369?)	PPB 067; MoV 282
	Armandia sp.	PPB 376; MoV 1370
	Armandia sp.	PPB 380; MoV 1368
	Ophelia sp1	PPB 602
	Polyophthalmus pictus (Dujardin 1839)	PPB 262; MoV 286
	Travisia forbesi	PPB 601
Orbiniidae	*Leitoscoloplos bifurcatus* (Hartman 1957)	PPB 016; MoV 672
	Naineris sp1	PPB 641
	Leodamas ohlini (Ehlers 1901)	PPB 299; MoV 673
	Leitoscoloplos cf. *latibranchus* Day 1977	PPB 607; MoV 680
Oweniidae	*Myriochele* sp1	PPB 109
	Owenia sp.	PPB 096; MoV 260
Paraonidae	*Aedicirea* sp1	PPB 581
	Aricidea fauveli Hartman 1957	PPB 014; MoV 1359
	Aricidea sp1	PPB 606; MoV 1361
	Aricidea suecica cf. *simplex* Day 1963	PPB 431
	Paraonides sp1	PPB 015; MoV 1360

Table A2. continued.

Family	Genus Species	PPB and MoV numbers
	Paraonides sp2	PPB 303; MoV 1357
	Paraonis gracilis (Tauber 1879)	PPB 193; MoV 1358
Pectinariidae	*Pectinaria antipoda* (Schmarda 1861)	PPB 320; MoV 636
Phyllodocidae	*Phyllodoce longipes* Kinberg 1866	PPB 518, 591(part), 060 (part); MoV 511
	cf. *Eteone* sp2	PPB 270
	Mysta platycephala (Augener 1913)	PPB 060 (part); MoV 1178
	Eteone sp3	PPB 587
	Eulalia sp1	PPB 571
	Eumida fuscolutata Eibye-Jacobsen 1991	PPB 335; MoV 510
	Genetyllis sp1	PPB 591
	Mystides sp1	PPB 539
	Paranaitis sp1	PPB 061
Pilargiidae	*Pilargiid* sp1	PPB 132
Poecilochaetidae	*Poecilochaetus* sp1	PPB 265
Polynoidae	*Eunoe* sp1	PPB 003
	Harmothoe spinosa Kinberg 1857	PPB 201
	Lobopelma microscala (Kudenov 1977)	PPB 103, 623, 779
	Paralepidonotus ampulliferus (Grube 1878)	PPB 004
	Malmgreniella phillipensis (Knox & Cameron 1971)	PPB 115
Sabellidae	*Amphiglena mediterranea* (Leydig 1851)	PPB 309
	Branchiomma sp1	PPB 521
	Euchone sp.	MoV 1755
	Euchone sp.	PPB 469; MoV 1802
	Fabricia sp1	PPB 561
	Megalomma sp1	PPB 120
	Myxicola infundibulum (Renier 1804)	PPB 019
	Pseudopotamilla reniformis (Linnaeus 1788)	PPB 552
	Sabella spallanzanii (Gmelin 1791)	MoV 1807
Scalibregmatidae	*Asclerocheilus* sp1	PPB 271
Serpulidae	*Dexiospira* sp1	PPB 565
	Eupomatus ralumianus (Augener 1927)	PPB 522
	Paralaeospira patagonicus Caullery & Mesnil 1897	PPB 553
	Pomatoceros terraenovae Benham 1927	PPB 137
	Serpulid sp1	PPB 544
Sigalionidae	*Sigalion* sp1	PPB 285
Sphaerodoridae	*Sphaerodorid* sp1	PPB 626
	Sphaerodoridium sp1	PPB 187
Spionidae	*Aonides oxycephala* (Sars 1962)	PPB 580; MoV 385
	Boccardia proboscidea Hartman 1940	PPB 066 (part)
	Carazziella phillipensis Blake & Kudenov 1978	PPB 066 (part)
	Carazziella victoriensis Blake & Kudenov 1978	PPB 066 (part)
	Laonice quadridentata Blake & Kudenov 1978	PPB 013, 519; MoV 381
	Malacoceros tripartitus Blake & Kudenov 1978	PPB 288; MoV 1124
	Polydora flava Claparede 1870	PPB 065
	Polydora sp11	PPB 615
	Polydora sp12	PPB 106
	Polydora protuberata Blake & Kudenov 1978	PPB 257
	Polydora sp14	PPB 325
	Polydora socialis (Schmarda 1861)	PPB 184
	Polydora sp3	PPB 220
	Polydora sp4	PPB 357
	Polydora sp9	PPB 576
	Prionospio yuriel Wilson 1990	PPB 012; MoV 396
	Prionospio aucklandica Augener 1913	PPB 063; MoV 1109

Table A2. continued.

Family	Genus Species	PPB and MoV numbers
	Prionospio wambiri Wilson 1990	PPB 183; MoV 395
	Prionospio sp4	PPB 658
	Prionospio coorilla Wilson 1990	PPB 229; MoV 397
	Prionospio paucipinnulata Blake & Kudenov 1978	PPB 295; MoV 1677
	Pseudopolydora paucibranchiata (Okuda 1937)	PPB 164
	Spio pacifica Blake & Kudenov 1978	PPB 423; MoV 389
Syllidae	*Autolytus* sp1	PPB 139
	Brania rhopalophora (Ehlers 1897)	PPB 560
	cf.*exogoninae* sp2	PPB 405
	Eusyllis brevicirrata Knox & Cameron 1971	PPB 192
	Exogone gemmifera Pagenstecher 1862	PPB 140
	Exogone sp1	PPB 543
	Exogone sp2	PPB 007
	Exogone sp3	PPB 089
	Exogone sp4	PPB 389
	Exogone sp5	PPB 390
	Exogone sp7	PPB 474
	Exogone sp9	PPB 528
	Haplosyllis spongicola (Grube 1855)	PPB 527
	Langerhansia cornuta (Rathke 1843)	PPB 636
	Opisthosyllis sp1	PPB 392
	Opisthosyllis sp2	PPB 584
	Pionosyllis sp1	PPB 277
	Pionosyllis sp2	PPB 490
	Pionosyllis sp3	PPB 515
	Sphaerosyllis semiverrucosa Ehlers 1913	PPB 540
	Sphaerosyllis sp10	PPB 156
	Sphaerosyllis sp2	PPB 542
	Sphaerosyllis sp3	PPB 599
	Sphaerosyllis sp6	PPB 517
	Sphaerosyllis sp8	PPB 399
	Sphaerosyllis sp9	PPB 529
	Streptosyllis sp1	PPB 427
	Streptosyllis sp3	PPB 481
	Streptosyllis sp4	PPB 554
	Syllides longocirrata Ørsted 1845	PPB 447
	Syllides sp2	PPB 585
	Syllis gracilis	PPB 341
	Syllis sp3	PPB 397
	Syllis sp4	PPB 555
	Syllis sp5	PPB 631
	Syllis sp6	PPB 440
	Trypanosyllis sp2	PPB 586
	Trypanosyllis zebra (Grube 1860)	PPB 526
	Typosyllis hyalina (Grube 1863)	PPB 480
	Typosyllis sp1	PPB 344
	Typosyllis sp3	PPB 446
Terebellidae	*Amaeana trilobata* (Sars 1863)	PPB 131; MoV 642
	Amphitrite rubra Hutchings & Glasby 1988	PPB 348; MoV 1264
	Hauchiella sp. MoV 1271	PPB 450; MoV 1271
	Lysilla sp. MoV 1273	PPB 345; MoV 1273
	Thelepus sp. MoV 1277	PPB 523; MoV 1277
	Eupolymnia koorangia Hutchings & Glasby 1988	PPB 204
	Lanassa sp. MoV 1274	PPB 632; MoV 1274
	Pista australis Hutchings & Glasby 1988	PPB 154 (part); MoV 538

Table A2. continued.

Family	Genus Species	PPB and MoV numbers
	Pista sinusa Hutchings & Glasby 1988	PPB 154 (part); MoV 1225
	Polycirrus porcata Knox & Cameron 1971	PPB 317; MoV 1255
	Proclea sp.	PPB 185; MoV 1275
	Proclea sp.	PPB 516; MoV 1276
	Thelepus extesus Hutchings & Glasby 1987	PPB 400; MoV 1187
Trichobranchidae	*Artacamella dibranchiata* Knox & Cameron 1971	PPB 391; MoV 1269
	Tererellides sp.	PPB 105; MoV 643
	Trichobranchid sp1	PPB 252
	Trichobranchus sp	PPB 226; MoV 630

Table A3. Mollusc species from Port Phillip Bay listed with Museum of Victoria (MoV) and equivalent Port Phillip Bay (PPB) species numbers. Sample phase indicates if species was collected during PPBES phase 1, 2, 3 or the scallop dredging effects study (SDE).

Family/species	PPB & MoV species numbers	Sample phase
Bivalves		
Arcidae		
Anadara trapezia (Deshayes 1840)	PPB 179; MoV 1561	1, 3, SDE
Barbatia squamosa (Lamarck 1819)	PPB 549; MoV 1723	1
Cardiidae		
Fulvia tenuicostata (Lamarck 1819)	PPB 068; MoV 180	1, 2, 3, SDE
Nemocardium (Pratulum) thetidis (Hedley 1902)	PPB 492; MoV 1569	1, 3, SDE
Venericardia bimaculata Deshayes 1852	PPB 056; MoV 181	1, 2, 3
Condylocardiidae		
Benthocardiella chapmani (Gatliff & Gabriel 1912)	PPB 230; MoV 1731	1
Radiocondyla pectinata Tate & May 1901	PPB 657; MoV 1732	1
Corbulidae		
Corbula cf. *gibba* (Olivi 1792)	MoV 1556	3, SDE
Crassatellidae		
Cuna concentrica Hedley 1902	PPB 429; MoV -	1
Cyamiidae		
Cyamiomactra balaustina Gould 1861	MoV 187	1
Cyamiomactra mactroides Tate & May 1900	PPB 373; MoV 188	1, 3
Cyamiomactra nitida Hedley 1908		1
Cyamiomactra communis Hedley 1905	MoV 186	SDE
Gastrochaenidae		
Gastrochaena tasmanica Tennison-Woods 1876	PPB 550; MoV 192	1
Hiatellidae		
Hiatella australis (Lamarck 1818)	MoV 196	SDE
Lasaeidae		
Melliteryx acupuncta (Hedley 1902)	PPB 025; MoV 1701	1, 2, SDE
Laternulidae		
Laternula creccina Reeve 1860	PPB 190; MoV 1584	1, 3
Limidae		
Limaria sp.		3
Lucinidae		
Wallucina assimilis Angas 1868	PPB 644; MoV 1740	1
Mactridae		
Mactra antecedens (Iredale 1930)	PPB 342; MoV 1741	1
Mactra jacksonensis Smith 1885	PPB 496; MoV 868	1, 3
Spisula trigonella (Lamarck 1819)	PPB 253; MoV 1703	1, 2
Raeta pulchella (Adams & Reeve 1851)	MoV 1567	3
Mesodesmatidae		
Paphies elongata (Reeve 1854)	PPB 306; MoV 1742	1
Montacutidae		
Montacuta semiradiata Tate 1889	PPB 026; MoV 1700	1, 2, 3
Mysella donaciformis Angas 1878	PPB 147, 057; MoV 889	1, 3, SDE
Myochamidae		
Myodora brevis (Sowerby 1829)	PPB 263 ; MoV -	1
Mytilidae		
Amygdalum beddomei Iredale 1924	MoV 208	SDE
Modiolus delfinicus Iredale 1924	PPB 459; MoV 943	1
Musculus ulmus Iredale 1936	PPB 260; MoV 207	1, 2
Musculista senhousia Benson 1842		
Mytilus edulis planulatus Lamarck 1819	PPB 134; MoV 1562	1, 2, 3
Trichomusculus barbatus Reeve 1858	PPB 454; MoV 206	1
Nuculidae		
Nucula pusilla Angas 1877	PPB 055, 603; MoV 1585	1, 3, SDE
Nucula obliqua Lamarck 1819	PPB 022; MoV 886	1, 2, 3, SDE

Table A3. continued.

Family/species	PPB & MoV species numbers	Sample phase
Ostreidae		
Ostrea angasi Sowerby 1871	PPB135; MoV 1557	1, 2, 3, SDE
Pectinidae		
Pecten alba Reeve,1852	PPB 034; MoV 315	1, 3, SDE
Periplomatidae		
Offadesma angasi (Crosse and Fischer 1834)	PPB 130; MoV 1702	1, SDE
Psammobiidae		
Soletellina alba (Lamarck 1818)	PPB 315; MoV -	1
Pteriidae		
Electroma georgiana (Quoy and Gaimard 1835)	PPB 198; MoV 1345	1, 2, 3, SDE
Semelidae		
Theora lubrica (Gould 1861)	PPB 024; MoV 1565	1, 2, 3, SDE
Solemyidae		
Solemya australis Lamarck 1818	PPB 610; MoV 1704	1
Solenidae		
Solen vaginoides Lamarck 1818	PPB 379; MoV 213	
Sportellidae		
Anisodonta subalata (Gatliff and Gabriel 1910)	PPB 347; MoV 1564	1, 2, 3, SDE
Tellinidae		
Tellina (Macomona) deltoidalis Lamarck 1818	PPB 705; MoV 1745	1
Tellina (Tellinella) albinella Lamarck 1818	PPB 146; MoV 925	1, 2
Tellina (Macomona) mariae (Tennison-Woods 1976)	PPB 199; MoV 888	1, SDE
Thraciidae		
Thracia lincolnensis Verco 1907	PPB 228; MoV 217	1, 2
Ungulinidae		
Diplodonta globularis (Lamarck 1818)	PPB 086; MoV -	1, 2
Veneridae		
Bassina (Callanaitis) disjecta (Perry 1811)	PPB 028;MoV 1560	1, 2, 3, SDE
Chioneryx cardioides (Lamarck 1819)	PPB 027; MoV 1566	1, 2, 3, SDE
Dosinia circinaria Deshayes 1853	PPB 321; MoV 1568	1, 2, 3
Katylesia rhytiphora (Lamy 1935)	PPB 148, 301; MoV -	1
Notocallista kingi (Gray 1826)	PPB 280; MoV -	1
Placamen placidum (Philippi 1844)	MoV 941	SDE
Tawera gallinula (Lamarck 1818)	PPB 498; MoV 1753	1, 3
Venerupis anomala (Lamarck 1818)	MoV 1563	1, 3, SDE
Gastropods		
Acmaidae		
Notoacmaea profunda calamus (Crosse & Fischer 1864)	PPB 387; MoV -	1
Aeolidiidae		
Aeolid sp.	MoV1573	3
Cerberilla incola Burn 1974	PPB 256; MoV 1574	1, 3, SDE
Unknown sp.	MoV 1572	3
Aglajidae		
Aglaja queritor (Burn 1974)	PPB 698; MoV 1721	1
Philinopsis taronga (Allan 1933)	PPB 691; MoV 1575	3
Barleeidae		
Badepigrus pupoides (Adams 1865)	PPB 388; MoV 1743	1
Buccinidae		
Buccinid sp.	PPB 136; MoV 1725	1
Cominella eburnea Reeve 1846	PPB 483; MoV 1726	1
Cerithiidae		
Bittium granarium (Kiener 1842)	PPB 166; MoV 832	1
Columbellidae		
Dentimitrella sp.	PPB 444; MoV 1729	1
Dentimitrella sp.	PPB 202; MoV 1730	1

Table A3. continued.

Family/species	PPB & MoV species numbers	Sample phase
Conidae		
Conus anemone Lamarck 1810	PPB 484; MoV 1733	1
Costasiellidae		
Costasiella sp.	MoV 1571	3
Calyptraeidae		
Calyptraea calyptraeformis Lamarck 1822	PPB 052; MoV 790	1, 3, SDE
Dialidae		
Diala magna Yaye 1891		3
Diala pagodula A. Adams 1862	PPB 697; MoV 1727	1
Diala semistriata Phillipi 1836	PPB 044; MoV 1728	1
Dorididae		
Doris sp.	PPB 508; MoV 1736	1
Fissurellidae		
Amblychilepas omicron (Crosse & Fischer 1864)	PPB 699; MoV 1737	1
Amblychilepas sp.	PPB 629; MoV 1738	1
Haminoeidae		
Haminoea maugeansis Burn 1966	PPB 453; MoV 1578	1, 3
Liboa brevis (Quoy & Gaimard 1833)	PPB 382; MoV 1577	3, SDE
Hermaeidae		
Aplysiopsis formosa Pruvot-Fol 1953		
Iravadiidae		
Nozeba sp.	PPB 053; MoV -	1, 2
Marginellidae		
Austroginella johnsoni (Petterd 1884)	PPB 426; MoV 873	1
Muricidae		
Bedeva paivae (Crosse 1864)	PPB 811; MoV 811	1, SDE
Pterynotus triformis (Reeve 1845)		1
Nassariidae		
Nassarius burchardi (Phillipi 1851)		1
Nassarius nigellus (Reeve 1854)	PPB 084; MoV 1699	1, 2 SDE
Nassarius pauperus (Gould 1852)	PPB 592; MoV 866	1
Nassarius pyrrhus (Menke 1843)		3
Naticidae		
Eunaticina umbilicata (Quoy & Gaimard 1833)	PPB 312, MoV 1559	1, 3
Polinices aulacoglossa (Pilsabry & Vanatta 1908)	PPB 054, MoV -	1
Polinices conicus (Lamarck 1822)	MoV1558	3
Sinum zonale (Quoy & Gaimard 1833)	PPB 255; MoV 828	1, SDE
Okenidae		
Okenia sp.	MoV 1576	SDE
Philinidae		
Philine angasi (Crosse & Fischer 1865)	PPB 104; MoV 798	1, 2, 3, SDE
Pyramidellidae		
Pyrgiscus fuscus (A. Adams 1853)	PPB 020; MoV 1579	1, 2, 3, SDE
Chemnitzia acicularis (A. Adams 1853)		3
Chemnitzia mariae Tenison Woods 1876	PPB 021	1
Retusidae		
Retusa sp.	PPB 085 ; MoV -	1
Scissurellidae		
Scissurella atkinsoni Tennison-Woods 1877	MoV 803	3
Stiligeridae		
Ercolania sp. MoV 1744	PPB 608; MoV 1744	1
Trochidae		
Clanculus cf. *aloysii* Tennison-Woods 1876	MoV 1580	3
Clanculus limbatus (Quoy & Gaimard 1834)	PPB 385; MoV -	1
Clanculus plebejus (Phillipi 1851)	PPB 386; MoV -	1

Table A3. continued.

Family/species	PPB & MoV species numbers	Sample phase
Clanculus sp. juv.	MoV 1581	3
Ethminolia vitiliginea (memke 1843)	PPB 284; MoV 836	1, 3, SDE
Phasianotrochus irisocontes (Quoy & Gaimard 1834)	PPB 650; MoV 1746	1
Turbinidae		
Astralium aurea (Jonas 1844)	PPB 640; MoV -	1
Munditia hedleyi (Pritchard & Gatliff 1899)	PPB 589; MoV 1739	1
Turridae		
Guraleus sp.	PPB 189; MoV 816	1, SDE
Zephyrinidae		
Janolus hyalinus (Alder & Hancock 1854)		
Chitons		
Acanthochitonidae		
Acanthochitona granostriatus Pilsbry 1894	PPB 618 (part); MoV 1734	
Acanthochitona gatliffi Ashby 1919	PPB 618 (part); MoV 1747	1
Acanthochitona pilsbryi Sykes 1896	PPB 618 (part), 718; MoV 1735	1, 3
Notoplax (Notoplax) wilsoni Sykes 1896	MoV 1583	3
Chitonidae		
Chiton (Rhyssoplax) tricostalis Pilsbry 1894	PPB 659; MoV 1750	1
Ischnochitonidae		
Ischnochiton carinulatus (Reeve 1847)	PPB701 (part), 643; MoV 1582	1, 3
Subterenochiton gabrieli (Hull 1912)	PPB 457; MoV 783	1, 3
Leptochitonidae		
Leptochiton matthewsianus (Bednall 1906)	PPB 682; MoV 1749	1
Cephalopods		
Octopodidae		
Octopus superciliosus Quoy & Gaimard 1832	PPB 234, MoV 1719	1

Table A4 Species of crustacea from soft sediments in Port Phillip Bay listed with Museum of Victoria (MoV) species numbers and equivalent Port Phillip Bay (PPB) species numbers. MoV numbers are used as species epithets for undescribed or unidentifiable species. Each species is registered on the Museum of Victoria database TAXA. Two additional introduced species from other habitats are included.

Taxa/Family	Genus/species	PPB & MoV numbers
Ostracoda: Myodocopida		
Cylindroleberididae	*Archasterope* sp.	PPB158, 224; MoV 1019
	Cycloleberis sp.	PPB436; MoV 1018,
	Parasterope sp.	PPB029; MoV 4
Cypridinidae	*Vargula* sp.	PPB032; MoV 1025
	Cypridinodes sp.	PPB030; MoV 8
	Skogsbergia sp.	MoV 17
	Vargula thielei (Chapman 1907)	PPB121, 248; MoV 1020
Philomedidae	*Euphilomedes* sp.	PPB099; MoV 1021
	Euphilomedes ferox Poulsen 1962	PPB281, 358; MoV 1026
	Euphilomedes sp.	MoV 1631
	Euphilomedes sp.	PPB031; MoV 18
	Euphilomedes sp.	MoV 20
	Philomedid sp. (specimen lost, family doubtful)	PPB247; MoV 1023
Philomedidae	*Scleroconcha* sp.	MoV 1754
Rutidermatidae	*Alternochelata* cf. *lizardensis* Kornicker 1982	PPB117; MoV 23
Sarsiellidae	*Sarsiella magna* (Poulsen 1965)	PPB107; MoV 25
Ostracoda: Podocopida		
Bairdiidae	*Bairdia* sp.	PPB660; MoV 1024
Cytheridae	*Cythereis* sp.	PPB124; MoV 1022
Cirripedia		
Archaeobalanidae	*Elminius modestus* Darwin 1854	PPB396; MoV 996
Balanidae	*Balanus variegatus* Darwin 1854	PPB619; MoV 1002
Leptostraca		
Nebaliidae	*Nebalia* sp. MoV1666	PPB329; MoV 1666
Stomatopoda		
Nannosquillidae	*Austrosquilla osculans* (Hale 1924)	PPB282; MoV 1619
Squillidae	*Squilla miles* Hess 1865	PPB680; MoV 721
Mysidacea		
Mysidae	*Australomysis incisa* (Sars 1883)	PPB501; MoV 617
	Haplostylus tattersalli Fenton 1990	PPB437; MoV 616
	Heteromysis cf. *waitei* Tattersall 1927	PPB500; MoV 1015
	Heteromysis sp.	PPB577; MoV 1612
	Paranchialina angusta (Sars 1883)	PPB499; MoV 1014
	Siriella vincenti Tattersall 1927	PPB076; MoV 1012
	Tenagomysis tasmaniae Fenton 1991	PPB227; MoV 1011
	Unknown sp. (single specimen lost)	PPB502; MoV 1614
Cumacea		
Bodotriidae	*Gephyrocuma pala* Hale 1936	PPB269; MoV 67
	Glyphocuma bakeri Hale 1936	PPB283; MoV 78
	Pomacuma australiae Zimmer 1921	PPB574; MoV 42
Diastylidae	*Anchistylis longipes* Hale 1945	PPB287; MoV 984
	Dimorphostylis cottoni Hale 1936	PPB048; MoV 65
Gynodiastylidae	*Dicoides fletti* Hale 1946	PPB297; MoV 51
	Gynodiastylis ambigua Hale 1946	PPB264; MoV 53
	Gynodiastylis concava Hale 1946	PPB462; MoV 59
	Gynodiastylis sp.	PPB418; MoV 1611
	Gynodiastylis sp.	PPB512; MoV 89
Leuconidae	*Austroleucon levis* (Hale 1945)	PPB047; MoV 45
	Eudorella sp.	PPB221; MoV 983

Table A4 continued.

Taxa/Family	Genus/species	PPB & MoV numbers
Tanaidaecea		
Apseudidae	*Apseudes* sp.	PPB223; MoV 1616
	Apseudes sp.	PPB651; MoV 1617
	Apseudes sp.	PPB129 ; MoV 568
	Apseudid sp.	PPB568 ; MoV 113
	Apseudid sp.	PPB569 ; MoV 575
Kalliapseudidae	*Kalliapseudes* sp.	PPB507 ; MoV 104
Paratanaidae	cf. *Leptochelia* sp.	PPB331; MoV 994
	cf. *Leptochelia* sp.	PPB100; MoV 111
Isopoda		
Anthuridae	*Amakusanthura olearia* (Poore & Lew Ton 1985)	PPB322 (part); MoV 355
	Apanthura isotoma Poore & Lew Ton 1985	PPB433; MoV 341
	Apanthura styphelia Poore & Lew Ton 1985	PPB322 (part); MoV 967
	Haliophasma canale Poore 1975	PPB445; MoV 338
	Haliophasma cribense Poore 1975	MoV 353
	Haliophasma cycneum Poore 1975	PPB712; MoV 966
	Haliophasma pugnatum Poore 1975	MoV 1681
	Haliophasma yarra Poore 1975	PPB685; MoV 965
Paranthuridae	*Bullowanthura pambula* Poore 1978	PPB075,441(part); MoV 348
	Colanthura peroni Poore 1981	PPB655; MoV 968
	Leptanthura boweni Poore 1981	PPB402; MoV 970
	Leptanthura diemenensis (Haswell 1884)	PPB075,441(part); MoV 345
	Leptanthura nunana Poore 1978	PPB119; MoV 972
	Ulakanthura lara Poore 1978	PPB434; MoV 349
	Ulakanthura marlee Poore 1981	PPB420; MoV 601
	Janiridae Ianiropsis sp.	PPB463; MoV 1597
	Janiridae Ianiropsis sp.	PPB442; MoV 980
Joeropsididae	*Joeropsis* sp.	PPB578; MoV 356
Munnidae	*Uromunna phillipi* Poore 1984	PPB668; MoV 414
Stenetriidae	*Stenobermuda* sp.	PPB330; MoV 964
Cirolanidae	*Cirolana harfordi* (Lockington 1877)	
	Eurydice tarti Bruce 1986	PPB488; MoV 973
	Natatolana gorung Bruce 1986	PPB191 (part); MoV 971
	Natatolana longispina Bruce 1986	PPB191 (part); MoV 242
	Natatolana woodjonesi (Hale 1924)	PPB033; MoV 241
Gnathiidae	*Gnathia camponotus* Cohen & Poore 1994	MoV 1607
Limnoriidae	*Limnoria raruslima* Cookson 1991	PPB176; MoV 963
Serolidae	*Heteroserolis australiensis* (Beddard 1884)	MoV 1270
	Heteroserolis tuberculata (Grube 1975)	PPB536; MoV 238
	Serolina acaste Poore 1987	PPB296 (part); MoV 959
	Serolina clarella Poore 1987	PPB296 (part); MoV 960
	Serolina minuta (Beddard 1884)	PPB296 (part); MoV 239
Sphaeromatidae	*Cerceis acuticaudata* (Haswell 1882)	PPB694; MoV 979
	Cilicaea latreillii Leach 1818	PPB404; MoV 975
	Cilicaeopsis granulata (Whitelegge 1902)	PPB579; MoV 235
	Cymodoce coronata (Haswell 1882)	PPB307; MoV 977
	Cymodoce gaimardii (Milne Edwards 1840)	PPB748; MoV 976
	Exosphaeroma sp.	PPB435; MoV 981
	Paracerceis sculpta (Holmes 1904)	
	Platynympha longicaudata (Baker 1908)	PPB693; MoV 978
	Sphaeromatid sp.	PPB273; MoV 1507
	Syncassidina aestuaria Baker 1929	PPB369; MoV 1600
Arcturidae	*Neastacilla deducta* Hale 1925	PPB363; MoV 248
Chaetiliidae	*Austrochaetilia capeli* Poore 1978	PPB491; MoV 957
Idoteidae	*Crabyzos longicaudatus* Bate 1863	PPB695; MoV 956
	Euidotea bakeri (Collinge 1917)	PPB654; MoV 958

Table A4 continued.

Taxa/Family	Genus/species	PPB & MoV numbers
Amphipoda		
Caprellidae	*Caprella equilibra* Say 1818	PPB672; MoV 684
	Caprella penantis Leach 1814	PPB673; MoV 1029
	Caprella scaura Templeton 1836	PPB300; MoV 1030
	Metaprotella cf. *haswelliana* Mayer 1882	PPB670; MoV 1031
	Metaprotella sp.	PPB259; MoV 1032
	Paracaprella alata Mayer 1903	PPB051; MoV 686
	Pseudoprotomima sp.	PPB671; MoV 1033
Phtisicidae	*Paraproto spinosa* (Haswell 1885)	PPB663; MoV 690
Ampeliscidae	*Ampelisca australis* Haswell 1879	PPB689; MoV 1036
	Ampelisca euroa Lowry & Poore 1985	PPB077; MoV 130
	Ampelisca toora Lowry & Poore 1985	PPB546; MoV 131
	Byblis mildura Lowry & Poore 1985	PPB038; MoV 132
Amphilochidae	*Amphilochid* sp.	PPB551; MoV 1038
	Ampithoe sp.	PPB661; MoV 1714
	Ampithoe sp.	PPB467; MoV 1303
Ampithoidae	*Cymadusa* sp.	PPB207; MoV 1713
Anamixidae	*Anamixis* sp.	PPB458; MoV 1715
Aoridae	*Aora mortoni* (Haswell 1879)	PPB466; MoV 591
	Protolembos drummondae Myers 1988	MoV 1670
Colomastigidae	*Colomastix* sp.	MoV 2328
Corophiidae	*Ampelisciphotis* sp.	PPB464; MoV 1299
	Cerapus sp.	PPB374; MoV 624
	Cheiriphotis sp.	MoV 548
	Corophium acherusicum Costa 1853	PPB611; MoV 1301
	Corophium insidiosum Crawford 1937 I	PPB611; MoV 1795
	Corophium sextonae Crawford 1937	MoV 2793
	Gammaropsis sp.	PPB562 ; MoV 1305
	Photis sp.	PPB126; MoV 1300
	Rhinoecetes sp.	PPB294; MoV 1302
	Xenocheira fasciata Haswell 1879	PPB465; MoV 151
Cyproideidae	*Moolapheonoides poontee* Barnard 1974	MoV 142
Dexaminidae	*Paradexamine churinga* Barnard 1972	PPB639; MoV 291
	Paradexamine dandaloo Barnard 1972	PPB563; MoV 1035
	Paradexamine lanacoura Barnard 1972	PPB461; MoV 293
	Paradexamine moorehousei Sheard 1938	PPB128; MoV 294
	Paradexamine thadalee Barnard 1972	PPB669; MoV 604
	Paradexamine sp.	PPB686; MoV 1043
Eusiridae	*Harpinioides* sp.	PPB210; MoV 264
	Tethygeneia sp.	PPB530; MoV 1304
Hyalidae	*Allorchestes compressa* Dana 1852	PPB714; MoV 1312
Iphimediidae	*Iphimediid* sp.	PPB171; MoV 1751
	Iphimediid sp.	PPB274; MoV 1752
Isaeidae	*Aetiopedes gracilis* Moore & Myers 1988	PPB425; MoV 359
Ischyroceridae	*Ericthonius* sp.	PPB365; MoV 1040
	Ischyrocerus sp.	PPB078; MoV 554
	Jassa marmorata Holmes 1903	MoV 1789
Ischyroceridae	*Jassa* sp.	PPB266; MoV 553
Leucothoidae	*Leucothoe assimilis* Barnard 1974	PPB175; MoV 133
	Leucothoe commensalis Haswell 1880	PPB720; MoV 456
	Paraleucothoe novaehollandiae Haswell 1880	PPB215; MoV 1034
Liljeborgiidae	*Liljeborgia dubia* (Haswell 1879)	PPB298; MoV 467
	Liljeborgia sp.	PPB222; MoV 1042
Lysianassidae	*Amaryllis macrophthalma* Haswell 1879	PPB276; MoV 146
	Cyphocarid sp.	PPB564; MoV 1317
—--	*Endevoura* cf. *mirabilis* Chilton 1921	PPB681; MoV 297

Table A4 continued.

Taxa/Family	Genus/species	PPB & MoV numbers
	Euonyx sp.	PPB211; MoV 1329
	Hippomedon cf. *denticulatus* (Bate 1857)	PPB083; MoV 1314
	Lysianassid sp.	PPB082; MoV 1318
	Lysianassid sp.	PPB421; MoV 1319
	Lysianassid sp.	PPB419; MoV 1320
	Lysianassid sp.	PPB355; MoV 1321
	Lysianassid sp.	PPB451; MoV 1322
	Lysianassid sp.	PPB473; MoV 1323
	Lysianassid sp.	PPB566; MoV 1324
	Lysianassid sp.	PPB567; MoV 1325
	Lysianassid sp.	PPB600; MoV 1326
	Lysianassid sp.	PPB612; MoV 1327
	Lysianassid sp.	PPB367; MoV 1328
	Orchomene sp.	PPB408; MoV 1330
	Parawaldeckia sp.	PPB470; MoV 1315
	Parawaldeckia sp.	MoV 290
	Sheardella tangaroa Lowry 1984	PPB472; MoV 1313
Melitidae	*Ceradocus rubromaculatus* (Stimpson 1855)	PPB279; MoV 363
	Ceradocus serratus (Bate 1862)	PPB127; MoV 364
	Dulichiella australis (Haswell 1879)	MoV 369
	Gammarella berringar (Barnard 1974)	PPB713; MoV 365
	Gammarella numbadi (Barnard 1974)	PPB583; MoV 1306
	Maera cf. *mastersi* (Haswell 1879)	PPB333; MoV 370
	Maera sp.	PPB532; MoV 1406
	Mallacoota diemenensis (Haswell 1879)	PPB468; MoV 482
	Melitid. sp.	PPB559; MoV 1459
	Melitid sp.	PPB688; MoV 1407
	Melitid sp.	PPB482; MoV 1409
Melphidippidae	*Cheirocratus bassi* Barnard & Drummond 1982	PPB678; MoV 595
	Hornellia sp.	PPB338; MoV 357
	Hornellia micramphopus (Stebbing 1910)	PPB556; MoV 1308
	Maerella sp.	PPB340; MoV 1796
Oedicerotidae	*Oediceroides* sp.	PPB318; MoV 1352
	Oedicerotid sp.	PPB036; MoV 1351
	Oedicerotid sp.	PPB310; MoV 1354
	Oedicerotid sp.	PPB428; MoV 303
Paracalliopiidae	Paracalliope australis Barnard & Drummond 1992	MoV 1669
Phoxocephalidae	*Birubius babaneekus* Barnard & Drummond 1978	PPB035; MoV 155
	Birubius cartoo Barnard & Drummond 1978	PPB049; MoV 157
	Birubius gelarus Barnard & Drummond 1978	PPB267; MoV 1046
	Birubius jirrandus Barnard & Drummond 1978	PPB547; MoV 1049
	Birubius lowannus Barnard & Drummond 1978	PPB570; MoV 160
	Birubius maamus Barnard & Drummond 1978	PPB291; MoV 161
	Birubius maldus Barnard & Drummond 1978	MoV 162
	Birubius mayamayi Barnard & Drummond 1978	PPB079; MoV 152
	Birubius myallus Barnard & Drummond 1978	MoV 1051
	Birubius panamunus Barnard & Drummond 1978	PPB037; MoV 164
	Birubius taldens Barnard & Drummond 1978	PPB422; MoV 1050
	Birubius yandus Barnard & Drummond 1978	MoV 166
	Birubius yorlunus Barnard & Drummond 1978	PPB605; MoV 489
	Booranus wangoorus Barnard & Drummond 1978	MoV 1053
	Brolgus tattersalli (Barnard 1958)	PPB414; MoV 168
	Kulgaphoxus cadgeeus Barnard & Drummond 1978	PPB073; MoV 1048
	Limnoporeia kalduke Barnard & Drummond 1978	MoV 1045
	Limnoporeia maranowe Barnard & Drummond 1978	MoV 1054

Table A4 continued.

Taxa/Family	Genus/species	PPB & MoV numbers
	Limnoporeia woorake Barnard & Drummond 1978	MoV 170
	Matong matong Barnard & Drummond 1978	PPB557; MoV 171
	Metaphoxus tuckatuck Barnard & Drummond 1978	MoV 1044
	Parharpinia villosa Haswell 1879	PPB558; MoV 1047
	Phoxocephalus kukathus Barnard & Drummond,1978	PPB438; MoV 172
	Tipimegus kalkro Barnard & Drummond 1978	MoV 1055
	Pontharpinia pinguis (Haswell 1880)	MoV 174
	Yammacoona kunarella Barnard & Drummond 1978	PPB609; MoV 175
Platyischnopidae	*Platyischnopus mam* Barnard & Drummond 1979	MoV 607
Stenothoidae	*Stenothoe* sp.	MoV 1671
Synopiidae	*Metatiron* sp.	PPB439; MoV 1353
	Synopia sp.	PPB687; MoV 136
	Tiron sp.	PPB353; MoV 1039
Urohaustoriidae	*Urohaustorius pulcus* Barnard & Drummond 1982	MoV 125
Urothoidae	*Urothoides kurrawa* Barnard & Drummond 1979	MoV 126
Caridea		
Alpheidae	*Alpheus euphrosyne* De Man 1897	PPB113; MoV 998
	Alpheus novaezealandiae Miers 1876	PPB332; MoV 997
	Athanopsis australis Banner & Banner 1982	PPB674; MoV 999
Crangonidae	*Philocheras victoriensis* (Fulton & Grant 1902)	PPB039; MoV 1000
Hippolytidae	*Hippolyte caradina* Holthuis 1947	PPB635; MoV 1003
Palaemonidae	*Macrobrachium intermedium* (Stimpson 1860)	PPB172; MoV 1001
Pasiphaeidae	*Leptochela sydniensis* Dakin & Colefax 1940	MoV 723
Thalassinidea		
Axiidae	*Axiopsis werribee* Poore & Griffin 1979	PPB050; MoV 1004
Callianassidae	*Biffarius arenosus* (Poore 1975)	PPB343; MoV 1005
	Callianassa ceramicus Fulton & Grant 1906	PPB415; MoV 1007
	Calliax aequimana (Baker 1907)	PPB679; MoV 1006
	Neocallichirus limosus (Poore 1975)	PPB108; MoV 719
	Trypaea australiensis Dana 1853	PPB715; MoV 1008
Upogebiidae	*Upogebia dromana* Poore 1975	MoV 1009, PPB070
Anomura		
Diogenidae	*Paguristes brevirostris* Baker 1905	PPB624, 588; MoV 1650
	Paguristes pugil McCulloch 1913	MoV 697
	Paguristes sulcatus Baker 1905	PPB664; MoV 1591
Galatheidae	*Galathea australiensis* Stimpson 1858	MoV 92
	Phylladiorhynchus pusillus (Henderson 1885)	MoV 91
Porcellanidae	*Polyonyx transversus* (Haswell 1882)	PPB197; MoV 1592
Brachyura		
Dromiidae	*Stimdromia lamellata* (Ortmann 1894)	MoV 1760
Goneplacidae	*Hexapus granuliferus* Campbell & Stephenson 1970	MoV 702
	Litocheira bispinosa Kinahan 1856	MoV 991, PPB173
Grapsidae	*Brachynotus spinosus* (Milne Edwards 1837)	MoV 709, PPB177
Hymenosomatidae	*Halicarcinus ovatus* Stimpson 1853	MoV 701, PPB370
	Halicarcinus rostratus (Haswell 1882	MoV 700, PPB155
Leucosiidae	*Philyra undecimspinosa* Kinahan 1856	MoV 741, PPB538
	Phylixia intermedia Miers 1886	MoV 711, PPB122
Majidae	*Notomithrax minor* (Filhol 1885)	MoV 706, PPB080
	Pyromaia tuberculata (Lockington 1877)	MoV 1659
Ocypodidae	*Macrophthalmus latifrons* Haswell 1882	MoV 990
Pilumnidae	*Heteropilumnus fimbriatus* (Milne Edwards 1834)	PPB533; MoV 988
Pinnotheridae	*Pilumnus rufopunctatus* Stimpson 1858	PPB802; MoV 989
	Pinnotheres hickmani (Guiler 1950)	PPB123; MoV 745
Portunidae	*Macropipus corrugatus* (Pennant 1777)	PPB371; MoV 707
	Nectocarcinus integrifrons (Latreille 1825)	PPB328; MoV 987

Table A5. Echinoderms recorded from Port Phillip Bay. MoV indicates an unpublished record of the species for the area and that specimens exist in the collections of the Museum of Victoria.

Class/species	First Australian record	First Port Phillip Bay record
Crinoidea		
Cenolia trichoptera (Muller 1846)	pre-1846	1880's (Bell 1888)
Cenolia tasmaniae (A H Clark 1918)	pre-1918	1979 (MoV)
Comatulella brachiolata (Lamarck 1816)	pre-1816	1880's (Bell 1888)
Ptilometra macronema (Muller 1846)	pre-1846	1880's (Bell 1888)
Antedon loveni Bell 1882	pre-1882	1880's (Bell 1888)
Antedon incommoda Bell 1888	1880's (Bell 1888)	1880's (Bell 1888)
Aporometra wilsoni (Bell 1888)	1880's (Bell 1888)	1880's (Bell 1888)
Antedonid sp sensu A M Clark 1966	1959 (Clark 1966)	1959 (Clark 1966)
Asteroidea		
Bollonaster pectinatus (Sladen 1883)	1873 (Sladen 1883)	1880's (Bell 1888)
Tosia australis Gray 1840	pre-1840	1892 (MoV)
Tosia magnifica (Muller & Troschel,1842)	pre-1847	1880's (Bell 1888)
Pentagonaster duebini Gray 1847	pre-1847	1957 (Clark 1966)
Plectaster decanus (Muller & Troschel 1843)	pre-1843	1880's (Bell 1888)
Nectria multispina H L Clark 1928	1885 (Clark 1966)	1880's (Bell 1888)
Nectria ocellata Perrier 1875	pre-1816	1957 (Clark 1966)
Nectria macrobrachia (H L Clark 1923)	1880's (Clark 1966)	1880's (Clark 1966)
Netrica pedicelligera Mortensen 1925	1881 (MoV)	1881 (MoV)
Nectria saoria Shepherd 1967		1963 (MoV)
Austrofromia polypora (H L Clark 1916)	1880's (Bell 1888)	1880's (Bell 1888)
Petricia vernicina (Lamarck 1816)	pre-1816	1880's(Clark 1966)
Nepanthia troughtoni (Livingstone 1934)	1880's (Clark 1966)	1880's (Clark 1966)
Paranepanthia grandis (H L Clark 1928)	1880's (Bell 1888)	1880's (Bell 1888)
Patiriella exigua (Lamarck 1816)	pre-1816	1976 (MoV)
Patiriella calcar (Lamarck 1816)	pre-1816	1889 (MoV)
Patiriella gunnii (Gray 1840)	pre-1840	1880's (Bell 1888)
Patiriella brevispina H L Clark 1938	1906 (MoV)	1880's (MoV)
Asterina scobinata Livingstone 1933	1889 (MoV)	1889 (MoV)
Asterina atyphoida Clark 1916	1880's (Clark 1966)	1880's (Clark 1966)
Coscinasterias muricata (Verrill 1867)	pre-1867	1880's (Bell 1888)
Allostichaster polyplax (Muller &Troschel 1844)	pre-1844	1889 (MoV)
Smilasterias irregularis H L Clark 1928	pre-1928	1980 (MoV)
Asterias amurensis Lütken 1871	circa-1986	1995
Uniophora granifera (Lamarck 1816)	pre-1816	1892 (MoV)
Ophiuroidea		
Conocladus australis (Verrill 1876)	pre-1876	1880's (MoV)
Ophiomyxa australis Lütken 1869	pre-1869	1880 (MoV)
Ophiacantha alternata A M Clark 1966	1929 (Baker & Devaney 1981)	1960 (Clark 1966)
Ophiacantha shepherdi Baker & Devaney 1981	1959 (MoV)	1988 (MoV)
Amphiura constricta Lyman 1879	1873 (Lyman 1879)	1901 (MoV)
Amphiura poecila H L Clark 1915	1901 (MoV)	1901 (MoV)
Amphiura elandiformis A M Clark 1966	1958 (Clark 1966)	1958 (Clark 1966)
Amphiura paviscutata A M Clark 1966	1960 (Clark 1966)	1960 (Clark 1966)
Amphipholis squamata (Della Chiaje 1828)	1873 (Lyman 1879)	1901 (MoV)
Amphistigma minuta H L Clark 1938	1929 (Clark 1938)	1988 (MoV)
Ophiocentrus pilosus (Lyman 1879)	1873 (Lyman 1879)	1959 (Clark 1966)
Ophiactis resiliens Lyman 1879	1873 (Lyman 1879)	1901 (MoV)
Ophiothrix caespitosa Lyman 1879	1873 (Lyman 1879)	1901 (MoV)
Clarkcoma canaliculata (Lutken 1869)	pre-1869	1959 (Clark 1966)
Ophionereis schayeri (Muller &Troschel 1849)	pre-1849	1901 (MoV)
Ophiarachnella ramsayi (Bell 1888)	pre-1888	1959 (Clark 1966)
Ophiopeza cylindica (Hutton 1872)	1880 (Clark 1966)	1880 (Clark 1966)
Ophiura kinbergi (Ljungman 1866)	1873 (Lyman 1879)	1959 (Clark 1966)
Ophiocrossota mutlispina (Ljungman 1866)	pre-1866	1880's (Clark 1966)
Ophioplocus bispinosus H L Clark 1918	1915 (MoV)	1982 (MoV)

Table A5 continued.

Class/species	First Australian record	First Port Phillip Bay record
Echinoidea		
Goniocidaris impressa (Koehler 1926)	1880's (Bell 1888)	1880's (Bell 1888)
Amblypneustes ovum (Lamarck 1816)	pre-1816	1880's (Bell 1888)
Holopneustes porosissimus L Agassiz 1846	pre-1846	1880's (Clark 1966)
Holopneustes inflatus Lütken 1872	pre-1872	1880's (Clark 1966)
Microcyphus zigzag L Agassiz 1846	pre-1846	1880's (Bell 1888)
Microcyphus annulatus Mortensen 1904	1880's (Clark 1966)	1880's (Clark 1966)
Microcyphus compus H L Clark 1912	1880's (Clark 1966)	1880's (Clark 1966)
Heliocidaris erythrogramma (Valenciennes,1846)	pre-1846	1880's (Bell 1888)
Pachycentrotus australiae A Agassiz 1872	pre-1872	1880's (Bell 1888)
Echinocardium cordatum (Pennant 1777)	pre-1854 (Gray 1854)	1880's (Bell 1888)
Clypeaster australasiae (Gray 1851)	pre-1851	1880's (Clark 1966)
Echinocyamus platytatus H L Clark 1914	1880's (Clark 1966)	1880's (Clark 1966)
Holothuroidea		
Plesiocolochirus ignava (Ludwig 1875)	pre-1875	1880's (Bell 1888)
Staurothyone inconspicua (Bell 1888)	1880's (Bell 1888)	1880's (Bell 1888)
Cucuvitrum rowei O'Loughlin & O'Hara 1992	1957 (Clark 1966)	1957 (Clark 1966)
Psolidiella adhaerens Hickman 1962	1954 (Hickman 1962)	1991 (MoV)
Cucumella mutans (Joshua 1914)	1891 (MoV)	1891 (MoV)
Neoamphicyclus lividus Hickman 1962	1940 (Hickman 1962)	1957 (MoV)
Lipotrapeza vestiens (Joshua 1914)	1891 (MoV)	1891 (MoV)
Tyone nigra Joshua & Creed 1915	1958 (Clark 1966)	1958 (Clark 1966)
Stichopus mollis (Hutton 1872)	1880's (Bell 1888)	1880's (Bell 1888)
Paracaudina australis (Semper 1868)	pre-1868	1880's (Bell 1888)
Leptosynapta dolabrifera (Stimpson 1855)	pre-1855	pre-1914 (Joshua 1914)
Trochodota allani (Joshua 1912)	1910 (Joshua 1912)	1911 (Joshua 1912)
Taeniogyrus sp. MoV 1643	1995 (MoV)	1995 (MoV)
Scoliorhapis theeli (Heding 1928)	1873 (Theel 1886)	1981 (MoV)

Table A6. Species list of fishes from Port Phillip Bay. All species except *Trygonoptera* sp. B (Last and Stevens 1994) without specific names e.g. *Nesogobius* sp. 1, are numbered from Gomon *et al.* (1994).

Family/species	Common name
Anguillidae	
Anguilla australis	Shortfin eel
Antennariidae (anglerfishes)	
Echinophryne crassipina	Prickly anglerfish
Echinophryne mitchelli	Spinycoat anglerfish
Echinophryne reynoldsi	Sponge anglerfish
Kuiterichthys furcipilis	Rough anglerfish
Phyllophryne scortea	Smooth anglerfish
Rhycherus filamentosus	Tasselled anglerfish
Aploactinidae	Velvetfishes
Aploactisoma milesii	Velvetfish
Neoaploactus tridorsalis	Threefin velvetfish
Apogonidae (cardinalfishes)	
Siphamia cephalotes	Woods siphon fish
Vincentia conspersa	Southern cardinalfish
Arripidae	
Arripis georgianus	Tommy rough
Arripis truttaceus	West Australian Salmon
Aracanidae (boxfishes)	
Aracana aurita	Shaws cowfish
Aracana ornata	Ornate cowfish
Atherinidae (hardyheads)	
Atherinason hepsetoides	Deepwater hardyhead
Atherinosoma microstoma	Smallmouth hardyhead
Atherinosoma elongata	Elongate hardyhead
Kestratherina brevirostris	Shortsnout hardyhead
Kestratherina esox	Pikehead hardyhead
Leptatherina presbyteroides	Silver fish
Aulopididae (threadsails)	
Aulopus purpurissatus	Sergeant baker
Berycidae (red snapper)	
Centroberyx australis	Yelloweye nannygai
Centroberyx gerrardi	Red snapper
Centroberyx lineatus	Swallowtail
Blenniidae	
Omobranchus anolius	Oyster blenny
Parablennius tasmanianus	Tasmanian blenny
Bothidae (lefteye flounders)	
Arnoglossus muelleri	Muellers flounder
Arnoglossus bassensis	Bass strait flounder
Lophonectes gallus	Crested flounder
Bovichtidae	
Bovichtus angustifrons	Dragonet
Pseudaphritis urvilli	Congolli
Branchiostomidae (/ancelets)	
Epigonichthys bassanus	Southern lancelet
Bythitidae (brotulas)	
Dermatopsis multiradiatus	Slender blindfish
Ogilbia sp.	Southern pygmy blindfish
Callanthiidae	
Callanthias australis	Splendid perch
Callionymidae (stinkfishes)	
Eocallionymus papilio	Painted stinkfish
Foetorepus calauropomus	Common stinkfish

Table A6 continued.

Family/species	Common name
Carangidae (trevallies)	
Naucrates ductor	Pilotfish
Pseudocaranx dentex	White trevally
Seriola lalandi	Yellowtail kingfish
Trachurus declivis	Jack mackeral
Trachurus novaezelandiae	Yellowtail horse mackeral
Carcharhinidae (whaler sharks)	
Carcharinus obscurus	Black whaler
Centrolophidae (trevallas)	
Seriolella brama	Warehou
Cheilodactylidae (morwongs)	
Cheilodactylus fuscus	Red morwong
Cheilodactylus nigripes	Magpie perch
Cheilodactylus spectabilis	Banded morwong
Dactylophora nigricans	Dusky morwong
Nemadactylu valenciennesi	Queen snapper
Nemadactylus macropterus	Jackass morwong
Chironemidae	
Chironemus marmoratus	Kelpfish
Chironemus georgianus	Tassled kelpfish
Clinidae (weedfishes)	
Cristiceps australis	Southern crested weedfish
Heteroclinus sp 1	Kuiters weedfish
Heteroclinus sp 2	Whitleys weedfish
Heteroclinus sp 3	Longtail weedfish
Heteroclinus sp 6	Milwards weedfish
Heteroclinus sp 7	Scotts weedfish
Heteroclinus adelaidae	Adelaide weedfish
Heteroclinus eckloniae	Kelp weedfish
Heteroclinus heptaeolus	Sevenbar weedfish
Heteroclinus johnstoni	Johnstons weedfish
Heteroclinus marmoratus	Shorttassel weedfish
Heteroclinus nasutus	Largenose weedfish
Heteroclinus perspicillatus	Spotshoulder weedfish
Heteroclinus roseus	Rosy weedfish
Heteroclinus tristis	Longnose weedfish
Heteroclinus wilsoni	Wilsons weedfish
Ophiclinops varius	Variegated snakeblenny
Ophiclinops gabrieli	Frosted snakeblenny
Ophiclinops gracilis	Blackback snakeblenny
Ophiclinops ningulus	Variable snakeblenny
Sticharium dorsale	Sand crawler
Clupeidae	
Etrumeus teres	Maray
Hyperlophus vittatus	Sandy sprat
Sardinops neopilchardus	Pilchard
Congridae (conger eels)	
Gnathophis sp.	
Conger verreauxi	Southern conger
Coryphaenidae (dolphinfishes)	
Coryphaena hippurus	Dolphinfish
Dasyatidae	
Dasyatis brevicaudata	Smooth stingray
Dinolestidae	
Dinolestes lewini	Longfined pike

Table A6 continued.

Family/species	Common name
Diodontidae (porcupine fishes)	
Diodon nichthemerus	Globefish
Allomycterus pilatus	Australian burrfish
Echeneididae (remoras, suckerfish)	
Echeneis naucrates	Slender suckerfish
Remora remora	Short suckerfish
Eleotrididae (gudgeons)	
Philypnodon grandiceps	Flathead gudgeon
Thalasseleotris adela	Dusky marine gudgeon
Engraulidae (anchovies)	
Engraulis australis	Australian anchovy
Enoplosidae (old wife)	
Enoplosus armatus	Old wife
Exocoetidae (flyingfishes)	
Hirundichthys rondeletii	Rondelets flyingfish
Galaxiidae (galaxiids)	
Galaxias maculatus	Common jollytail
Gempylidae (gemfish)	
Thyrsites atun	Barracouta
Gerreidae (silver biddies)	
Paraquula melbournensis	Silverbelly
Girellidae (drummer, luderick)	
Girella zebra	Zebrafish
Girella tricuspidata	Luderick
Gnathanacanthidae (red velvetfishes)	
Gnathanacanthus goetzeei	Red velvetfish
Gobiesocidae (clingfishes)	
Alabes dorsalis	Common sore-eel
Alabes hoesei	Dwarf short-eel
Aspasmogaster liorhyncha	Smoothsnout clingfish
Aspasmogaster occidentalis	Western clingfish
Aspasmogaster tasmaniensis	Tasmanian clingfish
Cochleoceps bicolor	Westerner cleanerfish
Genus C sp. 1	Grass clingfish
Gobiidae (gobies)	
Acanthogobius flavimanus	Yellowfin goby
Arenigobius bifrenatus	Bridled goby
Arenigobius frenatus	Halfbridled goby
Callogobius mucosus	Sculptured goby
Favonigobius lateralis	Longfin goby
Favonigobius tamarensis	Tamar River goby
Gobiopterus semivestitus	Glass goby
Nesogobius sp. *1*	Girdled goby
Nesogobius sp. *2*	Threadfin goby
Nesogobius sp. *3*	Twinbar goby
Nesogobius sp. *4*	Groovedcheek goby
Nesogobius sp. *5*	Sicklefin sandgoby
Nesogobius sp. *6*	Opalescent sandgoby
Nesogobius sp. *7*	Speckled sandgoby
Nesogobius hinsbyi	Orangespotted goby
Nesogobius pulchellus	Sailfin goby
Pseudogobius olorum	Bluespot goby
Redigobius macrostoma	Largemouth goby
Tasmanogobius gloveri	Marine goby
Tasmanogobius lasti	Lagoon goby
Tridentiger trigonocephalus	Trident goby

Table A6 continued.

Family/species	Common name
Gonoryncidae (sandfishes)	
Gonorynchus greyi	Beaked salmon
Hemiramphidae (garfishes)	
Hyporhamphus melanochir	Southern sea garfish
Heterodontidae (Port Jackson sharks)	
Heterondontus portusjacksoni	Port Jackson shark
Hexanchidae (6 and 7 gilled sharks)	
Heptranchias perlo	Sharpnose 7 gill shark
Notorynchus cepedianus	Broadnose sevengill shark
Kyphosidae (drummer – see family Scorpidiae)	
Labridae (wrasses)	
Achoerodus gouldi	Western blue grouper
Bodianus unimaculatus	Eastern blackspot pigfish
Dotalabrus aurantiacus	Pretty Polly
Eupetrichthys angustipes	Snakeskin wrasse
Notolabrus fucicola	Saddled wrasse
Notolabrus tetricus	Bluethroat wrasse
Ophthalmolepsis lineolata	Maori wrasse
Pictilabrus laticlavius	Senator wrasse
Pseudolabrus psittaculus	Rosy wrasse
Notolabrus parilus	Orangespotted wrasse
Lampridae (moonfish)	
Lampris guttatus	Spotted moonfish
Leptscopidae (sandfishes)	
Crapatalus munroi	Pink sandfish
Molidae	
Mola ramsayi	Southern ocean sunfish
Monacanthidae (leatherjackets)	
Acanthaluteres spilomelanurus	Bridled leatherjacket
Acanthaluteres vittiger	Toothbrush leatherjacket
Brachaluteres jacksonianus	Southern pygmy leatherjacket
Eubalichthys gunnii	Gunns leatherjacket
Eubalichthys mosaicus	Mosaic leatherjacket
Meuschenia australis	Brownstriped leatherjacket
Meuschenia flavolineata	Yellowstriped leatherjacket
Meuschenia freycineti	Six spine leatherjacket
Meuschenia galii	Bluelined leatherjacket
Meuschenia hippocrepis	Horseshoe leatherjacket
Meuschenia scaber	Velvet leatherjacket
Nelusetta ayraudi	Chinamen leatherjacket
Scobinichthys granulatus	Rough leatherjacket
Thamnaconus degeni	Degens leatherjacket
Moridae (morid cods)	
Eeyorius hutchinsi	Finetooth beardie
Lotella rhacina	Largetooth beardie
Pseudophycis bachus	Red cod
Pseudophycis barbatus	Bearded rockcod
Mugilidae (mullet)	
Aldrichetta forsteri	Yelloweye mullet
Mugil cephalus	
Mullidae (goatfish/red mullets)	
Upeneichthys vlamingii	Red mullet
Myliobatididae (eagle rays)	
Myliobatis australis	Eagle ray

Table A6. continued.

Family/species	Common name
Phyllopteryx taeniolatus	Common seadragon
Pugnaso curtirostris	Pugnose pipefish
Stigmatopora argus	Spotted pipefish
Stigmatopora nigra	Widebody pipefish
Stipecampus cristatus	Ringback piepfish
Urocampus carinirostris	Hairy pipefish
Vanacampus phillipi	Port Phillip pipefish
Tetraodontidae (toadfish)	
Arothron hispidus	Stars and stripes toadfish
Arothron firmamentum	Starry toadfish
Contusus brevicaudus	Prickly toadfish
Contusus richei	Barred toadfish
Omegophora armilla	Ringed toadfish
Tetractenos glaber	Smooth toadfish
Trachichthyidae (roughies or sawbellies)	
Optivus sp. 1	Violet roughy
Paratrachichthys sp.	Sandpaperfish
Trachichthys australis	Roughy
Trachipteridae (ribbonfishes)	
Trachipterus aurawatae	Ribbonfish
Triakidae	
Furgaleus macki	Whiskery shark
Galeorhinus galeus	School shark
Mustelus antarcticus	Gummy shark
Trichiuridae	
Lepidopus caudatus	frostfish
Triglidae (gurnards)	
Chelidonichtys kumu	Red gurnard
Lepidotrigla mulhalli	Deepwater gurnard
Lepidotrigla papilio	Spiny gurnard (may be comprised of two species)
Lepidotrigla vanessa	Butterfly gurnard
Pterygotrigla polyommata	Latchet
Tripterygiidae (threefins)	
Apopterygion alta	Tassled threefin
Grahamina gymnota	Barebacked threefin
Norfolkia clarkei	Common threefin
Norfolkia cristata	Crested threefin
Norfolkia incisa	Notched threefin
Uranoscopidae (stargazers)	
Kathetostoma laeve	Common stargazer
Urolophidae (stingarees)	
Trygonoptera mucosa	Westen stingaree
Trygonoptera sp. *B*	Eastern shovelnose stingaree
Urolophus cruciatus	Banded stingaree
Urolophus gigas	Spotted stingaree
Urolophus paucimaculatus	Sparsely spotted stingaree
Zeidae (dories)	
Cyttus australis	Silver dory
Zeus faber	John dory

Table A7. Native, introduced and cryptogenic species recorded from the different regions of Port Phillip Bay (see Chapter 2). Information derived from the taxonomic reviews, MAFRI Port of Geelong survey (1998) and CRIMP bay-wide survey (1995–96): + species recorded from literature and museum collections; ++ species collected during either MAFRI Geelong and/or CRIMP surveys. Blank spaces denote no distributional information.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
PLANTS						
Algae – endemic	*Caulerpa cactoides*		++			
	Gracilaria cf secundata		++			
	Gracilaria sp 2		++			
	Gracilaria sp 3		++			
	Hymenena sp 1		++			
	Labospira sp 1		++			
	Lenormandia marginata		++			
	Nizymenia australis		++			
	Plocamium sp 1		++			
	Rhodophyta sp 3		++			
	Sargassum sp 1		++			
	Thuretia sp 1		++			
	Ulvaria sp 1		++			
Algae – exotic	*Antithamnionella spirographidis*	+				
	Asperococcus compressus	+				
	Chondria arcuata	+				
	Cladophora prolifera			+		
	Codium fragile ssp. *tomentosoides*		+			
	Deucalion levringii	+		+		
	Gymnogongrus crenulatus	+	+			
	Medeiothamnion lyalli	+			+	
	Polysiphonia brodiaei	+		+		
	Polysiphonia senticulosa (pungens)	+	+		+	
	Schottera nicaeensis	+		+		
	Solieria filiformis	+				
	Sorocarpus micromorus				+	
	Stictyosiphon soriferus	+	+	+		
	Ulva fasciata	+				
	Undaria pinnatifida	+	+			
Algae – cryptogenic	*Acinetospora crinita*		+	+	+	
	Antithamnionella ternifolia	+				
	Audouinella pacifica	+				
	Audouinella simplex	+				
	Bangia atropurpurea	+	+	+		
	Bryopsis plumosa	+	+			
	Centroceras clavulatum	+	+	+		
	Ceramium flaccidum	+				
	Ceramium rubrum	+				
	Chaetomorpha aerea	+	+	+	+	
	Chaetomorpha capillaris	+				
	Chaetomorpha linum	+				
	Cladostephus spongiosus	+	+	+		
	Colpomenia peregrina	+	+	+		
	Colpomenia sinuosa	+	+	+		
	Cutleria multifida	+	+		+	
	Derbesia marina	+				
	Dictyota dichotoma	+	+	+	+	
	Ectocarpus fasciculatus			+	+	
	Ectocarpus siliculosus	+		+	+	
	Enteromorpha compressa	+				
	Enteromorpha intestinalis	+				

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region 1	2	3	4	5
	Erythrotrichia carnea		+	+		
	Feldmannia globifera	+		+	+	
	Feldmannia irregularis		+	+	+	
	Feldmannia lebelii			+		
	Gelidium pusillum	+	+	+	+	
	Gymnothamnion elegans			+		
	Hildenbrandia occidentalis var *yessoensis*	+				
	Hildenbrandia rubra	+				
	Hincksia granulosa	+	+	+	+	
	Hincksia mitchellae	+		+	+	
	Hincksia ovata	+			+	
	Hincksia sandriana	+	+		+	
	Kuckuckia spinosa		+		+	
	Leathesia difformis			+		
	Myrionema strangulans		+	+		
	Nemalion helminthoides			+	+	
	Petalonia fascia	+	+		+	
	Petrospongium rugosum			+		
	Peyssonnelia conchicola	+				
	Pilayella littoralis		+		+	
	Polysiphonia subtilissima	+	+			
	Pterocladia capillacea	+		+		
	Punctaria latifolia	+	+		+	
	Scytosiphon lomentaria	+	+		+	
	Sphacelaria fusca	+				
	Stylonema alsidii	+				
	Ulva lactuca	+	+			
	Ulva rigida	+				
	Ulva stenophylla			+		
Dinoflagellates – endemic	*Diplopelta parva*		++			
	Dinophysis acuminata		++			
	Gonyaulax grindleyi		++			
	Gonyaulax spinifera		++			
	Gymnodinium sp 1		++			
	Katodinium rotundatum		++			
	Protoperidinium compressum		++			
	Protoperidinium conicoides		++			
	Protoperidinium conicum		++			
	Protoperidinium sp 1		++			
	Proreccentrum gracile		++			
	Scrippsiella trochoidea		++			
	Scrippsiella sp 1		++			
Dinoflagellates – exotic	*Alexandrium catenella*	+				
Dinoflagellates - cryptogenic	*Alexandrium minutum*					
	Alexandrium tamarense		++			
	Gymnodinium mikimotoi					
	Gymnodinium pulchellum					
Phytoplankton – endemic	*Apedinella spinifera*		++			
	Ceratulina pelagica		++			
	Chaetoceros compressus		++			
	Chaetoceros curvisetus		++			
	Chaetoceros debilis		++			
	Chaetoceros decipiens		++			
	Chaetoceros diadema		++			
	Chaetoceros didymus		++			
	Chaetoceros lorenzianus		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Chaetoceros pseudocurvisetus		++			
	Chaetoceros sp 1		++			
	Chrysochromulina sp 1		++			
	Cocconeis sp 1		++			
	Dictyocha sp 1		++			
	Ebria tripartita		++			
	Hemiselmis virescens		++			
	Heterosigma carterae		++			
	Leptocylindrus medeterraneus		++			
	Licmopora sp 1		++			
	Navicula sp 1		++			
	Navicula sp 2		++			
	Nitzschia closterium		++			
	Nitzschia sp 1		++			
	Plagioselmis prolonga		++			
	Prymnesium sp 1		++			
	Pseudo-nitzschia pungens		++			
	Pyramimonas sp 1		++			
	Rhodomonas salina		++			
	Skeletonema costatum		++			
	Striatella unipunctata		++			
	Teleaulax acuta		++			
Seagrasses – endemic	*Halophila australis*		++	++	++	
	Zostera muelleri		++	++	++	
ANIMALS						
Sarcodina – endemic	*Elphidium* sp 1		++			
	Pyrgo sp 1		++			
	Triloculina affinis		++			
Porifera – endemic	*Calcarea* sp 1	++		++		
	Calcarea sp 2	++		++	++	
	Callyspongia sp 1			++		
	Callyspongia sp 2			++		
	Chondropsis sp 1	++	++	++		
	Crella incrustans	++		++	++	
	Darwinella n.sp.			++		
	Demospongiae sp 4		++			
	Demospongiae sp 5		++			
	Dendrilla rosea		++	++		
	Dictyoceratid sp 2		++			
	Dysidea n.sp.		++			
	Dysidea sp 2		++			
	Echinoclathia macropora			++		
	Halichondria sp 1		++			
	Halichondria sp 2	++	++	++	++	
	Halichondria sp 3		++			
	Halichondria sp 4		++			
	Haliclona sp 1	++	++	++		
	Haliclona sp 2		++			
	Haplosclerid sp 1		++			
	Ircinia sp 1	++	++			
	Ircinia sp 2	++				
	Jaspis sp 1		++			
	Lissodendoryx sp 1			++		
	Microciona sp 1				++	
	Mycale sp 1	++	++	++	++	
	Poecilosclerid sp 2	++				

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Spongia sp 1			++		
	Suberitidae sp 1		++			
	Suberites sp 1	++		++		
	Sycon sp 1		++			
	Sycon sp 2		++			
	Tedania sp 1		++	++	++	
	Tedania sp 2		++	++	++	
	Tethya sp 1		++			
	Unknown sp 1		++			
Porifera – exotic	*Aplysilla rosea*			++	++	
	Corticium candelabrum			+		
	Dysidea avara			+		
	Dysidea fragilis	++				
	Haliclona heterofibrosa		++			
	Halisarca dujardini	++				
Porifera – cryptogenic	*Callyspongia pergamentacea*			+		
	Darwinella australianensis			+		
	Darwinella gardneri					
	Lissodendoryx isodictyalis			+		
	Phorbas cf. *tenacior*					
	Tedania anhelans			+		
Cnidaria: Hydrozoa – endemic	*Algaphenia parvula*			++	++	++
	Algaophenia sp 1				++	
	Algaphenia sp 2			++		
	Anthozoan sp 1		++			
	Bimeria australis		++			
	Campanularia caliculata	++			++	
	Campanularia gigantea				++	
	Campanularia sp 1		++			
	Clytia sp 1	++				++
	Cricophorus nutrix		++			
	Ectopleura ralphi				++	
	Eudendrium generale	++	++		++	
	Halopteris buskii				++	
	Lovenella sp 1		++		++	
	Monotheca flexousa	++	++	++	++	++
	Obelia geniculata				++	++
	Obelia sp 1				++	
	Plumularia setaceoides	++	++		++	++
	Plumularia obliqua					++
	Sertularella robusta	++	++		++	++
	Sertularella simplex					++
	Sertularia marginata				++	++
	Sertularia tenuis	++	++	++	++	++
	Sertularidae sp 1	++				
	Stereotheca elongata			++		
	Turritopsis sp 1		++			
Hydrozoa – exotic	*Amphisbetia operculata*			+		
	Antennella secundaria			+	+	
	Bougainvillea muscus (ramosa)	++	++			
	Clytia hemisphaerica	++	++	++	++	++
	Clytia paulensis	++	++	++	++	++
	Ectopleura crocea	++	++		++	
	Filellum serpens			+	+	
	Halecium delicatulum			++	++	++
	Monotheca obliqua	+	+	+		

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Obelia dichotoma (australis)	++	++	++	++	++
	Phialella quadrata			+	+	+
	Plumularia setacea	++		++	++	++
	Sarsia eximia (radiata)		++	++	++	++
	Turritopsis nutricula	++	++	++	++	
Platyhelminthes –	*Turbellarian* sp 1		++			
endemic	*Turbellarian* sp 3		++			
exotic	*Euplana gracilis*					
Nemerteans – endemic	*Nemertean* sp 1	++	++			
	Nemertean sp 2	++	++			
	Nemertean sp 3	++	++			
	Nemertean sp 4	++	++			
	Nemertean sp 5		++			
	Nemertean sp 6		++		++	
	Nemertean sp 7		++		++	
	Nemertean sp 9		++			
	Nemertean sp 12		++			
	Nemertean sp 13		++			
Nematoda – endemic	*Monhysterid* sp 1		++			
Annelida: Polychaeta –	*Anaitides longipes*	++	++			
endemic	*Amaeana trilobata*		++			
	Ampharete sp 1		++			
	Amphitrite pachyderma	++	++			
	Augeneria verdis		++			
	Arabella sp 1	++				
	Arenicola sp 1	++				
	Aricidea sp 1		++			
	Armandia intermedia		++			
	Armandia sp 1	++				
	Artocamella dibranchiata		++			
	Asychis glabra		++			
	Barantola lepte	++	++			
	Boccardiella sp 1	++				
	Capitella capitata	++	++			
	Capitella sp 1	++	++			
	Caulleriella sp 1		++			
	Ceratonereis amphidonta	++				
	Ceratonereis limnetica	++	++	++	++	++
	Ceratonereis mirabilis	++			++	
	Ceratonereis pseudoerythraeensis			++	++	++
	Ceratonereis sp 1	++	++			
	Chaetozone sp 1		++			
	Cheilonereis sp 1	++				
	Cirratulidae sp 1	++				
	Cirratulidae sp 2	++				
	Cirriformia filigera	++	++		++	
	Diplocirrus sp 1		++			
	Dorvillea australiensis		++			
	Euchone sp 1	++				
	Eumida fuscolutata		++			
	Eumida sanquinea	++	++	++		
	Eunicidae sp 1	++				
	Eunice vittata	++				
	Eunice laticeps		++			
	Eunice cf. *australis*		++			
	Eunice sp 1	++				

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Eupolymnia koorangia	++	++			
	Exogoninae sp 1	++	++			
	Flabelligeridae sp 1	++				
	Glycera americana	++	++			
	Glycera tridactyla		++			
	Glycera sp 1	++	++			
	Goniada maculata	++				
	Goniada sp 1	++				
	Goniadidae sp 1	++				
	Haploscoloplos sp 1		++			
	Harmothinae sp 1				++	
	Harmothinae sp 2		++		++	
	Harmothinae sp 3				++	
	Harmothoe spinosa		++			
	Harmothoe sp 1	++	++			
	Harmothoe sp 2	++				
	Hesionid sp 2		++			
	Heteromastus filiformis	++				
	Hyboscolex dicranochaetus	++	++			
	Hydroides heteroceros	++	++			
	Isoida sp 1		++			
	Laonice quadridentata		++			
	Leitoscoloplos bifurcatus	++	++			
	Leitoscoloplos normalis	++				
	Leitoscoloplos sp 1	++				
	Lepidonotinae sp 2			++		
	Lepidonotinae sp 3		++			
	Lepidonotus argus			++		
	Lepidonotus glaucus		++			
	Lepidonotus oculatus	++	++			
	Lumbrineridae sp 1		++			
	Lumbrineris latreilli	++	++		++	
	Lumbrineris sp 2		++			
	Lysaretidae sp 1			++		
	Lysidice sp 1	++				
	Malacoceros sp 1	++				
	Maldane sarsi	++				
	Magelona cf. dakini		++			
	Magelona sp 1	++				
	Magelona sp 2	++				
	Magelonidae sp 1	++				
	Malmgrenia microscala		++			
	Malmgrenia sp 2		++			
	Marphysa sp 1		++			
	Mediomastus californiensis		++			
	Naineris sp 1	++				
	Neanthes vaalii	++				
	Nephtyodae sp 1		++			
	Neptys australiensis		++			
	Neptys inormata		++			
	Nephtys sp 1		++			
	Nereididae sp 1	++				
	Nereis cockburnensis	++				
	Nereis sp 1		++			
	Nereis sp 2	++				
	Nerimyra longicirrata		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Notomastus torquatus	++	++			
	Notomastus sp 1	++	++			
	Notomastus sp 2		++			
	Olganereis edmondsi	++	++			
	Ophelia multibranchiata	++				
	Ophelidae sp 1	++				
	Orbinidae sp 1	++				
	Orbinidae sp 2	++				
	Paralepidonotus ampulliferus		++			
	Paraonis gracilis		++			
	Pomatoceros terraenovae	++				
	Perinereis amblyodonta	++	++			
	Perinereis variodentata	++				
	Phisidia echuca	++				
	Phyllodocidae sp 1	++	++			
	Phyllodocidae sp 2	++				
	Phyllodocidae sp 3	++				
	Phyllodoce sp 1		++			
	Phyllodoce sp 2		++			
	Pilargidae sp 1	++				
	Platynereis dumerilii antipoda		++	++		
	Podarke angustifrons		++			
	Podarke microantennata	++				
	Polydora sp 1	++	++			
	Polydora sp 2		++			
	Polyonidae sp 1		++			
	Polyophthalamus pictus	++	++			
	Prionospio aucklandica		++			
	Prionospio coorilla		++			
	Prionospio multipinnulata	++	++			
	Prionospio yuriel		++			
	Prionospio sp 1	++				
	Prionospio sp 2	++				
	Pseudonereis sp 1		++			
	Pseudopolydora sp 1	++				
	Rhinothelepus lobatus	++				
	Sabella sp 1	++	++			
	Sabellidae sp 1	++				
	Sabellastarte indica				++	++
	Sabellastarte longa			++	++	
	Schistomeringos loveni	++	++			
	Scoloplos cylindrifer	++				
	Scoloplos johnstonei	++				
	Scoloplos sp 1	++				
	Serpulid sp 1		++			
	Serpulid sp 2		++			
	Serpulid sp 3		++			
	Sigallon bandaeensis		++			
	Simplisetia amphidonta		++			
	Spionidae sp 1	++				
	Streblosoma sp 1	++	++	++		
	Syllis gracilis	++	++			
	Syllis sp 1				++	
	Syllis sp 2		++			
	Syllis sp 4		++			
	Syllis sp 5		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Syllis sp 6		++			
	Syllidae sp 4				++	++
	Syllidae sp 1	++		++		
	Syllidae sp 2				++	
	Syllidae sp 3				++	
	Terebella cf. ehrenbergi		++			
	Terebellidae sp 1	++	++			
	Terebellidae sp 2	++				
	Terebellidae sp 3	++				
	Terebellidae sp 4	++				
	Terebellides sp 1		++			
	Tharyx sp 1		++			
	Tharyx sp 2		++			
	Tharyx sp 3		++			
	Thelepus setosus	++	++			
	Trichobranchidae sp 1		++			
	Typosyllis variegata		++			
	Typosyllis prolifera	++				
	Typosyllis sp 1	++	++		++	
	Vermiliopsis sp 1	++				
Polychaeta – exotic	*Boccardia proboscidea*	+				
	Euchone limnicola	++	++	++	++	++
	Hydroides norvegica		+			
	Mercierella enigmaticus	+				
	Myxicola infundubulum		+			
	Neanthes succinea	+	+	+	+	+
	Pseudopolydora paucibranchiata	+	+	+		+
	Sabella spallanzanii	++	++		++	++
Oligochaeta–endemic	Oligochaete sp 1		++			
Mollusca: Gastropoda –endemic	*Aglaja taronga*		+			
	Austrocochlea odontis		+	+		
	Bedeva paivae	+	++			+
	Calyptraea (Sigapatella) calypt		++			
	Cantharidella tiberiana	+	++			
	Cantharidus irisodontes		++			
	Cantharidus pulcherrimus			+		
	Cellana tramoserica	+				
	Clanculus limbatus		++		+	
	Clanculus plebejus	+	+		+	
	Cominella eburnea		+			
	Cominella lineolata	+	+	+		
	Cymatiella verrucosa		+			
	Dendrodoris carneola		+			
	Dendrodoris nigra		+			
	Doris carneroni		+			
	Ethminolia vitilignea		++			
	Ethminolia tasmanica	++	++			
	Haliotis rubra	+			+	
	Hipponix australis				+	
	Liloa brevis		++			
	Mitrella semiconvexa		+			
	Montfortula rugosa		+			
	Nassarius burchardi	+	++			
	Nassarius pauperatus	+				
	Nassarius (zeuxis) pyrrhus		++			
	Notoacmea sp 1		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region 1	2	3	4	5
	Nototodarus gouldi		++			
	Patelloides alticostata	+	+	+		
	Phasianotrochus sp 1	++				
	Philine angasi		++			
	Retusa pelyx				+	
	Siphonaru diemenensis	+	+	+	+	
	Strombiformis topaziaca		+			
	Thais orbita	++	+	+	+	+
	Turbo undulatus	+	+	+		
Gastropoda – exotic	*Aplysiopsis formosa*			++		
	Janolus hyalinus	+	+			
Polyplacophora – endemic	*Acanthochitona kimberi*				+	
	Acanthochitona pilsbryi		++		+	
	Acanthochitona retrojecta	+		+		
	Acanthochitona saundersi	+				
	Acanthochitona sp 1			+		
	Ischnochiton variegatus	+	++			
	Notoplax sp 1			+		
	Plaxiphora albida		++			
Bivalvia – endemic	*Amesodesma* sp 1	++				
	Anomia trigonopsis	++				
	Barbatia pistocia		+			
	Barnea australasiae	++				
	Chioneryx cardioides		++			
	Corbula sp 1	++				
	Corbula stolata	++	++			
	Corbulidae sp 1	++				
	Edenttellina typica	++				
	Electroma georgiana	++	++			
	Eumarcia fumigata	++	++		++	
	Fulvia tenuicostata		++			
	Hiatella australis			++		++
	Hiatella subulata		++			
	Ibla quadrivalvis		++			
	Katelysia rhytiphore	++	++			
	Lasaea australis	++				
	Laternula creccina		++			
	Melliteryx acupunctum		++			
	Mimachlamys asperrina		++			
	Musculus ulmus		+			
	Mytilidae sp 1		+			
	Mysella donaciformis	++				
	Mytilus edulis planulatus	++	++		++	++
	Notospisula cf trigonella		++			
	Offadesma angasi	++	++			
	Ostrea angasi	++			++	
	Paplies sp 1		++			
	Pecten fumatus		++			
	Pholas australasiae		++			
	Solemya australis				++	
	Soletellina sp 1	++	++			
	Spisula trigonella	++				
	Tellina deltoidalis		++			
	Tellina (Macomona) mariae	++				
	Tellina sp 1	++				
	Tellinidae sp 1	++				

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Unknown sp c	++			++	
	Unknown sp *e*	++				
	Venerupis anomala	++	++		++	
	Venerupis sp 1		++			
	Xenostrobus inconstans	++				
Bivalvia – exotic	*Corbula gibba*	++	++			++
	Crassotrea gigas		+			
	Musculista senhousia	++	++			
	Raeta pulchella	++	++			
	Theora lubrica (fragilis)	++	++	++	++	++
Cephalopoda – endemic	*Euprymna tasmanica*		++			
	Hapalochlaena maculosa		+			
	Idiosepius notoides		++			
Chelicerata –endemic	*Ammotheid* sp 1		++			
Arthropoda: Ostracoda – endemic	*Archasterope* sp 1	++				
	Cypridinidae sp 1		++			
	Cypridinidae sp 2		++			
	Empoulsenia sp 1		++			
	Euphilomedes sp 1	++	++			
	Parasterope sp 1	++				
	Sarsiella magna	++				
Copepoda – endemic	*Calanoida* sp 1	++				
Cirripedia – endemic	*Balanus trigonus*	++	++			
	Balanus variegatus	++	++		++	
Cirripedia – exotic	*Balanus amphitrite*	++	++	++	++	++
Cirripedia –cryptogenic	*Balanus variegatus*	++	++	++	++	++
	Elminius modestus	++	++		++	
Leptostraca–endemic	*Nebalia* sp 1	++	++			
Decapoda – endemic	*Alpheus cf euphrosyne*		++			
	Alpheus villosus		++			
	Alpheus sp 1		++			
	Amarinus laevis	++				
	Brachynotus spinosus	++				
	Brachyura juv.	++				
	Caridea sp 1	++				
	Callianassa arenosa	++	++			
	Callianassa limosa		++			
	Chlorotocella spinicauda	++	++		++	
	Crangonidae	++		++	++	
	Diogenidae	++		++		
	Dittosa undecimspinosa	++				
	Grapsidae sp 2	++				
	Halicarcinus ovatus	++	++	++	++	
	Halicarcinus rostratus	++	++			
	Hippolyte caradina	++	++			
	Hymenosomatidae sp 1	++				
	Leptomithrax gaimardii		++			
	Leptomithrax stemcostulatus	++				
	Leptomithrax sp 1				++	
	Litocheira bispinosa	++	++			
	Macrobrachium intermedium	++	++	++		
	Macrophthalmus latifrons	++				
	Micropagurus acantholepis	++				
	Natantia sp 1	++				
	Naxia aries		++			
	Nectocarcinus integrifons	++	++	++		

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Nectocarcinus sp 1	++				
	Neocallichirus limosus		++			
	Notomithrax minor	++	++		++	
	Nyctiphanes australis		++			
	Paguristes pugil	++				
	Palaemon serenus	++				
	Paragrapsus gaimardi	++	++			
	Parapandalus leptorhynchus		++			
	Penaeoidea juvenile	++				
	Petaloma lateralis		++			
	Philocheras flindersi	++			++	
	Philocheras obliqus	++		++		
	Philocheras victoriensis	++	++			
	Phylladiorhynchus pusillus		++			
	Phlyxia intermedia	++	++			
	Pilumnopeus serratifrons		++			
	Pilumnus monilifer	++	++		++	
	Pilumnus sp 1	++	++		++	
	Pilumnus sp 2			++		
	Pinnotheres hickmani	++				
	Pontophilus intermedius		++			
	Squilla larvae	++				
	Strimdromia lateralis		++			
	Synalpheus tumidomanus	++	++			
	Thacanophrys spatulifer		++			
Decapoda – exotic	*Cancer novaezelandiae*	++				
	Carcinus maenas	++	++	++	++	
	Pyromaia tuberculata	++			++	++
Dendrobranchiata – endemic	*Lucifer hanseni*	++				
	Lucifer sp 1		++			
Mysidacea – endemic	*Australomysis acuta*	++	++			
	Heteromysis waitei		++			
	Paranchialina angusta		++			
	Tenagomysis tasmaniae	++	++			
	Tenagomysis sp 1		++			
Cumacea – endemic	*Anchistylis longipes*	++				
	Austroleucon levis	++				
	Dicoides fletti		++			
	Dimorphostylis cottoni	++	++			
	Glyphocuma bakeri	++				
Tanaidacea – endemic	*Aspeudes* sp 1	++				
	Dikonophoran sp 1	++				
	Kalliapseudes sp 1		++			
	Leptochelia sp 1		++			
	Paratanais ignotus		++			
	Tanaid sp 1		++			
Isopoda – endemic	*Amakusanthura oleania*		++			
	Amakusanthura pimelia		++			
	Bullowanthura pambula		++			
	Cerceis acuticaudata		++			
	Cilicaea crassicaudata		++			
	Cilicaea latreillii	++				
	Cilicaeopsis granulata	++	++			
	Crabyzos longicaudatus		++			
	Cruranthura microtis	++				
	Cymodoce coronata	++	++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Cymodoce gaimardi	++	++			
	Euidotea stricta	++				
	Eurydice tarti		++			
	Exosphaemora sp 1		++			
	Flabellifera sp 1	++				
	Flabellifera sp 2	++				
	Gnathia cf latidens	++				
	Gnathidae sp 1				++	
	Haliophasma cribense		++			
	Heteroserolis longicaudata	++				
	Ianiropsis sp 1	++				
	Janira sp 1	++				
	Leptanthura diemenensis		++			
	Munna sp 1		++			
	Natatolana corpulenta		++			
	Natatolana woodjonesi	++	++			
	Neostacilla deducta	++		++		
	Paranthura microtis	+				
	Praniza larva	++				
	Sphaeroma quoianum	++				
	Zuzara venosa	++				
Isopoda – exotic	*Cirolana harfordi*		++			
	Paracerceis sculpta	++				
Amphipoda – endemic	*Allorchestes compressa*	++	++			
	Amaryllis macrophthalma	++	++			
	Ampelisca tilpa	++	++			
	Amphilochus sp 1			++		
	Aora mortoni	++	++			
	Atylus sp 1	++				
	Birubius babaneekus	++	++			
	Birubius panamunus		++			
	Brolgus tattersalli	++	++			
	Byblis mildura	++	++			
	Cerodocus doolibah	++				
	Colomastix sp 1	++	++			
	Corophidae sp 3	++				
	Corophidae sp 4	++				
	Corophidae sp 5	++				
	Corophium sp 1		++			
	Cymadusa sp 1	++	++	++		
	Cyphocaridae sp 1	++				
	Dexaminid sp 1		++			
	Dulichiella australis		++			
	Elasmopus sp 1	++	++			
	Ericthonius sp 1	++				
	Gammarella beringar		++			
	Gammaridea sp 1	++				
	Gammaridea sp 2	++				
	Gammaridea sp 3	++				
	Gammaridea sp 5	++				
	Gammaridea sp 6	++				
	Gammaropsis sp 1		++			
	Gitanopsis cf. difficilis	++				
	Hyale crassicornis		?			
	Hyale rubra		?			
	Isaeidae sp 1	++				

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Isaeidae sp 2	++				
	Jassa sp 1		++			
	Leucothoidae sp 2	++				
	Leucothoe spinicarpa		++			
	Leucosiidae juveniles	++				
	Liljeborgia aequabilis	++	++			
	Lysianassid sp 1	++		++		
	Lysianassid sp 2			++		
	Lysianassid sp 4		++			
	Lysianassid sp 5		++			
	Maera mastersi	++	++			
	Mallacoota subcarinata	++	++	++		
	Metaprotella cf haswelliana		++			
	Naraphreonoides mullaya	++	++			
	Oedicerotid sp 1	++				
	Paracorophium sp 1	++	++	++		
	Paradexamine dandaloo	++	++			
	Paradexamine churinga	++				
	Paradexamine lanacoura	++	++			
	Paradexamine marlie	++	++			
	Paradexamine thadalee	++	++			
	Paraleucothoe novaehollandiae	++	++			
	Paraproto spinosa		?			
	Parawaldeckia sp 1	++				
	Photis sp 1	++	++		++	
	Phoxocephalus kukathus		++			
	Stenothoe miersi	++	++			
	Stenothoe valida	++	++			
	Tethygeneia sp 1	++				
	Tipimegus thalerus			++		
	Urohaustorius halei	++				
Amphipoda – exotic	*Corophium acherusicum*	+	+	+	+	
	Corophium insidiosum	+				
	Corophium sextonae		++	+		
	Jassa marmorata	++	++			
Amphipoda – cryptogenic	*Caprella acanthogaster*		?			
	Caprella scaura	++	++	++		
	Caprella equilibra	++	++			
	Caprella penantis		?			
Sipuncula – endemic	*Edwardsia* sp 1		++			
	Phascolion sp 1		++			
Echiura – endemic	*Anelassorhynchus porcellus*		++			
	Metabonellia haswelli		++			
Bryozoans – endemic	*Adeonellopsis bachata*		++			
	Adeonellopsis foliacea		++			
	Amathia sp 1		++			
	Caberea glabra		++			
	Celleporaria sp 1	++	++	++	++	++
	Celleporaria cristata	++				
	Celleporina rota			++		++
	Cheilostome 1		++			
	Cheilostome 2		++			
	Cheilostome 3		++			
	Cheilostome 4		++			
	Crassimarginatella papulifera		++			
	Cribicellina sp 1					++

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Cyclicopora longipora	++		++		
	Didymosella larvalis			++	++	
	Emma rotúnda			++		
	Membranipora perfragilis				++	
	Membranipora sp 2		++			
	Mucropetraliella elleri		++	++	++	
	Parasmittina sp 1					++
	Plagioecia sarniensis	++				
	Pyripora sp 1			++		
	Sinupetraliella litoralis		++	++	++	
	Tricellaria monotrypa					++
	Tricellaria aculeata				++	
	Tryphyllozoon moniliferum		++			
Bryozoa – exotic	*Aetea anguina*	++		++		++
	Amathia distans	++	+			
	Bowerbankia spp	+				
	Bugula calathus	+				
	Bugula flabellata	++	++			++
	Bugula neritina	++	++	++		
	Bugula simplex	+				
	Bugula stolonifera	+	+	+		
	Celleporella hyalina	+		+	+	+
	Conopeum reticulum	++	++	+	+	
	Cryptosula pallasiana	++	++	++	++	
	Electra pilosa	+	+	+	++	+
	Fenestrulina malusii	+		+		
	Membranipora membranacea	+	+	+	+	+
	Microporella ciliata	+		+	+	
	Schizoporella unicornis		++			
	Scruparia ambigua	+		+		
	Scrupocellaria bertholettii				+	
	Scrupocellaria scrupea	+	+	+	+	+
	Scrupocellaria scruposa	+	+	+	+	+
	Tricellaria occidentalis	++	++	++	++	++
	Watersipora arcuata	+		+		
	Watersipora subtorquata (subovoidea)	++	++	++	++	++
Bryozoa - cryptogenic	*Celleporaria albirostris*					
	Hippothoa divaricata					
	Membranipora savartii					
	Parasmittina trispinosa					
Phoronida – endemic	*Phoronis* sp 1		++			
Echinodermata:						
Asteroidea – endemic	*Allostichaster polyplax*		++			
	Coscinasterias muricata	++	++			
	Patiriella brevispina	++	++			
	Uniophora granifera	++	++			
Asteroidea – exotic	*Asterias amurensis*	+	+		+	
Ophiuroidea – endemic	*Amphipholis squamata*	++	++	++	++	++
	Amphiura constricta	++				++
	Amphiura elandiformis		++			
	Amphiura sp (juv)	++		++		
	Ophiactis tricolon	++				
	Ophiactic resiliens					++
	Ophiocentrus pilosus		++			
	Ophiothrix caespitosa			++		++
	Ophiura kinbergi		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
Ophiuroidea – cryptogenic	*Amphiura parviscutata*		++			
Echinoidea – endemic	*Amblypneustes ovum*		++			
	Echinocardium cordatum		++			
	Heliocidaris erythrogramma		++			
Holothuriodea – endemic	*Leptosynapta dolabrifera*		++			
	Leptosynapta sp 2		++			
	Stichopus mollis		++			
	Taeniogyrus sp.		+			
	Trochdata allani		++			
Hemichordata – endemic	*Enteropneust* sp 1		++			
	Enteropneust sp 2		++			
Chordata:						
Ascidacea – endemic	*Aplidium* sp 1			++		
	Ascidia sydneiensis	++	++			
	Ascidia thompsoni	++				
	Ascidian sp 1		++			
	Ascidian sp 13		++			
	Ascidian sp 14		++			
	Ascidian sp 16		++			
	Asterocarpa humilis	++			++	
	Botrylloides sp 1	++				
	Botryllus sp 1	++				
	Cnemidocarpa etheridgii		++			++
	Cnemidocarpa radicosa	++				++
	Cnemidocarpa sp 1		++			
	Corella eumyota	++				
	Didemnidae sp 1	++	++	++		++
	Didemnidae sp 1	++	++			
	Diplosoma sp 1		++			
	Halocynthia dumosa	++				++
	Halocynthia hispida		++			
	Herdmania momus			++		
	Microcosmus squamiger		++			
	Molgula ficus	++	++			
	Molgula sp 1		++			
	Polycarpa penduculata	++		++		
	Polycitorella mariae		++			
	Polyclinum fungosum			++		
	Pyura fissa	++				
	Pyura gibbosa draschii	++		++		
	Pyura stolonifera	++	++	++		
	Pyura tasmanensis	++	++	++	++	
	Pyura sp 1	++	++	++	++	
	Stolonica australis			++		
	Sycozoa sp 1		++			
	Syniocum sp 1			++		
Ascidians – exotic	*Ascidiella aspersa*	++	++	++	++	++
	Botrylloides leachi	++	++	+	++	
	Botryllus schlosseri	++			++	
	Ciona intestinalis	++	++			
	Molgula manhattensis	+				
	Styela clava	++	++	++		
	Styela plicata	++	++			++
Pisces – endemic	*Acanthaluteres spilomelanurus*		++			
	Acanthaluteres sp 1		++			
	Aldrichetta forsteri		++			

Table A7. continued.

Taxa/status	Species	Port Phillip Bay region				
		1	2	3	4	5
	Arenigobius bifrenatus		++			
	Arripis georgiana		++			
	Atherinosoma microstoma		++			
	Brachaluteres jacksonianus		++			
	Callogobius mucosus		++			
	Clinidae sp 1	++				
	Contusus brevicaudus		++			
	Cristiceps australis	++	++			
	Favonigobius lateralis		++			
	Gobiidae sp 1	++				
	Genypterus tigerinus		++			
	Gymnapistes marmoratus		++			
	Heteroclinus sp 1		++			
	Hyperlophus vittatus		++			
	Hyporhamphus melanochir		++			
	Kaupus costatus		++			
	Labridae sp 1		++			
	Muraenichthys breviceps		++			
	Nesogobius hinsbyi		++			
	Nesogobius sp 3		++			
	Neoodax balteatus		++			
	Notolabrus fuciola		++			
	Parablennius tasmanianus		++			
	Platycephalus bassensis		++			
	Rhomobosolea tapirina		++			
	Scobinichthys granulatus		++			
	Sillaginodes punctata		++			
	Siphaemia cephalotes		++			
	Stigmatopora argus		++			
	Stigmatopora sp 1		++	++		
	Tetractenos glaber		++			
	Vincentia conspersa		++			
	Vincentia sp 1	++		++		
Pisces – exotic	*Acanthogobius flavimanus*	+	++			
	Acentrogobius pflaumi	+	++			
	Forsterygion lapillum	++	++			
	Tridentiger trigonocephalus	++				

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Port Phillip Bay in southeastern Australia borders the major metropolitan areas of Melbourne and Geelong. The bay has been a focus of shipping activity since the mid-1800's and is currently a major destination for domestic and international shipping. Port Phillip Bay has also been the focus of a number of historical biological surveys, making possible an evaluation of the historical patterns of invasion by exotic marine species.

This report details current status of the introduced and cryptogenic species in the bay through: taxonomic reviews of the literature and museum collections; new field surveys; documentation and re-analysis of the possible impacts of exotic species; and an evaluation of the broad patterns of invasions and likely introduction vectors.

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