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Workshop on Rock Lobster Ecology and Management

edited by
B. F. Phillips

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Introduction

In 1986 Patricia Briones Fortesan and Enrique Lozano Alvarez from Universidad Nacional Autonoma de Mexico spent six weeks in Australia under the Australia/Mexico Science Agreement. To make the maximum use of this opportunity, a workshop on rock lobster ecology and management was held at the CSIRO Marine Laboratories in Perth from 17 to 21 November 1986.

Participants at the workshop were encouraged to present on-going research, rather than reviews of published material. Because of this, only abstracts of the presentations are published here. Although considerable discussion took place after all presentations and during an afternoon of discussion on the last day, there were no formal rapporteurs or reports of sessions.

Included in this volume are reviews of the history of rock lobster research in Australia and New Zealand, together with selected bibliographies.

Abstracts

Abstracts

Individual transferable quotas — a proposed new management regime for the New Zealand rock lobster fishery

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The current management regime for the New Zealand rock lobster fishery has major deficiencies. Limits on the number of vessels have not been sufficient to prevent fishing effort from increasing to the detriment of stocks. Further it has led to overcapitalisation and poor economics of rock lobster harvesting, particularly in areas where catch rates have declined.

Management by Individual Transferrable Quotas is likely to be introduced in the near future. A national Total Allowable Catch is to be set and apportioned among current rock lobster fishermen in relation to their current involvement and commitment in the fishery.

Future adjustments to the Total Allowable Catch will be made by the Government purchasing or selling quotas.

Successful management by Individual Transferrable Quotas will depend on monitoring the natural abundance of rock lobster, in particular changes in recruitment, migration and natural mortality.

Gross habitat selection and survivorship of small juvenile western rock lobsters in the laboratory

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A preliminary series of laboratory experiments was performed to determine:

- The preferred gross habitat of juvenile western rock lobster (6.5–10.5 mm CL).
- Predation of small lobsters in benthic habitats by *Pelsartia humeralis* (sea trumpeter)

Small lobsters significantly preferred artificial *Posidonia*. Predation of small lobsters by *Pelsartia humeralis* was markedly higher in *Posidonia* than in the limestone caves and rock rubble.

The implications of these experiments are:

- Small lobsters have a preferred habitat.
- Predation of small lobsters in structurally simple habitats is high.

Field and laboratory growth studies of *Panulirus ornatus*

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Growth data were collected from 126 *Panulirus ornatus* in Torres Strait and on the northeast coast of Queensland during tag–recapture studies from 1980 to 1986. The mean time at large was 146 days (range 27–1331). Lobster size ranged from 38.1 to 125.5 mm CL. Growth rates varied widely for a given size (range 0.02–0.27 mm CL/day) A relative growth rate was estimated from the size increments of field lobsters, and aquarium growth records were used to calculate absolute growth and age of *P. ornatus* in the Torres Strait.

Ecology and behaviour of the puerulus stage of the red rock lobster *Jasus edwardsii*

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Most planktonic *Jasus edwardsii* pueruli caught in nets away from the shore have been taken on the continental slope, although a few were taken in deep 100 m) waters further offshore. Those on the continental shelf were on or near the sea bottom during the day and rose into the water column at night. Close to shore at night, the pueruli were sometimes at the surface.

Catches of pueruli on collectors set to depths of 100 m off two localities on the east coast of the North Island suggest that most settlement occurs in inshore areas at depths 12 m, although some settlement was observed down to 50 m. The reasons for variation in settlement on inshore collectors checked at least weekly (and sometimes twice weekly) for more than one year at one of these sites, Castlepoint, is unknown.

Probable trans-Tasman population continuity in Australasian stocks of *Jasus* subgroup *lalandii* rock lobsters

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Jasus subgroup *lalandii* populations in New Zealand and southeastern Australia are probably homogeneous, with significant gene flow occurring across the Tasman Sea. The long-lived phyllosoma stage is widespread in the south Tasman Sea. Populations of late juvenile and adult rock lobsters on both sides of the Tasman Sea are genetically very similar, with a polymorphic Esterase 1 locus. However, variable levels of polymorphism were also found in Australia for the lactate dehydrogenase locus. There is much geographic variation and overlap in the morphological features previously identified as separating the New Zealand and Australian populations. Furthermore, the presence of non-uniform colouring on the antennal flagella is much more widespread in New Zealand than previously reported.

Management research on the New Zealand rock lobster *Jasus edwardsii*

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Both yield-per-recruit and surplus production analyses suggest that fishing effort is much higher than necessary in the rock lobster fishery in New Zealand. Only a small increase in equilibrium yield could be obtained, but the risk associated with excess fishing effort and reduced standing stocks should be reduced by rehabilitating stocks.

Managers propose to introduce ITQs to this fishery in 1987. This will be done without reducing present catches and future catch reductions will occur only through government purchase of quota. The fishery will thus continue without effective effort restriction for at least a couple of years.

A new research program has been initiated to supply management's information needs. Needs were identified as 1) to protect the stock to the greatest extent possible with the existing static controls; 2) to detect recruitment decreases as soon as possible; 3) to develop a stock rehabilitation strategy that can be sold to Treasury; 4) to track stock and fishing mortality in order to assess management impacts; 5) in the long term to understand stock recruit relationships.

Specific programs to address these needs are: 1) evaluating the yield and egg-per-recruit implications of the present size limit in light of new growth and fecundity information; 2) to establish regular catch sampling; 3) to continue surplus production and other modelling, if possible with standardized effort estimates; 4) to track stock using relative abundance estimates from catch sampling, and to estimate fishing mortality rate from SFDs; 5) to develop a time series of stock, recruit and pre-recruit abundance estimates.

Spiny lobster research in Mexico

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There are several species of Palinurids in Mexico, but *Panulirus interruptus* (a temperate species occurring on the Pacific coast) and *Panulirus argus* (a tropical species occurring in the Caribbean) make up the bulk of the catch.

A description of the fishing methods and regulations governing each fishery will be presented, and an outline given of the management and biological research in Mexico.

The production trends will be described, as well as the difficulties of obtaining reliable catch-per-unit-effort data for the different fisheries, which use a large variety of catching methods.

Juvenile and pre-recruit spiny lobsters *P. argus* in Quintana Roo, Mexico

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Panulirus argus supports an important and growing fishery in the Mexican Caribbean, and has been the target of a large research program by the National University of Mexico's Marine Research Station at Puerto Morelos, state of Quintana Roo, since 1982.

In 1985, CSIRO and UNAM began a joint research program on juvenile and subadult *P. argus*. As part of this, 3,464 spiny lobsters were tagged in Bahia de la Ascension, a large bay in the central zone of the coast of Quintana Roo. The lobsters of Bahia de la Ascension are fished by a special method, whose development and evolution during the last few years will be described.

The tagging was carried out during the closed season. Fishermen recaptured 750 lobsters, mainly during the first three months of the next fishing season.

Some preliminary results on population structure, growth, mortality and movements of these animals will be discussed.

Conservation of recruitment of the western rock lobster *(Panulirus cygnus)* by improving survival and growth of undersized lobsters captured and returned by fishermen to the sea

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The rock lobster fishery in Western Australia is one of the largest in the world, with catches in the years 1974/75 to 1983/84 averaging about 10,000 tonnes. The fishery which involves around 720 boats, is managed on a limited entry basis. The regulations require that all pots incorporate an escape gap, and that all berried females and undersized lobsters must be returned to the sea. Despite the escape gaps, some 16–20 million undersized lobsters are handled each season.

Fishermen handled the undersized lobsters in one of six ways, ranging from immediately returning them to the water, to sorting only after a line of pots (20–30 pots) has been pulled and reset.

Laboratory experiments on undersized lobsters exposed to direct sunlight and shade showed that mortality increased with increasing length of exposure and increasing temperature. Additional experiments showed that the growth increment was significantly reduced. Behavioural observations in the field showed that the activity of undersized lobsters returned to the water decreased with increasing exposure, and the loss from predation increased. In experiments in the laboratory, octopus predators only killed or injured exposed animals. Tagging trials showed a significant decrease in recapture rates with increasing exposure. Damage (number of appendages lost) and displacement from the point of capture were also found to significantly reduce recapture rates.

The combination of these factors produced an estimated seasonal mortality of 14.6%, and after taking into account natural mortality, this would have resulted in a loss of over $A13 million (1984/85 price) to the fishery. As these factors also reduce growth rate, there are additional losses.

Conservation measures were taken to reduce the mortality of undersized lobsters. During 1981 and 1982 an eighteen-month education program was conducted to publicise the effects of poor handling methods on the survival of undersized lobsters. This program was followed by a survey of rock lobster fishermen in 1983–84 that showed that handling techniques had improved significantly since the education program. In 1987 it was made an offence to have undersized lobsters on board a vessel for more than five minutes.

Between 1983 and 1985, field trials were undertaken, using both research and commercial vessels, to test various sizes, numbers and placements of escape gaps within a pot, to determine what combination was most effective in reducing the number of undersized lobsters captured, without reducing the catch of legal sized lobsters. In late 1986, a regulation was proclaimed requiring all lobster pots to be fitted with at least 3 escape gaps of 54 mm x 305 mm (2 more than had previously been used)

The improvement in handling methods and the use of two extra escape gaps was estimated to have reduced handling mortality by about 75%.

Studies on juvenile *Homarus americanus* in southwestern Nova Scotia, Canada

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Studies on the diet, behaviour, movement, growth and densities of juvenile *H. americanus* have recently been conducted by several scientists (A. Campbell, R. W. Elner, P. Lawton, G. Sharp) in southwestern Nova Scotia. A method of consistently collecting post-settlement larvae has not yet been successfully developed. However, juveniles of 20 mm carapace length have been regularly sampled with SCUBA and traps since the early 1980s.

The diet of lobsters in this area covers a wide range of plants and animals, with molluscs, crustacea, echinoderms and polychaetes being important food items. The mean stomach fullness and number of taxa types per stomach was lower in winter than in summer. Behavioural time-budget analyses indicated that juvenile lobsters were nocturnally active within or close to available shelter. Monthly samples over three years (1982–84) in a 4.5 ha study area (fished commercially) indicated that, although the mean density of lobsters declined slightly (0.1 to 0.5 per m^2), the mean carapace length and biomass increased (2 to 3 g dry wt per m^2). Seasonal increases in mean carapace length occurred during July–October, probably due to moulting and immigration.

Concomitant sampling of the sympatric crabs *Cancer borealis* and *C. irroratus* indicated that, although *C. irroratus* (0.3 per m^2) was more abundant than *H. americanus* or *C. borealis* (0.05 per m^2), there was a higher biomass per m^2 of the lobsters than of either of the crab species.

The effect of environmental factors and spawning stock on the puerulus settlement of the western rock lobster

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The relationship between the level of puerulus settlement and the recruitment to the fishery 4 years later has been shown to reliably predict the strength of recruitment. Whilst it is generally accepted that the early larval stages are moved offshore by wind-driven surface currents, the factors involved in their return to the coast are still not known.

The effect of winter/spring storms, which are usually associated with westerly winds, on the return of the puerulus was investigated, using rainfall at 8 coastal localities as an index of the storms. This resulted in a multiple correlation correlation of 0.78 (n=17) in the multiple regression between puerulus settlement (logarithmically transformed) and the rainfall during the mainly winter months (July–September) and spring (October–November) However the residuals of this relationship showed a significant positive autocorrelation (Durbin-Watson statistic of 0.66). Initial examination indicates that these residuals are not related to the index of abundance of spawning stock. Since the cause of this autocorrelation has not been determined, it has been quantified and incorporated into the relationship to improve the fit. This was done using a two-stage regression procedure, which resulted in a multiple correlation coefficient of 0.90.

The effect of the abundance of spawning stock on the level of puerulus settlement was then examined and found to be not significant. This is not surprising since there was little variation (+30%) in the index of abundance of spawning stock for the period examined. However it is important to continue to document the role of the spawning stock, especially as the poor rock lobster season expected in 1986/87 may result in a low spawning stock after 1 or 2 years. Having identified an environmental (rainfall as an index of westerly winds) which is possibly affecting puerulus settlement we may be in a better position to evaluate the effect of the size of the spawning stock.

Studies on the breeding stock of the western rock lobster, *Panulirus cygnus*: an overview

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The fishery for the western rock lobster, *Panulirus cygnus*, contributes significantly to the economies of both Western Australia and Australia. This fishery has experienced a very high rate of exploitation in recent years, which has led to concern that the abundance of the breeding stock of this species may be adversely affected. Coincident with this was concern that the index of abundance of the spawning stock currently in use may not have been adequately reflecting real changes in the size of the breeding stock.

Studies on the breeding stock of the western rock lobster were initiated in 1984 with the aim of improving the index of the abundance of the spawning stock and, if necessary, to propose new independent indices.

This paper critically examines the components of the existing index, data for which are drawn from a number of sources including previous biological research programs, voluntary research log books and commercial monitoring operations, discusses the aims of the program and presents preliminary results from research conducted in the past two and a half years.

Design improvements in the western rock lobster tag

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The western rock lobster tag designed by Chittleborough (1974) is used extensively in the studies on the breeding stock of this species. The loss of tag identity due to the mutilation of the numbered plastic tubing, caused by the biting and chewing of other rock lobsters, is a significant problem in these tag and multiple recapture experiments. This paper presents preliminary data from laboratory tank trials in which a variety of tag materials was used in an attempt to construct a more robust tag for use in rock lobster research.

Feeding experiments with early juvenile stages of the western rock lobster, *Panulirus cygnus*

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Settlement studies suggest there may be high mortality in the early stages of juvenile *P. cygnus*, which could be the effect of predation and niche and food limitations. Predation by fish is believed to be significant (Howard, pers. comm.); niche studies are in progress. Food availability has been invoked to explain growth differences between lobsters from different geographical sites. The guts of older juvenile stages of *P. cygnus* contain a high proportion of natural plant materials (algae and seagrass).

A study was made of the ingestion rates and energy benefit to early juvenile stages of *P. cygnus* of three "natural" dietary plant materials — calcareous algae (*Metagoniolithon* spp.), seagrass leaves with surface epiphytes (*Posidonia* spp. and epiphytic algae), and fleshy red algae (*Hypnea* sp.) Values are compared with data from mussel (*Mytilus edulis*) diets.

A group of *P. cygnus* collected immediately after settlement (January 1986) were kept in aquaria and their ability to ingest and derive energy from the plant diets was determined at four stages of development: 7–9 mm, 10–14 mm, 15–19 mm and 22–29 mm carapace length. The biomass of ingested food and fecal production, gut retention periods, C/N content and caloric values of food and faeces, respiration rates were determined for each size group. Observations were made of diel feeding patterns.

Preliminary energetic, carbon and nitrogen budgets are described and the relative energy values of each food type are considered in relation to "resting" respiration energy needs of each size group of *P. cygnus*.

Lipofuscin ageing pigments as a chronological ageing criterion for the western rock lobster: a non-event

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The pigment lipofuscin has been shown to accumulate with time in various tissues of animals from most phyla. Lipofuscin concentrations are thought to reflect physiological age and have been related to the chronological age of some organisms or cohort determination of populations. As a criterion for determining the age of the western rock lobster is needed for resource management and further biological studies, we examined the possibility of using lipofuscin.

The size of the western rock lobster is determined by carapace length. Field and aquarium studies indicate this morphometric parameter may be a poor measure of chronological or physiological age.

Techniques of extracting and assaying lipofuscin in the tissues of the western rock lobster are described. Criteria for expression of the lipofuscin content of different tissues are discussed. The lipofuscin content of eye and tail muscle tissues of the western rock lobster (*Panulirus cygnus*) and the eye tissue of scampi (*Metanephrops andamanicus*) are considered as a function of the carapace length of animals from five geographical areas. The extreme variability in these data probably reflects both variation in lipofuscin accumulation rates in animals in different geographical locations and the intrinsic problems of using carapace length to describe specimen age. It may be possible to utilise the lipofuscin content of eye or tail muscle to determine age groups or annual cohorts of the western rock lobster within a geographical site.

While lipofuscin content may have potential as a criterion for age determination in the western rock lobster, evaluation of its efficacy would require long-term assessment (5–7 years) of animals in aquarium studies and tagging/tag–recapture experiments. However, lipofuscin accumulation can be greatly affected by variations in diet and other environmental factors influencing metabolic rates. Hence, data from this preliminary study do not provide assurance that the investment of limited resources in such a study would demonstrate that lipofuscin is a sensitive and practical criterion for age determination in *P. cygnus*. The immediate needs of management may be more readily met by present techniques, including the continued and medium-term tagging experiments with populations at different geographical sites.

Interactions of the western rock lobster (*Panulirus cygnus*) and seagrass epifauna

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The interactions of rock lobsters and epifaunal prey were studied at two contrasting sites in Western Australia: Seven Mile Beach and Cliff Head, near Dongara. At Seven Mile Beach the smallest size class of rock lobsters (30 mm carapace length) fed predominantly on epifauna in *Amphibolis* beds, while larger rock lobsters foraged on reef tops and in mixed *Halophila*/ *Heterozostera* beds, and had a largely herbivorous diet dominated by filamentous coralline algae. At the Cliff Head site, however, the larger rock lobsters ate a trochid mollusc, *Cantharidus lepidus*, which recruited here (but not at Seven Mile Beach) in high densities in February. The presence of this trochid probably accounts for the previously documented higher growth rates of rock lobsters at Cliff Head than at Seven Mile Beach.

Field experiments indicated that the foraging activities of rock lobsters at Cliff Head had a significant impact on the population dynamics of *C. lepidus*. Most of the mortality of the largest size-classes of *C. lepidus* in *Amphibolis antarctica* beds is probably caused by rock lobster predation. Blue manna crabs at Cliff Head also exploited the abundant trochid resources in autumn 1985. This additional major predator on *C. lepidus* hastened the reduction in mollusc abundance, and presumably increased the period during which food resources were suboptimal for the growth of rock lobsters.

Diagnosis of lobster diseases

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Diseases can affect production in a lobster fishery. They can be lethal or sublethal and can occur at any stage in the life cycle of the lobster. The adult western rock lobster appears to be relatively free of disease. Information is lacking, however, on the occurrence of disease in juvenile lobsters and its possible influence on recruitment. A study was therefore undertaken to determine the nature and occurrence of disease in juvenile western rock lobster sampled from the wild. The approach used in this study and the preliminary findings from the 23 lobsters so far examined will be the topic of this presentation.

Diagnostic criteria used in the study of lobster disease are similar to those used in disease investigations in other animal species. They include external signs and the presence of pathogenic organisms or pathological features in preparations of fresh or preserved tissues. Information on specific diagnostic criteria used in the western rock lobster study will be presented. The application of histopathology to disease diagnosis will be emphasised, using examples of disease conditions in two other decapod crustaceans: a freshwater crayfish and a freshwater prawn.

Modelling recruitment to the western rock lobster fishery and subsequent exploitation

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A model of the western rock lobster fishery is currently being developed to im- prove the estimate of mortality and the effect of a change in the minimum lega size of retained rock lobster. The model is length-based, with rock lobsters o each sex falling into one of three moult stages: "just moulted", "intermediate" and "ready to moult", with the relative catchability of each stage adjustable.

New recruits to the legal-sized and exploited population (which are assumed tc have a sex ratio of 1:1), enter into the "just moulted" category, together with le- gal-sized lobsters that have just moulted. Animals graduate to the subsequen moult stage at the end of each month, until they again become "ready to moult' Moulting is currently represented in the model as occurring at the beginning o December, February, and June, with moult increment determined from the sex and current carapace length of the rock lobster.

Monthly fishing mortality for each length class is determined from the total an- nual number of potlifts, the proportion of annual effort expended during each month, the period of fishing within each month, the proportion of effort withir each of four depth zones during the month, the area of each depth zone, and the proportions of rock lobster of each length within each of the depth zones. These proportions have been obtained from analysis of log book data, com- mercial statistics, and data from a length-monitoring program.

All entries in the number-at-length table are initialised to zero. An iterative pro- cedure is then followed to recompute the table at the beginning of each month. Iteration continues until the transient response associated with the initial values placed in the table is no longer evident. At this stage an estimate o~ the steady- state yield associated with the specified level of recruitment is determined. The catch within each grade category is also obtained by assigning the estimated catch in each length class, through a tail weight/carapace length relationship, to the various size categories into which processors grade the processed product.

Estimates of the catchability coefficient and the instantaneous coefficient of natural mortality are obtained by varying these parameters to give the best fit of the distribution of estimated catches in the various grade categories with the ac- tual grade category data obtained from the fishery.

The relationship between climate, interannual variability in the oceans and stocks of lobster in Australia and New Zealand

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The Subtropical Convergence is a broad zone of convergence that runs across the ocean to the south of the Australian continent and across the southwest Tasman Sea between Australia and New Zealand. As Tasmania lies on the Subtropical Convergence, the waters surrounding the Island are very sensitive to changes in the position of the Convergence from year to year. Forty years of oceanographic observations on the east coast of Tasmania have revealed great interannual variability in the position of the Convergence, which shifts to the north in El Nino years. The strength of the westerly winds over Tasmania and the Great Australian Bight also has a significant effect. Research into the plank- ton biomass, the timing of the spring bloom, the structure of the food chain and the recruitment to commercial fisheries in South Australian and Tasmanian wa- ters has revealed a significant interannual variability in all these parameters. It appears that a number of commercial stocks, including crayfish and rock lob- sters, are heavily influenced by the interannual variability in the oceanography of the Tasman Sea and the waters to the south of the Australian continent.

Recruitment to the rock lobster fishery in Tasmania between 1960 and 1984

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The fisheries for the spiny rock lobster *Jasus novaehollandiae* in waters around the island of Tasmania have been managed for over 100 years. Stocks are conserved by a relatively high minimum legal length, first introduced in 1885. Since 1921 the gear has been cane traps (known as pots) with less than 40 pots per boat allowed. Limited-entry licensing was introduced in 1967 to achieve economic objectives. The development and effectiveness of this technique are discussed.

Seasonal recruitment in four of the five fishing areas has been determined for the 22 years between 1963/64 and 1984/85. Initial stock size (N_o) is estimated by regressing catch-per-potday against cumulative catch, using the method developed by Leslie. As N_o consists of recruits (N_s) and the survivors from the previous season's fishing, recruitment in the season t+l can be estimated. Spawning biomass was estimated by summing the biomass of pre-recruit year classes measured at the season of recruitment and allowing for natural mortality.

The paper discusses trends in recruitment, apparent changes in the catchability coefficient in some areas and the likely stability of the fisheries under the expected levels of high fishing mortality.

Predation on juvenile western rock lobsters in nursery habitat: Does it occur and is it significant?

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As part of a trophic study of the fish community of nearshore limestone reefs of Western Australia, fish stomach contents were examined for evidence of predation on juveniles of the western rock lobster (*P. cygnus*). Six species were found to have ingested *P. cygnus.* Of these, *Psammaperca waigiensis* (sand bass), *Pelsartia humeralis* (sea trumpeter), *Pseudolabris parilis* (brown-spotted wrasse) and *Plectorhyncus flavomaculatus* (goldspotted sweetlips) were among the ten most abundant fish in gillnet collections from the study site. *P. cygnus* formed a significant portion of the diet of *Psammaperca waigiensis,* but was 5% of the dietary volume of other species.

Predation, which occurred at all times of the day, was concentrated on small, newly settled *P. cygnus* (8–15 mm carapace length). The vulnerability of lobsters to predation was strongly related to size. The temporary cryptic habits of newly settled stages appears likely to be a response to high predation risk.

Estimation of mortality due to predation is hampered by lack of information on the natural densities of both fishes and small rock lobsters. However, the potential exists for thousands of lobsters per hectare each year, which suggests that predation may critically affect the mortality of p. cygnus on nursery reefs.

Foraging movements of juvenile western rock lobsters, *Panulirus cygnus*, George

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The foraging movements of juvenile western rock lobsters were studied by tracking the animals with an electromagnetic tracking device. Lobsters (55–68 mm carapace length) were caught in baited pots set around test reefs. Tags emitting electromagnetic pulses were glued to the carapace of the animals. Each tag had a unique signal, which was picked up by a series of aerials laid on the sea floor. The tracking area (approximately 16000 m^2) was covered by fifty 12 m x 12 m aerials separated from each other by a distance of 6 m.

A series of pilot experiments established that the lobsters behaviour was not affected detectably by the physical presence of the tags or by the electromagnetic signals that the tags produced.

The greatest distance that lobsters were found to travel during a single night was 800 m. At least 50% of the population travelled 300 m in a night. Their foraging direction did not appear to be random. The tags indicated that the lobsters spent more time in the *Heterozostera* and *Halophila* seagrass beds and the *Heterozostera* and *Halophila* habitat with *Amphibolis* seagrass. Night diving observations suggest that lobsters that stopped within aerials enclosing both types of seagrasses were feeding.

Behaviour of bay lobsters (Decapoda : Scyllaridae), *Thenus* spp.

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Naturalistic aquaria were used to examine diel patterns of activity, food searching and feeding, concealment, sediment preference, locomotion, moulting, and interaction.

From several thousands of hours of observations it was established that bay lobsters have a circadian activity rhythm with four components and representing distinct time phases. Two phases — an evening phase (1600 to 2000 h) and a morning phase (0000 to 0800 h) — were characterised by increased activity levels predominantly involving searching/foraging behaviours. During the day phase (0800 to 1600 h), lobsters remained buried in the sediment with only the eyes and antennules exposed. The night phase (2000 to 2400 h) was characterised by less activity than in adjacent phases.

Lobsters spent up to 70% of their active period in food searching and feeding behaviours. Although visual cues were unimportant in locating food items, other sensory mechanisms were well developed. Involvement of the pereiopods and antennules was particularly significant.

Concealment behaviour was well developed. A fixed routine of body movements enabled lobsters to bury beneath a shallow layer of sediment in less than two minutes.

Clear preferences for mud-silt sediments and for coarse sand sediments were displayed by *T. orientalis* and *Thenus* sp. A respectively. It was hypothesised that this differential preference represented character displacement of these coexisting species.

Examination of locomotion revealed advanced swimming ability facilitated by specialised morphological adaptation. It was hypothesized that this ability evolved from the familiar tail flick behaviour, in response to the limited carrying capacity of the environment.

The sequence of behavioural events prior to ecdysis were typical of lobsters in general, although the period taken to shed the old exoskeleton was considerably less.

The absence of agonistic behaviours and evidence of dominance/subordinance hierarchies in bay lobsters suggests that individuals of these species rarely interact. Courtship and mating behaviours, as described for clawed and spiny lobsters, were similarly absent.

A hypothesis was generated to account for the nature of Thenus behaviour and particularly the dissimilarity of several behavioural aspects with those of Nephropid and Palinurid lobsters. Environmental effects were considered to be of primary significance.

Temporal variability of seagrass beds in a coastal reef system

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The seagrass beds at Seven Mile Beach, Dongara provide habitat and forage for the western rock lobster. Although little is known of the relationship between the area and density of seagrass cover and the numbers of western rock lobster, it is obvious that these parameters are dynamic.

Aerial photographs taken at different times of year over many years show that the area covered by seagrasses changes from year to year. However, aerial photographs taken in January in three successive years showed that the area of bare sand, at least changes little. Data from underwater transects (regularly recorded twice a year) show that large changes in seagrass density and area covered occur within years. Seagrass distribution as indicated by aerial photographs and underwater transects taken at the same time, show similar patterns.

Winter storms remove seagrass cover, which grows back in summer. The seagrass beds are in shallow (2 m deep) water and wind-driven waves have a strong effect on some of the more weakly held seagrasses. The tops of patch reefs are covered by the strongly held *Amphibolis antarctica* and *griffithii*, which do not change seasonally.

Breeding and rearing of genus *Jasus*

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Mating experiments were undertaken with adults of *Jasus lalandii* from South Africa, *J. edwardsii* from New Zealand and *J. novaehollandiae* from Australia. The two last mated, spawned and hatched larvae successfully.

Phyllosoma of *J. lalandii* hatched in the laboratory survived longer than those of *J. edwardsii, J. novaehollandiae* and *Panulirus japonicus*, the Japanese spiny lobster. *Jasus lalandii* is therefore considered the better species for larval-rearing experiments.

Seasonal changes in the depth distribution of the red rock lobster, *Jasus edwardsii* (Hutton), in northeast New Zealand

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Seasonal changes in the depth distribution of the red rock lobster, *Jasus edwardsii*, in the Leigh Marine Reserve, northeast New Zealand were investigated with a visual transect method. There was little change in the overall density of *J. edwardsii* on a reef over the three years of sampling. However, when densities of males and females were examined separately at sites at three depths, large fluctuations were found.

Females exhibited the clearest pattern. In shallow areas 10 m) highest densities (x S.E.) of females occurred in April/May (10.3 +1- 2.5 per 100 m^2) and lowest densities in August/September (0.8 +1- 0.4 per 100 m^2) each year. In deep areas (17–25 m) the pattern was reversed, with highest densities occurring in August/September and lowest in April/May.

The most regular changes in the abundance of male *J. edwardsii* occurred at mid-depths (10–17 m) where the highest densities in each year occurred in September/October(7.0 +1- 3.2 SE per 100 m^2).

These cyclic changes in the density of male and female *J. edwardsii* profoundly influenced the sex ratio and size distribution of rock lobsters at each depth, and suggest that components of the same population were moving up and down a reef. This was confirmed by tagging and resiting part of the population.

These data are discussed in relation to moulting and the reproductive activities of *J. edwardsii*.

Comparison of of densities and size frequency of rock lobster (Palinuridae) populations amongst localities in northeast New Zealand

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The densities and size frequencies of two species of rock lobster (Palinuridae), *Jasus edwardsii* and *Jasus verreauxi*, within the Leigh Marine Reserve were compared to populations at five other localities in northeast New Zealand. The Reserve populations have been protected from commercial and recreational fishing since 1975, whereas both species are subject to intensive fishing at all but one of the other localities.

At each locality, five shallow-water sites, separated by distances of between 100 metres and several kilometres were examined. At each site 15 randomly placed 10 x 10 m quadrats were searched. The carapace lengths of all rock lobsters encountered were estimated.

Both species of *Jasus* were found at most localities. However the densities of *Jasus verreauxi* were very low and overall comprised less than 1% of the 1642 rock lobsters counted during the survey. The densities of *J. verreauxi* were similar at all localities and all individuals were immature.

In comparison the Reserve contained higher densities of *J. edwardsii* than any other locality. In addition large numbers of animals above the minimum legal size were found only in the Marine Reserve, where they comprised 69% of the population. Several hypotheses that could explain these results are discussed.

Standardisation of descriptive nomenclature and illustration of lobster larvae and post-larvae

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Knowledge of the taxonomy of lobster larvae and post-larvae has progressed beyond the difficulties of assigning these early developmental stages to genus.There is a need now to standardise the scope and format of descriptive texts and figures, because:

- previous texts and figures are often not detailed enough to establish the identity of larvae of different species within the same genus, nor to relate larvae of unknown identity to those of the many unknowns already described in the literature

- the nomenclature used in describing the external features of these stages is often variable, sometimes confusing, and occasionally imprecise.

Some basic suggestions to remedy the situation are summarised. These include the use of a standard morphological and morphometric "check list" and an illustrative format to cover fine-scale taxonomic characters as well as the gross morphology of phyllosoma, puerulus or nisto stages of the Palinuridae.

Research into the eastern rock lobster population off New South Wales

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Rock lobsters have been exploited off New South Wales since 1873. The recorded catch declined between 1955/56 and 1978/79 but thereafter increased. During 1982/83 research was undertaken to provide baseline information on the principal species of the catch, *Jasus verreauxi*.

Sexually mature females (seteosed pleopods) only occurred in the northern region of the fishery. The smallest size at which females possessed setae on the endopodites of the pleopods was 130–134 mm CL. Eggs were first carried on the setae at 140–144 mm CL.

The present legal minimum length for *J. verreauxi* in New South Wales of 104 mm CL would appear too small, but to increase this would affect a significant proportion of what is essentially a single-species fishery.

Application of random coefficient models to rock lobster growth

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Random coefficient models provide a convenient way of modelling individual growth and variability in animals. They can be used to estimate such population parameters as average growth and variability. Data on the growth of laboratory animals are used to illustrate the concepts and a generalisation of the method for capture–recapture data with animals of unknown initial age is described.

The Leeuwin Current and the rock lobster

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A major feature of the ocean circulation off western Australia is the Leeuwin Current, a stream of tropical water that flows southwards along the continental shelf during autumn and winter (March to October). Drifting buoys and thermal imagery from NOAA satellites reveal a complex pattern of eddies, meanders and shelfbreak jets associated with the Leeuwin Current system.

Having spent the winter hundreds of kilometres offshore, late stage planktonic larvae of the western rock lobster *Panulirus cygnus* approach the shelf in late winter and spring. They enter to the active puerulus stage in the vicinity of the shelf break, and swim inshore to settle in the coastal reefs. Meanders associated with the Leeuwin Current may contribute to this onshore transport. Studies of interannual coastal sea levels (used as an indicator of the "strength" of the current) and levels of puerulus settlement indicate that high settlement levels are associated with high sea levels, and hence with the strength of the southerly flow. As interannual sea levels correlate with El Nino/Southern Oscillation (ENSO) phenomena, the puerulus settlement and the eventual catch of the rock lobster fishery appear to be linked with ENSO events.

Reassessment of methods of estimating the density and mortality of juvenile rock lobsters (*Panulirus cygnus*)

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Reassessment of early data, plus additional information, indicates that tag–recapture estimates using baited traps do not produce valid estimates of the densities or mortalities of juvenile *P. cygnus* in the nursery reefs. This is because tagged and untagged animals are not equally liable to capture, age classes within the population are not sampled equally, and there is still movement between populations on the reefs January/February tag–recapture period. Juveniles move between reefs over distances of at least 745 m. Emigration of animals from the test reefs between sampling dates artificially inflates the estimates of natural mortality.

Visual estimates made by divers were evaluated as an alternative method of obtaining an index of juvenile densities and compared with the catches made by first-night trapping, including sampling with a net isolating the test reef. Both methods produce estimates of similar precision, are rapid, and because resampling is not required, need less manpower and resources than tag–recapture methods. However, the visual estimates are limited to times of good visibility. No truly satisfactory method of producing valid estimates for all the year classes in the nursery reefs is as yet available.

Simulation models of rock lobster populations from areas of widely divergent yields on the Cape west coast

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Read by **L. Beckley**

(Abstract of paper submitted to "Benguela–86". Payne, Gulland, Brink (eds.).*S. Afr. J. Mar. Sci.* 5)

Since the 1960s, yields of the Cape rock lobster *Jasus lalandii* have declined greatly in the Namaqualand (northern Cape) region from 31°5',5 (Doring Bay) north to the Orange River. The rock lobster population in this region is crowded into a narrow subtidal fringe within the kelp beds, whereas further south, animals approaching sexual maturity tend to move offshore to deeper waters, so that adults are found in depths of 70 m or more. Females attain sexual maturity at a smaller size in the Namaqualand region (and in Namibia) than further south, and growth rates of adults are retarded.

Simulation models are used to show how stunted juvenile growth and increased rates of natural mortality can result in typical growth, and increased rates of natural mortality can result in the typical size distributions observed in the Namaqualand region. This is contrasted with simulations for typical southern grounds where growth rates of both adults and juveniles are faster. The demographic models illustrate the effects of reduced growth and survival on population fecundity, fecundity per recruit and yield per recruit, assuming constant average annual recruitment in all areas.

The simulations demonstrate that overcrowding and stress, brought about by a diminution in the habitat area available to lobsters in the Namaqualand region, appear to have led directly to reduced production and yields. These areas are characterised by the presence of very low levels of dissolved oxygen in near sea-bed waters just outside the kelp beds. Oxygen deficiency is thought to have increased in the central and northern Benguela system since the 1960s as a result of changes in the rate of phyto-detrital deposition and decay in this highly eutrophic system.

Yields of rock lobsters in the Benguela upwelling area — past and present

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Read by **L. Beckley**

(Abstract of paper submitted to "Benguela–86". Payne, Gulland, Brink (eds.).*S. Afr. J. Mar. Sci.* 5)

Earlier studies suggested that yields of *Jasus lalandii* in the northern Cape and Namibia had declined as a result of severe overfishing and progressive reductions of minimum size limits, especially between 1960 and 1970. Although catches were temporarily boosted to artificially high levels by reductions in minimum size, evidence is presented that suggests that sustainable yields have declined largely as a result of environmental changes during and after the 1960s. It is postulated that a progressive expansion of oxygen-deficient shelf water may have forced lobsters to occupy a much reduced habitat in shallow waters, where overcrowding has resulted in reduced growth and survival, and production and yields have declined accordingly. Increased competition for food and space in the better oxygenated shallows has led to a diminution in the size at sexual maturity of female lobsters and reduced adult growth rates. In addition, low levels of dissolved oxygen may have direct physiological effects on rates of feeding, growth and mortality.

Possible reasons for the likely change in oxygen concentrations prior to and after the 1960s are discussed. Reduced grazing of phytoplankton by planktonic herbivores (zooplankton and clupeoid fish) as well as increased phytoplankton production per se are considered to be possible causative factors leading to the carbon overloading prevalent in the central and northern Benguela system since about 1960.

Studies on lobsters in the New Guinean region

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Abstract not available.

The ecological role of juvenile western rock lobsters in shallow-water seagrass communities

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Juveniles of the western rock lobster, *Panulirus cygnus*, use seagrass beds in inshore reefs in Western Australia for shelter and for feeding. At Seven Mile Beach, Dongara, beds of mixed seagrasses (*Halophila ovalis* and *Heterozostera tasmanica*) contain high densities of infaunal species and occur close to juvenile rock lobster dens. The seagrass infauna consists mainly of small individuals of species able to grow rapidly and produce several generations in a year. Many of them are potential food for rock lobsters, as well as for bottom-feeding fish and other demersal crustaceans.

Calculations of the biomass and food requirements of juvenile rock lobsters indicate that the biomass of infauna in the area is inadequate to support fully the density of lobsters observed, even without allowing for competition by other predators. This suggests both that the growth of rock lobsters may be food-limited, and that overall predation levels on the infaunal community are high. Predation may, therefore, significantly affect the structure of benthic communities, and possibly also influence their secondary production.

Experimental and manipulative studies are in progress to examine in detail the trophic interactions of rock lobsters and the infaunal community, both to quantify the amount of secondary production utilised by rock lobsters, and to examine their role in structuring the infaunal community. In the field, fine-mesh (5 mm) cages are being used as exclosures to examine the short term behaviour of the infaunal community in the absence of predation by larger demersal fish and crustaceans, including rock lobsters. Enclosure cages are being used to examine the effect of juvenile rock lobsters on the abundance of individual infaunal species, and to estimate their natural feeding rates. The field work is being supplemented by small-scale laboratory studies on the feeding behaviour of juvenile rock lobsters, and on the growth rates of individual infaunal species.

Initial research into growing-on of New Zealand red rock lobster, *Jasus edwardsii*

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Market development and exploitation of New Zealand red rock lobster (*Jasus edwardsii*) has been rapid. Overseas demand continues to make it one of the largest income earners in the New Zealand fishing industry.

Recent surveys of rock lobster populations, however, indicate that the species is being overfished. Growing-on juvenile and puerulus stages held in captivity is one option to supplement depleted stocks and supply overseas markets.

At Portobello Marine Station, Dunedin, New Zealand, 100 juveniles (40 to 70 mm carapace length) have been held in captivity for more than 8 months, with only one death.

During the next two years, experiments on the effects of diet, density, downstream inhibition and eyestalk ablation on growth and survival of individual animals will be conducted.

Initial work has shown that juvenile rock lobster can be reared over the long term on a single-species diet (e.g. *Chione stutchburyi*). Growth rates on this diet match those recorded in the wild when captive lobsters are held at ambient temperature.

Growth and moult data from density experiments are being accumulated. Observations of behaviour suggest captive-reared lobster may not be suitable for restocking purposes. These animals feed in the open during daylight, which may lead to high mortalities when returned to the wild.

Movements and den habitation patterns of *Panulirus ornatus* in the Torres Strait

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Daily surveys of dens in the shallow reefs of the Torres Strait indicate that the lobsters have a scattered distribution and that they move frequently. Although the lobsters do not seem to move between reefs, their mobility results in their being distributed relatively unpredictably between dens and between different areas within a reef. This scattered, unpredictable distribution means it is better for a diver to move widely across a reef and sample a number of areas than to concentrate effort in a single area by fishing all available dens.

Availability of food for juvenile rock lobsters (*Panulirus cygnus*) vertical partitioning of food in the sediment

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The vertical distribution of sediment-dwelling macrofauna was investigated in three habitats in the nursery grounds of the rock lobster *Panulirus cygnus.* This forms part of a study of the production and community dynamics of the benthos in relation to predation by juvenile *P. cygnus.*

Meadows of seagrasses *Heterozostera tasmanica* and *Halophila ovalis*, in mixed stands, provided a macrofaunal biomass seven times greater than the biomass in neighbouring meadows of *Amphibolis griffithii.* Unvegetated habitats provided a negligible biomass of macrofauna.

The biomass of macrofauna was composed mainly of polychaetes, which equalled the combined biomass of all other taxa. Polychaetes were distributed to a depth of 150 mm below the sediment surface, with 50% of the biomass deeper than 30 mm. Crustaceans, the second taxon in biomass, were concentrated almost entirely in the upper centimetre of sediment. Molluscs, the third taxon in biomass, were distributed throughout the sediment column. Low mollusc biomass at the surface may reflect high predation rates. The results are discussed in relation to the habitat and diet of juvenile rock lobsters.

Management of the Torres Strait Tropical Rock Lobster fishery under the Torres Strait Treaty

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Fisheries management under the Torres Strait Treaty requires that the parties to the treaty — Australia and Papua New Guinea — enter into arrangements with respect to fisheries to protect the traditional way of life and livelihood of the traditional inhabitants, allow them maximum opportunity for participation, conserve the fisheries resources of the Protected Zone, and aim for a level of "optimal utilisation".

The tropical rock lobster fishery in Torres Strait involves a number of issues that make its management more of a problem than in the other jointly managed fisheries. These are: the interaction of the prawn and lobster fisheries; the migration of rock lobsters between Australia and PNG; and the need for the two countries to establish an equitable catch-sharing agreement in an atmosphere of sometimes conflicting economic priorities.

Management strategies involve continuing monitoring of the various sectors of the fishery, consultation between Islanders, industry and government, and regular update of management approaches.

Rock Lobster Research in Australia

B. F. Phillips

Introduction

Substantial fisheries are based on all the major rock lobster stocks in Australia. Australia is the largest exporter of rock lobsters in the world. Their landed value in 1986/87 was estimated to be worth A$220 million. *Panulirus cygnus* George from Western Australia comprises 60% of the total catch, but there is also a small catch of the southern rock lobster *Jasus novaehollandiae* Holthuis near Albany and Esperance. *J. novaehollandiae* is caught around the south coast of Australia from Western Australia to southern New South Wales and in Tasmania. The eastern rock lobster *Jasus verreauxi* (Milne-Edwards) is caught in New South Wales, and also occasionally in Victoria and Tasmania. The only apparent potential for additional exploitation of wild stocks is the mixture of tropical species from north Australian waters, which are either too sparse or too isolated for successful exploitation.

The history of research into rock lobster stocks in Australia is reviewed in this paper. Each species is treated separately and the research is described in approximately chronological sequence. The review is not exhaustive but covers the significant publications to 1987. Unpublished theses are referred to when they contain relevant material. Biological research has been emphasised but some papers on management, economics and occasionally marketing have been included where appropriate.

Western Rock Lobster

The fishery for the western rock lobster *Panulirus cygnus* George is one of the major rock lobster fisheries in the world and the most valuable single-species fishery in Australia, accounting for approximately 35% of the country's gross income from fisheries products (Morgan 1980b). Because of its importance, the western rock lobster has been subject to a long period of study, the nature of which has varied with increasing knowledge of the fishery, the animal and its environment.

Research

Some observations on moulting, growth, spawning and incubation and the larvae of *P. cygnus* were made by F. Aldrich from 1911 to 1938 (Chittleborough 1967). However, detailed studies of the western rock lobster began in 1946, when, as a result of representations from the Western Australian Chief Inspector of Fisheries (A. J. Fraser) to the Chief of the CSIRO (then CSIR) Division of Fisheries (Dr H. Thompson), K. Sheard was assigned to conduct research on this species. In 1953 he was joined by R. W. George. Studies from 1946–61 were concentrated on the commercial fishery and the collection of catch, effort, and catch-composition data (Beck and Sheard 1969; Sheard 1949, 1954, 1962; George 1957, 1958, 1962). These data on the early development of the fishery have proved invaluable in its management. There could be few better examples in Australian fisheries of the value of collecting statistics.

A new phase of western rock lobster research stemmed from the formation of the Western Fisheries Research Committee in November 1961. A joint research project on the western rock lobster was developed, with the Western Australian Department of Fisheries and Fauna being responsible for studies on the exploited phase and CSIRO Division of Fisheries and Oceanography for the recruitment phase.

The Western Australian Fisheries Department studies of the exploited phase, initiated by B. K. Bowen, included growth rates, size composition of the catch, catch rates and size at maturity. Bowen (1963) published the results of his research on escape gaps, after which a 2-inch escape gap was introduced in 1966.

Bowen and Chittleborough (1966) reported the first attempt at stock assessment, and recommended urgent research on growth, mortality and migration, and more detailed catch records. This led to the introduction of fishermen's research log books, a monitoring program in four major fishing areas, and tagging programs in the coastal and Abrolhos fisheries.

A commercial monitoring program was started in 1971 to monitor vessels at sea. To provide a basis for observing long-term trends in the fishery, observers on board commercial vessels sampled rock lobsters from four ports in four depth categories in each month of the fishing season. Size composition by sex and breeding state were recorded.

Morgan (1972) reported on the fecundity of the western rock lobster and Morgan (1974a, 1974b) described the results of his studies on catchability and density estimation based on a series of monthly tag–recapture experiments over several years.

Morgan and Barker (1974, 1979, 1982) and Brown and Barker (1985) published a series of reports on the rock lobster fishery, including monitoring data. The reports cover all but six of the years between 1961 and 1983.

Morgan (1977, 1979a, 1980a) examined a number of stock assessments models for the fishery, including the SCHAEFER, GENPROD, PRODFIT and delayed recruitment models used to estimate maximum equilibrium yield at the fishing effort at which the yield is maximised for the *P. cygnus* fishery. Morgan (1979b) discussed the advantages and disadvantages of each model, and concluded that the four yield models considered provide, at best, a crude representation of the dynamics of the exploited stock. The models do, however, provide a good fit to the observed catch and fishing effort data up to the values of effort so far encountered. Morgan (1980c) also examined the dynamic pool models and concluded that improved estimates of growth and mortalities were required before these models could be useful.

CSIRO transferred R. G. Chittleborough to Perth early in 1963. The main part of his research was on the ecology of juvenile densities, growth and mortalities, and an examination of artificial shelters to increase habitat. Pond rearing of rock lobsters, tag design, home range, homing and dominance in juveniles were also examined (Chittleborough 1970, 1974a, 1974b, 1974c, 1974d, 1975, 1976a, 1976b, 1979). Studies of rock lobster larvae were also carried out from HMAS *Diamantina*, whenever cruises could be arranged (Chittleborough and Thomas 1979). B. F. Phillips was appointed to the project in 1967 to study settlement of the puerulus stage and growth and survival of the early postlarval stages (Phillips 1972, 1975a, 1975b, 1975c, 1977, 1979, 1981, 1982, 1986; Phillips *et al.* 1979; Phillips *et al.* 1981; Phillips and McWilliam 1986). D. A. Ritz carried out larval studies from 1968 to 1970 (Ritz 1972a, 1972b), but this work was terminated because of the lack of a suitable vessel.

Larval research began again in 1973 with CSIRO's charter of the RV *Sprightly*. D. W. Rimmer was appointed to the larval program in 1973 (Rimmer 1980; Rimmer and Phillips 1978, 1979; Griffiths and Rimmer 1977) and P. A. Brown in 1976. In addition to the rock lobster studies, G. R. Cresswell, T. J. Golding, F. M. Boland, G. Symonds and B. V. Hamon carried out oceanographic studies from 1973–1976 in the southeastern Indian Ocean as part of the overall project. The larval and oceanographic work being carried out from RV *Sprightly* ended in January 1977 when the vessel was moved to New South Wales for studies of the East Australian Current.

A bibliography of physical oceanography in south-west Australian waters was published by Pearce (1983). Studies of the Leeuwin Current and its effect on coastal processes and larval recruitment levels of *P. cygnus* are in press (Pearce and Phillips). A special project, the "LUCIE experiment", to study the Leeuwin Current and its effect on the environment off Western Australia and its interactions with the recruitment of the larvae of commercial species, particularly the western rock lobster, was undertaken by CSIRO in 1987. No results from this study are yet available.

W. Dall joined the program early in 1969 to study the physiological aspects of moulting and growth in juveniles. He moved to Cleveland at the beginning of 1975 to lead the prawn research program as Officer-in-Charge of the Northeast Regional Laboratory. The physiological studies were continued in Perth by M. C. Barclay and D. M. Smith, under W. Dall's direction, until they were also transferred to Cleveland in 1976 (Dall 1974a, 1974b, 1975a, 1975b, 1975c, 1977, 1980; Dall and Barclay 1977, 1979; Dall and Smith 1977, 1978a, 1978b).

Behavioural studies of juveniles were made by J. P. R. Hindley from 1973 to 1976, when he was transferred to Cleveland, and by a visiting American scientist J. S. Cobb (1981). V. B. Meyer-Rochow (1975a, 1975b) examined the structure and sensitivity of the eye of the puerulus and adult stages and then studied sound production and the responses to sounds of the same stages (Meyer-Rochow and Penrose 1974; Meyer-Rochow *et al.* 1982).

Chittleborough continued his studies on juveniles until 1976, when he left to join the Western Australian Department of Conservation and Environment. In 1977 L. M. Joll began a study of the food and feeding of the juveniles (Joll 1982; Joll and Crossland 1983; Joll 1984; Joll and Phillips 1984; Maller *et al.* 1983).

A study of octopus predation (Joll 1977) estimated the annual loss of rock lobsters in pots to be about 200,000. Norton (1981) reported that catches by amateurs amounted to no more than 2% of the professional catch. A study of the fishery-induced mortality of undersized rock lobsters (Brown and Caputi 1983, 1985, 1986) indicated significant losses of rock lobsters due to handling. Recommendations to remedy this problem, which have been introduced, include multiple escape gaps in the traps and the immediate return of undersized animals to the water by the fishermen.

Cannon *et al.* (1981) reported that the arsenic in the western rock lobster was in the form of the non-toxic arsenobetaine.

Studies of the laboratory growth, longevity and development of the reproductive condition in juveniles were carried out by Phillips *et al.* (1977), while Phillips (1983) examined the migrations and growth rates of the juveniles as they move from the shallow inshore reefs to the deeper areas of the continental shelf.

A synthesis of larval juvenile and adult data on spawning stock, puerulus settlement, juvenile densities and eventual catch (stock/recruitment relationships) was published by Morgan *et al.* (1982) The development of a successful method of predicting the annual catch four years in advance, using as its basis the levels of puerulus settlement, was suggested by Phillips (1986). An independent method of predicting recruitment to the fishery was developed by Caputi and Brown (1986), based on estimates of juvenile abundance from the data from the commercial monitoring program.

A study of the feeding range of the juveniles and of their response to a bated trap was conducted by Phillips *et al.* (1984), Jernakoff and Phillips (1986, 1988) and Jernakoff *et al.* (1987).

In 1985 C. F. Chubb began a three-year study to revise estimates of the breeding stock of *P. cygnus.* Substantial changes to the indices used by Morgan *et al.* (1982) have been made (Chubb, personal communication).

Bowen and Hancock (in press) have examined effort limitation in the rock lobster fishery, and Phillips and Brown (in press) have reviewed the research conducted for management of *P. cygnus,* up to 1986.

Eastern and Southern Rock Lobsters

The eastern rock lobster *J. verreauxi* is the basis of a small fishery in New South Wales. The New South Wales catch is made up of both *J. verreauxi* and *J. novaehollandiae,* the greater part (estimated at about 150 t per year) being *J. verreauxi.*

The southern rock lobster *J. novaehollandiae* Holthius is the principal rock lobster species of south-eastern Australia and supports a fishery dating back to the days of early settlement.

Australia annually produces about 3,400 t of southern rock lobsters, mainly from Tasmania, Victoria and South Australia. Southern rock lobsters also contribute to the rock lobster landings of Western Australia (about 20 t annually) and New South Wales (not recorded separately).

Research

Apart from an unpublished honours thesis (Lie 1969), no study of the biology of *J. verreauxi* has been made.

Until 1963 *J. novaehollandiae* was known as *J. lallandii* (Holthius, 1963). Winstanley (1973a) reviewed the history of the Tasmanian southern rock lobster fishery and its management. Fielder (1962a, 1962b, 1962c, 1964, 1965a, 1966) described growth, food, feeding and locomotion in *J. novaehollandiae.* Fielder and Olsen (1967) synthesised the historical data for the Tasmanian, South Australian and Victorian fisheries.

Hickman (1945, 1946) reported details of the fecundity of *J. novaehollandiae* in Tasmania and Winstanley (1977a, 1977b, 1977c) summarised much of the general biology and detailed research into its growth, movement and migration off Tasmania, South Australia and in Victoria.

Studies of puerulus settlement off South Australia (Lewis 1975, 1977, 1981a) showed greatest settlement in July and August, eight to nine months after hatching; the extent of settlement varies markedly from year to year. McWilliam and Phillips (1986) have suggested a method of separating the phyllosoma larvae of *J. verraeuxi* and *J. novaehollandiae*.

Lewis (1981b) published an annotated bibliography of the southern rock lobster, with a subject index. This publication also lists unpublished materials that may be available from the authors or employers.

Tropical Rock Lobster

Panulirus versicolor (Latreille), *Panulirus polyphagus* (Herbst), *Panulirus penicillatus* (Oliver) *Panulirus homarus homarus* (Linnaeus) and *Panulirus longipes femoristriga* (Von Martens) all occur in northern Australia, but they are either too rare or too far from centres to make these stocks a commercial proposition.

However, *Panulirus ornatus* (Fabricius) is widely distributed through the Indo-Pacific area. It is fished commercially in Sri Lanka, on the east coast of Africa, New Caledonia, Papua New Guinea and Australia. The largest fisheries for this species, in Torres Strait, Australia and the adjacent Gulf of Papua (Papua New Guinea), yield a total annual landed value of about A$5 million.

Papua New Guinea has diver-based fisheries operating from Daru and Yule Islands at the western and eastern ends, respectively, of the Gulf of Papua. The diver fishery at Daru operates all year round; the fishery at Yule is seasonal, generally operating during the northwest monsoon period from November/December to March/April. The Daru divers fish shallow coral reefs in northern Torres Strait, while the Yule divers fish shallow inshore reefs (less than 5 m deep) surrounding Yule Island and along the adjacent coast. Australia's diver-based fishery on Thursday Island fishes reefs in Torres Strait and along the northeast coast of Queensland.

Until 1983, *P. ornatus* was also caught by Papua New Guinean trawlers fishing in the Gulf of Papua during the annual breeding migration of *P. ornatus* from Torres Strait into the Gulf of Papua. The migration usually takes place in October and November, but catches have been made as early as September and occasionally continue until December (see Moore and MacFarlane, 1984). Australia also had a trawler-based fishery for *P. ornatus*. That fishery was seasonal, the catches being taken by Australian prawn trawlers, usually between September and October, in and around the Great North East Channel of Torres Strait. Both these trawler-based fisheries were closed by legislation brought into effect in August 1984 (Williams, 1986).

Research

A preliminary survey of the Torres Strait tropical rock lobster resource was made by the pearling survey vessel *Paxie* in 1959 (V. Wells, unpublished data, CSIRO Archives, Canberra).

Australian research on the *P. ornatus* fishery in Torres Strait began in 1973 with a brief assessment of the resource, its abundance and potential, size composition, catch-per-unit-effort and fishing techniques (Chittleborough 1974). A study of the marine resources in Torres Strait was commissioned by the Queensland Fisheries Service in 1974. The study was undertaken by R. R. Pyne. An extensive area of Torres Strait was surveyed in 10 cruises of LFB *Trade Winds*. The findings from this study were confidential and have never been published. However, a summary of some of the results was included in Phillips *et al.* (1983). Pyne (1970, 1974) continued his studies in Papua New Guinea and completed his doctoral dissertation on *P. ornatus*.

After Australia and Papua New Guinea signed the Torres Strait Treaty in December 1978, and in response to enquiries from Papua New Guinea, a joint Papua New Guinea/Australian research program was initiated in 1979. The main aims of the Australian research were to document the Australian fishery for *P. ornatus* and investigate its biology.

The major lobster fishery is the commercial dive fishery, which accounts for around 75% of the total landings. Catch records prior to 1980 were irregular, and have been consistently available only since 1980. They indicate a general trend towards increasing catches (from 124 t in 1980 to 207 t in 1985) and decreasing catch-per-unit-effort (from 28.7 kg/dinghy/day in 1974 to 18.2 kg/dinghy/day in 1984) (Phillips *et al.* 1983). The dive fishery is based primarily on three- and four-year-old animals, which comprise more than 80% of the catch (Channells 1986; Channells *et al.* in prep.). Although the Torres Strait is the most important fishing area, the lobsters on the east coast of Queensland are a significant part (approximately 15%) of the Australian diver catch (Channells *et al.* in prep.).

Tagging studies have shown that lobsters in the Australian waters of the Torres Strait take part in the annual breeding emigration to the coast of Papua New Guinea (Bell *et al.* 1986) but that lobsters on the east coast of Queensland do not move into the Torres Strait or Gulf of Papua (Bell *et al.* 1987). Genetic analysis is currently being carried out to determine whether the east coast lobsters are a separate stock from the Torres Strait and Gulf of Papua lobsters (Salini *et al.* 1986). Larval settlement of lobsters has been observed only on the east coast of Queensland, chiefly between March and September (Phillips *et al.* 1983).

It is possible that the lobsters on the east coast of Queensland and the Torres Strait are recruited from different sources (Bell *et al.* 1987). Until they reach the age of three or four years the rock lobsters remain on local reefs, foraging on small shells and crustaceans (Joll and Phillips 1986). Although they move frequently over short distances, they do not travel far until they take part in the annual breeding emigration, at which time the Torres Strait animals, at least, move up to 500 km over comparatively short times (Prescott *et al.* 1986). The physical stress of undertaking this emigration may be enough to cause the death of a large proportion of these lobsters. This possibility is being investigated, as it is extremely important for the fishery to know whether *P. ornatus* in the Torres Strait only reproduce once in a lifetime.

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History of Biological Research into the Rock Lobsters of New Zealand

J. D. Booth

Three rock lobster species are reported from New Zealand waters. The most abundant and widespread is *Jasus edwardsii* (Hutton) occurring from the Three Kings Islands in the north to the Auckland Islands in the south, and east to the Chatham Islands. This species is very similar in appearance to *J. novaehollandiae* from southern Australia and *J. lallandii* (southern Africa). It is also similar to *J. paulensis* (St Paul and Amsterdam Islands — Indian Ocean), *J. tristani* (Tristan da Cunha, Gough Island and Vema Seamount — Atlantic Ocean) and *J. frontalis* (Juan Fernandez — Pacific Ocean). Current annual landings of *J. edwardsii* are 5000–5500 tonnes.

Much less abundant is the packhorse or green rock lobster *J. verreauxi* (H. Milne-Edwards). This species is also widespread, but occurs most commonly in the north and northeast of the country, and is also found off eastern Australia. Although it has comprised less than 1% of the total annual New Zealand rock lobster landings in recent years, greater landings (in excess of 100 t per year) were made in the past.

The third species belongs to the genus *Projasus*. George (1976) predicted the occurrence of this genus in deep waters near New Zealand. Specimens have recently been trawled off the east coast of the North Island (Booth 1984a), and are currently being described.

Unsuccessful attempts were made late in the 19th century and early 20th century to introduce and establish the European lobster *Homarus gammarus* in southern New Zealand (see Anderton 1907; Thomson and Anderton 1921; Marine Department Report on Fisheries for 1932 and 1937).

This paper traces the history of biological research into *J. edwardsii* and *J. verreauxi*. It focuses mainly on the results of studies carried out in New Zealand, although important overseas references have also been covered. The principal biological studies of both species appearing in scientific journals, as well as in various popular publications, are dealt with broadly chronologically. Similarly, unpublished theses have also been covered. Only key references pertaining to the early descriptions of the species and discussions of rock lobster taxonomy have been cited. For more detail on name changes and the early descriptions see Archey (1916) and Kensler (1967a).

Apart from the papers referred to in the section on "Rock lobster landings", papers on the fishery and its management have been referred to only where biological data have also been given. Reports dealing with such topics as flesh quality, processing and marketing have been omitted. Some of this work has been referred to in the two annotated bibliographies of New Zealand rock lobsters (Kensler 1967a; McKoy 1979a).

The large amount of biological data now available on the rock lobsters of New Zealand makes indices to the literature useful. Therefore, subject and geographical indices are given at the conclusion of the paper.

Rock Lobster Landings

Rock lobster landings according to port of landing, and the numbers of vessels engaged in the fishery, are available from early in the 20th century until 1974 in the annual "Report on Fisheries" from the Ministry of Agriculture and Fisheries (formerly Marine Department). The data for 1975–78 exist as unpublished MAF statistics. The data from 1979 on have been published in the Fisheries Research Division Occasional Publication: Data Series (e.g., Sanders, 1986). Also available for 1963–73 and 1979 onwards are the landings and effort data according to area fished (Annala and King 1983).

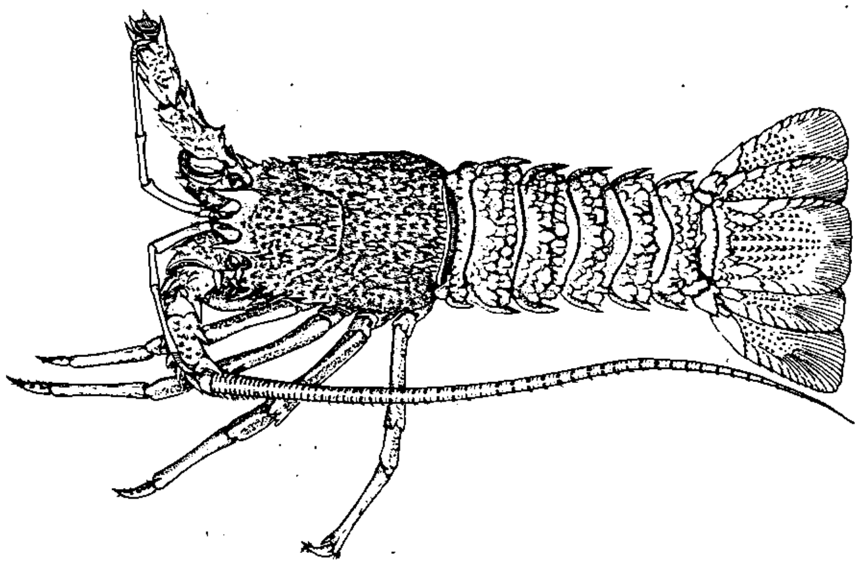

Fig. 1 The red rock lobster *Jasus edwardsii* (female) (drawing by Dr R. B. Pike, first published in *N. Z. J. Mar. Freshw. Res.* 1967, 1: 413)

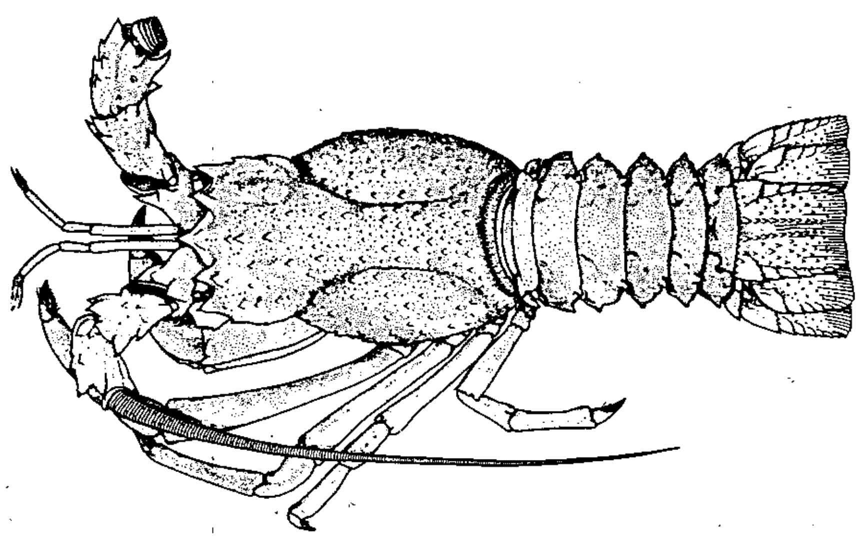

Fig. 2 The packhorse rock lobster *Jasus verreauxi* (male) (drawing by Dr A. B. Pike, first published in *N. Z. J. Mar. Freshw. Res.* 1967, 1: 414)

Biological Research

Early studies

The first published research into New Zealand's rock lobsters included the original description of *J. verreauxi* (as *Palinurus verreauxi*) by Milne-Edwards (1851) and *J. edwardsii* (as *Palinurus edwardsii*) by Hutton (1875). Kirk (1880) mistakenly thought that a particularly large *J. verreauxi* from Northland was a different species and named it *Palinurus tumidus* (see Archey 1916). Most studies in the late 19th and early 20th centuries focussed on the anatomy, external morphology and taxonomy of the two species, and, for *J. edwardsii*, included discussion of the discreteness of the species (Archey 1916; Chilton 1907: Haswell 1882; Miers 1876; Parker 1884, 1887, 1889). The first studies of early development concerned the morphology and some aspects of behaviour of the naupliosoma, first-stage phyllosoma and puerulus stages of *J. edwardsii* (Anderton 1907; Archey 1916; Thomson 1907), and the morphology of the puerulus stage of *J. verreauxi* (Archey 1916).

Important distributional data for both species became available early in the 20th century, mainly as a result of government-sponsored experimental trawling and exploration work (Ayson 1924; Chilton 1907; 1911; Waite 1909; Young, 1929). The first account of the growth of juvenile *J. edwardsii* was given by Young (1926).

Little research on rock lobsters was published between the late 1920s and the early 1960s. Even the great expansion in fishery landings soon after World War II, resulting from development of markets for frozen tails in the United States, did not immediately lead to increased research. Thorn (1939) summarised the state of rock lobster stocks around New Zealand. Bradstock (1950) followed trends in catch composition of *J. edwardsii* landings near Wellington during 1947 and 1948, and also reported on aspects of reproduction (including size at onset of maturity of females and fecundity) and limb loss. His small tagging study, the first published, yielded some data on growth and movements. Yaldwyn (1958, 1965) extended the distribution of *J. edwardsii* to include the Snares and Auckland Islands, the southernmost locations known for any palinurid species. In the first paper Yaldwyn also included an important discussion of previous distributional data. Holthuis (1963) compared the external features of *J. edwardsii* with those of *J. novaehollandiae* and *J. lallandii.*

First full-time research

Concern about the state of the rock lobster stocks, and particularly about the declines in landings in some areas, led to the appointment in Wellington in 1961 of Dr R. B. Pike, the first full-time rock lobster biologist. The account of his research into *J. edwardsii* (Pike, 1969) focussed on the growth and development of the fishery (covering the years 1936–65) in terms of landings and number of licences, the size and sex composition of exploited and unexploited stocks, and aspects of reproduction. His widespread catch samples of both *J. edwardsii* and *J. verreauxi*, many unpublished, form the most comprehensive data of their type for the early years of the fishery, and have been useful in work published much later (Annala *et al.* 1980; Booth 1984e).

The appointment of Dr C. B. Kensler to rock lobster research in Wellington in 1965 led to a major contribution to our basic biological knowledge of New Zealand's rock lobsters (George and Kensler 1970; Kensler 1966, 1967b, c, d, e, 1968, 1969, Kensler and Skrzynski 1970). In collaboration with Dr A. W. George of the Western Australian Museum, he provided support for the separation by Holthuis (1963) of the New Zealand species of *Jasus edwardsii* from *Jasus* species elsewhere, and further refined the associated key. Kensler also summarised available data on the distribution of both *J. edwardsii* and *J. verreauxi* in New Zealand waters. Analyses were given of landings data for the first two years (late 1965–67) of the *J. edwardsii* fishery at the Chatham Islands, and for the period 1962–66 of the *J. verreauxi* fishery in northern New Zealand. Kensler also investigated aspects of reproduction, which led to descriptions of the size of *J. verreauxi* at onset of maturity, the fecundity of both species, and notes on the occurrence, culture and feeding of early juvenile *J. edwardsii.* His account of size-at-maturity of *J. verreauxi* led to an increase in the minimum legal size for that species, which sought unsuccessfully to allow females to spawn at least once before entering the fishery.

Other material on rock lobsters appeared during the mid- and late-1960s. Several general accounts of rock lobster biology were published (e.g., Pike 1966; Sorensen 1969; Street 1969a), although none reported significant new results. The taxonomy and phylogeny of *Jasus* spp. were discussed (George 1969; George and Main 1967; Holthuis and Sivertsen 1967), with the species group possibly

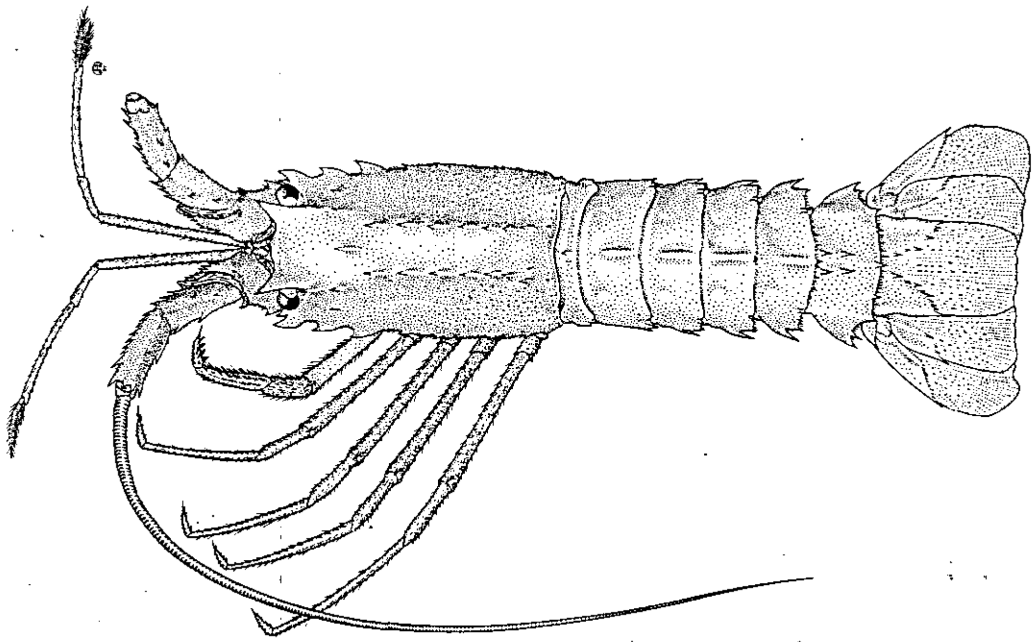

Fig. 3 *Projasus* sp. (male) from east coast of New Zealand (drawing by Mr W. A. Webber, National Museum, Wellington)

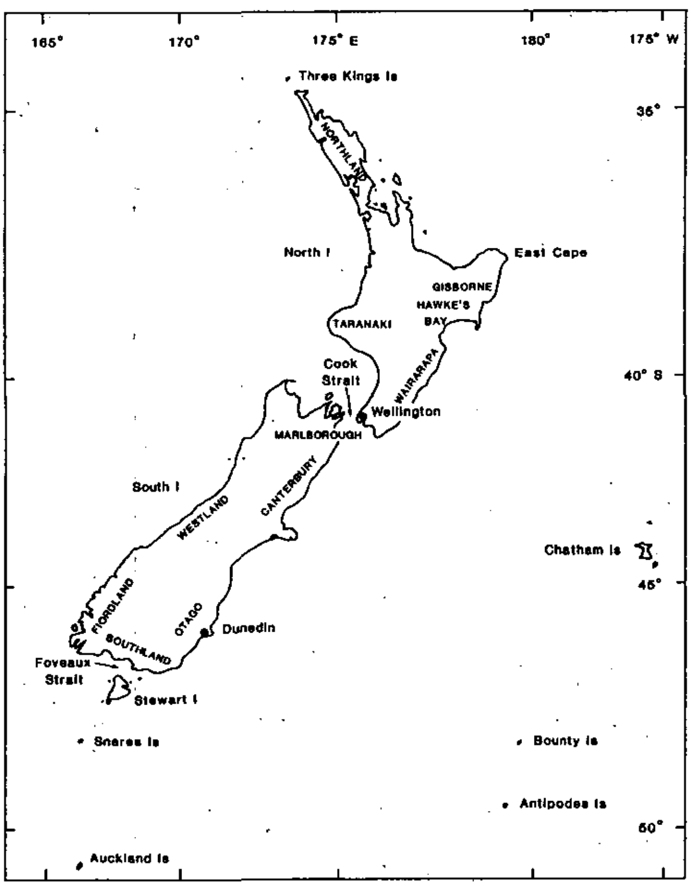

Fig. 4 Map of New Zealand showing location of regions and places mentioned in text and geographic index. (Kermadec Islands lie 980 km northeast of East Cape.)

evolving from a single circumpolar species. Williamson (1967) suggested Australia as a possible source of larvae for New Zealand rock lobsters, a proposal later extended by Winstanley (1970). Walsh (1964) described various behavioural patterns of *J. edwardsii* in tanks and in the field, and also investigated the structure and function of the antennule. Batham (1967) reported on egg hatching and on the development and feeding behaviour of early-stage *J. edwardsii* phyllosoma. Binns and Peterson (1969) described the role in adults of the antennal gland in nitrogen excretion. The behaviour of *J. edwardsii* with respect to escape gaps in pots was reported (Ritchie 1966; Street 1966; Bain 1967a), and Bain (1967b) gave morphometric data relating total length to carapace length for that species.

Much of the pioneering work on the growth, behaviour and ecology of *J. edwardsii* was carried out by Mr R. J. Street, who was based in Dunedin. His major studies, which began in 1965, were made off the Otago, Southland, Stewart Island and Fiordland coasts. They included dive observations and the first widespread tagging to be conducted in New Zealand (Street 1969b, 1970, 1971, 1973a,b). He was the first to recognise the importance of long-distance, alongshore movements in rock lobster recruitment.

During this early period, Street also reported on many other aspects of *J. edwardsii* biology and the commercial fishery, including breeding, morphometrics, predators, fishing pressure, fishery landings and catch composition.

Record landings lead to increased research

Record high landings of rock lobsters in the late 1960s (almost 11,000 tonnes in 1968) stimulated further biological research. Messrs A. F. Coombs and J. H. A. Lesser, both based in Wellington, began studies in 1968, initially focussing on population dynamics and reproductive biology respectively. Coombs's study of the phenomenal rise in landings of *J. edwardsii* at the Chatham Islands and the effect of fishing on these stocks remains, so far, in manuscript form. But his studies on pot effectiveness, and on the relationship between catch per unit effort and population size, led to a paper on the monitoring of activity of captive rock lobsters. He also presented popular accounts of rock lobster biology (Coombs 1972, 1974a,b). Lesser first described the early larval development of both species of *Jasus*. Later he went on to give the full phyllosoma development of *J. edwardsii*, as well as an account of the general ecology and distribution off the Wairarapa coast of the phyllosoma and puerulus stages of this species (Lesser 1974, 1978).

Other work on *J. edwardsii* during the early 1970s concerned octopus predation in pots (Ritchie 1972), feeding and other behaviour (Anon. 1974; Hickman 1972; Scally *et al.*. 1974; Tunnicliffe *et al.* 1974), moulting and growth, including some of the physiological changes occurring during moulting (Chaplin 1973), the biochemistry of haemocyanin (Stewart *et al.* 1973) and salinity tolerances (Stead 1973). Additional total length to carapace length morphometric data were also published (Sorensen 1970, 1971).

New areas of study begin

Further expansion of rock lobster biological research began in 1973 with the appointment in Wellington of Drs J. D. Booth and J. L. McKoy, and a year later Dr J. H. Annala. Overall directions of their early work, which focussed mainly on *J. edwardsii*, are outlined in Anon. (1976, 1980a) and Booth *et al.* (1978). Their main study areas follow.

Investigation into *J. edwardsii* larval recruitment involved further observations on the distribution and ecology of late stage phyllosomas and pelagic pueruli off the east coast of the North Island, the development of a collector to measure puerulus settlement, observations on puerulus size and development, the ecology of puerulus settlement, and the implications of seasonal, annual and geographic patterns of settlement around the coastline. These results, in conjunction with ocean current patterns, led to hypotheses and conceptual models of larval recruitment for particular localities (Bolt and Booth 1983; Booth 1979a, 1980a, 1983a,c,d, 1984b, 1985, in press; Booth and Bowring in press; Booth and Tarring 1982, 1986; Bycroft 1986a; Michael and Booth 1985; Street and Booth 1985). For *J. verreauxi*, investigations into factors influencing phyllosoma distributions, into the occurrence and distribution of phyllosomas and pueruli around New Zealand, and into the presence of nursery areas, led to a description of the recruitment mechanism for the species (Booth 1979b; 1983e; 1986a).

Several more studies of *J. edwardsii* growth were made, providing information for yield calculations, and covering both sexes over wide size ranges in widespread localities (Annala and Bycroft 1984, 1985 in press a; Booth 1980b; Booth and Midgley 1980; McKoy 1985; McKoy and Esterman 1981). Many of these studies involved the use of tags that remain in place over several moults. Estimates of moult increment, moult frequency and annual growth were made, in some instances leading to growth curves. The increment and frequency of moulting of *J. verreauxi* near the minimum legal size were reported by Booth (1978b).

The first estimates of total and fishing mortality rates were made, with high levels of exploitation becoming apparent. Results were published for Gisborne, Otago and Stewart Island (Annala 1977, 1979, 1980b; McKoy 1980; Saila et *al.* 1979).

Several studies of the reproductive biology of *J. edwardsii* were important for management. They dealt with the size of females at onset of maturity mating behaviour, fecundity, and egg incubation (Annala and Bycroft 1984, in press b; Annala, McKoy, Booth and Pike 1980; Anon. 1974; Booth 1983a; Mcffoy 1979b; McKoy and Leachman 1982; Tarring 1980). Studies of *J. verreauxi* considered size of females at onset of breeding and distribution of breeding females (Booth 1984e; 1986a).

Studies of movements of both species, particularly longdistance movements and their importance in recruitment, were made at several widespread localities (Annala 1981; Annala and Bycroft 1983, 1984; Booth 1979b, 1980b, 1983b, 1984d, 1986a; McKoy 1983).

Modelling of *J. edwardsii* fishery landings and effort data in conjunction with growth and mortality data led to the first yield estimates (Annala 1977; Annala and Esterman 1986; Saila *et al.* 1979).

Other work on both species dealt with distribution and catch composition (Annala and Bycroft 1984; Booth 1983a, 1984f, 1986a; Booth and Saxton 1983; Michael and Booth 1985), stock definition and genetic variation (Smith *et al.* 1980), feeding behaviour (McKoy and Wilson 1980), morphometrics (Annala *et al.* 1986), and the management implications of various biological data (Booth 1984f, 1986a).

Other workers, many of them university students completing theses, were active in *J. edwardsii* research from the mid-1970s. Street continued his studies in the south of New Zealand (see Anon. 1980c), focussing mainly on pre-recruit abundance, growth, movements and fishery landings (Street 1980; Street and Booth 1985). There were studies on the structure and function of the eye (Allan 1979; Meyer-Rochow and Tiang 1984; Tiang 1981), on larval hatching (MacDiarmid 1985), and on feeding and other behaviour (Andrew 1984; Dean 1979; McCardle 1983). MacDiarmid's (1987) study of the ecology of rock lobsters in a rocky reef community in Northland included information on the distribution and density of the animals, behaviour, movements, growth and reproduction. Several studies were published on the biochemistry of *J. edwardsii* haemocyanin (Ellerton, Blazey and Robinson 1977; Ellerton, Collins, Gale and Yung 1977; Ellerton et *al.* 1983; Rahimah 1984; Robinson and Ellerton 1977). Further yield estimates for the New Zealand rock lobster fishery were made, and some time-series analyses of Gisborne landings data presented (Fogarty and Murawski 1986; Saila et *al.* 1980). McWilliam and Phillips (1987) described some mid- and late-phyllosoma stages of *J. verreauxi*.

Current research

The continuing high value of rock lobsters, particularly when sold live on the Japanese market, has led to the live export of substantial quantities (164 t in 1985) of *J. edwardsii* and generated great interest in rock lobster culture (Booth 1981b; 1984g; McKoy 1977; NZ Fishing Industry Board 1980; Wear 1979). In 1986, Mr N. D. Rayns began a doctoral study at the Portobello Marine Laboratory of the University of Otago on optimising conditions for the growth and survival of captive juvenile *J. edwardsii*, and investigating some factors affecting moulting frequency. Complementing this study has been the work in Wellington of Mr T. J. B. Hollings of the New Zealand Fishing Industry Board on the influence of raised temperature on growth and survival of juveniles. Professor J. Kittaka at Kitasato university, Iwate Prefecture, Japan, has had success raising larvae of *Jasus* species, including *J. edwardsii*.

At the time of submission of this paper, Booth's studies of *J. edwardsii* larval recruitment continue, focussing mainly on puerulus settlement patterns and their relationship to the fishery, and on determining major sources of larvae. In addition, Street continues his pre-recruit surveys and tagging for growth and movements in southern New Zealand. Dr P. A. Breen was appointed in 1986 in Wellington to continue other rock lobster studies, particularly those relating to population dynamics and analyses of catch and effort data. The need for a minimum legal size measure based on some body structure apart from the tail led to further morphometric data being analysed (Breen *et al.* in press) . Much of the experimental culture work described above continues.

Summary

Biological research into New Zealand's rock lobsters has therefore followed the pattern observed for many other marine species. Initial studies dealt with the external morphology and systematics of the species, followed by investigations into the geographic distribution of the animals. Expansion in fishery landings led to studies of growth, reproductive biology, and later recruitment. At the same time, studies of behaviour and physiology began. Finally, yield estimates and models of stock dynamics were developed. With little opportunity for expansion of the wild fishery, culture techniques are now under investigation.

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Subject Index

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Geographic Index

This index contains only publications that can be identified as being specific to certain regions (for regions, see Fig. 4)

Jasus edwardsii

Several areas	Annala (1976), Annala and Bycroft (in press b), Annala et a). (1986), Annala and Esterman (1985; 1986), Annala and King (1983), Annala, McKoy, Booth and Pike (1980), Anon. (1971), Breen et a). (1987; in press), Booth (1978a; 1980a; 1984b; c; 1985), Booth and Tarring (1982), George and Kensler (1970), Kaberry and Pike (1967) Kensler (1967d) Pike (1969) Sanders (1986), Sorensen (1970; 1971), Thorn (1939).

Jasus verreauxi

Northland	Booth (1978b; 1979b; 1983e), Booth and Bycroft (1980; 1982), Kensler (1967b; c), Kirk (1880).
Offshore islands	Booth and Saxton (1983) Chilton (1911)
Several areas	Annala and King (1983), Booth (1981a; 1984d; e; 1986a), Kensler (1967d), Kensler and Skrzynski (1970), Sanders (1986)

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