Research for Management of the Ornate Tropical Rock Lobster, *Panulirus ornatus*, Fishery in Torres Strait:


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March 1994
This report summarizes research carried out by CSIRO on the ornate rock lobster, *Panulirus ornatus*, fishery in Torres Strait during the 1990–1993 triennium. The program investigated: the annual relative abundance of the rock lobster stock in Torres Strait and the strength of the recruiting year-class; the catch and effort of the Islander diver fishery; aspects of the biology of the breeding population in the far northern Great Barrier Reef; and made annual assessments of the potential yield.
National Library of Australia Cataloging-in-Publication Entry

Pitcher, C. R.

ISBN # #### ###### #

1. Lobsters — Torres Strait — Population dynamics. I. Skewes, T. D. II. Dennis, D. M. III. CSIRO Marine Laboratories. IV. Title. (Series : Final Report (CSIRO Division of Fisheries) ; no. ###).

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Acknowledgments

This research was funded by the Commonwealth Department of Primary Industries and Energy, through the Australian Fish Management Authority as part of its Torres Strait Protected Zone fisheries research program.

The Bureau of Rural Sciences, through the Torres Strait Fisheries Scientific Advisory Committee was responsible for vetting the research proposal and reviewing progress.
The commercial fishery for the Torres Strait ornate tropical rock lobster began in the late 1960's and has become a major income earner for Torres Strait Islanders. Effort in the fishery has increased substantially since the 1960's and the research that CSIRO carries out is essential for ecologically sustainable management of the resource. Past research has provided basic information on the life history of the ornate tropical rock lobster, particularly the existence of an annual breeding migration out of Torres Strait to the north east as far as Yule Island at the eastern Gulf of Papua. The migration causes substantial changes in the Torres Strait population and fishery. Lobsters at the breeding grounds are in very poor physiological condition and by the end of a short breeding season virtually all lobsters die. Subsequently, however, other breeding grounds were discovered in Australian waters of eastern Torres Strait, but the extent and mortality rate of this population remains to be determined. More recently, research has been directed at assessment of the fishery for management. In 1989, the abundance of the lobster stock in Torres Strait was estimated, thus enabling the first estimates of the exploitation rate and potential yield. The stock has been surveyed annually since then and annual assessments have been done using an escapement model. Details of these and other research activities during 1990-1993 are summarised below.

The annual population surveys have provided fishery independent information on the relative strengths of the exploited and pre-recruit year-classes that is invaluable for assessing the status of the stock. They also provided annual estimates of growth and mortality rates and evaluation of commercial catch and effort data. The surveys have also forewarned of future fishable stock sizes, even though the actual 1993 stock fell short of predictions due to significant environmental changes — indeed the surveys provided insight into the causes and mechanisms of the 1993 short-fall. Of further concern is the possible impact of the environmental changes on settlement grounds as the 1993 recruitment was the lowest recorded and will likely flow through to a small stock in 1994.

The CPUE of the Islander catch reflect changes in lobster abundance, as expected from the results of the annual relative abundance surveys. Nevertheless, it appears that catchability may increase when lobster abundance is low, thus countering decreases in CPUE to some extent. The difference in catch rate of free-divers and hookah-divers continued to reduce over the three year period and there is no evidence that continued use of hookah is detrimentally affecting the catch-rate of free divers. The magnitude and interannual variation of the CPUE measures from the Island based fishery and the freezer boat sectors are different and there are indications that Islander CPUE may reflect changes in abundance more closely than freezer boat CPUE.

Small juvenile lobsters were found throughout western Torres Strait, mainly coinciding with the broad range of habitats occupied by adults, and showed no apparent depth preferences; most juveniles were found between 7-9 m. Density of juveniles at Mabuiag Island in 1992/93 was low (36 Ha⁻¹). Analysis of variance of juvenile abundance data
indicated that survival rate within the first year may be high. The juveniles grew an average 6 mm CL per month in the first year of post-settlement life which is the fastest growth rate documented for a palinurid lobster. Post-pueruli and juveniles sheltered in holes in rock substrata that matched closely their body diameter and length. There was a shift in habitat with growth; juveniles <40 mm CL preferred holes in rock covered by macro-algae (eg. Sargassum sp.) whereas larger juveniles preferred bare holes and crevices. The pueruli settling into Torres Strait measured ~6 mm carapace length and settlement occurs during winter, after an oceanic larval phase of about 6 months.

The ornate rock lobster in Torres Strait is very fast growing, perhaps the fastest growing of any palinurid studied. Growth varies on both spatial and temporal scales: spatial variability may the result of environmental factors such as temperature and/or food availability; temporal variability may also be a result of environmental factors and/or density dependant effects. The fishery exploits only one year-class (the 2+) for only about 1 year, thus the catch would be susceptible to variations in the modal size of this year-class as well as its abundance.

The breeding population studies showed that there is a significant, though patchy, lobster population actively breeding in shallow water in eastern Torres Strait. The size-frequency distribution of this population indicates that these lobsters may not suffer catastrophic mortality after breeding as occurs in the breeding population of the eastern Gulf of Papua. Recent surveys also indicated that the shelf edge outside the far northern Great Barrier Reef is narrow with small relic reefs but these support a persistent breeding population in relatively high densities. However, it remains necessary to confirm the distribution, abundance and mortality rate of the breeding population in the far northern Great Barrier Reef — this is planned for 1996.

The puerulus collector trials were not particularly successful; as a consequence, expansion of the sub-project to full-scale sampling was not justified and it was thus suspended. It is possible that the poor catches of pueruli in the collectors reflected very low numbers of pueruli in the water column and/or that collectors could not compete with abundant natural settlement habitat. It is also possible that the large distance between the settlement grounds and the larval retention area in the north western Coral Sea causes massive depletion of pueruli from the water column as they move west from the edge of the Great Barrier Reef to the central and western Torres Strait. It was still considered that puerulus collectors would be valuable for providing annual settlement indices, forecasting recruitment into the fishery, detecting of the effect of any significant changes in the fishery or disturbances in the environment and estimating compensatory processes occurring in the first year of benthic life.

To provide stock-assessment advice for management, data collected in the field continued to be integrated into a stock-assessment model of the fishery. The first assessment, in 1990 included an analysis of yield-per-recruit that indicated that the minimum size would only improve yield at levels of fishing mortality much higher than current levels. The model was extended to consider the proportion of the population that
escapes fishing to emigrate and breed and, based on 1989 data, it was estimated that fishing mortality \((F)\) could be increased 4-fold (to \(F=0.4\)), giving an average potential yield estimate of \(>800\) t, and yet leave a conservative escapement of about 74%. It was advised that increased effort should be encouraged in the diver fishery. Since then, annual fishery independent surveys provided updated parameters that enabled the model to be refined and now, based on average levels of recruitment, the potential long term average yield estimate is \(\approx 390\) t. The recruitment data for one year can be used to forecast the potential yield (at \(F=0.4\)) for the following year. However, the 1993 stock was smaller than expected from the relatively large 1992 recruitment, possibly as a result of natural environmental changes. The 1993 recruitment was the smallest yet surveyed, perhaps for similar reasons, and the predictions for 1994 are not optimistic. There are uncertainties in the assessment due to variability in parameters but these, and a variety of other uncertainties, may be reduced by additional data collection and these needs are addressed below.

Annual surveys of the Torres Strait lobster population will continue to provide indices of recruitment and stock abundance. At the same time, the Islander catches will also be monitored to provide catch and effort information, and the size-distribution of the catch.

Islanders are concerned that commercial lobster fishing in deeper waters near their communities will reduce lobster numbers on their home reefs. In response, estimates will be made of the rate of movement of lobsters into shallow water from surrounding deep water.

The seasonality of breeding by lobsters in eastern Torres Strait will be sampled annually. Also, in 1996, the distribution and abundance of the breeding population will be estimated by diver survey of the reefs and remote vehicle surveys of deeper waters.

The distribution of lobster settlement ground in Torres Strait and micro-habitat use by post-puerulus will be documented in 1996.

The information arising from field research will continue to be assessed using fishery stock assessment models and outputs from these assessments will be provided to managers.

Additional research needs that have not been specifically funded include: analysis of the time series of logbook data together with information from the fishery independent research surveys; collection of catch size-distribution data from commercial vessels and accurate details on spatial effort patterns — these will reduce current uncertainties and enable significant revision of the stock assessment model; and studies of larval distribution in response to current patterns and key environmental factors in the north western Coral Sea would provide the final link between studies of the breeding population and recruitment into Torres Strait.
In Australia, most commercial fishing for the ornate tropical rock lobster, *Panulirus ornatus* (Fabricius), occurs in Torres Strait, with some activity along the far north-east coast of Queensland. Historically, lobsters have been fished by the traditional inhabitants of Torres Strait probably for several centuries before commercial fishing began in the late 1960s. These lobsters will not enter pots, so they are speared by divers fishing from small dinghies. Initially, there were about 3-4 small (~10 m) freezer vessels that processed catch from a total of about 10 dinghies. The fishery gradually developed through the 1970s and during the 1980s there were about 15 small freezer boats active throughout the area and each processed catch from 1-6 dinghies (Channells et al 1987). Independent Islander involvement in the fishery also increased during the 1980s and it became a major source of income for Torres Strait Islanders.

The annual catch of lobster tails from Torres Strait in the 1970s ranged from 68 to 124 tonnes (t). Catches during the 1980s were variable, averaging almost 200 t, with a peak catch of 350 t in 1986 (Channells et al 1987; AFMA unpubl. data). In the early 1990s, catches have been similarly variable, averaging about 175 t.

The first Australian management measure was introduced in 1981 — a ban on daytime trawling for migrating lobsters. Subsequently, a total ban on trawling for lobsters was legislated in 1984. Since then, the fishery has been managed under Article 22 of the Torres Strait Treaty ratified between Australia and Papua New Guinea (PNG) in 1985 (Haines 1986). The Treaty established the Torres Strait Protected Zone, in which the traditional way of life and livelihood of the inhabitants is to be protected. The main management measure for ornate rock lobsters is strict entry criteria intended to prevent any increase in non-Islander involvement in the fishery and encourage Islander participation and restricting participation by non-Islanders (Channells et al 1987). The treaty also provides for catch-sharing arrangements between Australia and PNG and for this purpose, the allowable catch of the fishery has, since 1987, been set as the catch of the diver fishery.

Currently, divers work from 4-6 m dinghies powered with ~40 hp outboard motors, and either use hookah compressors or free dive. Between 300-400 dinghies operate from island communities and most divers return their catch to island based processors or semi-permanently moored mother vessels. There are also about 2 dozen licenses for small fishing vessels (~8-18 m), although only about half are active regularly throughout the area, each freezing the catch from 1-6 dinghies.

Free divers generally take lobsters from coral outcrops in waters 1-4 m deep while hookah divers generally take lobsters from rocky holes and crevices in the deeper grounds (4-15 m) between reefs. Although lobsters are found on most reefs in Torres Strait and the north-eastern Queensland coast, the principal fishing grounds are around Thursday Island, Orman and Warrior Reefs in Torres Strait. Divers report that it is now necessary to fish additional grounds in deeper waters to maintain
catch rates at levels experienced over past years. Fishing occurs throughout the year, with lower activity during October-December and peak catches during March-August. Most boats operate during neap tides when currents are slower and the water is clearer.

Fishing effort (in terms of number of participants, boats, days worked per year, or hours worked per day) has increased substantially since the fishery began, though total effort is unknown. At the same time, the catch per hour has decreased to roughly one-third of that 15-20 years ago — hence, there is a continuing need for quality assessment and monitoring of the lobster stocks to provide advice to managers.

Recent management measures include: a minimum size limit of 100 mm tail length, introduced in 1988; the catch sharing arrangements required under the treaty with PNG were implemented in 1990 with a specified number of PNG dinghies permitted to fish in the Australian side of the protected zone; a two month ban (October/November) on hookah gear was introduced in 1993 in response to Islander concerns of over-fishing in traditional reef fishing areas; the TAC of the fishery is still set as the catch of the diver fishery.

There have been no formal studies of the economic status of the fishery; however, the average annual catch of the fishery is about 200 t tail weight and prices paid to fishers vary between $15-$35 per kg. Thus the first-purchase value of the fishery is ~A$5 million and it is a major source of income for Torres Strait Islanders. The lobsters are sold on both domestic and overseas (mainly USA) markets. Individual incomes would be highly variable, nevertheless, daily catch rates mostly range between 20-40 kg per diver/dinghy and professional divers may work about 90 days per year. Costs are relatively low: capital input for a dinghy based fisher is about $6K for an aluminium dinghy, outboard motor and basic dive gear; hookah equipment would cost an additional ~$2.5K (the replacement periods would be about 2-3 years) — operating costs comprise mainly petrol, oil and maintenance totalling perhaps $40-$80 per day; dinghy driver’s are often paid a percentage of the catch. Costs of operating freezer vessels would be substantially
higher: capital investment could range between $30K to over $100K with daily running costs being similarly variable — most freezer vessels are supported by several dinghies which would help cover the increased running costs.

**Lobster life history**

Past research has provided fundamental information on the life history of the rock lobster. Larval development occurs in the Coral Sea and takes about six months, after that, lobster post-larvae settle during winter into small holes in the seabed in the nursery grounds of central and western Torres Strait and grow very quickly, recruiting into the fishery about one year later at ~100 mm tail length. These juvenile and sub-adult lobsters are fished until they are just over 2½ years old. At this time, in spring each year, most emigrate from Torres Strait to breed and catch rates decline markedly. Tagging studies have shown that some of the emigrating lobsters moved north east into the Gulf of Papua, undergoing reproductive development at the same time (Moore & MacFarlane 1984). The tagging studies also showed that lobsters on reefs off the north east Queensland coast do not participate in the migration across the Gulf of Papua but in general tended to move to the south east — there is little or no movement of individuals from the north-east coast of Queensland into Torres Strait (Bell et al 1987). Nevertheless, the populations in the two areas are indistinguishable genetically (Salini et al 1986). It is highly likely that rock lobsters from the east coast of Queensland come from the same breeding stock as the resource in Torres Strait, given the genetic similarities of the populations and the ocean current patterns in the north-west Coral Sea that could disperse larvae to both areas from breeding grounds off the southern coast of PNG and northern Great Barrier Reef (Pitcher et al 1992b).

Prawn trawlers used to target the migrating lobsters and catches up to ~200 t were recorded, but this activity was banned in 1984 (Williams 1986). Some of the migrating lobsters move as far as the coastal reefs of the eastern Gulf of Papua where there is a breeding ground (MacFarlane & Moore 1986). This breeding population forms the basis of a seasonal artisanal fishery around Yule Island which lasts only a few months during the summer. This fishery existed in traditional form prior to written history but the origin of the lobsters became known only in the early 1980s. The lobsters on these Papuan coastal reefs are in very poor physiological condition (Trendall & Prescott 1989) — the muscles are wasted and the blood is very watery — and virtually all lobsters die after the breeding season and this is why the Papuan artisanal fishery lasts only 2–4 months (Dennis et al 1992). Such catastrophic mortality is very unusual for lobsters, as most species can live and breed for more than 10 years.

Until recently, the coastal reefs of the eastern Gulf of Papua were the only significant known breeding grounds. Yet perhaps only a minority of the several million lobsters which emigrate from Torres Strait actually migrate across the Gulf of Papua each year and only a fraction of those arrive at Yule Island. It was suspected that the remainder migrate to other, largely unknown, breeding grounds and in the 1989/90 summer, a small research submarine was used to survey the Gulf of Papua and far northern Great Barrier Reef for other lobster breeding
The previous triennium's research on the ornate tropical rock lobster began, in mid 1987, with a basic understanding of stock structure and movement patterns, particularly the existence of an annual breeding migration north east out of Torres Strait into the Gulf of Papua as far east as breeding grounds around Yule Island. Lobsters at these breeding grounds were in very poor physiological condition and by the end of the short breeding season they had all disappeared. Research during the triennium was directed at determining: the causes of this disappearance; the ocean current patterns that may provide recruitment to Torres Strait; the existence of settlement grounds in far western Torres Strait; the impact of the migration and fishing activities on the Torres Strait stock; and whether other breeding populations existed in the Gulf of Papua or northern Great Barrier Reef. Also, attention was turned to stock assessment for management, primarily by making an estimate of the actual abundance of lobsters in Torres Strait and initiating annual fishery independent surveys of the stock. These activities were detailed in Pitcher et al (1992b) but are summarised below.

**Breeding lobster mortality:** The cause of the annual decline of the breeding lobster population on the coastal reefs near Yule Island, PNG, was investigated in early 1989, using several complementary methods. The Yule Island fishery followed a typical pattern of punctuated rise and then a rapid decline that was not associated with any observed movement of lobsters off the coastal reefs into deeper water. Tag returns indicated that fishing pressure was responsible for >30% of the decline, but the natural mortality rate was even higher (>10-fold greater than in Torres Strait), probably due to stress of migrating and breeding. The important implication is that if all breeding populations suffer similar catastrophic mortality then settlement into the fishing grounds each year may depend entirely on the breeding success of the preceding years emigration which should therefore be conserved.

**Sources of recruitment:** A series of satellite tracked buoys were released in deep water off Yule Island to test whether lobster larvae hatched at Yule Island could potentially be transported to Torres Strait. The buoys moved rapidly eastward to the end of the PNG mainland and then turned south and later south west toward the north Queensland coast. This pattern of movement indicated the presence of a clockwise gyre in the northern Coral Sea which has the potential to carry larval lobsters from PNG waters back to Torres Strait.

**Western settlement grounds:** The extensive seagrass beds of far western Torres Strait were surveyed in October 1987 for the occurrence of juvenile lobster nursery grounds that could supply recruits to the fishery farther east. Only 18 lobsters were seen at a rate of 0.35 lobsters per kilometre of bottom surveyed and none of these were newly settled juveniles. The survey indicated that the area was not a significant
settlement ground for lobsters nor did it appear to support a significant adult population. Other work showed that the major settlement occurs in central Torres Strait in the same area as the fishing activity.

**Population changes due to migration:** Three years of fieldwork showed that marked changes occur in the lobster population around August each year as a result of the annual breeding emigration. The movement of larger lobsters out of the fishery begins between early August and early September and lasts for 4 to 8 weeks; after which mostly only smaller lobsters remain in Torres Strait. More female than male lobsters emigrate, causing the sex ratio to be biased towards males after the emigration. Lobsters undergo a maturation moult before they emigrate; this was evident as one or more large peaks in moulting activity that coincided with the third lunar quarter.

**Size-structure and growth:** The growth rate and life history of the ornate lobster were investigated by a variety of methods on new and previous data. The growth curve was re-estimated from tag-recapture, aquarium growth, settlement and hatching data. Size–distributions from the Torres Strait population, the catch and the emigratory population showed that the population in Torres Strait comprised mainly 1+ and 2+ lobsters, that the catch consisted mostly of 2+ lobsters with smaller and variable numbers of 1+ lobsters, and that the emigratory population consisted mainly of 2+ lobsters with some 3+ males. Size-frequency data from different areas of Torres Strait and from different years showed that growth varied temporally and spatially.

**Catch monitoring:** Catch and effort of Torres Strait lobster fishermen were monitored as part of assessing the impact of the fishery on the stock. Analysis showed that divers using hookah equipment could catch more lobsters per hour than free divers but that continued use of hookah did not appear to impact the catch rate of free-divers. Interannual variability in CPUE appeared to reflect changes in the abundance of the fishable stock which, in turn, reflected variability in recruitment.

**Breeding grounds survey:** The Gulf of Papua and far northern Great Barrier Reef were surveyed for the existence of other lobster breeding grounds in depths from 30 to 200 m using a small research submarine. High densities were seen on a few deep (30–100 m) reef habitats on the edge of the shelf of the far northern GBR; but very few lobsters were found in the Gulf of Papua or in deep water adjacent to the coastal reefs of the eastern Gulf. It was thought possible that the far northern GBR supported an important breeding population. However, it will be necessary to confirm the extent of the far northern GBR breeding grounds and the abundance of these breeding lobsters, as well as determine whether these lobsters suffer catastrophic mortality after breeding as occurs in the breeding population at Yule Island.

**Survey of lobster abundance:** The lobster stock in a 25,000 km² area of Torres Strait was estimated in June 1989, by making visual counts of the number of lobsters in strip transects, after pilot studies in 1988 confirmed the feasibility of a full-scale survey. The main survey took seven weeks and analysis of the transect data provided an estimate of abundance between 11–17 million lobsters. The surveyed population was sampled concurrently to determine its size structure and provided
an estimate of the stock size for the fishery between 2,200-3,350 t tail weight, which was roughly 10-fold greater than the 1989 catch of about 240 t. This indicated that the level of exploitation was low and that the fishery was unlikely to be under threat at present and may even support greater effort. The survey also provided information on the benthic habitat of central and western Torres Strait. The distribution and relative abundance of the seagrasses were estimated visually and mapped, as were the distribution of substratum types and epibenthic macrobiota; pearl oyster abundance was also estimated.

**Stock assessment:** To provide stock status information to management, data collected in the field was synthesised using a variety of stock-assessment methods. Analysis of yield-per-recruit showed that at 1989 levels of fishing mortality, and with the minimum size of 100 mm tail length, yield was only ~20 gm per 1.5 year-old recruit — this was very low compared with other fisheries. The minimum size restriction did not improve yield and would only become important at very high levels of fishing mortality. That analysis also showed that a proposed closure for October-December, would not have had the desired effect of increasing yield by preventing growth overfishing but probably would have decreased total catch by up to 30 t. The stock-assessment was extended to consider the proportion of the population that escapes fishing to emigrate and breed. With 1989 levels of fishing mortality, escapement was ~93% of the numbers that could emigrate and breed if there was no fishing at all; in comparison with almost all other fisheries, this was a very high escapement rate. The assessment showed that a 4-fold increase in fishing mortality would have permitted a substantial increase in catch while retaining a conservative escapement of about 74% — given the 1989 stock estimate, the projected average yield was estimated at just over 800 tonnes. The assessment indicated that increased effort should be encouraged in the diver fishery.

**Objectives: 1990–1993**

More recently, research has focussed on the measurement of parameters such as lobster abundance, fishing and natural mortality, settlement and recruitment, and the extent of the breeding grounds. This information is essential for sustainable development of the fishery through sound stock assessment. The overall objectives for the project during the 1990–1993 triennium were to accurately quantify fishery dynamics parameters for input into models that provide potential catch levels as output, and develop monitoring systems to assess the impact of implementation of the catch levels. Such an empirical approach with a feedback loop was necessary as many variables were and are still unknown. The following specific objectives for the period July 1990 to June 1993 will be designated sub-projects throughout this report.

- **Annual population surveys:** to obtain an unbiased annual index of the relative abundance of all year-classes of lobsters (including 1+) in Torres Strait. — This will provide information on the relative abundance of the stock and recruits, growth and mortality rates.

- **Islander catch monitoring:** to obtain length-frequency distributions and underlying catch-effort data from the fishery. — This, in conjunction with the annual population surveys, would provide information on total mortality, growth, fishing pressure and size
selection (bias) by fishermen, as well as CPUE of Islander fishermen which is not recorded by logbooks.

- **Juvenile ecology:** _to provide information on micro-habitat use by post-puerulus and distribution of puerulus settling sites._ — This information would assist protection of lobster nursery grounds and provide data on juvenile growth and mortality rates which are necessary for further development of stock assessment models.

- **Puerulus sampling:** _to provide an index of the initial settlement of lobsters into Torres Strait and its timing._ — It was anticipated that this information would enable forecasting of recruitment into the fishery 2 years in advance and provide the earliest feedback detection of the impact of any changes in the stock, fishery or management.

- **Growth measurement:** _to provide more detailed knowledge of growth and variation in growth._ — This information was required for input into stock assessment models (data from other sub-projects).

- **Mortality estimation:** _to provide data on natural mortality and fishing mortality._ — These data are essential inputs for fisheries dynamics models that have maximum sustainable yield or yield per recruit as outputs (data provided by other sub-projects).

- **Stock assessment modelling:** _to provide outputs for the management of the lobster fishery based on input fisheries dynamics parameters obtained from field research sub project._ — Detailed models enable assessment of the fishery's sensitivity to parameter estimates and can provide possible outcomes of different management strategies (eg. changing level of effort, minimum size etc).

The objectives of the project were reviewed regularly and some variations to the initial objectives were approved by the reviewing committee (the Torres Strait Fisheries Scientific Advisory Committee) — these changes lead to a decrease in budgeted expenditure. The puerulus collector sub project was not expanded to full scale sampling because the trial collectors caught unsatisfactory numbers of pueruli, possibly because the habitat requirements of *P. ornatus* pueruli differ from those of species for which the collector designs originated. Research effort was instead directed to studies of the lobster breeding population in eastern Torres Strait, the importance of which had been recognised previously by TSFSAC, with the following objectives.

- **Breeding population studies:** _to document the basic ecology of the breeding lobster population in eastern Torres Strait and to estimate the mortality rate of the breeding lobsters._ — other important questions included the size and extent of the population.

This report is organised into sections that correspond to each of the above objectives.
Annual population surveys

In May/June 1989, CSIRO carried out a major survey of the ornate tropical rock lobster *Panulirus ornatus* stock in central and western Torres Strait (Pitcher et al., 1992a). Data from this survey, which involved quantitative sampling of measured (4 × 500 m) transects at 600 sites, provided information on the absolute abundance of lobsters and the relative proportions of commercially fished and pre-recruit year-classes. Subsequent to the major stock survey in 1989, CSIRO has undertaken annual surveys of relative abundance at the 100 of the original 600 sites that accounted for 85% of the lobsters observed at the time. At each site, located accurately using a GPS navigator, two research divers counted and sampled all lobsters encountered during a fixed-duration (20 minutes) linear transect dive. Sampled lobsters are later measured and sexed to provide size distribution data. Data from each survey provides information on the relative strengths of the exploited and pre-recruit year-classes, and on growth and mortality rates. The 1989 survey data was adjusted to match subsequent surveys due to the necessary change in methods between the two types of surveys. The annual survey data is also compared with data from the Islander-catch monitoring sub-project (see Section 2) to allow assessment of changes in commercial catch corresponding with changes in abundance of different year classes.

![Size-frequency distributions of the islander catch and survey population](image)

Fig. 1-1. The size-frequency distributions of the islander catch landed at Mabuiag and/or Badu Islands in June from 1989 to 1993 and the size-frequency distribution of the Torres Strait lobster population surveyed by research divers in June/July in the same years. The Islander catch and survey population histograms are scaled by CPUE of the islander fishery and survey abundance respectively.

The surveyed population comprised mainly two size-modes in all years, representing 1+ and 2+ year-class lobsters, with a very small 3+ year-
class component (Fig. 1-1). The average size of the 1+ year-class lobsters was estimated at ~40 mm tail width, while 2+ year-class lobsters averaged ~70 mm tail width. The commercial catches were also comprised of these age classes, however, the 1+ year-class components were truncated due to the imposed minimum size limit of 100 mm tail length (≈52 mm tail width, Fig. 1-1). The 1+ year-class is the pre-recruit/recruiting year-class and the 2+ year-class is the exploited year-class or the "fishable stock". In all years, except 1989, the 1+ year-class was relatively more abundant than the 2+ year-class.

![Relative lobster abundance](image)

**Fig. 1-2.** Relative abundance of 1+ year-class and 2+ year-class lobsters in central and western Torres Strait, estimated from annual surveys between 1989 and 1993.

**Recruitment**

The relative abundance of the recruiting year-class (1+ year olds) increased between 1989 and 1992 (Fig. 1-2), with the 1992 recruiting year-class being the largest since the surveys began. Larger recruitments probably occurred before the surveys began, i.e. the 1985 and 1988 recruiting year-classes may have been the largest and second largest, as they gave rise to the largest and second largest catches.

The 1993 recruiting year-class was the smallest since the surveys began (Fig. 1-2); only ~55% of that in 1992, ~57% of that in 1991, ~79% of that in 1990), which may be a result of major habitat changes in the nursery grounds (see below). This low recruitment is likely to flow through to a low stock abundance in 1994 (see below) and possibly also a small commercial catch.

**Fishable stock**

The fishable stock, in any one year, comprised mostly the 2+ year-class and a proportion of the 1+ year-class that was greater than the minimum legal size of 100 mm tail length (≈52 mm tail width). The relative abundance of 2+ year-class lobsters in 1990 and 1992 were similar, but less than half as abundant as in 1989. The 1991 and 1993 2+ lobsters were in similar abundance, but only half that in 1990 and 1992 (Fig. 1-2). The 1993 2+ year-class was the smallest since the surveys began (Fig. 1-2) — this was contrary to expectations given the 1992 recruiting year-class was the largest since the surveys began and may also be a result of major habitat changes in the fishing grounds (see below).
These interannual variations in relative abundance of the 2+ year-class are reflected in interannual variations in CPUE of 2+ lobsters in the Islander catch — the relationship between these two indices of 2+ abundance is relatively close (see Fig. 2-3, Section 2). Total annual catches are only loosely related to interannual variations in 2+ abundance (Section 7), presumably because total effort also varies interannually.

It was anticipated that the 2+ stock in a future year could be forecast from the relative abundance of the previous year’s recruiting year-class, by applying mortality rates estimated by tracking the relative abundance of 1+ in one year to the 2+ in the following year, given some consistency in mortality rates among years. Noting the change in survey methods between 1989 and 1990, the data from subsequent surveys (1990 to 1993) should be the most reliable for estimating mortality and making forecasts. Indeed, there is a somewhat similar ratio of 1+:2+ in both the 1990 to 1991 to 1992 surveys (i.e. 1:0.37 & 1:0.51 respectively, Fig. 1-3 — which corresponds to an average survival of ~44% and indicates a total mortality rate of $Z \approx 0.82$ — Section 7). By applying this mortality rate to the large 1992 recruiting year-class, it was expected that the 1993 fishable stock and consequent commercial catch would be the largest since 1989. However, as discussed above, this did not occur; the survey data (Fig. 1-2) and islander catch monitoring (see Section 2) suggested that the fishable stock had actually declined markedly, possibly because of habitat changes in north west Torres Strait. As a result of these changes, the ratio of 1+:2+ in the 1992 to 1993 surveys was 1:0.18 (Fig. 1-3) — which would suggest a total mortality rate of $Z \approx 1.69$. Nevertheless, the 1993 total commercial catch was about average, and greater than that of 1992 and 1991, providing evidence that mortality was not as high as $Z \approx 1.69$ and that other factors were involved.

The relationship between the relative abundance of 1+ in one year to the 2+ in the following year (Fig. 1-3) was not as close as expected. This may be due to changes in the rate of natural mortality between years (e.g. density dependant effects, or environmentally induced density independent effects) or changes in the distribution of lobsters between...
years (e.g. due to habitat modification, or shelter or food distribution). It is also possible that changes in the way fishers exploit the 1+ and 2+ year classes in different years (e.g. Fig. 2-2, Section 2, which shows that 1+ lobsters have become a significant part of the total catch in recent years) could alter the relationship between 1+ abundance in one year and 2+ abundance in the subsequent year.

Changes in the distribution of fishing effort in 1993 indicate that the apparent unusual decline in the 1993 stock may have been primarily due to a change in lobster distribution. Catch rates on the north western grounds, which usually support high abundances of lobsters, were low in 1992 and poor in 1993 and some freezer boat operators moved to the eastern reefs, Warrior/Dungeness/Three Sisters, in 1993. A change in distribution from west to east was evident by separating the survey data into four quadrants and making interannual comparisons of the relative abundances among the three best sampled quadrants (Figs. 1-4ab). This showed that large (2+ year-class) lobsters were relatively more abundant in the south east quadrant in 1992 and 1993, which appears to corroborate the perceived change in distribution based on freezer boat activities. The relative abundance of pre-recruit (1+ year-class) lobsters also declined in the north west quadrant (including Mabuiag Island) during 1992/1993. This presumed change in distribution may not have been well represented in the survey because the sampling sites were optimised based on the distribution in 1989.

![Fig. 1-4](image_url). Numbers of lobsters caught in 3 quadrants (NE quadrant omitted due to lack of data) of western Torres Strait during annual surveys between 1989-1993. a) 1+ year-class; b) 2+ year-class.

The cause of the presumed change in distribution and the low catch rates in the north western area may be related to changes in habitat. A decline in seagrass cover in the north western area was detected by research divers undertaking the annual lobster surveys and a recent study by CSIRO in north western Torres Strait confirms a significant decline in the distribution, abundance and biomass of seagrasses and an increase in sediment mobility in the area — these may have indirectly impacted the lobster population by changing shelter and/or food availability and possibly causing a movement to other areas, perhaps
with an associated increase in mortality as well. The habitat changes may have also had an impact on recruitment as it was also very low in 1993, particularly in the north western area (Fig. 1-4).

Conclusions

The annual population surveys have provided fishery independent information on the relative strengths of the recruiting and exploited - year-classes which has been valuable for assessing the status of the stock. They also provided annual estimates of growth and mortality rates and evaluation of commercial catch and effort data. The surveys have also forewarned of future fishable stock sizes, even though the actual 1993 stock fell short of predictions due to significant environmental changes — indeed the surveys provided insight into the possible causes and mechanisms of the 1993 short-fall. Of further concern is the possible impact of the environmental changes on settlement grounds as the 1993 recruitment was the lowest recorded a will likely flow through to a low stock in 1994.
Catch monitoring

Information on catch and effort are fundamental to assessing the impact of any fishery on a stock (Gulland 1983) and for this reason annual monitoring of the CPUE of the Islander based sector of the Torres Strait rock lobster fishery has been carried out since 1988. This monitoring is necessary for several reasons: this sector of the fishery is not monitored by any other means and there are differences between this sector and the freezer boat sector of the fishery that is monitored by AFMA logbooks, i.e. it contains a significant free diving component and it is susceptible to localised depletion as it lacks the mobility of the freezer vessel fleet. Monitoring takes place in the area around Mabuiag and Badu Islands.

The CPUE collected by CSIRO is also important because of the concurrent length frequency data that is collected. Measures of CPUE cannot be used for precise stock assessment because the catch is made up of varying proportions of the two fishery year classes (see Section 1, Fig. 1-1). Length-frequency data collected concurrently with the CPUE monitoring enables the calculation of separate CPUE for each year-class component of the catch. Combined with other sub-projects, these data contribute to the assessment of the stock.

Continued monitoring of the catch and effort of the Islander based fishery during 1990-1993 showed significant interannual differences in CPUE. Since monitoring began in 1988, the highest catch rates were recorded in 1989 (3.99 kg/hr), followed in descending order (least squares means) by 1988 (2.11 kg/hr), 1992 (1.97 kg/hr), 1990 (1.95 kg/hr), 1991 (1.87 kg/hr) and the lowest Islander CPUE was recorded in mid-1993 (1.63 kg/hr — Fig. 2-1). These differences were expected from the results of the annual stock surveys which showed similar trends in relative abundance of the fishable stock (Section 1). The catch monitoring again showed that the catch rate of hookah-divers was greater than free-divers (Fig. 2-1) though the difference between the two methods has steadily reduced.

![Fig. 2-1. The catch (kgs) per hour of effort for Torres Strait lobster divers based at Mabuiag Island (error bars are 95% C.I.). The results of ANOVA and post-hoc Tukey HSD tests (@ 5% level) are shown. There has been considerable variability in the relative exploitation of the 2+ and 1+ year-classes during the monitoring period — this is](image-url)

There has been considerable variability in the relative exploitation of the 2+ and 1+ year-classes during the monitoring period — this is
demonstrated by using the catch size-frequency to separate the CPUE on the two year-classes. When the abundance of the 2+ year-class is low, fishing pressure increases on the largest of the 1+ year-class and the proportion of 1+ lobsters in the catch increases (Fig. 2-2). This may lead to interannual variability in the size-selection (recruitment) curve and the level of fishing mortality applied to the recruits as they grow into the exploited size-classes (Section 7).

![Fig. 2-2](image)

**Fig. 2-2.** The catch per unit effort (CPUE) of 1+ year-class lobsters (dashed line) and 2+ year-class lobsters (solid line) in the Islander catch between 1989 to 1993. The dotted line shows the percentage of 1+ year-class lobsters in the islander catch.

Comparisons with other CPUE and catch data

The catch and effort of the freezer boat fleet (from AFMA log books) is clearly different from the Islander CPUE (Fig. 2-3). Not only were there differences in magnitude, there were also different patterns of year to year variation — the correlation between the two measures is not significant \( (P = 0.322) \) and only ~25% of the variation is in common \( (r^2=0.242) \). The differences between the two sectors of the fishery may be related to differences in fishing behaviour/practices, the mobility of the freezer boat fleet, effort and areas fished, or changes in the number or composition of the group of operators volunteering log book returns. The Islander CPUE was expected to be a reasonable proxy for lobster abundance in the vicinity because the data was collected by researchers in the field, the majority of the fishing effort in the monitored area was recorded, the number of fishermen was large and their composition was reasonably consistent among years.

Interannual variation in the CPUE measures were not closely reflected by total annual catch (Fig. 2-3). The Islander CPUE reflected the catch slightly more closely \( (P = 0.062, r^2 = 0.623) \) than the freezer boat CPUE \( (P = 0.098, r^2 = 0.535) \). The annual catches were not as variable as the CPUE data suggesting that effort may increase in years when the lobster abundance is lower, thus helping to stabilise the total catches from year to year.
As shown above, the catch length frequency can be used to provide separate CPUE estimates for each year-class component of the catch. As the 2+ year-class is fully recruited to the fishery at the time the CPUE data is collected, it should be a reasonable indicator of the abundance of the 2+ lobsters. Indeed there is a significant relationship between the CPUE of the 2+ lobsters in the Islander catch and the number of 2+ lobsters seen during the annual surveys ($P = 0.007$, $r^2 = 0.870$ — Fig. 2-4). Although the relationship between CPUE and relative abundance was quite close, it was not a linear one to one relationship. When the ratio of 2+ CPUE to 2+ abundance (which is equivalent to the relative probability of capture) is compared against 2+ abundance (Fig. 2-5), there appeared to be a trend, ($r^2 = 0.121$), though not significant ($P = 0.500$), in that the lower the abundance, the higher the relative probability of capture (Fig. 2-5). This is especially true for the years since 1990 ($P = 0.102$, $r^2 = 0.806$). This may indicate that the catchability coefficient is similarly inversely related to abundance, perhaps because divers were fishing relatively harder, per unit of effort, when abundance was lower and/or the good fishing grounds around the western islands may have a concentrating effect on lobsters. Thus, effective fishing mortality ($F$) per unit effort was greater when abundance was lower.
Conclusions

The CPUE of the Islander catch reflects changes in lobster abundance, as demonstrated by a close relationship between CPUE and relative lobster abundance as measured by the annual population surveys. Nevertheless, it appears that catchability may increase when lobster abundance is low, thus countering decreases in abundance to some extent. The difference in catch rate between free-divers and hookah-divers became progressively less over the three year period and there was no evidence that continued use of hookah was progressively reducing the catch-rate of free divers. The magnitude and interannual variation of the CPUE measures from the Island based fishery and the freezer boat sector were different and there were indications that Islander CPUE may reflect changes in abundance more closely than freezer boat CPUE.
Juvenile ecology

The juvenile stages of the world's major commercially important spiny lobsters have received increased attention in recent years and several advances in management methods have arisen from this research. Interannual indices of settlement of the puerulus of western rock lobster, *Panulirus cygnus*, have been used by researchers to accurately predict the size of commercial western rock lobster catches four years in advance (Phillips 1986). In Florida, the discovery of a critical settlement habitat (algal clumps, mainly *Laurencia* spp.) for post-larval stages of the commercially important *Panulirus argus* alerted management to the need to protect these habitats to assure future productivity (Marx 1986). In contrast, little was known about the ecology of post-larval and small juvenile ornate rock lobsters in Torres Strait as, until recently, research on this life-stage was limited.

The ecology of larval, post-larval and small juvenile ornate rock lobsters, *Panulirus ornatus*, in Torres Strait was investigated between mid-1991 and late-1993. Research divers carried out several surveys of likely settlement and nursery habitats in western and southern Torres Strait based on general habitat information gained from past research. Intensive surveys were carried out in a 10 nm² area north east of Mabuiag Island between August 1992 and March 1993 to determine: early growth rates, timing of settlement, density of juveniles and habitat and micro-habitat preferences of newly-settled and juvenile lobsters.

An extensive diver survey of far-western Torres Strait (west of longitude 142°E, Fig. 3-1), carried out by CSIRO and the Papua New Guinea Department of Fisheries and Marine Resources in 1987 showed that area was not an important settlement ground for *P. ornatus* nor did it support a significant adult lobster population. Consequently, more recent surveys were undertaken east of longitude 142°E, between Cape York in the south and Mabuiag Island in the north. These surveys were undertaken mainly in conjunction with other sub-projects. The exact locations of sites were recorded using a GPS navigator and stored on a computer database.

In September and October 1991, divers found 74 newly-settled lobsters at 46 sites situated 2-6 km north east of Mabuiag Is. These lobsters provided preliminary information on settlement timing and size distribution. In June 1992, a ~160 nm² area around Kagar and the Damun group of reefs, east of Cape York, was surveyed for habitat suitable for post-pueruli and juveniles. Suitable habitat was found adjacent to the reefs only; the seabed graded into mud generally within 2-3 nm of the reefs. No newly-settled lobsters were observed, probably because at this time of year they would have been barely visible as tiny, transparent pueruli. In December 1992 and March 1993, areas around Twin, Mt Ernest and Passage Islands, were surveyed for suitable settlement and nursery habitat. Observations of newly-settled lobsters in these areas extended the known depth of settlement; post-pueruli were found in depths to 21 metres. In April 1993, an Islander diver surveyed 8 areas around Badu Island for suitable nursery habitats and
found more than 50 small juveniles. Post-pueruli and/or small juveniles were observed to be patchily distributed during these surveys (Fig. 3-1) and during the annual lobster population surveys (Section 1).

**Fig. 3-1.** Map of Torres Strait showing sites (marked by asterisks) where *Panulirus ornatus* post-pueruli and/or juveniles were observed during diver surveys. The hatched area indicates the location where quantitative surveys were undertaken (see below).

**Fig. 3-2.** Map of the southern Orman Reefs, north east of Mabuiag Island, showing sites sampled for newly-settled and small juvenile lobsters. Filled circles represent sites where newly-settled and/or small juveniles were found.

*Quantitative survey*

Intensive quantitative surveys were carried out at 54 sites in a 10 nm² area north east of Mabuiag Island (Fig. 3-2), between August 1992 and March 1993 to investigate the ecology of newly-settled and juvenile
lobsters. At each site, located using a GPS navigator, a research diver searched the seabed for juveniles over a 185 m (0.1 nm) × 2 m transect. Juveniles were counted and as many as possible were collected. The diameter and depth dimensions of the shelter of each juvenile collected were measured, using vernier callipers, and the micro-habitat immediately around the shelter was photographed for later analysis of micro-habitat requirements. Juveniles were measured at the completion of each dive and the overall habitat was recorded using a set of standardised categories of substrate and biota.

Table 3-1. Number of newly-settled and juvenile Panulirus ornatus collected at the Mabuiag Island study site between August 1992 and March 1993.

<table>
<thead>
<tr>
<th></th>
<th>1992</th>
<th>1993</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>September</td>
</tr>
<tr>
<td># Juveniles</td>
<td>37</td>
<td>62</td>
</tr>
</tbody>
</table>

A total of 263 newly-settled and small juvenile lobsters were found in the study area during the quantitative surveys (Table 3-1). The density of juveniles increased between August 1992 and March 1993 (Fig. 3-3), however, the difference in numbers observed between months was not significant (one-factor ANOVA, $P=0.156$). The increase in density of juveniles between August and September 1992 was probably due to recruitment of pueruli into the area during September (see Fig. 3-4), and possibly due to research divers missing some newly-settled lobsters in August due to their tiny size and lack of colouration. The consistency in density of juveniles after September 1992 may have indicated that survival of the 1992 juvenile population was good.

The density of juvenile $P. ornatus$ at Mabuiag Island during the 1992/93 surveys averaged ~36 individuals per hectare which is much lower than densities reported for other palinurid lobsters. For example, the density of post-puerulus stage Panulirus cygnus varied between 900

![Mean number of juveniles](image-url)
and 16900 per hectare in different habitats at Seven Mile Beach, Western Australia (Jernakoff 1992) and juvenile Panulirus argus were found at a density of 278 per hectare in algal beds in Florida USA (Marx and Herrnkind 1985). However, results of the 1993 annual lobster population survey (see Section 1) indicated that the recruiting year-class (which settled in 1992) was the smallest since the surveys began in 1989; therefore, the density of juveniles recorded in 1992 was probably lower than average.

Growth in the first year after settlement was investigated by interpreting modal progressions in the juvenile size frequency distributions. All size frequencies consisted of a number of component distributions suggesting that settlement was pulsed rather than continuous (Fig. 3-4). The largest component in the August 1992 size frequency distribution had a modal size of 15 mm carapace length (CL) (Fig. 3-4). This group grew to 53 mm CL in March 1993, which equates to 38 mm CL growth in 6 months or ~6 mm CL per month. By July 1993, about one third of the juvenile population (now 1.5 years old) had grown larger than the imposed minimum size limit of 100 mm tail length or ~75 mm CL (Fig. 3-4). This component of the juvenile population has become more prominent in the islander catch in recent years probably as a result of relatively low numbers of 2+ lobsters (see Section 1, Fig. 1-3).

Timing of settlement was estimated by assuming that mean puerulus size (~6 mm CL see below) adequately indicated size at settlement and then back-calculating the timing from post-settlement growth rates. The largest component in the August 1992 size frequency, which had a modal size of 15 mm CL, had grown ~9 mm CL since settlement which equates to about 1.5 months of growth. Therefore, this group probably
settled in early-July 1992. Juveniles sampled in September and October 1991 were significantly smaller than those sampled during the same months in 1992 (Fig. 3-4), which suggests that most settlement occurred earlier in 1992 than 1991. Such interannual differences in timing will effect when lobsters recruit to the fishery and possibly the total annual commercial catch.

Several substratum types were encountered during the juvenile surveys (Table 3-2). Only hard substrata (consolidated rubble, rock pavement and raised boulders) were inhabited by juveniles. No juveniles were found in seagrass beds during the surveys. Further, no juvenile *P. ornatus* were captured during beam trawl surveys for penaeid prawns on seagrass beds in central and western Torres Strait over a two year period (Clive Turnbull, QDPI, pers comm and pers. obs.). No juveniles were found on living reef, possibly due to increased predation pressure in these areas.

<table>
<thead>
<tr>
<th>Substratum type</th>
<th>Sand silt</th>
<th>Coral rubble</th>
<th>Consolidated rubble</th>
<th>Rock pavement</th>
<th>Raised boulders</th>
<th>Living reef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>25070</td>
<td>2130</td>
<td>15360</td>
<td>9810</td>
<td>1200</td>
<td>90</td>
</tr>
<tr>
<td>% of Area</td>
<td>47</td>
<td>4</td>
<td>29</td>
<td>18</td>
<td>2</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Juvenile *P. ornatus* showed no apparent depth preferences in the Mabuiag Island study area or in other areas surveyed (Fig. 3-5). There was also no relationship between juvenile size and depth (Fig. 3-6).

**Fig. 3-5.** Densities of juvenile *Panulirus ornatus* recorded during 370 m² transects at different depths in western Torres Strait.
Fig. 3-6. Size of juvenile *Panulirus ornatus* against inhabited depth with frequency of depths surveyed.

Fig. 3-7. Relationships between size of juvenile *Panulirus ornatus* and their shelter dimensions in natural habitat in western Torres Strait. Regression curves shown are 

$Y = 21.942 + 14.73(X^2)$, $r^2=0.695$ for entrance diameter vs tail width and

$Y = -55.789 + 31.101(X^2)$, $r^2=0.529$ for shelter depth vs carapace length.
A total of 73 photographs of the shelters of juvenile lobsters and surrounding 1 m² of habitat were analysed to assess micro-habitat preferences. Most (68/73) juveniles (10-70 mm CL) were found in cylindrical-shaped shelters in hard substrate on the seabed. Only large juveniles (>40 mm CL) were found in open crevices, more typical of the adult "den" (Trendall and Bell, 1989). All juveniles observed were solitary (all >½ m apart). Shelters of most (36/47) small juveniles (<40 mm CL) were covered by macro-algae (typically *Sargassum* spp. or *Padina* spp.), whereas for larger juveniles (>40 mm CL) most (22/26) shelters were bare.

There was a significant relationship between the cross-sectional dimensions of small juvenile lobsters (tail width) and their shelters (entrance diameter, $r^2=0.695$), and to a lesser extent ($r^2=0.529$) between juvenile length and depth of the shelter (Fig. 3-7).

**Puerulus larvae**

A modified two fathom prawn net (30 mm stretched mesh panels and a 2 mm square mesh cod-end), designed to collect lobster puerulus larvae in the top 50 cm of the water column was trialled in western Torres Strait in June/July of 1992 and 1993. This time of year was chosen to coincide with a time when the planktonic puerulus larvae were presumably in highest abundance in the water column, i.e. just before settlement (see above). The net was tethered to an anchor line at dusk and retrieved the following morning for each trial. Over 12 nights of sampling, four pueruli and one late-stage phyllosoma were caught. This result corresponds with the low densities of juveniles observed on the seabed during the surveys (see above). The mean size of these pueruli was 6 mm carapace length and this information was used to help estimate the timing of settlement from monthly size frequency data (see above).

**Conclusions**

Small juvenile lobsters were found throughout western Torres Strait, mainly coinciding with the broad range of habitats occupied by adults. Most juveniles were found between 7-9 m, but showed no apparent depth preferences. Density of juveniles at Mabuiag Island in 1992/93 was low (36 H⁻¹). Analysis of variance of juvenile abundance data indicated that survival rate within the first year may be high. The juveniles grew an average 6 mm CL per month in the first year of post-settlement life which is the fastest growth rate documented for a palinurid lobster. Post-pueruli and juveniles sheltered in holes in rock substrata that matched closely their body diameter and length. There was a shift in habitat with growth; juveniles <40 mm CL preferred holes in rock covered by macro-algae (eg. *Sargassum* sp.) whereas larger juveniles preferred bare holes and crevices. The pueruli settling into Torres Strait measured ~6 mm carapace length and settlement occurs during winter, after an oceanic larval phase of about 6 months.
Growth and size–structure

Growth rate is an important parameter in fisheries science and is a essential component of stock assessment models. A growth curve for the ornate rock lobster in Torres Strait was previously estimated by a variety of methods of analysis of aquarium and tag-recapture data (Trendall et al 1988; Pitcher et al., 1992b; Phillips et al., 1992). Recent work has described growth of newly settled juveniles (see Section 3, Juvenile Ecology) and spatial and temporal variability in growth.

Variation in the modal size of the 1+ and 2+ year-classes of ornate lobsters among years at the same location was investigated using size-frequencies from the Islander catch monitoring sub-project (Fig. 1-1). Females were used to test for interannual differences because the female 2+ component of the catch can be resolved with confidence, by modal analysis. In contrast, the male stock includes variable numbers of 3+ animals that make interpretation of modal analysis difficult. In any case, the results for males and females were similar.

There was a significant difference in the modal size of the 2+ year-class among different years ($P<0.0005$, Fig. 4-1). The largest difference, between 1990 and 1988, was 7.8 mm CL ± 0.7 mm (95%CI) — about 8% by CL and 25% by tail weight. The reasons for the interannual differences in growth rates are not known but there appears to be a loose negative relationship between year-class strength and modal size (although not significant, $P = 0.107, r^2 = 0.518$) — i.e. the stronger the year-class the smaller the average size of the 2+ lobsters (Fig. 4-1). This may indicate density dependant controls on growth rate. Another possible cause of size differences is variability in the timing of settlement (see Section 3).

Variation in modal size of ornate lobsters between different areas of the Torres Strait fishery was assessed by analysing size-frequency distributions from the annual population surveys (“Mix”, Macdonald & Pitcher 1979). Central and western Torres Strait was divided into four quadrants, centred at 142°34’ E and 10°11’ S, and the modal size of the 1+ and 2+ year-classes by sex were compared for each year. There was

Fig. 4-1. Size of 2+ females in the Islander catch against the CPUE of 2+ lobsters.
a significant difference in the size of lobsters in the different quadrants (ANOVA, \( P<0.05 \)). Generally, lobsters in the south east sector of the fishery were significantly smaller than those in the north west and lobsters in the south west were intermediate (Fig. 4-2). The largest difference in size occurred in 1990 for 1+ females and was about 46% by CL (18.7 mm CL ± 4.4 mm 95% CI). South eastern 1+ lobsters were 7.1 mm CL (± 6.3 mm, 95% C.I.) smaller on average than 1+ lobsters in the north west, and south east 2+ lobsters were 8.3 mm CL (± 4.4 mm, 95% CI) smaller on average than in the north west. Such differences reflect a considerable variation in the growth coefficient \( k \) (assuming no change to \( L_\infty \)) and have considerable impact on stock assessment (e.g. estimates of size and weight at age).

**Fig. 4-2.** Results of "Mix" analysis of the size-frequencies of the survey population showing the average CL (error bars are 95% C.I.) of the a) 1+ and b) 2+ lobsters in the different quadrants of Torres Strait.

**Conclusions**

The ornate rock lobster in Torres Strait is very fast growing; to our knowledge, it is the fastest growing of any palinurid studied. Growth varies on both spatial and temporal scales: spatial variability may the result of environmental factors such as temperature and/or food availability; temporal variability may also be a result of natural variability in the environment, density dependant effects and/or variation in the timing of settlement. The fishery exploits only one year-class (the 2+) for only about 1 year, thus the catch would be susceptible to variations in the modal size of this year-class as well as its abundance.
Section 5

Introduction

Puerculus collectors

Devices designed to attract and retain the settling puerulus larval stage of spiny lobsters at the end of their pelagic phase have been used successfully in other lobster fisheries to study keys aspects of the recruitment process; further, they have provided an annual index of the initial settlement of lobsters into the fishery that has hence enabled forecasting of recruitment into the fishery and subsequent catch several years in advance (e.g. Western Australia, Tasmania, New Zealand, Cuba, Florida and others — reviewed in Phillips & Booth 1994). A settlement index would also provide the earliest detection of the effect of any significant changes in the fishery or disturbances in the environment and reveal the extent of any compensatory processes in the first year of benthic life.

A wide variety of designs of collector have been used successfully in other lobster fisheries (see Phillips & Booth 1994). The settling puerulus larvae usually exhibit a preference for a design and placement of collector that in some way mimics the settlement habitat. In this sub-project, several designs of collector, based on those used successfully elsewhere, were trialled and sampled regularly at a number of locations throughout Torres Strait.

Previous work

The use of collectors for sampling P. ornatus puerulus was attempted along the north east Queensland coast in the early 1980's. The collectors did catch lobster pueruli but the trials were not particularly successful probably due to excessive fouling and loss of collectors arising from long intervals between sampling that lead to poor settlement and missing samples. These problems indicated the importance of careful placement, regular maintenance, and frequent sampling of collectors. The collector trials initially had some problems with corrosion of the stainless steel frames but the use of high grade marine aluminium solved these.

1990-1991 trials

Five designs of lobster puerulus collectors were trialled near reefs in the western Torres Strait in 1990-1991, as a first step in the development of an annual index of the initial settlement of lobsters into the area of the fishery. It was anticipated that following successful trials, the best design would be deployed in pairs at approximately 25 locations adjacent to likely settlement grounds throughout Torres Strait. This strategy was proposed because, in other fisheries, collectors within sites exhibit less variability than among sites. It was also intended to monitor environmental signals (eg. wind, salinity, temperature, ENSO, cyclones etc.) as these may influence settlement.

The trial collectors were sampled every lunar phase and plates were exchanged every second sampling. Settlement onto other man-made structures (eg. wharf piles, pearl rafts) and natural habitat was also monitored every lunar month during the dry season and every second lunar month in the wet. The collectors initially required several months to become properly conditioned (ie. supporting a community of food
and fouling organisms) before they were expected to successfully sample pueruli. Although some pueruli were collected during the trials, the collectors caught unacceptably low numbers of pueruli. Observations revealed that post-pueruli had settled into certain natural habitats in the vicinity of some of the collectors but also indicated that the habitat requirements of settling pueruli may differ from those of lobster species for which the collector designs originated. This suggests that a rather different collector design may be more appropriate for Torres Strait.

The puerulus collector trials were not particularly successful and consequently, expansion of the sub-project to full-scale sampling was not justified and it was thus suspended. It is possible that the poor catches of pueruli in the collectors reflected very low numbers of pueruli in the water column (see Section 3) and/or that collectors could not compete with abundant natural settlement habitat. It is also possible that the large distance between the settlement grounds and the presumed larval retention area in the north western Coral Sea causes massive depletion of pueruli from the water column as they move west from the edge of the Great Barrier Reef to the central/western Torres Strait. Such an effect was experienced by Australian consultants (Phillips, pers. comm.) setting up puerulus collectors for *P. argus* in Cuba, even though the distances involved were much less — the solution was to move the collectors from inside the bay to the lee of the barrier reefs separating the bay from the Caribbean Sea. Perhaps a similar solution would have been successful in Torres Strait.

It was still considered that functional puerulus collectors would be valuable for providing annual settlement indices, forecasting recruitment into the fishery (as for western rock lobster — Phillips 1986), detecting of the effect of any significant changes in the fishery or disturbances in the environment and estimating compensatory processes occurring in the first year of benthic life.
Breeding population studies

Until recently, the coastal reefs of the eastern Gulf of Papua were the major known breeding grounds of the Torres Strait ornate tropical rock lobster. Yet perhaps as few as 1% of the several million lobsters which emigrate from Torres Strait arrive on these reefs each year and it was thought that most lobsters moved to the edge of the continental shelf in the Gulf of Papua and the far northern Great Barrier Reef. These areas were surveyed for breeding lobsters, in early 1990, using a small manned research submarine (Prescott & Pitcher 1991). Very few lobsters were found in the Gulf of Papua and it was considered that the mortality of lobsters migrating into the Gulf of Papua could be extremely high. High densities were observed at a few sites in the far northern Great Barrier Reef which indicated that the area may support a significant breeding population. However, it remained necessary to confirm the extent of the far northern Great Barrier Reef breeding grounds and the abundance of breeding lobsters therein, as well as determine whether these lobsters suffer catastrophic mortality after breeding as occurs in the breeding population of the eastern Gulf of Papua.

During the last triennium, two short field trips were made to the far northern Great Barrier Reef to collect more information on the breeding population in the area and to assess the feasibility of larger scale studies.

1992 field studies

In February 1992, a pilot survey using the FRV Tiger Star was conducted in the vicinity of Murray Island to assess the feasibility of sampling the deepwater breeding lobster population using tangle nets and traps, and also to explore the distribution and abundance of lobsters in shallower water and sample them by diving; the underlying objective was to obtain size-frequency data to estimate mortality rates. Some deepwater habitats observed from the submarine were mapped.

Neither the nets or the traps caught lobsters, primarily because sharks destroyed the nets and took the baits out of the traps; also, it became evident that the Tiger Star had limited capability for deepwater work. More than 100 man-dives were done and measurements of around 100 lobsters were made. All lobsters were in breeding condition, with females either having eggs (27%), ripe ovaries (57%), or at least showing evidence of past matings. These lobsters were also very large (Fig. 6-1), the average sizes (males: 131 mm CL, females: 112 mm CL) were larger than at Yule Island (males: 110 mm CL, females: 106 mm CL) or in the western Torres Strait fishery (males: 106 mm CL, females: 97 mm CL). The Beverton & Holt model indicated that the mortality rate of males may have been around \( Z \approx 0.8 \)–1.2 and for females \( Z \approx 1.8 \)–2.2; which were higher than in western Torres Strait (where \( Z \approx 0.9 \)), but less than at Yule Island (where \( Z \approx 10 \)–12). However, these estimates should be regarded as preliminary because the sample size was only small and did not include the deeper water (>30 m) population. The lobster population in shallow water was probably small but significant, with a very patchy distribution. Three other species of tropical rock
lobsters (\textit{P. versicolor}, \textit{P. l. femoristriga} and \textit{P. penicillatus}) were also caught and \textit{P. versicolor} made up a significant proportion of the artisanal catch. One commercial vessel had recently begun to fish in the area and intended to continue as catch-rates were worthwhile. Fishers reported that lobsters with eggs may be found throughout the year, which was another indication that the mortality rate may not be as severe as at Yule Island, but fishers did not know if there was any seasonal pattern in breeding activity.

![Fig. 6-1. Size-frequency distributions of male and female \textit{P. ornatus} from the breeding population in shallow water of the far northern Great Barrier Reef, compared with those of lobsters from western Torres Strait and Yule Island.](image)

1993 field studies

Further work was initiated in two areas. First, arrangements were made to gather catch data from fishermen working in the eastern Torres Strait shallow water fishing grounds to yield information on the distribution, physiological condition, mortality rates and seasonality of reproductive activity of lobsters in that area. Second, a field trip was undertaken to test methods and logistics for establishing the distribution and abundance of breeding lobsters in deeper water on the edge of the continental shelf.

A commercial freezer boat operator was encouraged to collect data, but a combination of bad weather and ill health limited data return. Efforts to gather data from Murray Island fishermen were frustrated by the lack of a reliable processing facility. This situation has now improved with the establishment of a freezer facility on Murray Island and cost effective information is currently becoming available.

The distribution and abundance of the deep water population was the focus of a field trip in February/March, 1993. The objectives of the trip were to traverse the shelf edge with side-scan sonar to map the location...
and extent of relic reefs in deeper water (features that had previously been identified as potential breeding lobster habitat), and then to census lobster abundance on these relic reefs with a remotely operated underwater observation vehicle (ROV). Several significant areas of habitat were identified by the side-scan, as well as the probable occurrence of suitable habitat over larger areas of the shelf edge, even though the side-scan did not perform as well as expected. The survey indicated that relic reefs in deeper water were limited, because the shelf edge was very narrow, in the northernmost sections of the GBR. However, south of Murray Island the shelf edge widened and deep relic reefs were encountered more frequently. Several target reefs that had been located by side-scan were investigated with the ROV and breeding lobsters were found and videoed, and their densities were estimated.

Densities where lobsters were found in the deep water reef habitat were of the order of 70 lobsters/ha. The ROV proved to be an effective tool for deeper water survey work, though it became apparent that a vessel would have to be specially set up prior to efficient ROV operations.

More evidence of a significant population of breeding lobsters on the outer Great Barrier Reef was gained — the reefs surveyed were additional to those observed during the 1990 submarine survey and the presence of breeding lobsters three years hence would appear to indicate some persistency in the population. However, the relic reefs are relatively small and the outer shelf edge is rather narrow, thus taking into account the probable limited areal extent of suitable habitat, the breeding lobster population on the shelf edge is probably not as large as the several millions estimated to emigrate from western Torres Strait each year — the deeper inter-reefal areas west of the outer barrier may be important also. More information on lobster densities and extent of habitat are needed to further quantify the eastern Torres Strait breeding population. A larger scale survey of breeding lobsters in eastern Torres Strait, including the inter-reefal and shallow water habitats, will be undertaken in 1996.

Conclusions

The breeding population studies showed that there is a significant, though patchy, lobster population actively breeding in shallow water in eastern Torres Strait. The size-frequency distribution of this population indicates that these lobsters may not suffer catastrophic mortality after breeding as occurs in the breeding population of the eastern Gulf of Papua. Recent surveys also indicated that the shelf edge outside the far northern Great Barrier Reef is narrow with small relic reefs but these support a persistent breeding population in relatively high densities. However, it remains necessary to confirm the distribution, abundance and mortality rate of the breeding population in the far northern Great Barrier Reef and this is planned for 1996.
**Stock assessment**

Data collected in the field research projects has continued to be synthesised into a stock assessment model of the ornate tropical rock lobster fishery to provide outputs relevant to management. During 1989–90, sufficient information first became available for a preliminary stock assessment (Pitcher et al 1992b). Initially, this included an analysis of yield-per-recruit (YPR), which assists the prevention of growth overfishing by indicating the minimum sizes that maximise yield for a range of fishing mortality (Gulland 1983). The YPR model was then extended to assess the potential impact of a proposed closed season and to assess the potential long term yield of the lobster stock through consideration of escapement. During 1990-93, the escapement model has been further developed, in particular by substituting early guesstimates of the natural mortality rate ($M$) with actual measured estimates forthcoming from the annual population surveys (Section 1). The model has been used to provide forecasts of the fishable stock one year in advance.

**Previous Assessment**

Key data which permitted the first, preliminary, stock assessment was collected during field research in 1989 — i.e. an estimate of the number of lobsters in the Torres Strait fishing grounds (Pitcher et al 1992a). The size of the fishable stock in that year was estimated to be 2,200-3350 t tail weight, compared with the catch in the same year of 249 t indicated that fishing mortality was low ($F \approx 0.1$). The stock size estimate ($B_0$) initially permitted a "rule-of-thumb" maximum sustainable yield model to be applied ($\text{MSY} \approx \frac{1}{2}MB_0$) and was also critical to subsequent, more complex models. In 1989, natural mortality rates were also unknown so estimates for similar tropical species were substituted (e.g. $M \approx 0.5$) giving an average potential yield estimate of 600 tonnes or more.

When the estimates of the natural and fishing mortality rates ($F \approx 0.1$, $M \approx 0.5$) became available in 1989, along with previous estimates of growth parameters ($K$, $L_{\infty}$) and length-weight relationships, it became possible to carry out the first, preliminary, analysis of yield-per-recruit (YPR). This takes into account the changes in the biomass of a year-class, with growth and mortality, and estimates the yield from each year-class (per recruit) for a range of $F$ and minimum size. In 1989, with $M$ guesstimated at 0.5, minimum size at 100 mm tail length and $F$ at ~0.1 the calculated YPR was about 20 gm (Fig. 7-1), which was very low compared with other lobster fisheries. At that low level of fishing pressure, the yield would have been slightly greater at smaller minimum sizes; although very small tails were more difficult to market.

Nevertheless, the minimum size certainly did not improve yield and, consequently, it was advised that enforcement of the minimum-size limit (which has a substantial cost) should be re-assessed. The YPR analysis also showed that a closed season, such as that which had been proposed for October through December, would be unlikely to have the desired effect of increasing yield by preventing growth-overfishing because the latter is not a problem in Torres Strait. The average catch for those months was ~30 t and a closure may well have reduced catch by up to that amount.
Yield would obviously increase with increased fishing pressure, and at very high $F$ (e.g. $F > 1.0$) a minimum size eventually became important (Fig. 7-1), but recruitment-overfishing was also to be avoided. However, the "rule-of-thumb" model used (above) was very simplistic and only intended for data limited situations — a more realistic model was desirable. The approach taken was to consider the proportion of the population that escapes fishing to emigrate and breed. In 1989, it was estimated that about 7 million lobsters emigrated from Torres Strait to breed and with a catch of ~240 t, $F \approx 0.1$ and $M \approx 0.5$, this was about 93% of the numbers that could emigrate and breed if there was no fishing at all (Fig. 7-2). In comparison with almost all other fisheries, this is a very high escapement rate. Theoretical fisheries yield models predict that production is maximised when the breeding stock is reduced to half (50%) of unfished levels, though empirical studies suggest that this level may lead to overfishing. For many stocks, a 30% reduction may be more appropriate (this is very conservative compared with the situation for western rock lobster where the breeding stock is now ~15% of unexploited levels, N. Hall pers. comm.). In the Torres Strait lobster fishery, it was estimated that if fishing mortality was increased four-fold (to $F \approx 0.4$) the resultant escapement would be a conservative 74%; in the case of the 1989 stock, the projected yield would be over 800 tonnes (Fig. 7-2). The projected yield would vary from year to year, because of recruitment fluctuations, but it was anticipated that recruitment could be assessed each year by a fishery independent research survey. Following consideration of the escapement model it was recommended that increased fishing effort by Islander divers should be encouraged.
Fig. 7-2. Abundance, monthly catch, and percent escapement of a cohort of ~12 million ornate rock lobsters (~that estimated to have produced the 1989 stock) following recruitment at age 18 months, for three levels of fishing mortality. Emigration occurs during August and September (months 32/33 and 44/45).

1990-1993 Developments

Each year since the 1989 survey of absolute stock abundance, smaller fishery independent surveys of relative abundance have been undertaken by sampling the lobster population in the middle of each year. These surveys provide an annual index of the relative abundance of the two year-classes in the Torres Strait population, including the strength of the recruiting year-class, and better estimates of growth and mortality. The Islander catch is also monitored in the middle of each year to provide catch and effort information, and the size–frequency distribution of the catch.

The improved parameter estimates have allowed the escapement model to be revised; in particular, natural mortality ($M$) is now estimated at about 0.8, and recruitment data (1+ year-class relative abundance) is available for each year which allows assessment, in advance, of the following year’s potential yield. The surveys have also shown that growth is spatially and temporally variable and that mortality may also vary annually — this variability will need to be incorporated into future revised models.

The assessment process involves analysis of the Islander catch monitoring and fishery independent survey data to provide parameter estimates (stock, recruitment, growth, natural and fishing mortality, length-at-capture) to enter into a straightforward stock assessment model from which the following year’s potential yield is estimated.

Data sources

The data on which the assessments are based (Table 7-1) includes information from the 1989 large scale survey of the absolute abundance of lobsters, the subsequent annual surveys of relative abundance (numbers by year-class at each site, sex, size-frequency, size-weight) which provide estimates of stock, recruitment, growth, natural mortality and length-at-capture, and information from the annual monitoring of the Islander fishery (catch, effort, size-frequency and sex of the catch) which provide estimates of relative abundance, fishing mortality,
length-at-capture. Pre-1989 data which have been used include tagging data for growth rates, and monthly catch and length-frequency that indicated the timing of the emigration. Though the data are obtained by the most reliable cost-effective means there are, nevertheless, always uncertainties and these are considered below.

The 1989 survey of absolute abundance (at ~600 sites) provided benchmark abundance data against which subsequent surveys of relative abundance (at 100 sites) are measured. That is, since 1989, the total number of lobsters has been estimated by comparing numbers observed in surveys with numbers observed at the same sites in 1989 after adjusting the 1989 numbers for changed methods. The adjustment was necessary because in 1989, 4 × 500 m measured transects were used but subsequently, 20 minute timed swims have been used — the adjustment involved correcting for distance swum and width covered (visibility) — this adjustment is obviously a source of uncertainty.

### Table 7-1. Key data, parameters, and algorithms underlying the stock assessment model for the ornate rock lobster: a) size selection (length-at-capture) curve; b) seasonal emigration; c) seasonal relative effort; d) parameters and algorithms.

<table>
<thead>
<tr>
<th>a) Month</th>
<th>Age (months)</th>
<th>Size (tail length mm)</th>
<th>Effort (% of F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤July</td>
<td>≤19</td>
<td>≤84</td>
<td>0</td>
</tr>
<tr>
<td>Aug</td>
<td>20</td>
<td>89</td>
<td>1</td>
</tr>
<tr>
<td>Sep</td>
<td>21</td>
<td>94</td>
<td>3</td>
</tr>
<tr>
<td>Oct</td>
<td>22</td>
<td>98</td>
<td>10</td>
</tr>
<tr>
<td>Nov</td>
<td>23</td>
<td>103</td>
<td>33</td>
</tr>
<tr>
<td>Dec</td>
<td>24</td>
<td>107</td>
<td>66</td>
</tr>
<tr>
<td>Jan</td>
<td>25</td>
<td>111</td>
<td>90</td>
</tr>
<tr>
<td>Feb</td>
<td>26</td>
<td>115</td>
<td>97</td>
</tr>
<tr>
<td>Mar</td>
<td>27</td>
<td>119</td>
<td>99</td>
</tr>
<tr>
<td>≥Apr</td>
<td>≥28</td>
<td>≥126</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b) Month</th>
<th>Age (months)</th>
<th>Size (tail length mm)</th>
<th>Emigration coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug</td>
<td>32</td>
<td>136</td>
<td>(1-0.55)</td>
</tr>
<tr>
<td>Sep</td>
<td>33</td>
<td>139</td>
<td>(1-0.18)</td>
</tr>
<tr>
<td>Aug</td>
<td>44</td>
<td>168</td>
<td>(1-0.55)</td>
</tr>
<tr>
<td>Sep</td>
<td>45</td>
<td>171</td>
<td>(1-0.18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c) Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.3</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.1</td>
<td>0.2</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

| d) Natural mortality rate: | M = 0.80 |
| A range of Fishing mortality: | F = 0.0-2.0 |
| Von Bertalanffy growth equation: | \( CL = 177 \times (1 - \exp(-0.386 \times t - 0.441)) \) |
| Tail-width vs carapace-length: | \( TW = (CL - 0.0895) / 1.4385 \) |
| Tail-weight vs tail-width: | \( WT = 2.438 + 0.00124 \times TW^{(2.955)} \) |
| Tail-length vs tail-width: | \( TL = TW / 0.52 \) |
| Monthly yield function: | \( Y_t = N_t \times F_{rel} \times WT \) |
| Cohort decay function: | \( N_{t+1} = N_t \times S \times SF \times E \) |

where: \( N = \) cohort size (%); \( F_{rel} = \) relative F on cohort depending on size-selection curve & seasonal effort; \( S = \) survival; \( SF = \) survival from fishing; \( E = \) emigration

The lobster population in Torres Strait comprises almost entirely 1+ and 2+ with very few older animals. The survey length-frequency data were

### Modelling methods
analysed by the computer program "Mix" to provide the proportions of 1+ and 2+ in the population (Section 1) — the numbers of recruits and stock size was estimated from these and the estimated total (Table 7-2). Mortality is estimated by following the decline in relative abundance of a cohort from the 1+ in one year to the 2+ in the following year.

The assessments are based on an iterative computer population model, with monthly time steps, that takes into account the following: selection (recruitment) curves; seasonal emigration patterns; seasonal effort patterns; natural mortality rates; a range of effort values; von Bertalanffy growth equation; tail-width and tail-length vs carapace-length; and tail-width vs tail-weight. The model begins with a cohort size of 100%, applies growth, mortality, effort and emigration, and outputs monthly yield, cumulative yield of the cohort, and size of the cohort. The model is independent of the number of recruits (1+), which can be entered into the model output to give a yield estimate. The model treats the entire fishery as a uniform whole, it is not partitioned into different areas. The details of the model, parameters, key data and outputs are shown in Tables 7-1 & 7-2.

Table 7-2. Annual catch of the Australian diver fishery, survey data, population estimates, mortality rate estimates, allowable catch (@ $F=0.4$) advice based on recruitment given prior to each year with the data and model available at the time, and potential yield (again @ $F=0.4$) estimates from the current model.

<table>
<thead>
<tr>
<th>Year</th>
<th>Catch</th>
<th>Survey</th>
<th>Population Est.</th>
<th>Mortality</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>Total</td>
<td>%1+ %2+</td>
<td>Millions 1+ 2+</td>
<td>$Z_{ext}$ $F_{ext}$ advice pot.</td>
</tr>
<tr>
<td>1978</td>
<td>119</td>
<td>40.7 59.3</td>
<td>14.10 5.74 8.36</td>
<td>0.10 ≥800 827</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>124</td>
<td>60.7 39.3</td>
<td>9.86 5.99 3.87</td>
<td>0.39 0.16 473 263</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>124</td>
<td>78.9 21.1</td>
<td>10.54 8.32 2.22</td>
<td>0.99 0.26 405 274</td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>150</td>
<td>67.1 32.9</td>
<td>12.93 8.68 4.25</td>
<td>0.67 0.13 495 381</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>193</td>
<td>74.9 25.1</td>
<td>6.38 4.78 1.60</td>
<td>1.69 0.41 440 397</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>130</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>207</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>349</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>242</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>216</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>243</td>
<td>759</td>
<td>60.7 39.3</td>
<td>9.86 5.99 3.87</td>
<td>0.39 0.16 473 263</td>
</tr>
<tr>
<td>1990</td>
<td>183</td>
<td>811</td>
<td>78.9 21.1</td>
<td>10.54 8.32 2.22</td>
<td>0.99 0.26 405 274</td>
</tr>
<tr>
<td>1991</td>
<td>166</td>
<td>995</td>
<td>67.1 32.9</td>
<td>12.93 8.68 4.25</td>
<td>0.67 0.13 495 381</td>
</tr>
<tr>
<td>1992</td>
<td>158</td>
<td>491</td>
<td>74.9 25.1</td>
<td>6.38 4.78 1.60</td>
<td>1.69 0.41 440 397</td>
</tr>
<tr>
<td>1993</td>
<td>189</td>
<td>~1.99?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>~1.99?</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The annual surveys indicated that the abundance of small pre-recruit 1+ lobsters varied considerably among years (Table 7-2). Each year, an estimate was made of the possible yield at $F = 0.4$, using the model with data and parameters available at the time, and this estimate was provided to mangers as advice on the "allowable catch" for the fishery (Table 7-2). Note that the current model gives different potential yield estimates because some parameter estimates have changed as new data became available and some of the underlying data has been re-analysed using more refined procedures. The 1992 1+ year-class was the largest since surveys began (about 4% larger than in 1991 and ~45% larger than in 1990). Consequently, it was predicted that the 1993 fishable
Current modelling on the 1992 survey data indicates that the potential yield for 1993 was \( \approx 397 \) t — though this would only have been achieved by a significant increase in fishing effort (to a level of fishing mortality, \( F \), of \( \approx 0.4 \)). It was expected that with the level of fishing current at the time (\( F=0.1-0.2 \)), the 1993 catch would have been significantly less than 397 t. Nevertheless, the 1993 catch (at 189 t) exceeded that of both 1991 and 1992 as predicted.

While the 1993 catch upheld predictions from 1992, the larger stock was not evident in the 1993 survey data (Fig. 1-1, Table 7-2) and there may be several possible explanations for this (Section 1). Changes in the distribution of fishing effort and observations during the survey indicate that the relative distribution of lobsters may have changed as a result of movements and/or mortality possibly in response to habitat changes in NW Torres Strait; e.g. seagrass dieback/sediment movement — these changes are currently being studied.

The habitat changes may have also impacted recruitment as, in contrast to the 1992 survey, the number of 1+ lobsters observed during the 1993 survey was the lowest since the surveys began (about 55% of that in 1992, \( \approx 57\% \) of that in 1991 and \( \approx 79\% \) of that in 1990). Predictions of fishable stock, total catch and catch rates for 1994, therefore, were not optimistic (Table 7-2).

The annual surveys appear to give reliable estimates of the relative abundance of the different age groups but also highlight the variable nature of the lobster population. Analyses of size-frequency data have shown that growth rates differ between years (Section 4). For example, growth rates were 10-14% slower in 1991 than in 1988. Also, the size of lobsters varies considerably from area to area in the fishery. Those in the south-east Torres Strait are significantly smaller than those in the north and north-east. Growth rates differ by as much as 40% between these areas, making generalisations about the lobster stock difficult. There is also variability in the estimate of natural mortality derived from the annual surveys, making modelling difficult. On-going population surveys will help refine these estimates.

There are also uncertainties in estimating fishing mortality (\( F \)). Comparison of total catch with 2+ stock biomass gives biased high estimates of \( F \) for years with small 2+ stock (i.e. \( F=0.26 \) \& 0.41 for 1991 \& 1993 respectively, Table 7-2) because a significant proportion of the catch is derived from the recruiting 1+ year-class and because catches are recorded over calendar years which do not match the timing of recruitment into and emigration from the fishery. A further indicator that the estimates of \( F \) for 1991 \& 1993 are biased high is that \( F \) is generally \( \approx \)proportional to effort (\( f \)) but \( f \) was not doubled in those years. These biased estimates of \( F \) can be ameliorated by separating effort on the year-classes using data from the catch and effort monitoring (Section 2) and by summing catches over a more appropriate interval (e.g. August to August). The model, which uses recruitment strength as an input rather than stock biomass, gives lower estimates of \( F \) in those years (i.e. \( F=0.22 \) \& 0.17 for 1991 \& 1993 respectively). Additional uncertainties that affect estimates of fishing
mortality include spatially and temporally variable growth rate and probably variable natural mortality rate ($M$); these need to be documented and taken into account.

Fishers operating near their island bases have expressed concern over declining catch rates. The current assessment indicates that these declines are in part due to lower recruitment over the past 3 years and also probably indicate local depletion on selected reefs as a result of higher effort with greater Islander participation over the last decade. The turnover rate of lobsters between the home reefs and populations further offshore is unknown although this is being addressed by current research.

It is also possible that the sources of recruitment to the fishery are limited because the breeding grounds may be restricted and the lobsters may breed only once and then die. The full extent of the breeding grounds is unknown, and this uncertainty has lead to the conservative approach in estimating potential yields.

There are many other uncertainties in data, assumptions/simplifications and other unknowns, these include: sampling variance generally, natural variability in timing of settlement, growth and mortality rates; possible bias (to larger lobsters) in the 1989 survey size-distribution; adjustment and matching of 1989 survey methods with subsequent methods; correction for "miss-bias" during sampling; distribution of survey sites relative to variability in lobster movement/distribution; spatial and interannual variability in seasonal effort patterns; variability in the size-selection (recruitment) curve dependent on relative abundance of year-classes, effort patterns and differences in fishing behaviour between Islander free-divers and commercial hookah divers (more size-distribution data is required from freezer vessel divers).

For future improvements in understanding/prediction, the model needs to take into account the spatial distribution of lobsters and fishing effort. Currently, the spatial distribution of effort is known only anecdotally — this needs to be documented accurately for a spatial modelling approach. Further, the model does not currently take into account known variance in size at age and size-weight relationships — these are likely to have a significant influence on stock assessment as the relationships are non-linear.

Assessments indicate that there is potential to increase catches for this fishery. An increase in fishing mortality (to $F=0.4$) would result in about 73% of the population surviving to emigrate and breed each year, compared with the unexploited situation, and a projected long term potential yield averaging ~400 t each year based on the average recruitment since 1989. The actual yield would vary from year to year, because of recruitment fluctuations, but could be assessed each year. For 1994, the potential yield is estimated at only ~200 t. Increased fishing effort by Islander divers should be encouraged, although local depletion could affect catch rates. The scientific analysis has questioned the need for a minimum size limit, unless effort increases significantly, as under current fishing regimes there appears to be little benefit for the cost of management enforcement of the 100 mm size limit.
Annual stock assessments of the ornate rock lobster are possible only because CSIRO conducts annual population surveys and records catch and effort trends of the Islander sector. These surveys and reporting of catch and effort should continue as an ongoing routine monitoring function. Though the logbook participation is only small, the data collection has been ongoing for ~10 years, over a range of stock sizes known from independent surveys, thus analysis of these data is now worthwhile. Better information on the location and extent of the breeding grounds is important to future assessments, as are better estimates of growth and mortality rates. Some analyses of local depletion rates and turnover between the offshore populations and the fished areas would be useful in clarifying the causes of local depletions. Additional details of the fishing activities of the freezer boat fleet would also be useful, in particular measurements of the size-distribution of the freezer boat catch and accurate details on spatial effort patterns.

To provide stock-assessment advice for management, data collected in the field continued to be integrated into a stock-assessment model of the fishery. The first assessment, in 1990 included an analysis of yield-per-recruit that indicated that the minimum size of 100 mm tail length would only improve yield at levels of fishing mortality much higher than current levels. The stock-assessment was extended to consider the level of escapement — the proportion of the population that escapes fishing to emigrate and breed. It was estimated that fishing mortality ($F$) could be increased 4-fold (to $F=0.4$), giving an average potential yield estimate of >800 t, and yet leave a conservative escapement of about 74%. It was advised that increased effort should be encouraged in the diver fishery.

Annual fishery independent surveys have provided data on stock abundance, recruitment, growth and mortality. The updated parameters enabled the model to be refined and now, based on the average level of recruitment, the average long term potential yield estimate is ~390 t. The recruitment data for one year can be used to forecast the potential yield (at $F=0.4$) for the following year. However, the 1993 stock was smaller than expected from the relatively large 1992 recruitment, possibly as a result of a large-scale seagrass dieback in north western Torres Strait that may have lead to increased mortality rates and altered lobster distribution. The 1993 recruitment was the smallest yet surveyed, perhaps for similar reasons, and the predictions for 1994 are not optimistic.

There are uncertainties in the assessment largely due to variability in growth and mortality rates and the impact of environmental disturbances. Estimates of other parameters (e.g. $F$) may be tuned by more refined analysis of data from existing sources and ongoing monitoring. A variety of other uncertainties may be reduced by additional data collection and these needs are addressed in "Future Research Priorities".

**Future data needs**

**Conclusions**
The following research has been funded for the next triennium:

The Torres Strait lobster population will be sampled in June each year to provide an annual index of the relative abundance of all year-class including the strength of the recruiting year-class. At the same time, the catch of Islander fishermen will also be monitored to provide catch and effort information, and the size-frequency distribution of the catch.

In response to concerns raised by some representatives of Torres Strait Island communities about the effect of commercial lobster fishing by hookah divers in deeper water (>5 m deep) adjacent to traditional "home-reefs" that are fished by Islander free-divers, the rate of replenishment of lobsters from deep water to a depleted shallow water population will be estimated.

The breeding lobster population in eastern Torres Strait will be sampled seasonally by monitoring commercial/artisinal fishing activities in the area and in 1996 by carrying out a diver survey of the shallow reefs (similar to the 1989 survey in western Torres Strait) and by surveying deeper waters with acoustic instruments and a remotely operated underwater observation vehicle. The underlying objectives will be to assess the distribution, abundance, physiological condition, mortality rates and seasonality of reproductive activity of the breeding population.

The Torres Strait wide distribution of puerulus settling sites and juvenile nursery grounds, and micro-habitat use by post-pueruli will be documented in 1996.

The information arising from field research will continue to be assessed using fisheries dynamics methods and outputs from these assessments will be provided to managers.

Additional areas that require further research, but have not been specifically funded, include: analysis of logbook data now that the time series is ~10 years long and covers a range of stock sizes known from independent surveys; seasonal collection and analysis of the size-distribution of the freezer boat catch and accurate details on spatial effort patterns to reduce current uncertainties in stock assessment; and studies of the distribution and abundance of phyllosoma larvae relative to the major current patterns of the north western Coral Sea and response of larvae to key environmental factors would provide the final link between the breeding grounds studies and recruitment into Torres Strait and determining the significance of the Great Barrier Reef population.


