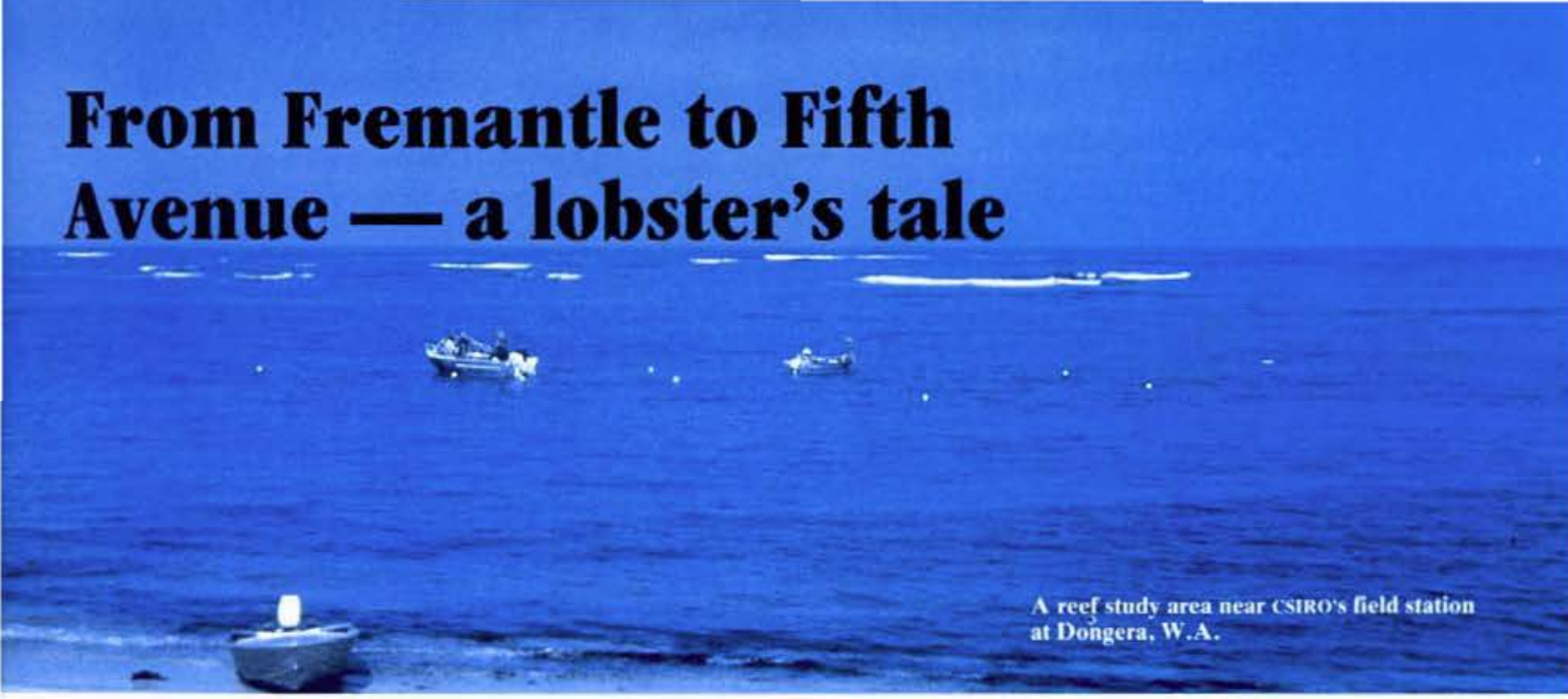
From Fremantle to Fifth Avenue — a lobster's tale



A reef study area near CSIRO's field station at Dongera, W.A.

What's $50 per lb in New York, walks along the floor of the Indian Ocean, and lays up to three-quarters of a million eggs in one go? If you know the answer is a western rock lobster, perhaps you also know that this crustacean is the basis of Australia's largest single-species fishery, accounting for almost 30% of the country's gross income from fisheries products. And that the fishery is one of the largest for rock lobsters in the world.

The western rock lobster accounts for 60% of the total Australian rock lobster catch. On top of its domestic consumption, Australia exports about 18 000 tonnes of lobster annually, valued at more than $130 million; 96% of the catch is exported to the United States as frozen uncooked tails.

The western rock lobster, scientifically known as *Panuliris cygnus*, occurs along the continental shelf off the coast of Western Australia from North West Cape (21° 45′S) to Cape Leeuwin (34 ° 22′S). The fishery dates back to the early 1900s. Since then, fishermen have expanded their operations from the two first centres — at Fremantle and Geraldton — and now set their pots over the coastal strip bounded near the shore by shallow coastal reefs and seaward by the shelf edge, where the water depth averages 200 metres. Fishing centres are dotted along the coast at places like the Abrolhos Islands, Geraldton, Dongara, Jurien Bay, Fremantle, and Bunbury.

Early investigations

Not surprisingly, the western rock lobster has become the object of extensive scientific investigation. Dr Keith Sheard of the then CSIRO Division of Fisheries carried out research on the biology of the species in the 1940s.

Then in the period 1959–65, the International Indian Oceanographic Expedition — at the time the largest international oceanographic investigation ever mounted, involving 20 collaborating countries and 40 research vessels — recorded for the first time comprehensive data on the waters, currents, and marine life in the Indian Ocean. Scientists from CSIRO followed up the Expedition's work with a series of studies on oceanic circulation, which also proved valuable to continuing studies on the rock lobster.

Dr Graham Chittleborough and his colleagues in what had become the Division of Fisheries and Oceanography added to the findings of early studies by Dr Ray George on the larval stage (or phyllosoma) by providing data on distribution, growth, and vertical movements. They concluded that the larvae were probably transported offshore into the Indian Ocean by wind-driven surface currents.

Dr Chittleborough and Mr Len Thomas of CSIRO found that western rock lobsters exist as free-floating planktonic larvae for the first 9–11 months of their life. During this time, they undergo a series of behavioural and developmental changes that are synchronized with circulation changes in the waters of the Indian Ocean.

Adult western rock lobsters are gregarious creatures that form groups of up to several hundred underneath crevices in limestone reefs on the sea floor, presenting octopuses and other predators with a mass of waving, spiny antennae. They can weigh up to 4·5 kg, although those caught in the lobster pots average about half a kilogram. They have a long life span, first mating at about 6 or 7 years of age. The scientists have kept one animal alive in captivity at the Western Australian State government's Marine Research Laboratories for 15 years.

The western rock lobster, *Panulirus cygnus*.

Most breeding adults live on reefs or areas of rocky sea floor about 40 to 60 km from the Western Australian coast. Mature western rock lobsters mate during the winter or early spring. At that time the male deposits sperm packets or 'tar spots' on the underside of the female, who in the spring and early summer scrapes the tar spot, which releases the sperm and fertilizes the eggs. These lobsters are nothing if not prolific — females lay from 300 000 to 750 000 eggs at a time. One 12-year-old held in captivity was estimated to have laid 22 000 000 eggs in her lifetime.

The female carries these eggs on the underside of her abdomen for 3 to 9 weeks. Then the newly hatched larvae rise to the surface and begin a journey that takes them hundreds of kilometres west into the open ocean.

The floating phase ...

Phyllosoma larvae are flat and leaf-like with long legs and protuberant eyes, a shape well adapted to a floating existence. The first phyllosoma stage is transparent and less than 2 mm long. At the end of their development, the phyllosomas reach a length of 35 mm.

Bright moonlit nights drastically reduce the catch of lobsters in baited pots.

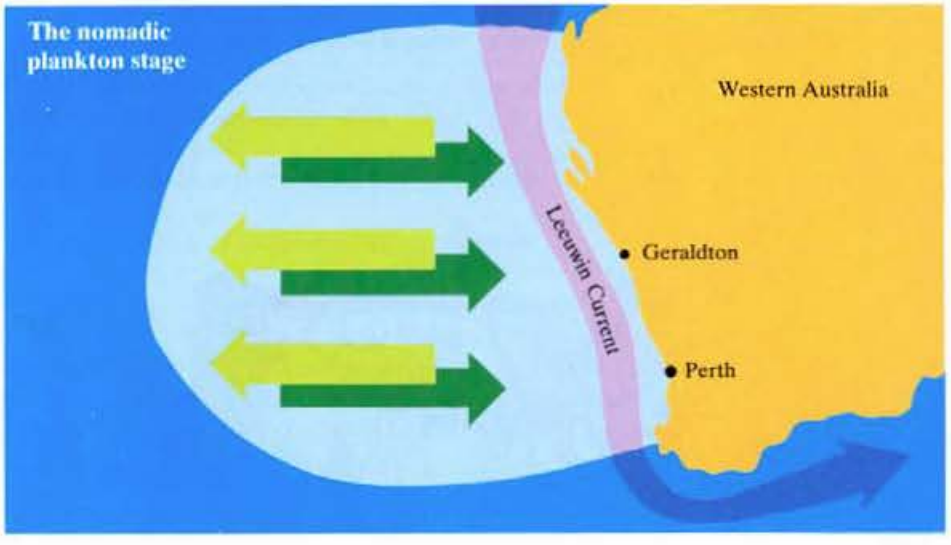
Dr David Ritz, then with CSIRO and now at the University of Tasmania, first observed that the newly hatched phyllosoma larvae swim strongly towards low-intensity light by beating their feathery legs. They undergo a daily vertical migration, rising towards the surface of the water at dusk and descending as the dawn approaches.

Dr Bruce Phillips of the CSIRO Division of Fisheries Research, who is stationed at the Organization's marine laboratories in Perth, demonstrated that this reaction to light results in the phyllosomas travelling long distances out to sea, away from the breeding grounds. His research confirmed Dr Chittleborough's idea that the vertical movements of the early phyllosomas concentrate them near the surface at night and at depths of 30–60 m during the day.

Lobster larval dispersal is a remarkable example of adaptive behaviour. This nocturnal rise exposes the phyllosomas to wind-driven currents that carry them away from the coast out into the south-eastern Indian Ocean. Hatching of the larvae occurs when the offshore surface current is at its strongest, ensuring that the plankton are transported offshore. In fact, Dr Phillips has found specimens in plankton samples taken as far as 1500 km out to sea. This is not exceptional — Dr Martin Johnson of SCRIPPS Institute of Oceanography, California, U.S.A, found the larvae of two American species at distances of 3330–3700 km from their probable origin.

Evidence that western rock lobster phyllosomas may travel vast distances on the currents comes from experiments using satellite-tracked buoys. Dr George Cresswell of the CSIRO Division of Oceanography released two of these in waters adjacent to Fremantle: one buoy arrived in Madagascar and the other reached the coast of Tanzania, both within 240 days, well inside the estimated 11-month larval life span.

Sampling shows that the bulk of the lobster brood, however, stays closer to home, within 375–1030 km offshore, directly west of the centre of distribution of the adult population. Surface water moves away from the shore at the rapid rate of about



The young larvae spend much of their nocturnal life at the surface, and are carried away from the coast by wind-driven currents (light green). As they mature, the larvae spend less time near the surface and subsurface circulation (dark green) brings them back towards the coast. They arrive at the coast when the Leeuwin Current, which could sweep them away into the Great Australian Bight, has abated.

Principal rock lobster fishing areas of Western Australia.

A puerulus — the last planktonic stage.

5·25 km per day, putting the larvae beyond the influence of the southward-flowing Leeuwin Current, which develops down the coast in late autumn–winter. Otherwise this current might carry the larvae as far east as the Great Australian Bight.

As they develop, phyllosoma larvae become less attracted to moonlight. Although the mid and late phyllosomas spend some time at or near the surface, they avoid the immediate surface layer on moonlit nights. Older phyllosomas spend their daylight hours at depths of 60–120 m, below the 50- to 70-m depth range of the early stages.

Altogether, these behavioural changes result in older larvae spending less time exposed to surface currents. And from May to October, while the larvae develop into the mid and late stages, the wind-driven surface offshore current is minimal.

The late-stage phyllosomas become subject instead to subsurface circulation forces. Since the water below the surface in the upper 300 m of the south-eastern Indian Ocean moves in a general direction towards the western coast of Australia, that is where late-stage phyllosomas generally head.

Once again, the tiny floating creatures display a critical sense of timing. The late-stage phyllosomas return to the coast at a time when the southerly-flowing Leeuwin Current has abated.

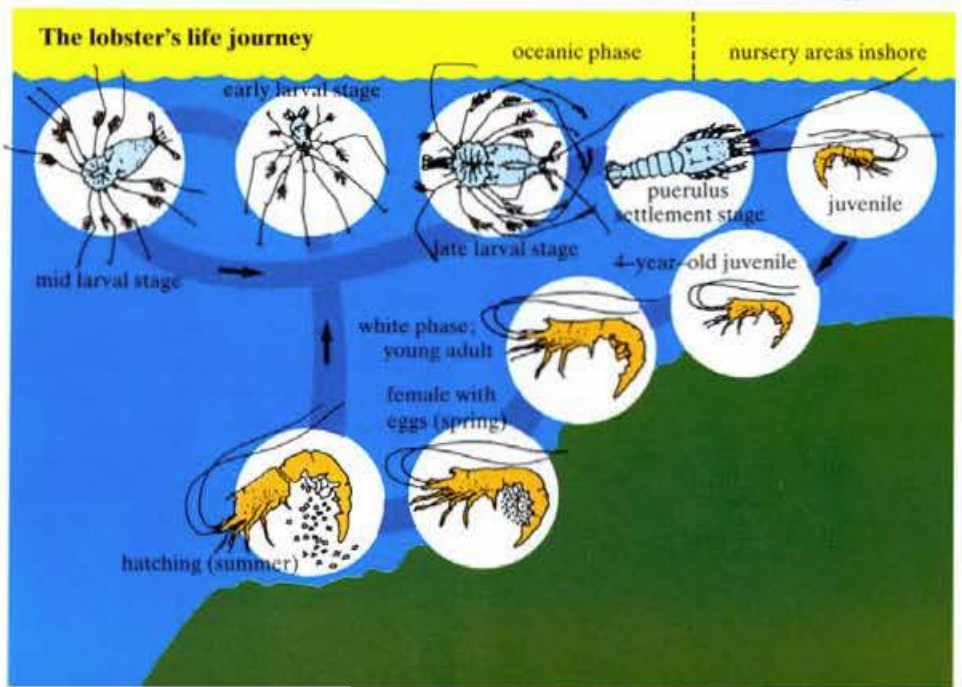
The western rock lobster has the longest planktonic cycle known for any *Panulirus* species. However, CSIRO scientists have observed many phyllosomas so far offshore that they would have no chance of returning to the Western Australian coast within the larval life span. These losses add to those due to predation and other natural hazards, with the result that only a small proportion of the original hatchlings reach the coast.

Dr Cresswell's satellite charts of buoy tracks have shown that, at the continental shelf edge, the circulation of water above the continental shelf is independent of the oceanic circulation. This gives the floating phyllosomas little opportunity to reach the coast; they need some swimming ability.

... hits the coast ...

So, before they reach the shelf, phyllosomas metamorphose into a semblance of the adult form — the small transparent puerulus stage. Dr Phillips estimated that the puerulus can swim at a rate of 0·33 metre per second against a current of 0·13 metre per second, making it well adapted for swimming across the shelf to the coastal settlement areas.

The puerulus stage settles in shallow, inshore limestone reef areas. Dr Phillips and Dr John Penrose of the Western Australian Institute of Technology, and Dr



A diver checks the artificial seaweed collector used to catch puerulus larvae as they return to the coast.

David MacMillan from the Zoology Department of the University of Melbourne, are investigating the possibility that the puerulus stage detects sound produced by waves breaking on the shore, or swell movements, to find its way to the settlement areas. Electron microscopic examinations of the tips of the antennae revealed to the scientists that the sound receptors are probably located in specialized hairs there.

Dr Penrose has been developing a simple sound recording and transmitting system that will permit experimental testing of the effects of underwater sound on free-swimming puerulus in the settlement reefs.

Dr Phillips and his team noticed that, when they sampled clumps of floating seaweed, a number of young puerulus could be found clinging to the weed. While working from boats using underwater lights, they have also noticed that puerulus are attracted to artificial seaweed held out to them.

Fishing licences have become highly priced and highly prized.

The CSIRO scientists have made use of the characteristically strong grasping response of the puerulus to capture settling animals. They moored collectors made of artificial seaweed at the surface of reef waters. The collectors were checked monthly, after each new moon period (when most of the puerulus settled). Dr Phillips and his co-workers found either puerulus or small post-puerulus juveniles in the 'traps'. So far, puerulus catches indicate that much of

In its travels from the coast far out to sea and back again, the western rock lobster undergoes many changes.

Stirring baby lobsters

Normally, the currents along the western seaboards of the world's continents are slow, and broad, and flow towards the equator. However, as the United States research vessel 'Discovery' found in 1957 and subsequent studies have confirmed, the current off Western Australia is an exception: it has no clear structure.

Wind drifts produced by the south-easterlies cause extensive offshore movement of surface water over a wide area of the south-eastern Indian Ocean. This effect is strongest in summer and weakest between May and October.

A permanent clockwise gyre centred at about 32°S and 100°E off the coast, whose existence was verified by Dr Bruce Hamon of CSIRO in 1965, moves subsurface water towards the coast and then southwards down the edge of the continental shelf.

In a narrow 20- to 100-km corridor just west of the continental shelf is the strong southward-flowing Leeuwin Current. This appears in late autumn or winter, and flows down to Cape Leeuwin and then eastwards into the Great Australian Bight.

Using satellite-tracked buoys, Dr George Cresswell, Mr Terry Golding, and a number of other CSIRO scientists have shown that it flows at almost 1 metre per second.

Other features of the Indian Ocean circulation off the Western Australian coast include clockwise and anti-clockwise eddies about 150 km in diameter — these occur mostly in summer.

Upwelling is virtually absent from the south-eastern Indian Ocean, resulting in nutrient-poor waters, low in plankton. And, as Mr David Rochford proved, the continental shelf waters are isolated from the larger-scale oceanic circulation; shelf waters flow northwards in summer and southwards during later autumn and winter.

the settlement occurs annually between September and January.

The extent of larval settlement fluctuates widely each year. In some years, in reefs already well stocked with older juvenile lobsters, Dr Chittleborough and Dr Phillips found that many settling larvae don't survive, simply because resources are limited. The two scientists raised the possibility that these 'excess' larvae be used to stock underpopulated reefs or be mass-reared in artificial ponds. Dr Chittleborough tested both prospects experimentally with some success, but the idea has yet to be proved economically sound.

The artificial seaweed collectors can also be used for long-range forecasting — catches indicate relative densities of puerulus settlement, which in turn help researchers predict commercial catches in future years. For example, low levels of settlement recorded in 1969/70 at Seven Mile Beach prefigured poor lobster harvests there in 1972/73 and 1973/74. Conversely, the highest commercial catches on record, in 1977/78 and 1978/79, reflected the high level of puerulus settlement in 1974/75.

... and fattens up ...

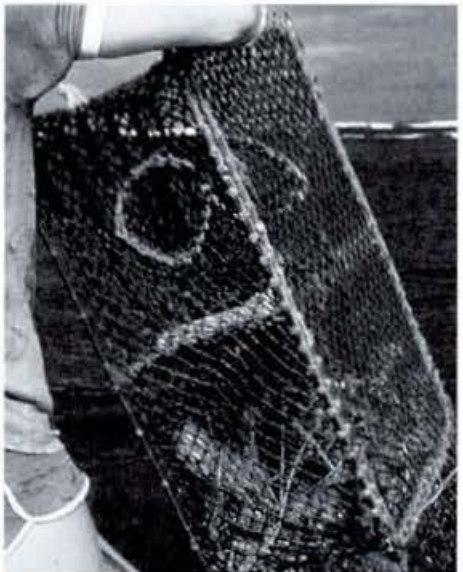
Eventually, the settling puerulus moults into a small pigmented rock lobster about 3 cm long. This remains in the shallow limestone reefs for up to 5 years before returning westward into deeper areas of the continental shelf.

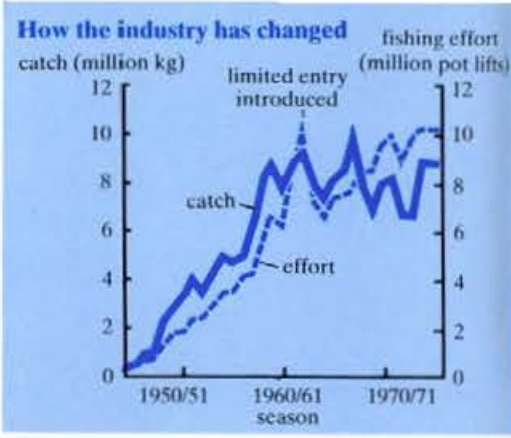
Dr Phillips, together with Professor Richard Ford, who is the Director of the Center for Marine Studies at San Diego State University, U.S.A., set up a number of feeding experiments using populations of juvenile rock lobsters at Seven Mile Beach during 1981. When completed, this study will enable them to test Dr Chittleborough's earlier hypothesis that the size of the food supply on the coastal reefs is the main factor determining the growth and survival of juvenile lobsters.

Future dangers may lie not in overfishing but in destruction of their habitat.

How far does a young lobster have to go to find a feed? That question is being answered through radio tracking experiments. Dr Phillips and Dr Peter Jernikoff, also of CSIRO, collaborated with the marine

Baited pots, another method of trapping lobsters for foraging-behaviour studies.





Catch and fishing effort for the Western Australian rock lobster fishery for the period 1944–76.

laboratories electronics section to make an electromagnetic tracking system for studying the foraging behaviour of spiny lobsters. Dr David Ram developed the system for his honours thesis at the University of Melbourne. Electromagnetic tags placed on the lobster's back emit pulsed signals, which are detected by loop antennae laid out in a grid pattern on the reef floor. Each loop is about 12 metres square.

Lobster-watchers track the movements of the animals using a tuned receiver inside a caravan on the beach adjacent to the grids. The caravan also houses an oscilloscope, used to interpret the signals from the tags. The pattern of movements that emerges somewhat resembles a tangle of wires — Dr Jernakoff is examining the effects that changing levels of moonlight, temperature, and water movement have on these foraging patterns.

Juvenile and adult rock lobsters carry out most of their gastronomic raids at night. (On the reefs, very hungry young animals may occasionally be seen during the day.) This night-time activity has significant consequences for the fishery — bright moonlit nights drastically reduce the catch of lobsters in baited pots and fishermen have learnt to reduce their efforts at these times.

Rock lobsters are not fussy about what they eat — starfish, sea urchins, brittle stars, seagrass snails, and small crab-like animals, and also seagrasses and brittle coralline algae, all feature in their diet. Dr Lindsay Joll, also from the Division's Perth marine laboratories, has been studying the diet of juvenile lobsters at Cliff Head and Seven Mile Beach, to determine the effect of different diets on the young lobsters' growth rate.

He found that the Cliff Head lobsters ate a wide range of plants and animals (mainly marine snails) and grew faster than their Seven Mile Beach counterparts, which consumed mainly chalky coralline algae.

Young lobsters are hearty eaters, especially after they moult. At 2 years of age, when they measure about 5 cm in length,

they will eat up to 9 g of flesh (such as abalone meat) per night after moulting. A growing rock lobster has to eat about 360 g of flesh to gain 100 g of body weight.

Dr Joll concluded that, considering the wide range of other reef organisms the young lobsters eat and their voraciousness, and also considering their high densities within the reefs, they must exert a large measure of control over the shallow reef plant and animal communities of Western Australia.

Dr Joll and Dr Chris Crossland have also studied the role that coralline algae play in the juvenile lobster's metabolism. These algae contain deposits of calcium carbonate (the chalky brittle substance in bones) within their tissues. Laboratory experiments with radioactively labelled calcium indicated that the lobster absorbs calcium from the algae in its gut and uses it during the hardening of the new shell just after moulting.

What eats lobsters? They disappear at a dramatic rate during their 4 years on the nursery reefs, from a density of about 30 000 individuals per hectare to 2000 per hectare. Dr Phillips and Dr Rob Howard are trying to discover the fate of the remainder.

The problem is that lobsters, being nocturnal creatures, don't give away many secrets in the dark. The scientists have seen little evidence of predation by other animals, but the dramatic reduction in numbers indicates that substantial predation must occur. Known predators include octopus and larger fish such as sharks. Cannibalism has occurred under laboratory conditions, but the gut contents of 'wild' rock lobsters indicate that it occurs infrequently in reefs.

... fit for the pot

At between 4 and 6 years of age, about the time their carapace, or upper shell, reaches the legal minimum size for the fishery (76 mm), the juveniles migrate offshore from the shallow reef areas of the shelf to depths of 30 to 150 m. This late-November migration takes the animals 25 km or more to the breeding grounds at sea.

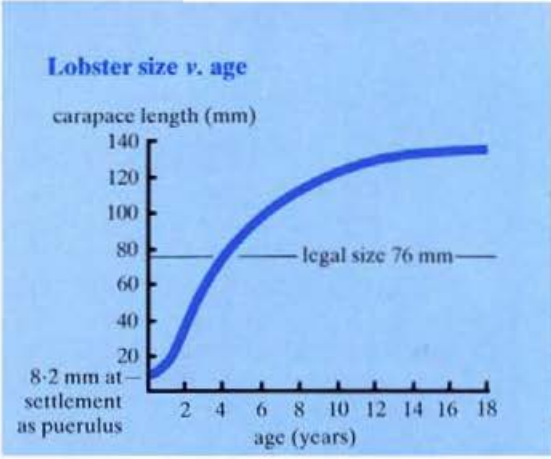
Panulirus cygnus is unique among the world's commercially fished rock lobster stocks in that a significant part of the commercial fishery is based on pale-coloured newly moulted migratory animals known locally as 'whites'. These adolescent lobsters change from their pale pink colour to the characteristic red-brown of the adult when they moult.

All crustaceans — prawns, crabs, crayfish, yabbies, and so on — grow via a stepped process, with length and weight of the animal increasing abruptly at each new change of its shell, called a moult. In the rock lobsters, moulting involves a complete metamorphosis at one stage — in the transition from the flattened phyllosoma larva to the lobster-shaped puerulus.

Since the 'whites' are newly moulted animals their food requirements are high — and so is their catchability by baited pots. Commercial fishermen take about one-third of their annual catch in the 6-week period during late November and December, when the migration begins.

Regulations controlling the size of first capture have been enforced since the fishery began. Originally introduced towards the end of last century to protect rock lobsters until they reached maturity, the size limit — a carapace length of 76 mm — has remained unaltered. The industry has adapted itself to this minimum size, so any significant change would require a reorganization of the marketing structure for the processed product. Further protection of undersized rock lobsters is provided by the compulsory inclusion of gaps in lobster pots to allow these to escape.

Since the start of the export fishery in 1944/45, both the lobster catch and the effort required by fishermen to take the catch, defined as the number of times they check a pot, have increased dramatically, resulting in an inevitable decline in the catch : effort ratio. During the 1940s and '50s, when fishermen needed to lift fewer pots for a reasonably high catch per unit effort, the only restriction on catches was the legal minimum length.



The relation between age and body length for the western rock lobster.

In the early 1960s, with the decline in catch per unit effort, the State government acted to protect the fishery by restricting the number of vessels entitled to fish for rock lobsters to 836 and limiting the number of pots each vessel was entitled to use. This pot allocation was fixed at three pots per foot of boat length, with a maximum of 200 pots per boat.

New vessels could operate in the fishery only if they replaced old ones, and they had to be the same size as the vessels replaced. These measures had the effect of decreasing total catch in the mid '60s, although the figure did recover a little in 1967. The

Tropical lobsters

The six tropical species of the genus *Panulirus* range across the northern coastline of Australia. While southern species like the western rock lobster are caught in baited pots or by trawling, the tropical species are usually caught by divers; they won't enter pots. The most commercially important tropical species is the ornate rock lobster, *P. ornatus*, found in Torres Strait and off the eastern coast of Queensland.

At the moment, the Torres Strait rock lobster industry is small, bringing in about $4–5 million per year. Torres Strait Islanders do most of the harvesting, using traditional methods and relatively simple equipment.

Because ornate rock lobsters are found in Australian waters in Torres Strait, and walk a few hundred kilometres across the seafloor to Papua–New Guinean waters to breed, the fishery is jointly managed by Australia and Papua–New Guinea.

Dr Phillips, Mr Stuart Bell, and Dr Peter Channells completed a 3-year study of the fishery in 1983. They recorded its history, and details of the present industry, including areas fished, landings, and the traditional methods used by divers, commercial dinghy and freezer-boat operations, and the trawlers.

Their study revealed that, in addition to the known Australian fishery in Torres Strait, as much as 15% of the Australian diver catch is taken by fishermen operating down the eastern coast of Queensland.

The biological research that CSIRO is carrying out from its base in Cairns includes an extensive tagging program as well as studies of aspects of the lobster's reproductive biology, levels of puerulus settlement, growth rates, food and feeding, genetic variation, and nocturnal movements.

The Torres Strait rock lobster.

earlier steep escalation of fishery effort was halted.

$1100 pots

The limited-entry policy has caused a number of problems, the main one being the fact that the fishing licences have become highly priced and highly prized. The licence is now valued at $1100 per pot or about $100 000 for an average licence. Further reducing boat or pot numbers would be very costly for both the industry and the State government.

In 1976, fishing effort again increased to pre-1963 levels. To help the government develop its management program, the Western Australian Department of Fisheries and Wildlife is carrying out management studies of the fishery. In addition, CSIRO is continuing its work on the juvenile lobsters and on rock lobster population dynamics.

Dr Gary Morgan, formerly of the Western Australian Marine Research Laboratories and now working in Kuwait, has studied the population dynamics and management of the lobster fishery using mathematical models. He has used his models to predict what will happen if present trends continue.

Over the past few years, the lobster-fishermen have managed to increase their fishing effort in order to realize higher catches. Whereas once they would fish about 15 days out of every month, they now spend up to 29 days per month at sea. By using echo-sounders to put their pots in the best positions, they can expect a better catch. In addition, they are using their maximum allowance of pots instead of a portion of their quota.

Altogether, these factors add up to a considerable change in effort. In 1973, lobster-fishermen carried out 9 800 000 pot lifts; the figure in 1981 was 11 200 000. Dr Morgan found that recent effort has been beyond the level required for a maximum economic yield, indicating the need for reduced fishing effort. Fishermen may need to slow down so as to reduce the year-to-year catch variation, which would stabilize marketing practices.

Dr Morgan investigated the factors affecting catchability of the western rock lobster. His results showed that its vulnerability varies seasonally and is also related to the size and the sex of the animals. He believes that monthly changes in vulnerability need to be taken into account in order to avoid serious bias in the measurement of effective fishing effort.

The white electromagnetic tag on this lobster emits signals that are monitored by researchers on the beach adjacent to the reef.

Predicting the catch

Dr Morgan, Dr Phillips, and Dr Joll have attempted to sort out the factors that determine the abundance of individuals at each stage of the lobster life cycle — larva, puerulus 'white', and spawning adult. For the phyllosoma larva, food availability, predation, and natural disasters are important in determining the population size; lack of space is not a problem for them as they float across the ocean off Australia's western coast.

The greatest abundance of later puerulus youngsters is produced by an initially small number of spawning females; larger numbers of spawning females actually produce fewer puerulus. Presumably, too many larvae may lead to a food shortage or increase the efficiency of predators.

Once the puerulus have settled into the reefs, the environment itself imposes limitations on the number of surviving individuals.

In 1975, Dr Chittleborough first pointed out that the availability of food on the coastal reefs is probably the main factor determining the survival of juveniles. The continuing studies on feeding, predation, and competition with other species will throw further light on this.

The numbers of puerulus settling on the reefs give an indication of the size of the future fishery, as the Seven Mile Beach data show. Seven Mile Beach is near the centre of the range of population.

The CSIRO researchers have concluded that the population abundance depends upon the intensity of fishing on spawning and pre-spawning animals. In the absence of natural catastrophes, if fishing effort is high enough the number of spawning female rock lobsters will be reduced, which, as noted above, can actually lead to a higher level of puerulus settlement. This would result in a good recruitment of 'whites' to the fishery. Dr Morgan, Dr Phillips, and Dr Joll think that the possibility of incorporating the relation between the various life history stages into a production model of the fishery, for use as a management tool, warrants further investigation.

The numbered discs on these lobsters help scientists to later relocate and identify tagged animals and determine their movements.

Dr Chittleborough has pointed out that future dangers to the western rock lobster population may lie not in overfishing but rather in the less obvious destruction of their habitat — the limestone reefs. Increasing urban and industrial development will have a significant impact on the vulnerable reefs and CSIRO's current coastal ecology research program aims at identifying the extent to which this will affect the rock lobster fishery.

Mary Lou Considine

More about the topic

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