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CRUSTACEAN FISHERIES

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Introduction

The Crustacea are one of the most diverse groups of aquatic animals, occupying a wide variety of habitats from the shore to the deep ocean and the tropics to Arctic waters, and extending into fresh water and in some cases on to land for part of their life history.

Crustacean species contribute in the order of 7 million tonnes annually, or about 6–8% of the total world supply of fish, according to FAO statistics. Approximately 75% of this volume is from harvesting wild stocks, with the remainder from aquaculture, dominated by the tropical marine and freshwater shrimps, crayfish, and crab species. Owing to their high market value as a sought-after high-protein food, crustaceans make up a disproportionate share of the value of the world's seafoods. As a result of their high value, crustacean fisheries are generally heavily exploited and require active management to be sustained. Research to underpin management of these resources has been undertaken in many parts of the world, and particularly Australia where, unusually, lobsters and shrimps are the dominant fisheries.

Crustacean fisheries are focused on the more abundant species, particularly those in relatively shallow, accessible areas. Shrimps are the most important wild fishery products, followed by the crabs, lobsters, and krill.

Biology and Life History

Fisheries research on crustacean stocks is significantly influenced by their unusual life history and biology. A unique feature of crustaceans is that they all must undergo a regular process of molting (casting off their outer shell or exoskeleton) to grow. Once the old shell is cast off, the animal absorbs water to swell or 'grow' to a larger size before the shell hardens. Volume increase at a molt varies between species, but typically results in a gain in the range of 10–60%. The molt also serves as an opportunity to regenerate damaged limbs, such as legs or antennae, although regeneration results in lower or even negative growth increments. This molting process occurs throughout all stages of the life history and is often correlated with environmental factors such as temperature, moon phase, or tidal cycles. Because of this mechanism, growth occurs as a series of discrete 'steps' rather than a 'smooth' increase over time and is complicated to measure. Growth rates are highly dependent on water temperature, with tropical and shallow-water crustaceans tending generally to grow much faster than those in cooler and deeper waters. As a result of the molting process, it is not possible to 'age' crustaceans using any of the usual methods (growth rings on bones or shells) applied to other fished species.

The molting process also significantly influences feeding activity and hence catch rates for all crustaceans. Prior to a molt, feeding activity is generally reduced, then ceases in the lead-up to the actual molt process. Following the molt the animals are particularly hungry, begin active feeding, and are more easily caught in baited traps or trawls, but contain relatively little meat for their shell size and are of lower market value.

These cyclic catches in crustacean fisheries are well known to fishers and are also crucial knowledge for fisheries stock assessment and industry management. Significant short-term gains in value of the catch can be achieved where the fishery management arrangements take them into account.

The second very important feature of crustaceans is that exploited marine species are generally highly fecund, producing large numbers of eggs (millions in some species) which hatch into pelagic larvae which in turn can be widely distributed by ocean currents. Typically, the early larval stages are of a different form to the adults, but after a series of larval stages the individual molts into a form resembling the adults. Larval stages generally have limited swimming ability but are able to migrate up and down within the water column, and often have behaviors which, in combination with tides and currents, result in active dispersal into 'nursery' areas suitable for the later juvenile and adult stages. The large numbers of eggs and larvae produced, together with widespread dispersal mechanisms common in the major marine crustacean species, make them relatively resilient to fishing pressure compared with the freshwater species.

The typical marine larval life history does not generally apply to the freshwater species, where some or all larval development stages occur within a much larger egg and live young are often produced to minimize downstream losses due to river flow. These alternative larval strategies adopted by freshwater crustacea are efficient but, owing to the relatively low numbers produced, make such species more susceptible to overfishing than their marine counterparts.

Marine Shrimps and Prawns

This group contains by far the most important crustacean fisheries. In marine waters two major families, the Penaeidae in tropical waters and the Caridea in cold waters, support most of the significant export fisheries. In tropical fresh waters, paleomonid shrimps of the genus *Macrobrachium* support the major commercial production.

The terms 'shrimp' and 'prawn' have no scientific basis and are used interchangeably in different parts of the world. For the purposes of this chapter, the more commonly applied term 'shrimp' will be used for simplicity.

A wide array of penaeid species are harvested from tropical to subtropical waters. These species have a complex life cycle where mated females spawn generally in coastal marine waters where eggs (hundreds of thousands per spawning) are broadcast freely and hatch as free-swimming planktonic nauplius larvae. After a series of larval molts, postlarvae actively move into estuaries and coastal embayments where they develop into the juvenile stage. Juveniles and subadults then actively migrate offshore using tidal flows to further develop, mate, and spawn at 6–12 months of age.

Coupled with these relatively short life cycles is rapid growth, but also high levels of natural mortality such that few individuals survive to more than 12 months of age, although some species may live to 2 or 3 years without fishing. High natural mortality does, however, allow for high but sustainable exploitation rates for most of this group of commercially important species, although there are some exceptions noted later.

Fishing for these species is generally by means of fixed nets in estuary mouths during the offshore migration of subadults, or by vessels otter trawling in waters offshore from the estuarine nursery areas. Penaeid shrimps are generally not catchable in traps.

Powered otter trawling for shrimp, which evolved in the Gulf of Mexico, has now been adopted worldwide as the main method for industrial-scale catching of the more valuable export market-sized adult shrimps. Otter trawling can only occur on smooth bottoms, usually sand or mud adjacent to nursery areas, and typically harvests approximately 20–50% of the shrimps in the path of the net. The remainder are generally buried in the sediments, particularly during the day. The exception to this is where some shrimp species (e.g. *Penaeus merguiensis*) form dense schools and generate turbid mud 'boils' as a defense against predators. This behavior, including mid-water swimming, allows very high exploitation rates and catches on some occasions, but has been noted to break down at high levels of exploitation and in areas where river/estuarine habitats and adjacent waters have become increasingly turbid.

Major fisheries for penaeid shrimps occur through the Gulf of Mexico and Central/South American coasts (*P. aztecus, P. setiferus, P. duorarum, P. braziliensis, P. californiensis and P. vannamei*), off the Chinese river deltas (*P. orientalis*), through south-east Asia (various *Metapenaeus* and *Penaeus* species), Indonesia–Papua New Guinea (*P. merguiensis*), Australia (*P. latisulcatus*, *P. esculentus/semi-sulcatus*, *P. merguiensis*), and the African coasts (*P. indicus*, *P. notialis*).

In addition to the large or more valuable penaeids, very large quantities of very small *Acetes* and sergestid shrimps are harvested, particularly in Asian coastal waters, by small-scale coastal fisheries.

The second commercially important group of shrimps comprises the caridean species, which occur predominantly in the Northern Hemisphere, in temperate to Arctic waters. Where they extend into more tropical waters, they do so only at greater depths with cold temperatures corresponding to Arctic waters. This group of shrimps is relatively long-lived (up to 4–6 years), spawning at several years of age. These species are also typically protandric hermaphrodites, growing into functional males before undergoing a series of molts to become female for the remainder of their life. Females produce larger but fewer eggs than the penaeid species, and carry them after spawning attached under their tail. The eggs remain attached for an extended period, undergoing some developmental stages within the egg before hatching into pelagic larvae which grow for several months before settling onto a wide range of habitat types. *Pandalus borealis* is a typical caridean shrimp for which the life cycle has been well studied and represents the general life history pattern for this important group.

Fishing occurs by both otter trawling and trapping with baited traps which are particularly effective for these species, unlike penaeids which do not trap easily. Major fisheries for these pandalid species occur in the northern Atlantic and north Pacific.

In the Antarctic zone, the major equivalent crustacean fishery is for euphausiids or krill (*see* **Krill**). These krill species are particularly abundant in the nutrient-rich Southern Ocean, where it is estimated that a biomass of 20 or more million tonnes occurs. Krill are small pelagic species which swim by way of modified walking legs (swimmerets), and generally undertake a diurnal migration between the surface and significant depths. They form dense schools on the surface, particularly at night, where they are a major source of food for Antarctic whales, seals, and fish stocks. Estimates of potential sustainable yield range into millions of tonnes per year, but the catch has been limited by processing difficulties to about 100 000 tonnes.

Crabs

Most commercially significant crabs belong to the Brachyara (true crabs) or Anomura (hermit crabs and king crabs) within the order Decapoda. They are generally characterized by a pair of claws, three pairs of walking legs, and a wide, flattened body. Crabs are probably the most highly developed, successful, and diverse of the crustaceans. They occupy a wide range of environments, from shallow tropical seas to deep ocean trenches, estuarine and fresh waters, and some species spend the majority of their life on land, only returning to the water to reproduce.

Reproductive patterns in crabs are diverse and often involve intricate courtship behaviors where the male protects the female before mating. Following copulation, crabs retain spermatozoa until egg laying, at which time fertilization takes place as the eggs are extruded. Spermatozoa can be retained by the female in a viable condition for considerable periods of time – more than a year in some species.

The important swimming crab species are generally resilient to heavy fishing pressure due to their often complex but efficient reproductive behavior and high levels of fecundity. Some species carry multiple broods of eggs, which are extruded, fertilized, and attached to the underside of the female during the early development stages. Numbers of eggs produced per year are frequently in the order of 50 000–500 000 per female, and over a million eggs are achieved by some species. Crab larval stages are known as zoea and most marine species have four or five zoeal stages before molting into a megalopa, which generally settles out of its planktonic existence.

In a number of cold-water crab fisheries (e.g. the important snow, tanner, king, and Dungeness fisheries) where breeding is more restricted, managers have elected to allow harvesting of males only, thereby giving complete protection to the brood stock. This precautionary approach, whilst useful for these species, imposes unusual constraints on research due to the inability to monitor female crabs in the commercial catch.

Most crab fishing worldwide is by use of traps. This method is preferred to most others because traps are simple to use (particularly in deep water) and labor-efficient, and the crabs are less likely to be injured. This latter fact is particularly important because it allows the product to be sold live, guaranteeing a better market price than frozen forms. Many other methods are used to catch crabs, including trawling, tangle netting, dredges, trotlines, and drop nets.

Interestingly, the majority of the large crab fisheries operate in tropical and Northern Hemisphere temperate and Arctic waters.

Table 1 shows that the three most important commercial crab species are all fast-growing 'swimming crabs', found in shallow tropical or temperate waters and embayments. These are a family of crabs which have a flattened, paddle-like hindmost leg used to burrow in sand and mud, or to propel them through the water during infrequent occasions when they 'swim' over short distances. They reach maturity and are harvested between 1 and 3 years of age.

The largest crab catches landed worldwide are those of gazami crab; however, a very substantial, but unspecified portion of these reported landings are from aquaculture operations. China alone produced 80 000 tonnes of gazami crab by aquaculture in 1997. The species has a wide distribution through the western Pacific and lives in shallow inshore waters in sheltered embayments. Stocking of waters with juvenile gazami crab has become widespread, particularly off the Japanese coast, and is considered to be economically effective.

Blue crabs occur in the western and central western Atlantic. The vast majority of the landings are made off the US coastline from states in the Gulf of Mexico and mid-Atlantic. The commercial fishery targets both hard crabs and peeler/soft crabs, soft-shelled crabs being considered a delicacy in the USA. Soft crabs have very recently molted and have a shell that has yet to become hard. While some of the peeler/soft crab product is taken with crab scrapes and other specialized methods capable of taking nonfeeding animals, the majority of the product is produced in operations which hold peelers in shedding tanks until molting occurs.

The snow, tanner, and king crabs, which are high on the list of important species in **Table 1**, are examples of moderately deep-water species occurring in cold water conditions. The distributional range of these species encompasses water <400 m deep (and, particularly for king and snow crabs, usually <200 m and colder than 10°C). These species are very slow growing when compared with the inshore warmer water species mentioned earlier. Their age at maturity is generally upward of 5 years and in most cases they enter into the commercial fishery over 8 years after settlement.

Over the long history of crab production in the north Pacific, large catches of king, tanner, and snow crabs have been made. Despite stock collapses of some species, this area is still important for its crab production and for the research efforts that have been made to understand the biology and management of these important stocks.

Crabs belonging to the *Geryon* and *Chaceon* genus (**Table 1**) are commercially important deep-water crabs. They have a wide depth range, but most of the commercially exploited populations tend to be in the 500–1000 m depth range. Water temperatures at these depths are typically less than 10°C and these animals are therefore slow growing. In Namibia, where the largest and one of the longest-standing *Chaceon* fisheries exists, the crabs take approximately 8 years to reach maturity.

Lobsters and Crayfish

Lobster and crayfish species support significant and high-value fisheries. The major commercial lobster species are marine and taken from tropical to cold temperate waters, while freshwater crayfish are mostly taken from tropical and subtropical regions. Most of the marine species have similar life history patterns, where females carry fertilized eggs externally under their abdomens. Following hatching, the larvae undergo a series of molts before taking up a benthic habitat and growing to adulthood, a process which can take many years. Freshwater crayfish

Table 1 World landings in order of quantity reported by FAO catch statistics for 1996

Common name	*Species name*	*1996 catch (tonnes)*
Gazami crab	*Portunus trituberculatus*	303 000
Blue crab	*Callinectes sapidus*	116 000
Blue swimmer crab	*Portunus pelagicus*	112 000
Snow and tanner crab	*Chionoecetes* spp.	100 000
King crab	*Paralithodes* spp.	81 000
Dungeness crab	*Cancer magister*	34 000
Edible crab	*Cancer pagurus*	29 000
Red crab	*Geryon*/*Chaceon* spp.	7000

The table excludes landings of mud crab (*Scylla* spp.), as the majority of that is produced by aquaculture.

species generally have a reduced larval life and hatch as small juveniles.

Fisheries are dominated by three groups, the *Homarus* species (large-clawed lobsters), the *Nephrops* species (small-clawed lobsters), and the palinurid group (spiny or rock lobsters, without claws). Catches of each of these groups are in the order of 60 000–80 000 tonnes annually.

Fishing is generally by baited traps (*Homarus* and most palinurid species), although some are taken by trawl (*Nephrops*), and diving (tropical *Panulirus* species). Freshwater crayfish are also taken by baited traps.

The major clawed lobster fishery is for *Homarus americanus* off eastern Canada and the USA. A similar-sized fishery for *Nephrops norvegicus* occurs off the European Atlantic coasts and through the Mediterranean. Spiny lobster fisheries for the *Panulirus* species occur through the tropics, with major fisheries in the Caribbean (*P. argus*) and Western Australia (*P. cygnus*). Smaller but significant fisheries for *Jasus* species occur in the temperate waters off southern Australia, New Zealand, and South Africa. The major freshwater crayfish fishery occurs in the southern states of the USA.

Stocks of these species have generally been resilient to fishing, with the exception of some *Jasus* species off Africa which have been significantly reduced over time.

Fishery Assessment Research

There are two fundamental biological issues to be addressed in the management of fish stocks (including crustaceans). The most important problem is to control the level of fishing such that there is sufficient breeding stock to continue to provide adequate supply of new recruits to the fishery. This is generally tackled using the relationship between breeding stock and recruitment. The second issue is to maximize the overall catch (and value). This problem is traditionally examined using a yield-per-recruit model which examines the trade-off between the increase in biomass through growth over time and the decrease in survival through natural and fishing mortality. The other biological studies undertaken, such as growth, migration, reproduction, and mortality, are generally the building blocks to enable the assessment of these two key issues.

There are three main differences in the biological assessment of crustacean fisheries compared with many finfish fisheries; they are growth, migration, and catchability. Growth by molting is probably the key difference between crustaceans and other marine species. Thus stock assessment needs to take into account the timing of the growth and the size increment at the molt. The frequency and size increment of molting usually decreases with age, especially after reaching maturity.

Crustacean growth contrasts with that of finfish populations, which can generally be modeled using a continuous growth model. Because crustaceans totally replace their outer shell with each molt they cannot be aged in this way, creating a major problem for stock assessment. This process also makes tag recapture less reliable for these species. As a consequence, age is usually estimated by following length frequencies of particular year-classes, although this is often possible for only the younger year-classes. Some recent work on measuring the age pigment, lipofuscin, which generally increases linearly with age and is not lost at the molt, may provide an opportunity in the future to regularly utilize age information in the stock assessment of crustaceans.

The second feature of crustaceans which sets them apart from finfish and affects their stock assessment is migration. While generally poor in swimming ability, crustacean species often undergo significant migrations linked to specific stages in their life cycle. For example, tropical shrimps and swimming crabs have specific behaviors which enable them to actively migrate offshore, utilizing ebb tidal flows, as they approach sexual maturity. Many spiny lobster species also undergo extensive directional migrations at a particular age, usually following a coordinated molt, marching in columns from shallow nursery areas to offshore spawning areas before reaching sexual maturity.

These migration 'events' are often of short duration and usually unidirectional. Such rapid, short-term interruptions to the normal, relatively sedentary behavior of crustaceans pose special constraints on stock assessment. That is, crustacean migration typically causes erratic changes in stock distribution and catches, contrasting with most finfish fisheries where the regular, more consistent swimming movements of the fish result in continuous redistribution of the stock.

Because molting is often synchronized and related to growth and migration, the catchability of many crustaceans is also typically inconsistent and often cyclic. For this reason, crustacean catch rates do not directly reflect the abundance of the stock and must be corrected for in the data sets utilized in stock assessments. To assess the status of exploited crustacean stocks which present these particular problems, long data series are extremely valuable, especially where they can be used to refine the catch rate–abundance relationship and in establishing the

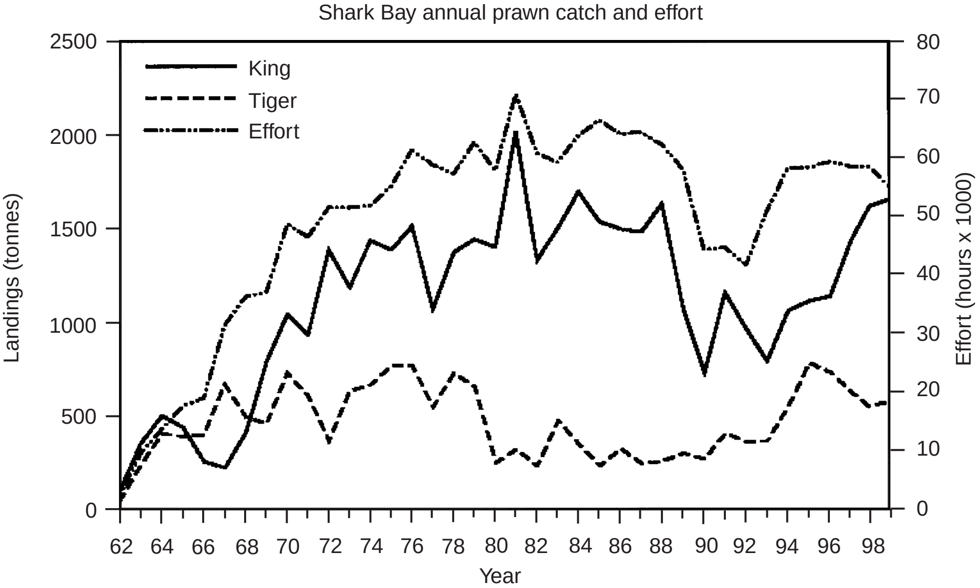

Figure 1 The time-series data on catch and fishing effort (hours trawled) for tiger prawns (*Penaeus esculentus*) and western king prawns (*P. latisulcatus*) since the inception of the Shark Bay (Western Australia) prawn fishery in 1962.

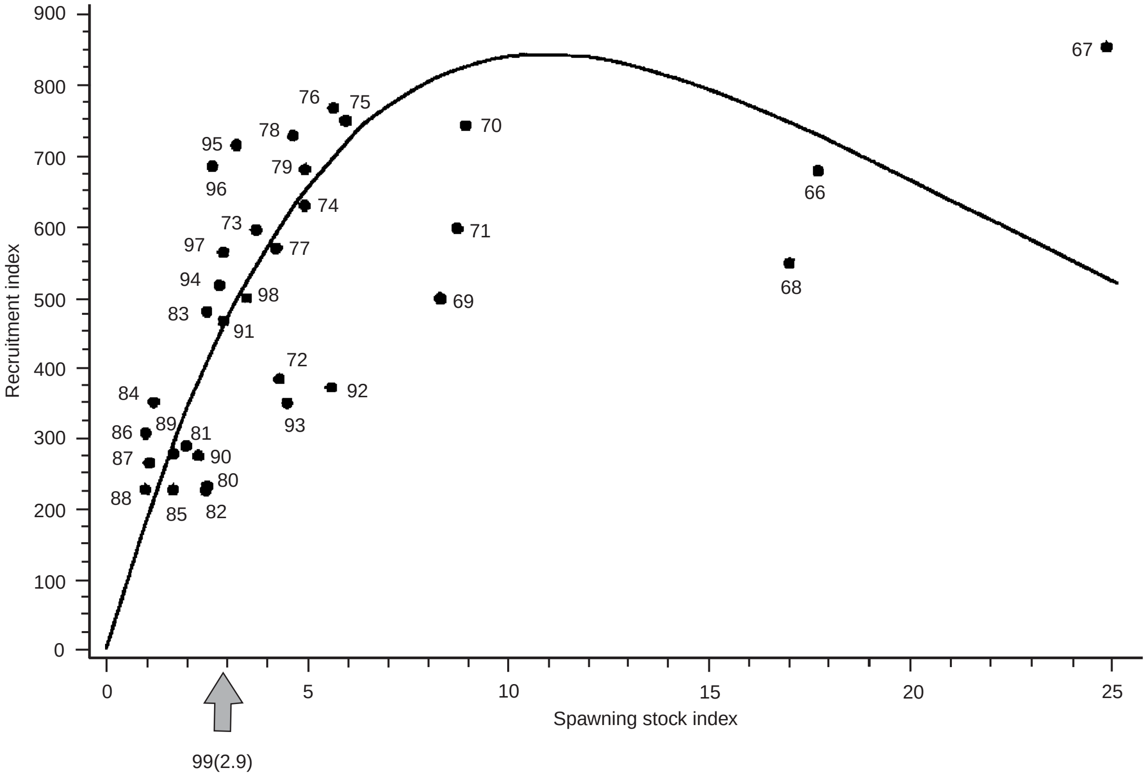

Figure 2 The relationship between spawner abundance and recruitment (1 year later) for the tiger prawn (*P. esculentus*) stock in Shark Bay (Western Australia). Year of recruitment is shown against each data point.

linkage between different life history stages. Such data can be used to assess the relationship between spawning stock, environmental factors, and recruitment to the fishery for managing the critical effects of fishing on the spawning stocks.

For example, the long time-series of data (**Figure 1**) was fundamental in assessing the cause of the collapse of tiger prawn stocks in Shark Bay, Western Australia. These data were used to evaluate the impact of fishing effort on the spawning stock and assess the reduction in fishing effort required for the fishery to recover to its optimal level.

Figure 2, derived from the historical data, shows the relationship between spawning stock levels and subsequent recruitment to the Shark Bay tiger prawn stock. This relationship, together with the reverse relationship between recruitment and surviving spawner abundance (in the same year) relative to variations in fishing effort targeting the stock, has been used to construct a simple model (**Figure 3**) to determine optimal levels of tiger prawn fishing effort. Management changes to redirect effort away from the species based on this modeling have resulted in a recovery of the tiger prawn stock (**Figure 1**).

Similarly, the use of catch predictions in the western rock lobster (*Panulirus cygnus*) fishery up to 4 years ahead using an index of abundance of settling puerulus (first post-larval stage) and juveniles entering the fishery has enabled fisheries management to be proactive rather than reactive to changes in stock abundance. This relationship, presented in **Figure 4**, shows that catch is determined by variations in puerulus settlement 3 and 4 years previously, and fishing effort during the year of recruitment to the fishery. Such predictive relationships have been used in Western Australia to adjust fishing levels in advance to ensure that breeding stock levels are maintained.

This development of predictive relationships using long-run data sets also enables environmental factors which may influence survival of larval stages, and catchability in crustacean stocks, to be examined. **Figure 5**, showing the relationship between rock lobster puerulus settlement and Fremantle sea level as an index of flow of the Leeuwin Current along the WA coastline, is an example of this type of analysis.

The availability of this type of relationship is particularly valuable to researchers attempting to

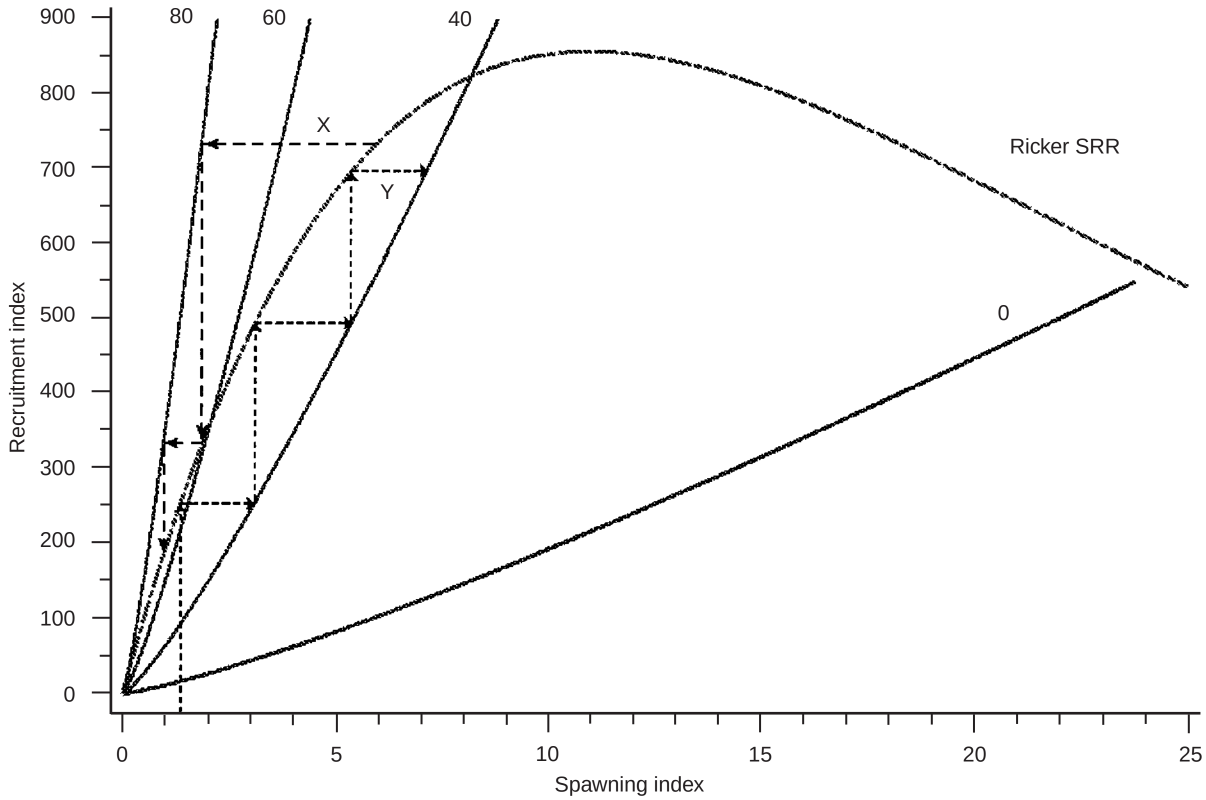

Figure 3 A model combining the spawner–recruit relationship (SRR) and recruitment to spawner (as affected by fishing effort) for the Shark Bay tiger prawn stock, which has been utilized to estimate optimal fishing effort levels. Trajectory ‘X’ shows the expected annual decline in recruitment and spawning stock at an unsustainable level of fishing effort (80 000 trawling hours). Trajectory ‘Y’ shows the converse stock recovery from low levels when fishing occurs at optimal levels of about 40 000 hours of trawling effort.

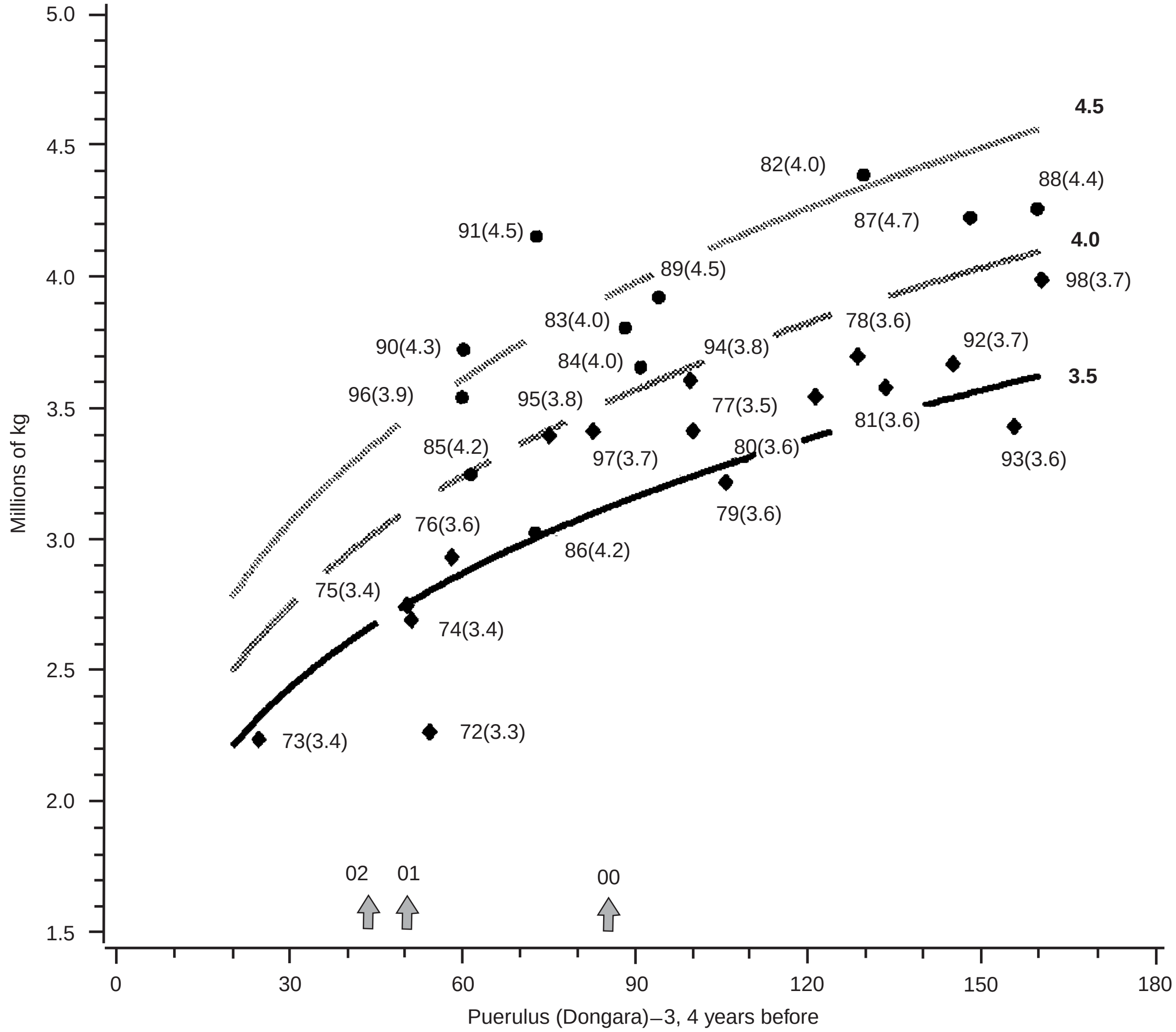

Figure 4 Catch forecast for western rock lobster in the northern part of its range, based on the level of puerulus settlement at Dongara 3–4 years earlier and the number of pot lifts. The catch year is shown with millions of pot lifts in brackets.

distinguish between the effects of fishing and short-term 'natural' variations in recruitment to the fishery caused by environmental influences. This is an important distinction, as a poor year-class due to environmental factors, coupled with high fishing effort, can combine to produce a very low breeding stock and trigger a long-term stock decline.

The second most important fisheries problem, optimizing yield per recruit to the fishery, is also particularly difficult to assess in crustaceans owing to the molting process. The resulting inability to age or reliably tag these species makes estimation of natural mortality and growth of pre-recruit year-classes relatively unreliable.

This has led to an 'adaptive' management approach using adjustments to sizes at first capture over a number of years to directly assess the resulting impact on catch. The alternative approach has been to develop complex simulation models based on length rather than age. These model-based assessments have improved significantly the ability to manage crustacean fisheries, but again where successful have relied heavily on long-run, detailed fishery databases for their testing and validation.

Crustacean Management Techniques

Management techniques applied to the significant tropical shrimp fisheries focus mainly on minimum trawl mesh sizes, accompanied by area and seasonal closures to optimize the quantity and size of shrimps caught. Many of these trawl fisheries also involve specific gear regulations to minimize unwanted by-catch. Owing to the highly variable annual recruitment to these fisheries, the most common and successful management approaches have involved

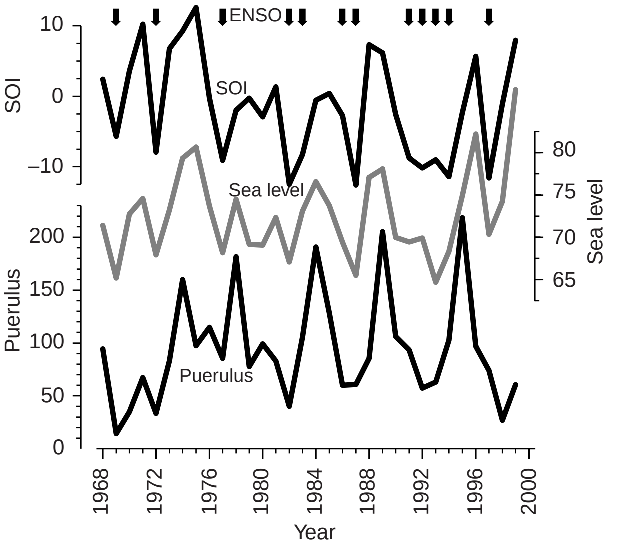

Figure 5 Annual mean values of Southern Oscillation Index (SOI), Fremantle sea level, and puerulus settlement at Dongara. ENSO (El Niño/Southern Oscillation) periods are indicated with arrows.

fishing effort controls and, more recently, transferable effort quotas. For the longer-lived, more consistent cold-water pandalid shrimp and krill fisheries, catch quotas are more applicable and often utilized.

Because of their larger individual size (and value) and the dominant method of capture (trapping) which facilitates live discarding of unwanted catch, the common management focus in crab fisheries is on legal minimum size regulations and protection for spawning females. Gear design rules specifying 'escape gaps' to reduce the capture of undersize crabs have become a common management tool for these fisheries. Overall management of the longer-lived temperate or deep-water crabs often involves catch quotas to ensure maintenance of breeding stocks and economic performance of fisheries. This methodology is less relevant to the faster-growing, more variable tropical crab fisheries, which lack the predictable recruitment and longevity necessary for effective catch quota management. In these fisheries, effort controls through limited entry are more useful and common.

The management techniques for high-value lobster stocks are generally similar to those for crabs, focusing on legal minimum sizes, associated gear controls, and female protection in the trap fisheries which dominate this crustacean sector. Historically, limited entry arrangements have been the most common overall management strategy for sustaining lobster fisheries, with 'individually transferable trap quotas' first applied in the 1960s to the Australian spiny lobster fisheries. Total catch quotas, applied more recently through 'individually transferable quotas', have also been utilized to control fishing, particularly for the more consistent, longer-lived cold-water lobster fisheries.

Conclusions

The high value of crustaceans has led to increasing exploitation pressures and the need for improved research assessments to underpin management. Stock assessment methods for crustacean fisheries, however, provide significant scientific challenges owing to the unique crustacean method of growth through molting. This mode of growth prevents the use of the long-established age-based methods applied to the more generic finfish and some molluscan fisheries.

The stock assessment approach adopted has therefore focused on direct measurement of recruitment and spawning stocks and the use of long-run fishery databases. The importance of using long-run data sets to validate and test length-based models has been critical to the more recent improvements in crustacean fisheries assessment for management.

See also

Demersal Species Fisheries. Dynamics of Exploited Marine Fish Populations. Fish Feeding and Foraging. Fish Locomotion. Fish Predation and Mortality. Population Dynamics Models.

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