CHAPTER 16

Deepwater Shrimp

Michael King

I. INTRODUCTION

Deepwater caridean shrimps appear to have a world-wide distribution in tropical waters. They have been caught in surveys using baited traps in depths between 200m and 800m off continents and islands in the Caribbean, the Indian Ocean and the Pacific Ocean.

The discovery of these shrimps, particularly those belonging to the genus *Heterocarpus*, in tropical Pacific Islands has encouraged some interest in commercial exploitation. Since the early 1970s caridean shrimps have been found in virtually all areas where surveys have been carried out. In most cases, however, catch rates have been insufficient to offset the high estimated costs of commercial fishing in deepwater. An exception to this is the case of Hawaii, where deepwater shrimps were commercially fished from the late 1960s up to the mid-1980s.

Most surveys carried out have addressed aspects of species distribution and relative abundance, but they have neglected to collect financial information regarding possible exploitation. For countries considering the development of deepwater shrimp fisheries, research should be directed towards answering basic questions relating to commercial exploitation. The most important of these are the estimated long-term (sustainable) catch rates, the likely market value of the product, and the projected costs of fishing.

This chapter summarises the research work and the results of surveys on deepwater shrimps in the Pacific region and provides a basis for assessing the fisheries potential in islands countries.

II. LIFE HISTORY AND POPULATION BIOLOGY

TAXONOMY

The two divisions Caridea and Penaeidea of the Natantian decapod crustaceans, contain most exploited species commonly referred to interchangably as either shrimps or prawns. Carideans include the commercially important cold and temperate water shrimps of the genus *Pandalus*, and penaeids include the

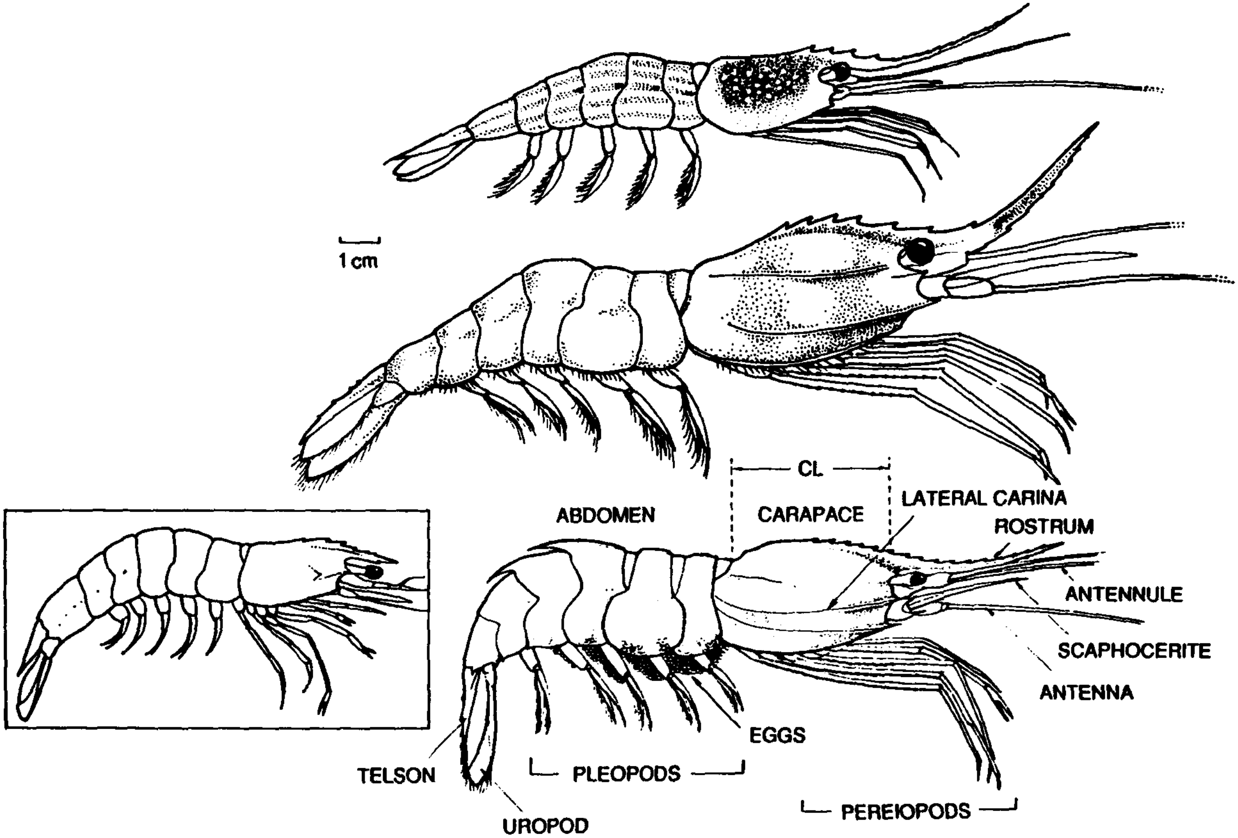


Figure 1. Three common species of caridean shrimps found in Pacific Island surveys; from top, *Plesionika edwardsii*, *Heterocarpus laevigatus*, and *Heterocarpus sibogae*. The bottom illustration shows the general external features referred to in the text; the standard method of measurement is shown as CL (carapace length - the distance from the posterior margin of the orbit to the posterior margin of the carapace). A penaeid shrimp is shown in the inset for comparison (see text).

widespread tropical and sub-tropical exploited species of the genus *Penaeus*.

Carideans differ from penaeids in that the pleuron (covering shell) of the second abdominal segment overlaps the pleura of both the first and the third segments and the third pair of walking legs does not have pincers (Fig. 1). Unlike penaeids, carideans carry fertilized eggs externally beneath the abdomen (commercially called the "tail"), which is often proportionally smaller than that of penaeids.

The majority of deepwater carideans caught off Pacific Islands belong to the family Pandalidae and most commercial interest has been in the larger species of the genus *Heterocarpus*. A large deepwater penaeid, *Plesiopenaeus edwardienus*, is also believed to have fisheries potential in some areas (Saunders and Hastie, in press).

A list of caridean shrimps found in several Pacific islands trapping surveys is given in Table I. Taxonomic details of carideans can be found in Crosnier and Forest (1973), Holthuis (1980), Chace (1985), Crosnier (1986; 1988) and Hanamura and Takeda (1987), and a key to western Pacific species is given in King (1984; 1986). The most recent revisions of the taxonomy of deepwater shrimps by Crosnier, and descriptions and colour plates of species caught in French Polynesia (Poupin *et al.*, 1990) suggest that some species referred to in previous work may require re-examination.

DISTRIBUTION

The *Heterocarpus* species, listed in Table I have at least an Indo-Pacific distribution and have been found in India and islands in the Indian Ocean as well as the Pacific islands listed in Table I (see King, 1986; 1988a for details). Deepwater shrimps have been found in virtually all Pacific islands where surveys have been attempted, although the species composition of the catch and catch-rates (see Section III) have varied among geographic locations.

Deepwater shrimps inhabit the steep outer reef slopes of islands and the continental slopes of large land masses. Their distribution is related to depth, with each particular species occupying different but overlapping depth ranges.

The smaller shrimps, *Parapandalus serratifrons* and *Plesionika edwardsii* are widely distributed in shallower water (under 400 m). Medium-sized *Heterocarpus* species predominate in catches over 400 m; *Heterocarpus sibogae*, which is commonly found in the south-western Pacific, appears to be replaced by *Heterocarpus ensifer* in the eastern and northern Pacific. One of the largest species found, *Heterocarpus laevigatus*, is widely distributed in Pacific islands in depths of more than 500 m and is the main target species. The general depth distribution of the more common species of deepwater shrimps is shown in Fig. 2.

Table I. The major species of caridean shrimps found in deepwater trapping surveys in Fiji (FIJ), Vanuatu (VAN), Western Samoa (SAM), Tonga (TON), Marianas (MAR), Hawaii (HAW), French Polynesia (FPO), Kiribati (KIR) and Palau (BEL). The trap abundance of each species is indicated as C (common), O (occasional), R (rare) or no letter (not recorded). From King, 1984; 1986; Moffitt and Polovina, 1987; Saunders and Hastie, in press; Crutz and Preston, 1987; Poupin *et al.*, 1990.

SPECIES	FIJ	VAN	SAM	TON	MAR	HAW	FPO	KIR	PAL
*Parapandalus serratifrons** Borradaile, 1899	C	C		C	C	C		O?	
*Plesionika edwardsii*** Brandt, 1851	C	C	C	C	C	O	O		O
Plesionika ensis A. Milne Edwards, 1881	O	O	O	O	O	R	O		O
Plesionika fenneri Crosnier, 1986							C		
Plesionika martia A. Milne Edwards, 1883		O			R	O		O?	O
Heterocarpus ensifer A. Milne Edwards, 1881	O	O		O	C	C	C	C	C
Heterocarpus sibogae Da Man, 1917	C	C	C	C	R		O		
Heterocarpus gibbosus Bate, 1888	C	O		R	R	O		O	O
Heterocarpus laevigatus Bate, 1888	C	C	C	C	C	C	C	C	C
Heterocarpus dorsalis Bate, 1888			O		O	O			O
Heterocarpus longirostris MacGilchrist, 1905					C				O

* = *Plesionika* ** = *longirostris* (Borradaille, 1899)

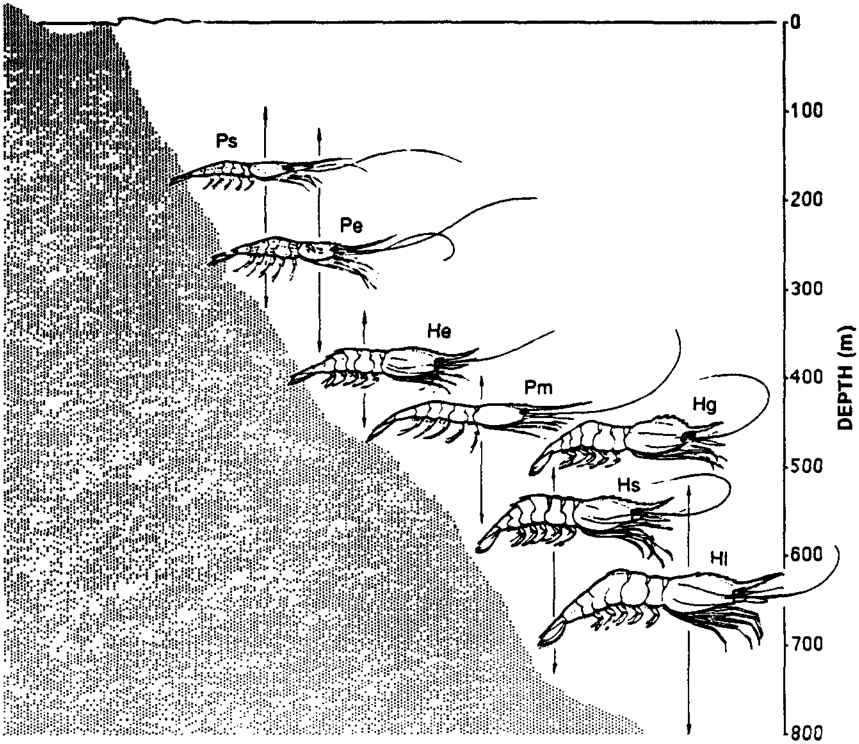


Figure 2. Depths (m) of maximum abundance of the most commonly found deepwater shrimps near Pacific islands. Species indicated, from shallow to deep water, are; Ps, *Parapandalus serratifrons*; Pe, *Plesionika edwardsii*; Pm, *Plesionika martia* and *Plesionika ensis*; He, *Heterocarpus ensifer*; Hg, *Heterocarpus gibbosus*; Hs, *Heterocarpus sibogae*; Hl, *Heterocarpus laevigatus*. The depth range shown for each species may vary with season and location; species may be distributed in smaller numbers over wider depth ranges.

There is some evidence that deepwater caridean shrimps move between different depths on the outer reef slopes. *Heterocarpus gibbosus* in Fiji appears to move between depths of about 450 m to 550 m seasonally (King, 1984). In Hawaii, *Heterocarpus laevigatus* migrates from depths of about 550 m to 700 m during the egg bearing season (Dailey and Ralston, 1986).

TROPHIC RELATIONSHIPS AND NUTRITION

Little is known about the trophic relationships of deepwater shrimps. In the field, shrimps have been found in the gut of snappers and even pelagic fish such as tuna.

In refrigerated aquaria, *Heterocarpus* species are rapidly attracted to a wide variety of food material including flesh and pelletized stock food placed on the substrate. In the absence of large pieces of food, the shrimps pick over the substrate with their periopods.

Studies off the north-west coast of Australia (Rainer, 1990) suggest that *Heterocarpus sibogae* feed on other crustaceans, fish, and foraminiferans, all of which could be benthic. A significant part of their diet, however, includes mid-water animals such as the small squid, *Abralia andamanica.*

REPRODUCTIVE BIOLOGY

Tropical caridean shrimp were originally thought to be protandrous hermaphrodites (Clarke, 1972; Wilder, 1977), as are temperate-water pandalids which change from males to females after the first few years of life. Subsequent studies revealed that tropical deepwater carideans have separate sexes (King and Moffitt, 1984; Moffitt and Polovina, 1987).

The sex of caridean shrimps can be determined by an examination of the shape of the endopods of the first pleopods (swimming legs); the endopod in males is broader and more leaf-shaped than in females. A mature male also possesses an appendix masculina situated between the appendix interna and the endopod of the second pleopod (Fig. 3). Eggs are carried externally on the pleopods of ovigerous females, and brood sizes (the number of eggs carried) may exceed 30,000 on the larger *Heterocarpus* species (King and Butler, 1985).

The mean sizes of reaching sexual maturity in females (defined as the size where 50 per cent of the female population is ovigerous) are given for several species in King (1986). Female *Heterocarpus laevigatus* reach sexual maturity between 40 and 43 mm carapace length which corresponds to a relative age of 4 to 4.6 years (King, 1983; Dailey and Ralston, 1986; Moffitt and Polovina, 1987); results from various locations are summarised in Table II.

The incidence of ovigerous females appears to vary with the time of the year. In Fiji, over 50 per cent of female *Heterocarpus laevigatus* were carrying

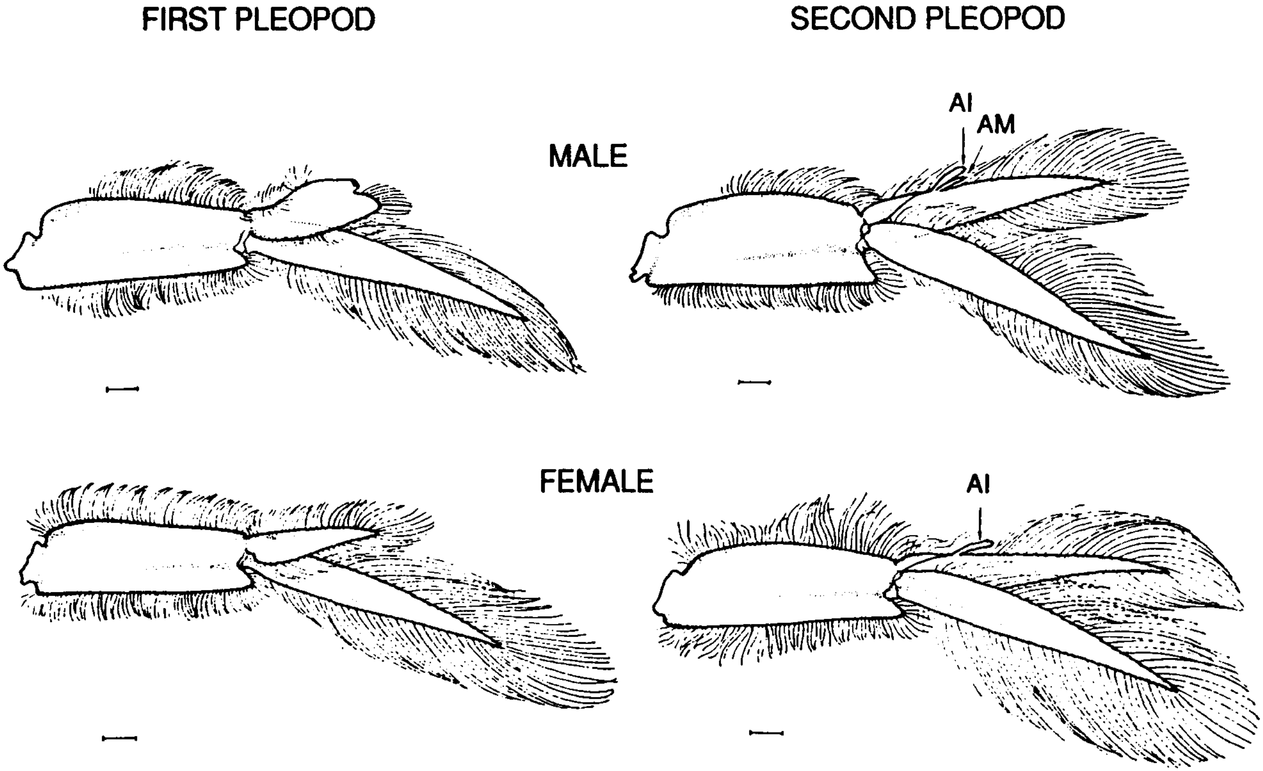


Figure 3. First and second pleopods (swimming legs) of *Heterocarpus sibogae* (from King and Moffitt, 1984). Horizontal scales indicate 1 mm. Left: the first pleopod showing (top) the male, and (bottom) the female endopod. Right: the second pleopod with the appendix masculina (AM) and appendix interna (AI) of the male (top) and the latter organ only in the female (bottom).

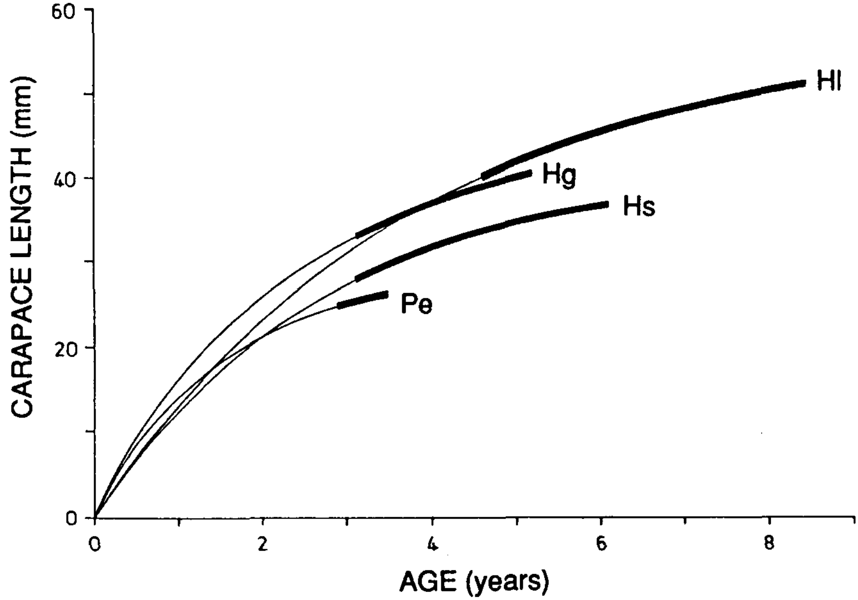


Figure 4. Growth curves for *Plesionika edwardsii* (L_∞=29.5mm, K=0.66), *Heterocarpus sibogae* (L_∞=41mm, K= 0.38), *Heterocarpus gibbosus* (L_∞=45mm, K=0.35), and *Heterocarpus laevigatus* (L_∞=57mm, K=0.27). The curves have been terminated at 90 per cent of the asymptotic lengths. The heavy part of each curve indicates female sexual maturity.

Table II. Summary of biological parameters of *Heterocarpus laevigatus* in Fiji (King, 1984; 1986), Hawaii (Daily and Ralston, 1986), and the Marianas (Moffitt and Polovina, 1987). The growth coefficient, K (yr^{-1}), and asymptotic carapace length, L_∞ (mm) are the von Bertalanffy growth parameters, M is the natural mortality rate (yr^{-1}) and, L_m and t_m are the mean length (mm) and relative age (years) at sexual maturity respectively.

Growth		Mortality	Reproduction			
Area	Sex	K yr^{-1}	L_∞	M yr^{-1}	L_m	t_m
Fiji	both	0.27	57.0	0.66	40.5	4.6
Hawaii	Male	0.35	57.9			
	Female	0.25	62.5		40.0	4.0
Marianas	both	0.30	55.2	0.75	42.7	4.5

eggs in April 1979, June and July 1980 and May 1981 (King, 1983). In Hawaii, the corresponding time period for the same species was October to January (Dailey and Ralston, 1986) and in the Marianas, November to February (Moffitt and Polovina, 1987). The spawning season of *Heterocarpus laevigatus*, therefore, appears to be in the winter season of each hemisphere.

GROWTH

The analysis of length-frequency data is the only practical method available for estimating growth in deepwater shrimps. Length-frequency distributions may be arranged sequentially over an extended time period, allowing the progression of modes to be followed. This method has been used to estimate the growth of several species in Fiji (King and Butler, 1985), and growth curves for four species (sexes combined) are shown in Fig. 4. *Heterocarpus laevigatus* in Hawaii (Dailey and Ralston, 1986) and the Marianas (Moffitt and Polovina, 1987) appear to have similar growth characteristics; the von Bertalanffy growth parameters for shrimps from various locations are summarised in Table II. In general, males grow more quickly than females but reach a smaller ultimate size.

It is not possible to age crustaceans by conventional means such as the analysis of growth marks as they have no persistent hard parts (the shell, or exoskeleton, is lost during moulting). Age has been inferred from growth studies based on the analysis of length-frequency data. Growth data for *Heterocarpus laevigatus* suggest that the largest size groups in the samples are over 8 years of age, although estimated ages assume that growth throughout life follows the von Bertalanffy curves shown in Fig. 4; this may not be so, particularly if larval growth differs markedly from that of adults.

MORTALITY

Length-frequency data have been used to estimate mortality rates for *Heterocarpus laevigatus* by examining the decrease in relative numbers with age. In Fiji, instantaneous natural mortality rates were estimated to be 0.66 yr^{-1} or about 48 per cent per year (King, 1986); in the Marianas an estimate of 0.75 yr^{-1} or about 53 per cent was obtained (Moffitt and Polovina, 1987). Results from various locations are summarised in Table II.

In an intensive trapping experiment for *Heterocarpus laevigatus* in the Marianas, catch rates dropped dramatically from 3.3 to 1.8 kg per trap-night over a 16-day trapping period (Ralston, 1986). This decrease in catch was attributed to a decline in shrimp numbers and suggests that the species may be particularly vulnerable to even moderate trapping.

A combination of slow growth rates with high natural mortality rates suggests that the biomass (weight) of shrimps from a given recruitment is maximised at an early age, after which the available biomass rapidly declines. Fig. 5 shows that the greatest biomass in an unexploited population occurs when shrimps are about 3 years old. In an exploited population, the maximum biomass would be displaced towards the left.

III. EXPLOITATION

FISHING METHODS

Deepwater shrimps in the Pacific islands countries are caught in baited traps. In adjacent countries with continental shelves, such as the north-west coast of Australia and the west coast of South America, *Heterocarpus* species are caught in trawl nets.

Several different types of baits and traps have been used in Pacific islands, and these are reviewed in King (1986). In general, baits of oily fish, such as tuna heads or mackerel, provide the highest catch rates.

Most traps are made from steel rod frames, covered with galvanized wire or

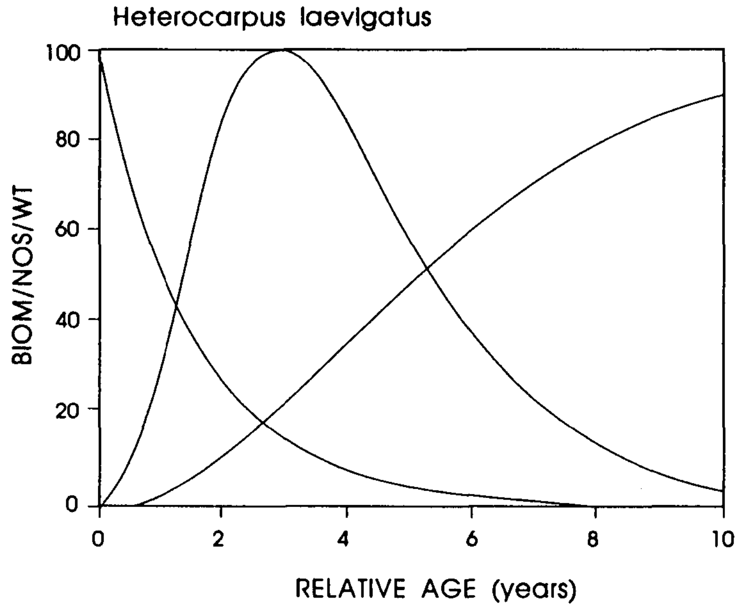


Figure 5. Estimated growth in individual weight, survival (relative numbers) and resulting biomass for a single recruitment of *Heterocarpus laevigatus* over age (years), expressed as a percentage of maximum values.

plastic mesh, and operate on the principle that shrimps, attracted to the bait hanging in the traps, enter cone-shaped entrances worked into the trap sides or top. Traps with side, rather than top, entrances appeared most efficient in Fijian surveys, although underwater observations from a submersible suggest that shrimps can more easily escape from side entrances (Gooding *et al.*, 1988). Escape from traps is generally not known, but the underwater observations suggest the need for the development of more efficient traps.

In trap fishing, the gear consists of two parts, a drop-line connected to one or more buoys, and a bottom-line along which the traps are attached. At the surface, a wood or bamboo marker pole with a brightly coloured flag and a counter-weight is used (Fig. 6). In areas of strong surface currents extra float buoys must be used to prevent the marker pole being pulled beneath the sea surface. Marine authorities in some areas may require a radar reflector or even a flashing light to be attached to the top of the marker pole. A weight of approximately 10 kg or a simple anchor is attached to a short length of chain at the join between the drop-line and the bottom line. Alternatively, particularly on areas of rocky sea-floor, large volume traps may be set individually from a single drop-line.

An echo-sounder is used to locate suitable fishing depths and areas where the sea floor slope is not too steep. Steep outer-reef slopes as well as rocky sea-floors possibly account for the greatest number of trap losses.

At the selected fishing location, the first trap is connected to the end of the drop-line and lowered over the windward side of the vessel. As the drop-line is fed into the sea, traps are connected at intervals of up to about 30 m; this spacing is to avoid competitive effects between traps. With the engine stopped, and the boat drifting off to leeward, pressure is kept on the drop-line to keep the traps in a straight line to avoid tangling. A drop-line, of a length equal to the depth of water plus about 25 per cent, is released before connecting the float buoys and marker pole and casting off.

Traps are usually left overnight and recovered on the following day. The most convenient type of winch to use for hauling is a "self-tailing" one in which the drop-line is firmly gripped by a pulley and stripped off by a metal peeler. Rope hauled in may be flaked down in bins or directly on the deck of the vessel.

FISHERIES IN THE SOUTH PACIFIC

Caridean shrimps have been commercially fished in Hawaiian waters since 1967 (Tagami and Ralston, 1988). At least 17 vessels, ranging in size from 7.5 m to 40 m, were active in deepwater shrimp trapping in Hawaiian waters during 1984 (Western Pacific Regional Fishery Management, 1984), when 159 tonnes (t) of deepwater shrimp with an ex-vessel value of US$780,000 were landed. Since

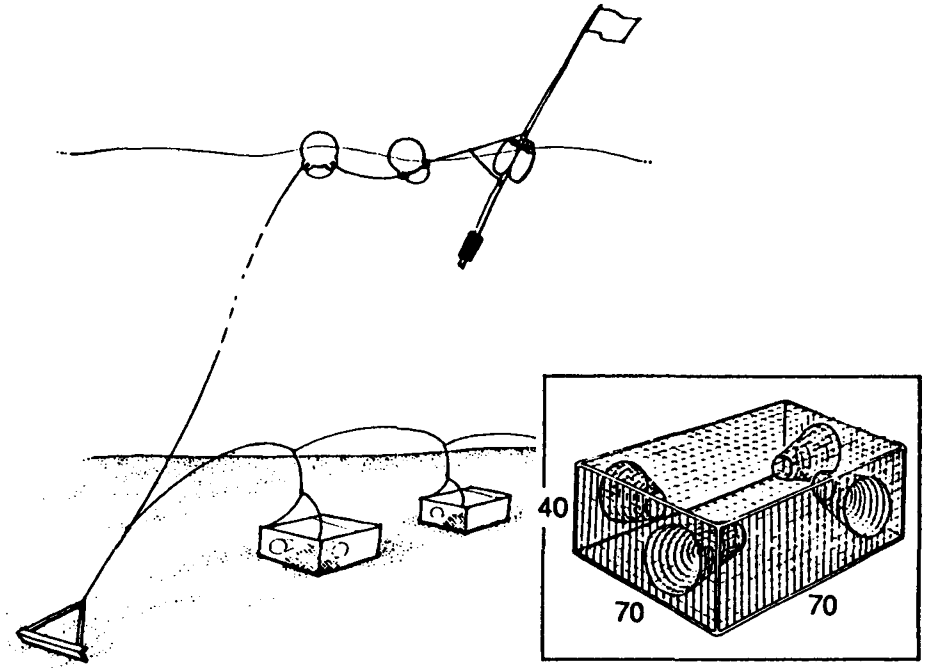


Figure 6. The general arrangement of a trap fishing rig for deepwater shrimps. In a commercial operation, a larger number of traps, or a single large trap may be set in a similar manner.

1985 the fishery has declined with larger vessels leaving due to the high costs of operation. More recently, however, the number of smaller vessels in the fishery has increased (Tagami and Barrows, 1988).

Small scale commercial trap fishing was attempted in Guam (Wilder, 1977; 1979) and commercial fishing trials using a large vessel were carried out in Fiji during 1982 (King, 1986). A commercial shrimp trapping vessel is presently negotiating to catch shrimps in the Federated States of Micronesia, using aluminium box-traps on a rig designed to reduce gear loss (M. Gawel, *pers. comm.*). Recent studies using a remote camera (Saunders and Hastie, in press) suggest that the use of a combined shrimp and deepwater crab (*Chaceon granulatus*) trap could result in a small scale fishery in Palau.

Trawl fisheries for caridean shrimps exist in adjacent countries. Areas on the continental slope of north-western Australia and in the Arafura/Timor Sea yielded about 200 t of *Heterocarpus sibogae* and *Heterocarpus woodmasoni* in 1989-90 and landings in Chile have decreased from a maximum of 6,619 t of *Heterocarpus reedi* in 1983 (Garland, *pers. comm.*).

It is difficult to compare the relative catch rates of deepwater shrimps in different islands due to the effects of using different traps, baits and soak times in the various surveys. Mean catch rates, at optimum depth ranges, in areas where surveys have been conducted using small traps (volume between 0.2 and $0.3 m^3$) vary from less than 1 kg to about 3 kg per trap per night (Table III). Larger traps, used by commercial fishermen in Hawaii, are reported to catch at least five times more shrimps than small traps (Methot, 1984). A commercial fishing vessel, using traps with a volume of $1.84 m^3$ in a survey of the Hawaiian Islands during 1983 and 1984, obtained an average catch-rate of 12 kg per trap-night (Tagami and Barrows, 1988).

PROCESSING

The handling of shrimps requires considerable care, more so, for example, than the handling of finfish. Shrimps, like many other crustaceans, are regarded as luxury food items and need to be treated as such to attract maximum market prices.

Enzyme-induced melanosis (black-spot) and "off-flavours" such as garlic-metallic taints, have caused marketing problems in deepwater shrimps. A condition known as "mushy-tail" is believed to be caused by *Vibrio* bacteria, which are normally resident on the shrimps (Gooding *et al.*, 1988). Because of the limited deck space, catch handling on a small vessel is limited to washing and storing the shrimps in iced sea-water. The shrimps should be stored under iced water to exclude air and reduce the possibility of enzyme-induced reactions.

The use of a larger vessel allows more sophisticated methods of shrimp preservation such as the on-board production of individually quick frozen (IQF) shrimps. Indeed, a large vessel operation may be the only method of obtaining shrimps of sufficient quality and quantity to develop export markets.

The major markets for shrimps are in Japan, the United States of America, Europe and Hong Kong. Other than European countries, these major importers border the Pacific and are, presumably, accessible to exporters in Pacific islands. However, a possible glut, mainly due to the increased production of penaeid shrimps from aquaculture, is predicted for these markets (van Eys, 1985). In Japan, a special market for pandalid shrimps, collectively known as *ama-ebi*, is likely to persist. Pandalid shrimp, with their sweet taste and "sticky" texture, are usually eaten raw in Japan.

Table III. Mean catch rates obtained from deepwater shrimp trapping surveys using small volume traps in Pacific Islands.

Location	Catch per Trap Depth (m)	(kg)	Reference
Hawaii (north-west group)	500-800	0.9	Gooding, 1984
Guam (west coast)	440-680	2.1	Wilder, 1977
Western Samoa (near Apia)	500-600	1.4	King, 1980; 1984
Tonga (near Nuku'alofa)	600-700	0.6	King, 1981; 1984
Fiji (near Suva)	450-650	1.2	King, 1984
Vanuatu (near Port Vila)	500-600	2.8	King, 1980; 1984
Vanuatu (north-west Efate)	450-500	1.1	de Reviers *et al.*, 1982
New Caledonia (Loyalty Is.)	800	2.0	Intes, 1978
New Caledonia (Mainland)	350-450	0.6	In: Crutz and Preston, 1987
Marianas	550-800	2.1	Moffitt and Polovina, 1987
Kiribati	400-500	1.0	In: Crutz and Preston, 1987
French Polynesia	550-650	0.3	Poupin *et al.*, 1990
Palau	500-800	>1	Saunders and Hastie (*in press*)

From marketing experience in Hawaii (Oishi, 1983), deepwater shrimps were found to be acceptable in four different forms. These are presented below ranked in terms of demand:

1. whole individually quick-frozen (IQF) shrimps
2. fresh (iced) whole shrimps
3. shrimp tails - (meat only)
4. shrimp tails - (with shell)

Large deepwater shrimps, individually quick-frozen and presented in 2 kg "shatter-packs" were found to be most acceptable on the Japanese market (Western Pacific Regional Fishery Management Council, 1984). To gain continued acceptance on the Japanese *ama-ebi* market, shrimps must be well-presented with no missing appendages.

Large whole (fresh, chilled) shrimp appear most acceptable for local markets, restaurants and tourist hotels. The low meat recovery rate of deepwater shrimps makes the marketing of shrimp tails (abdomen) less attractive commercially; tail flesh generally accounts for less than 30 per cent of the total shrimp weight.

A processing company based in Hawaii estimated that up to 1.3 t per week could be absorbed by local markets without depressing prices (Oishi, 1983). Other Pacific countries, without large populations and tourist industries, may have much smaller local demands for deepwater shrimps.

IV. RESEARCH AND METHODS OF ASSESSMENT

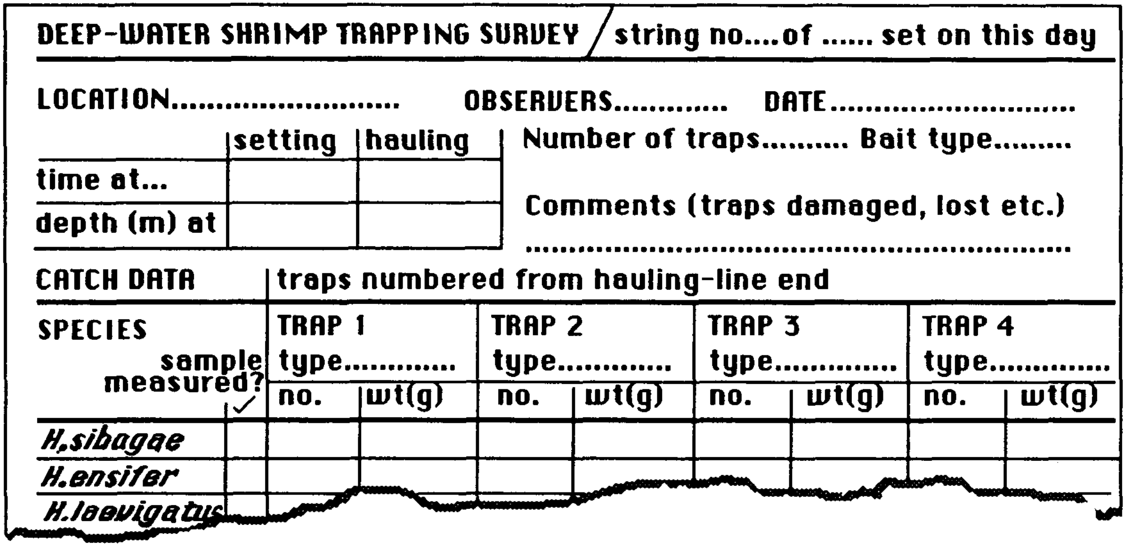
For countries considering the development of deepwater shrimp fisheries, the following questions are most relevant:

Are the catch rates (based on preliminary surveys) high enough to justify commercial development? If they are, at what level of exploitation are the catch rates sustainable?

Is the market value of the product (price per kg paid to fishermen) likely to be high enough to offset the high costs of fishing in deep water?

Although mean catch rates may be determined by standard survey techniques, the results obtained cannot be extrapolated to the long-term exploited situation. Under conditions of full exploitation (at the point of maximum sustainable yield) catch-rates are likely to be approximately one half of those recorded in initial surveys. Estimating sustainable yields and levels of exploitation are more difficult undertakings, and some methods are discussed below.

The economic aspects of potential commercial operations have generally not been adequately addressed in deepwater shrimp surveys; an exception is a study in Kiribati by Crutz and Preston (1977). A practical method of examining potential economic viability using "break-even" curves is presented below.



DEEP-WATER SHRIMP TRAPPING SURVEY / string no....of ...... set on this day

LOCATION.......................... OBSERVERS............ DATE...........................

	setting	hauling
time at...		
depth (m) at		

Number of traps.......... Bait type.........

Comments (traps damaged, lost etc.)

....

CATCH DATA | traps numbered from hauling-line end

SPECIES	sample measured?	TRAP 1 type............		TRAP 2 type............		TRAP 3 type.............		TRAP 4 type.............	
	✓	no.	wt(g)	no.	wt(g)	no.	wt(g)	no.	wt(g)
H.sibagae									
H.ensifer									
H.laevigatus									

Figure 7. Portion of a field data collection sheet for deepwater shrimp surveys. One sheet is filled in for each string of traps set and length-frequency data sheets are attached.

SURVEY TECHNIQUES

Most surveys carried out from Pacific islands have been similar in that baited traps were set, either individually or in a string, at right angles to a transect line running from depths of about 250 m to about 800 m. Catch and effort data is best recorded by species, with catch weight and numbers caught per trap per night (Fig. 7). If traps are set as late as possible on one day and collected as early as possible on the following day, a night's fishing effort may represent between 14 to 18 hours "soak time".

V. STOCK ASSESSMENT TECHNIQUES

A flowchart summarising a methodology for assessing shrimp stocks is given in Fig. 8 (based on Munro, 1983; Polovina and Ralston, 1986). The numbers in Fig. 8 represent three separate parts of the assessment programme; these are 1) fishing at different depths along transects set at right angles to depth contours, 2) intensive (depletion) fishing at an isolated location, and 3) fishing over a large area (at many locations around the island). The three parts of Fig. 8 are described below.

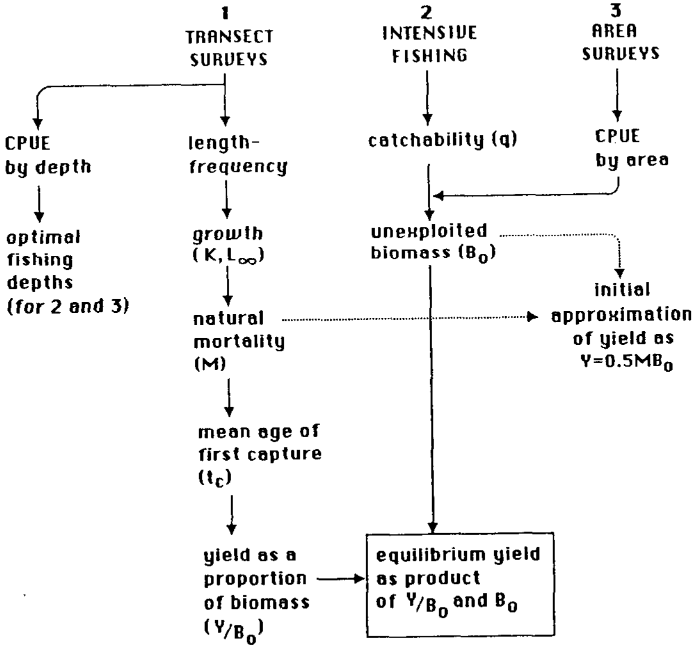


Figure 8. The collection and use of data to assess deepwater shrimp resources.

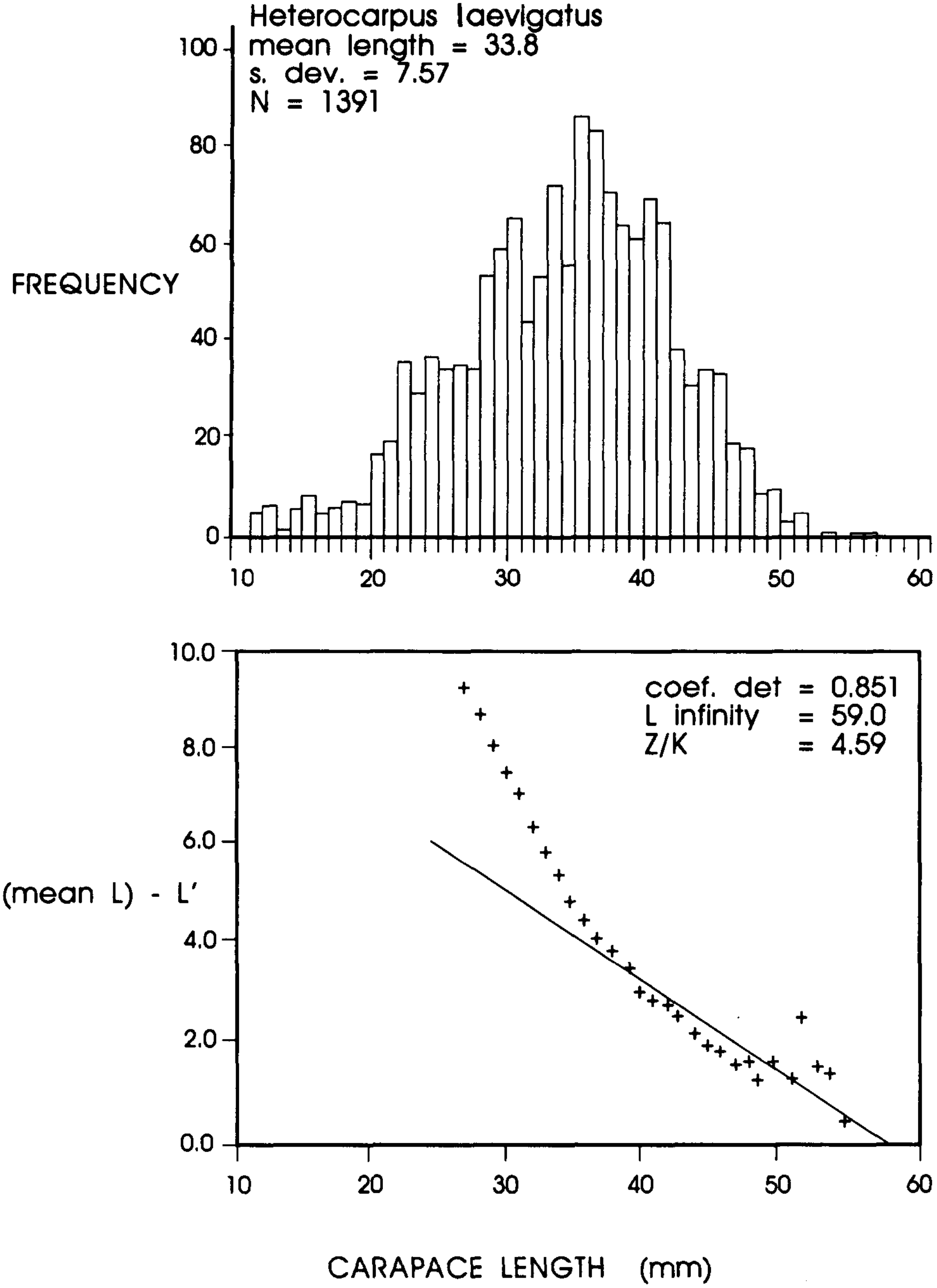
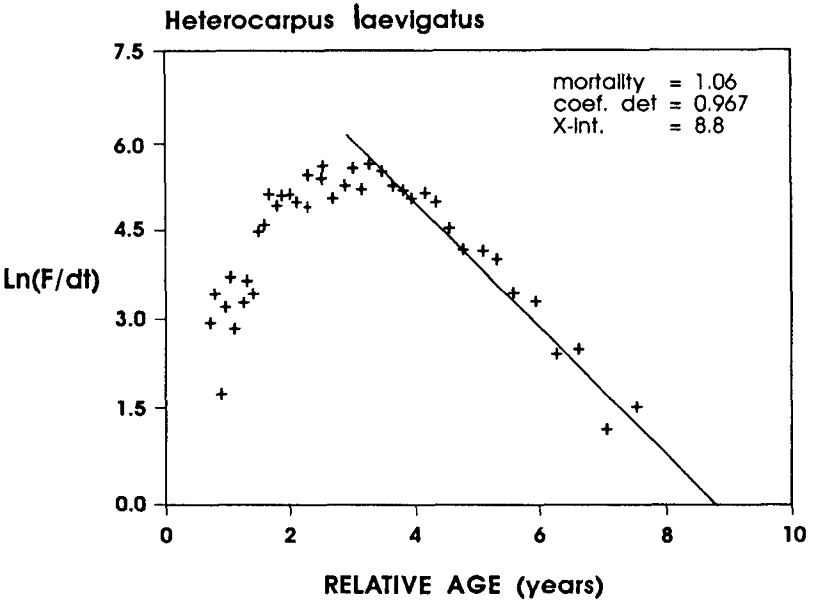


Figure 9. TOP: Combined length-frequency data for *Heterocarpus laevigatus* in Fiji. BOTTOM: A modified Wetherall Plot; the regression line is fitted through points greater than 35 mm carapace length.



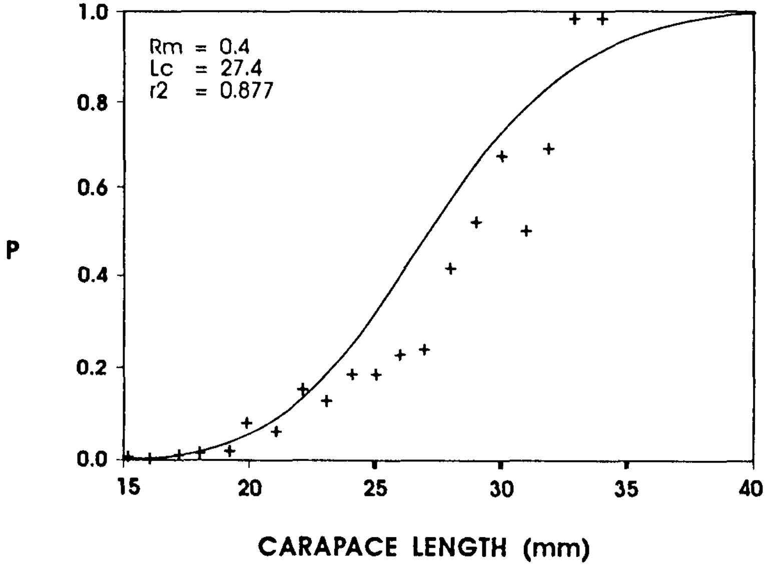


Figure 10. Analyses of the length-frequency data shown in Fig. 9. TOP: A length-converted catch curve. BOTTOM: A plot of probably of capture against carapace length (mm); the mean length at first capture (at 50 per cent probability) is 27.5 mm.

1. Setting traps along transects at selected locations allows the depth distributions of the various component species to be determined. Surveys at regular intervals in the same location will also allow the collection of a time-series of length-frequency data.

The combined length-frequency data, in the fully vulnerable size ranges may be analysed to estimate L_∞ by means of a Wetherall plot (Wetherall 1986; Pauly, 1986). An example, using data collected in Fiji, is given in Fig. 9.

The growth coefficient K may be estimated from the time series of length-frequency data either manually (by tracing the progression of modes with time), or by using software such as ELEFAN (Brey and Pauly, 1986) with L_∞ held fixed at the estimated value from the Wetherall plot.

Once growth parameters are obtained, mortality rates may be estimated by means of length-converted catch curves (Pauly, 1983). If natural mortality rates are known, age at first capture (t_c) can be estimated from a plot of probability of capture against carapace length from the ascending part of the catch curve (Pauly, 1984). Examples of graphical outputs (using the computer program LFANAL; King, 1988b) for these analyses are given in Fig. 10.

2. Depletion experiments involve intensive fishing in an isolated location. A Leslie or DeLury plot of the reduction of catch per unit effort (CPUE) with cumulative catch will provide an estimate of the stock size and, more important, the catchability coefficient, q.

In an intensive trapping experiment in Hawaii, the catchability of *Heterocarpus laevigatus* was estimated as 0.001945 trap-night^{-1} (Ralston, 1986).

3. Surveys in different sub-areas will allow an insight into the differential distribution of the resource around the whole area of interest by comparing CPUE in the various sub-areas. CPUE (as an index of relative abundance) is related to the absolute abundance by the catchability coefficient (q). The number of vulnerable shrimp in each of the chosen sub-areas may be estimated by multiplying the area of available habitat by CPUE/q.

ESTIMATES OF YIELD

A rough estimator of the potential annual yield (Y) in an unexploited stock is:

$$Y = 0.5MB_o$$

where M is the natural mortality and B_o is the initial biomass (Gulland, 1983).

Although this equation is likely to overestimate yield (Beddington and Cooke, 1983; Garcia *et al*,. 1987), it may be useful in providing an initial upper limit for a prospective fishery.

Potential yield may also be estimated by using Beverton and Holt analyses (Beddington and Cook, 1983; Polovina, 1986; Polovina and Ralston, 1986). For species with known population parameters (for example K, M, and t_c), the ratio of yield to unexploited recruited biomass, Y/B_o, may be calculated from the Beverton and Holt yield equation (*e.g.* by using tables in Appendix 2 of Beddington and Cooke, 1983). The equilibrium yield is estimated as the ratio of yield per unexploited biomass (Y/B_o) multiplied by the unexploited biomass estimated from the depletion experiments.

A graph of sustainable yield against fishing mortality generally shows yields increasing rapidly at low levels of fishing mortality but more slowly at higher levels. Assumptions of constant recruitment may be violated at higher levels of fishing mortality, when recruitment may decline, in spite of marginal predicted increases in yield. Maximum sustainable yield may be estimated as the yield corresponding to the level of fishing mortality, F, where an increase in one unit of F increases the catch by 0.1 of the amount caught by the first unit of F (Gulland, 1983; Polovina and Ralston, 1986); on this basis the level of equilibrium yield and corresponding level of fishing mortality may be estimated.

Some estimates of sustainable yield are given in Table IV.

Table IV. Estimates of sustainable yield for deepwater shrimps.

Area	Yield ($kg.nmi^{-2}$)	Source
Mariana Archipelago	200	Moffitt and Polovina, 1987
Hawaiian Islands	40	Tagami and Ralston, 1988

ECONOMIC CONSIDERATIONS

Many shrimp trapping surveys carried out in Pacific islands countries have neglected to include the collection of financial information related to potential exploitation.

Financial information can be collected concurrently with initial trapping surveys (King and McIlgorm, 1989), and it should include estimates of the likely market value of the product and the projected costs involved in a commercial fishing operation. Costs are comprised of the initial investment (the purchase price of a suitable vessel and fishing gear), fixed costs (crew wages, repairs, vessel depreciation, and insurance), and running costs (fuel, gear replacement, bait and ice). The sum of the fixed and running costs represent the total annual operating costs.

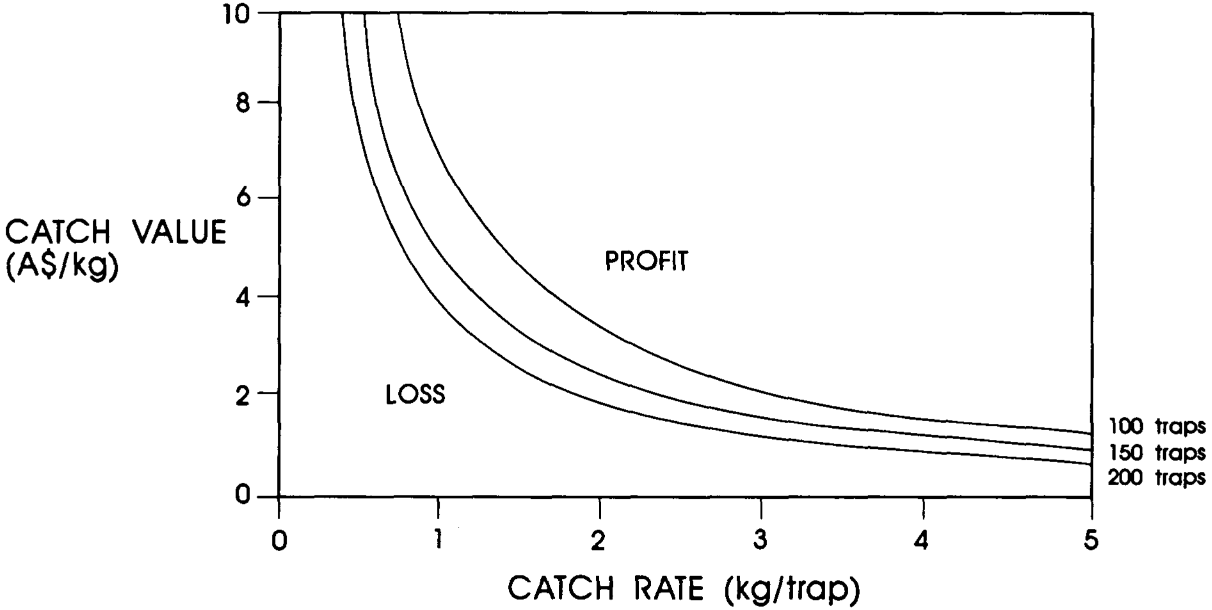


Figure 11. Projected break-even curves for a small vessel using either 100, 150, or 200 traps in a deepwater shrimp fishery; graphical output from the computer program FINANAL (King in prep.). Curves based on a static analysis of one vessel's costs (data from Crutz and Preston, 1987) without a consideration of the timing of returns. Currency is in Australian dollars.

The economic viability of a commercial operation may be viewed from the possible effects of predicted catch per unit effort and product prices on a vessel's net return. This is most conveniently shown by constructing break-even curves (where returns to fishermen just balance the total costs of fishing); an example based on data collected in Kiribati (Crutz and Preston, 1987) is shown in Fig. 11.

The example given in Fig. 11 suggests that if mean long-term catch rates are under about 2 kg.trap^{-1}, realizable market prices may not cover the fishing costs involved. It is notable that the mean catch per trap and market prices paid to fishermen are the most important factors in determining commercial success. Fishing effort, in terms of number of traps used, is less important.

The methods described above provide guidelines for assessing the potential of deepwater shrimp fisheries. Even brief surveys may suggest what the long-term catch rates are likely to be, and a knowledge of the depth-distribution and area occupied by the target species may suggest the likely magnitude of the exploitable shrimp resource.

With a knowledge of sustainable catch-rates, product value, and projected fishing costs, fisheries managers will be in a position to assess the viability or otherwise of a deepwater shrimp fishery. Financial analyses of potential commercial operations are crucial to avoid over-investment in a fishery where operating costs are high and where available stocks are likely to support only a small number of vessels.

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