Fishery, Population Dynamics and Breeding Biology of *Panulirus homarus* (L.) on the South Coast of Sri Lanka

Thesis submitted for the Degree of
Doctor of Philosophy

In the
University of Stirling

by

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September 1991

This thesis is dedicated to my loving parents

DECLARATION

The work reported in this thesis is the result of my own investigations carried out at National Aquatic Resources Agency, Colombo, Sri Lanka. It has not been nor will be submitted concurrently in candidature for any degree, in this or any other university.

D. S. Jayakody.

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ACKNOWLEDGEMENTS

I wish to acknowledge the help and invaluable guidance rendered by the principal supervisor Dr. D. S. Mc Lusky (University of Stirling) and the additional supervisor Dr. A. Ansell (Scottish Marine Biological Association, Oban).

I am also grateful to the Chairman and the Director General of the National Aquatic Resources Agency (NARA), for providing me necessary facilities throughout this study programme.

I am indebted to the Agricultural Research Project (ARP) of Sri Lanka, who sponsored my study program.

My thanks are also extended to Dr. Danial Pauly and Mr. F.C. Gayanilo of ICLARM, Philippines, who helped me in analysing length frequency data during an individualized training course in fish stock assessment in Philippines.

My thanks are also due to Dr. C. B Kensler FAO/UNDP, for his help given to me during field visits by providing a vehicle and advice.

Thanks are also due to Messrs H.A.R.E Perera, M.G.K Gunawardana, T. A. Rajapaksa and T. Upasena (Research Assistants of NARA) for their help given during data collection and to Ms. Marilyn Nash (Computer Advisor, University of Stirling) for the help given during computer analysis.

I am most grateful to Sunil Siriwardena and Rangani Siriwardena for their invaluable help given to me during my stay in Scotland.

Throughout the period of my study, my wife Nayana and my children Surani and Nalini were my constant inspiration and main reason for success and for their patience and understanding I am eternally grateful.

ABSTRACT

This study is aimed to provide an understanding of the spiny lobster fishery of the south coast of Sri Lanka. Most of the spiny lobster fisheries of the world are subjected to heavy exploitation due to the increasing demand. The use of hazardous fishing methods however is known to cause serious problems in the developing countries, including Sri Lanka where considerable percentage of berried females and under sized lobsters are caught each year.

The fishery for spiny lobster in the coastal waters of the south coast is carried out by non-mechanized out-rigger small canoes with trammel nets, bottom set gill nets and lobster rings. Around 200mt of lobsters is caught each year in the study area by a fishing fleet of 315 crafts. Around 80% of the lobster production consisted of *Panulirus homarus*.

Lobsters were found to occur all year round, but the fishery is restricted to the non-monsoon period (August-March) due to operational difficulties.

The analysis of catch and effort statistics indicated a maximum sustainable yield of 190-200 mt and an optimal daily effort of 300 crafts. The length-based analysis indicated that the resource is over exploited and a reduction in effort by about 20.5% is necessary to put the fishery back to an equilibrium level.

Experimental fishing tests revealed that the lobster rings cause the least damage to the population, while the trammel net was the most harmful by including 77% of sub-legal lobsters in catches. This study indicated the possibility of having two spawning and recruitment pulses separated by an interval of 4-5 months. Fecundity estimates ranged between 116,000 - 601,000. Nearly two-third of the total egg production was contributed by lobsters of 60-79mm carapace length range. The fishery is reproductively supported by 3-4 year lobsters. This resource in the study area appears to be overfished with respect to its reproductive potential.

The use of trammel nets and free access to the fishery are the two main points which should be carefully controlled. The fishery should be managed by using less harmful fishing gear (eg. lobster rings) and by introducing a proper licensing system to control fishermen entering into the fishery.

CHAPTER 1

1. Introduction.

The family Palinuridae (Phylum Arthropoda: Class Crustacea), generally known as spiny or rock lobsters, is a commercially important marine and brackish water group with a large number of genera. Lobsters comprise 207,949mt or 6.50% of the world's marine crustacean catch of 3,194,400 mt (FAO, 1988). There are four types of lobsters namely, spiny lobster, clawed lobster, slipper lobster and coral lobster. Family Palinuridae (spiny lobsters) and family Nephropidae (clawed lobsters) support some of the most valuable fisheries in the world. Because of this, the population ecology and related characteristics of these two groups have been investigated extensively by many fishery biologists in various parts of the world. Family Scyllaridae (slipper lobsters) and family Synaxidae (coral lobsters), support only minor fisheries and the knowledge of these two groups is much poorer.

In 1981, the clawed lobster total was made up almost entirely of *Homarus americanus* (American lobster), *Nephrops norvegicus* (Norway lobster) and *Homarus gammarus* (European lobster), all of which live in the North Atlantic. The combined total of these three species was more than the various commercial species of spiny lobsters distributed in all the major oceans of the world; *Jasus*, *Panulirus* and *Palinurus* (FAO, 1981).

Spiny lobsters are characterised by a large inflated and often spiny carapace or head shield covering the forward part of the body, a pair of stiff thorny antennae extending from the head region, five pairs of walking legs and a powerful abdomen or tail terminating in a flexible and somewhat leathery tail fin. They are distinguished from the true lobsters by the absence of large crushing claws characteristic of the latter animals as well as the presence of the flexible tail fin.

Spiny or rock lobsters are a very successful group of benthic decapod Crustacea, comprising about 49 species, distributed around the world (Kanciruk, 1980). Their habitat varies greatly among species and they occupy littoral to deep (>400 m) marine habitats in tropical and subtropical waters as well as in certain temperate regions (Prem-Kumar and Daniel, 1975). In many parts of the world lobsters are caught in baited traps or tangle nets. Most of the tropical and subtropical species belong to the genus *Panulirus* and are caught mainly by South Africa, Cuba, Western Australia, the United States, Brazil, Japan, Mexico, Saudi Arabia and India.

There is a continuously increasing demand for all species of lobsters all over the world and this is reflected in their increasing value. As a result, both spiny and clawed lobster populations have been subjected to intense fishing pressure with an annual catch at or above maximum sustainable yield. Scientists working on lobster resources have developed numerous biological, economical and bio-economical models for the management of lobster fisheries, but unfortunately most of these models have not been fully successful so far because of the limited nature of the available data. Lobster fisheries of most parts of the world are hampered by stock assessment difficulties as well as severe economic problems. Recently a great deal of interest has been generated towards lobster aquaculture specially in Japan, Canada, the United States, Australia and New Zealand.

According to Prem-Kumar and Daniel (1975), out of the species recorded from the Indian ocean, four species namely, *Panulirus homarus*, *Panulirus ornatus*, *Panulirus versicolor* and *Panulirus penicillatus* are commercially exploited in the Indian region. In terms of it's species diversity Sri Lanka is renowned for a rich Palinurid fauna. Six species of Panulirid lobsters have been recorded from Sri Lankan waters (De Bruin, 1962), as follows.

a) *Panulirus homarus* (Linnaeus, 1758)

b) *Panulirus ornatus* (Fabricius, 1798)

c) *Panulirus versicolor* (Latreille, 1804)

d) *Panulirus longipes* (A. Milne Edwards, 1868)

e) *Panulirus penicillatus* (Oliver, 1791)

f) *Panulirus polyphagus* (Herbst, 1796)

Of these, *P. homarus* (Fig. 1.1) dominates, with a contribution of around 70 - 80% of the total lobster production of the south coast of Sri Lanka (Jayakody and Kensler, 1986).

The commercial fisheries of spiny lobsters in Sri Lanka are restricted to various narrow stretches of rocky areas of the inshore region along the coast line. During the early 1980s, the possibility of earning more foreign exchange by increasing exports gave new impetus to the hitherto less exploited spiny lobster industry in Sri Lanka. As a consequence of this increasing demand, several lobster processing factories were established along the south coast and appreciable quantities of frozen lobsters and lobster tails are exported annually. Exploitation of spiny lobster resources, which remained as a subsistence fishery at some centres along the Sri Lankan coast until the 1980s, has developed into a profitable venture. With the onset of the lobster season more than 500 canoes are involved in fishing activities along the south coast and also in each year a considerable number of fishermen from other parts of the country migrate to the south coast for lobster fishing. For commercial purposes, lobsters are graded into six market categories according to their weight (gm): a) 50-110, b) 110-250, c) 250 -450, d) 450-550, e) 550-650 and f) 650 - 1000. Of these the 250 - 450gm group fetches the highest export price. The average market value of a kilogram of spiny lobsters of 250 - 450gm group ranges from 700 -800 Sri Lankan rupees

Fig. 1.1 ***Panulirus homarus*** **(Linnaeus)**

(The picture shows the colour range of the species)

(SL.Rs) which is equivalent to £10 - 11. The spiny lobster fishery in Sri Lanka is a considerably important foreign exchange earner with 95% of the catch being exported. Approximately, 5% of the landings are consumed locally mainly in tourist hotels. After 1982, Sri Lanka's annual lobster production varied around 600 mt and out of which, around 30% is contributed by the south coast fishery. Initial estimates for the lobster production of the south coast were made by Jayakody and Kensler (1986) and according to them the total production for 1985/86 season was around 200 mt. After 1982, the lobster export figures showed a gradually declining trend. In 1990, the export of 185 mt of spiny lobsters valued to a maximum of 86.4 million SL.Rs.

Since spiny lobster populations are subjected to heavy exploitation, the introduction of a suitable management strategy appears to be most important if the fishery is to provide the maximum benefit to the community. Fishermen employ several different methods to catch spiny lobsters, and a single stock may be the target of all the different methods. In this connection, selection of an appropriate level of fishing effort to achieve the optimum yield by using a suitable yield assessment model may be important. With the introduction of higher fishing pressure on lobster resources, management becomes essential and knowledge regarding the optimal sustainable yield of desirable lobster species becomes necessary. This requires a body of knowledge concerning the dynamics of lobster populations, including an understanding of the mechanisms by which lobster stocks are produced, and how their numbers are regulated, the effect of fishing on a stock, and kinds, quantities and sizes of lobsters that can be taken on a continuous basis by different kinds of fishing.

Where research is concerned, work on spiny lobsters in Sri Lanka appears to be scanty. De Bruin (1960, 1962, 1969, 1970), described the capture methods, distribution, ecology and biological aspects of spiny lobsters. Apart from catch estimate studies made by Jayakody and Kensler (1986) and Jayakody (1987), for the south coast spiny lobster fishery and Jayawickrama (1991) for the west coast fishery, no scientific study on spiny lobsters has been conducted in Sri Lankan waters.

In addition to catching legal sized lobsters, fishermen collect a considerable quantity of undersized lobsters. These undersized lobsters are usually inadequately recorded. So far no information is available on the stock - recruitment relationship of spiny lobsters in Sri Lankan waters and thus it becomes impossible to decide how large should be the stock of breeding females required for adequate annual recruitment.

As the Sri Lankan lobster fishery is a free access public fishery, the most appropriate way of controlling fishing effort would be to limit the numbers of fishermen taking part in the fishery. Introduction of a suitable minimum size and setting it above the size at maturity may also be a useful solution. When all these were taken into consideration, it appeared that the major objective of this study should be to examine the biology of *Panulirus homarus*, to determine the effect of commercial exploitation and to produce the information necessary to advise the Sri Lankan government on suitable management measures necessary to ensure the future rational utilization of the spiny lobster resource. The present investigation was therefore undertaken particularly to study the fishery, reproductive biology and population dynamics of *Panulirus homarus* and also to obtain a better knowledge of the other co-occurring *Panulirus* species for the introduction of a proper management model.

1.1 Spiny lobsters in the world fishery scene.

1.1.1 Annual landings - major countries and species.

During the 1950s to 1960s, the principal producers of spiny lobster were South Africa, Australia, New Zealand, Cuba, Brazil, the United States and Mexico. The South African fishery was based mainly on *Jasus lalandii* (Heydorn, 1969b). The fishery of the Australian west coast was based principally on *Panulirus argus* and that of the south east coast was based on *Jasus novaehollandiae*. The west coast fishery yielded approximately 8000t annually, and the south east coast 4000t per year (Bowen, 1980).

The New Zealand fishery is based principally on *Jasus edwardsii* and its present annual production is approximately 3500 t per year. The major fisheries of Cuba, Brazil, and the United States are based on the spiny lobster *Panulirus argus*. In 1974, the *Panulirus* fisheries of the United States produced approximately 6000t per year, while Cuba and Brazil produced 10,000t and 8000t respectively (Bowen, 1980). *Panulirus laevicauda* is also taken in substantial numbers in Brazil, accounting for about one fifth of the countries production. Along the coast of California, there is a relatively small fishery for *Panulirus interruptus* with an annual production of approximately 100t. This species is also caught in Mexico. Some of the more common species of Palinuridae living in tropical waters and their production figures are given in Table 1.1.

As far as Norway lobster *Nephrops norvegicus* is concerned, the fishery based on waters in north eastern Europe, the Mediterranean and north western Africa yielded around 62382 mt in 1988, which was very much higher than the recorded spiny lobster production of the world (FAO, 1988). The total annual production of the genus *Panulirus* is 56121 mt of which, around 50% consisted of *P. argus* and *P. cygnus* (FAO, 1988).

1.1.2 Collapsed spiny lobster fisheries.

South Africa was undoubtedly the most important lobster fishing and marketing region of the African continent during the early 1950s (Soares-Rebelo, 1964). It produced about 75-80% of the annual output of the live lobsters in Africa. This fishery is based mainly on *Jasus lalandii.* In 1952, the annual production was around 24000t but it had collapsed to a level of 8000t towards the end of 1970s(Bowan, 1980).

According to Pollock and Shannon (1987), this large decline in catches happened as a result of environmental changes during and after the 1960s. It is postulated that a progressive expansion of oxygen deficient shelf water may have forced lobsters to occupy a much reduced habitat in shallow waters, where overcrowding has resulted in reduced growth, survival and production, thus yields have declined accordingly. In the spiny lobster fishery off the west coast of Africa, an experimental series of reductions and finally suspension of the legal minimum length resulted in a constant fall in annual production (Bayers, 1979). Of the other spiny lobster fisheries, the decline of New Zealand's spiny lobster fishery at the Chatham Islands is perhaps the most striking example (Annala, 1977). Odemar, Bell, Haughan and Hardy, (1975), reported that commercial landings of the Californian spiny lobsters decreased from 933449 pounds (424.3 mt), in 1950 to 160025 pounds (72.74 mt) in the

1974/75 season. *P. homarus* fishing in Kanyakumari district on the south west coast of India has declined from 1045111 numbers in 1965 to 171260 in 1967. Accordingly, a catch of 91 lobsters per fishing unit in 1965 had dropped to 55 per unit in 1967 (George, 1973). The results given by Sanders and Bouhlel (1984) for the *P. homarus* fishery in Republic of Yemen indicate that a catch weight of 166.4 mt in 1972/73 had dropped to 52.3mt in 1982/83. The south coast spiny lobster fishery in Sri Lanka has been studied by Jayakody and Kensler (1986), and according to them the total production of 200mt in 1985 had dropped to 110mt in 1986.

Table 1.1 Production figures of some of the major spiny lobster fisheries in the tropical region.

Species	Area of significant fishery	Production (ton)
Panulirus longipes	Thailand,India, Pakistan, Southeast Asia	3700
Panulirus ornatus	Papua New Guinea, East Africa	540
Panulirus penicillatus	Reunion, Pacific Islands, Galapagos	400
Panulirus homarus	East Africa, Indonesia India, Sri Lanka, Thailand	1100
Panulirus argus	Caribbean, Brazil	22,800
Panulirus laevicauda	Brazil	3000
Panulirus regius	North-west Africa, Portugal	450
Panulirus gracilis	Equador, Panama	270
Panulirus polyphagus	Sri Lanka, India	100

(Table given by Morgan (1980) has been updated according to the available data in the literature)

1.1.3 Spiny lobster fishing methods and gear.

A variety of fishing methods and gear are employed in spiny lobster fisheries in different countries. In India, spiny lobsters are caught by traps, pots, a type of anchor shaped hooks and gill nets. To a lesser extent they are also taken in trawl nets (Joseph, 1971). In South African waters, *Jasus lalandii* is caught in shallow waters using drop nets, whereas in deeper waters (>100m), they are caught by traps (pots), operated by powered vessels (Bowen, 1980). On the west coast of Australia, where a major fishery for *Panulirus cygnus* exists, three types of lobster pots are used to catch them :

a) wooden - " batten"

b) stick or cane - " beehive"

c) Wire - " beehive"

Generally the smaller spiny lobsters of up to 3-4 years of age inhabit the shallow water reefs in depths of 7m where "batten" pots are used. The "beehive" pots are used in waters of all depths. Cast nets and arrowhead traps are used to catch spiny lobster *P. homarus*, which is the main commercial fishery in the East Aden (George, 1963). These cast nets are those employed to catch sardine and measure about four meters in diameter. To catch lobsters, these nets are cast from the edge of the shelving reefs over the sublittoral rocks and the fishermen dives into about two meters of water to disturb by hand the lobsters living under the rocks. When the lobsters are tangled in the nets and after gathering the weighted ring line, the fishermen bring the catch to the reef for sorting.

In Philippine waters, spiny lobsters *Panulirus penicillatus* are caught by hand picking in shallow waters and also by spear fishing (Arellano, 1989). The *P. ornatus* fishery in Papua New Guinea is mainly carried out by diver fishermen (75%), and the remainder by prawn trawlers (Bell,Channells, MacFarlane, Moore and Phillips, 1987).

In Republic of Yemen, fishermen use entangling set nets to catch *P. homarus*. Typically, some 3 - 5 of these nets, each about 100m long and several meters in depth are operated by fishermen using 7m long out board motor boats. In addition to the set nets, cast nets are sometimes used in very shallow waters (Sanders and Bouhlel, 1984).

In Sri Lanka, particularly in the south coast, fishing is highly affected by the south-west monsoon, which prevails from April/May to August/ September. As lobster fishing is mainly done by small non-mechanized outrigger canoes, prevailing rough weather conditions during monsoonal months automatically limit fishing activities. In Sri Lankan waters fishermen use four different fishing methods to catch spiny lobsters along the south coast, namely: a) Lobster rings b) Bottom set gill nets c) Trammel nets and d) Skin diving (see Fig. 4.2).

1.2 The Sri Lankan spiny lobsters.

According to "Zoological Survey of India" and the literature available in the region, there are eight valid species of the genus *Panulirus* White 1847, in the Indian Ocean, namely:

Panulirus japonicus (von Siebold), *Panulirus longipes* (A. Milne Edwards), *Panulirus penicillatus* (Oliver), *Panulirus cygnus* (George), *Panulirus homarus* (Linnaeus), *Panulirus versicolor* (Latreille) , *Panulirus ornatus* (Fabricius) and *Panulirus polyphagus* (Herbst). Of these, *P. longipes*, *P. penicillatus*, *P. homarus*, *P. versicolor*, *P. ornatus* and *P. polyphagus* have been so far recorded from Sri Lankan waters (De Bruin, 1962, Jayakody and Kensler, 1986).

1.2.1 Distribution and abundance.

The species distribution of *Panulirus* around the coast of Sri Lanka is shown in Fig. 1.2. *P. homarus* dominates the south and west coasts, *P. ornatus* the north and *P. versicolor* the east coast (De Bruin, 1962). In the north, particularly close to Delft Island, Nainativu and Punkuduthivu (Jaffna area), five species of *Panulirus* were observed, of which, *P. ornatus* was the dominant species (De Bruin, 1962). Although *P. versicolor* dominated on the east coast, high densities of *P. polyphagus* were observed around the Mullattivu area situated on the north eastern part of the country (Fig. 1.2). Off Mullattivu, the sea bottom consists of mud which is not the normal habitat for lobsters. *P. polyphagus*, which was not recorded from any other part of the country was caught here during trawling operations (De Bruin, 1962). Kalkudah area of the east coast, where a considerable area of coral reefs is available is dominated by *P. versicolor*. The reefs between Patnangalle and Galle of the south coast and Galle to Negombo of the west coast are dominated by *P. homarus*. To obtain a clear understanding about the species distribution and species composition around the country, in addition to Figure 1.2, a species composition chart has been prepared and is shown in Table 1.2.

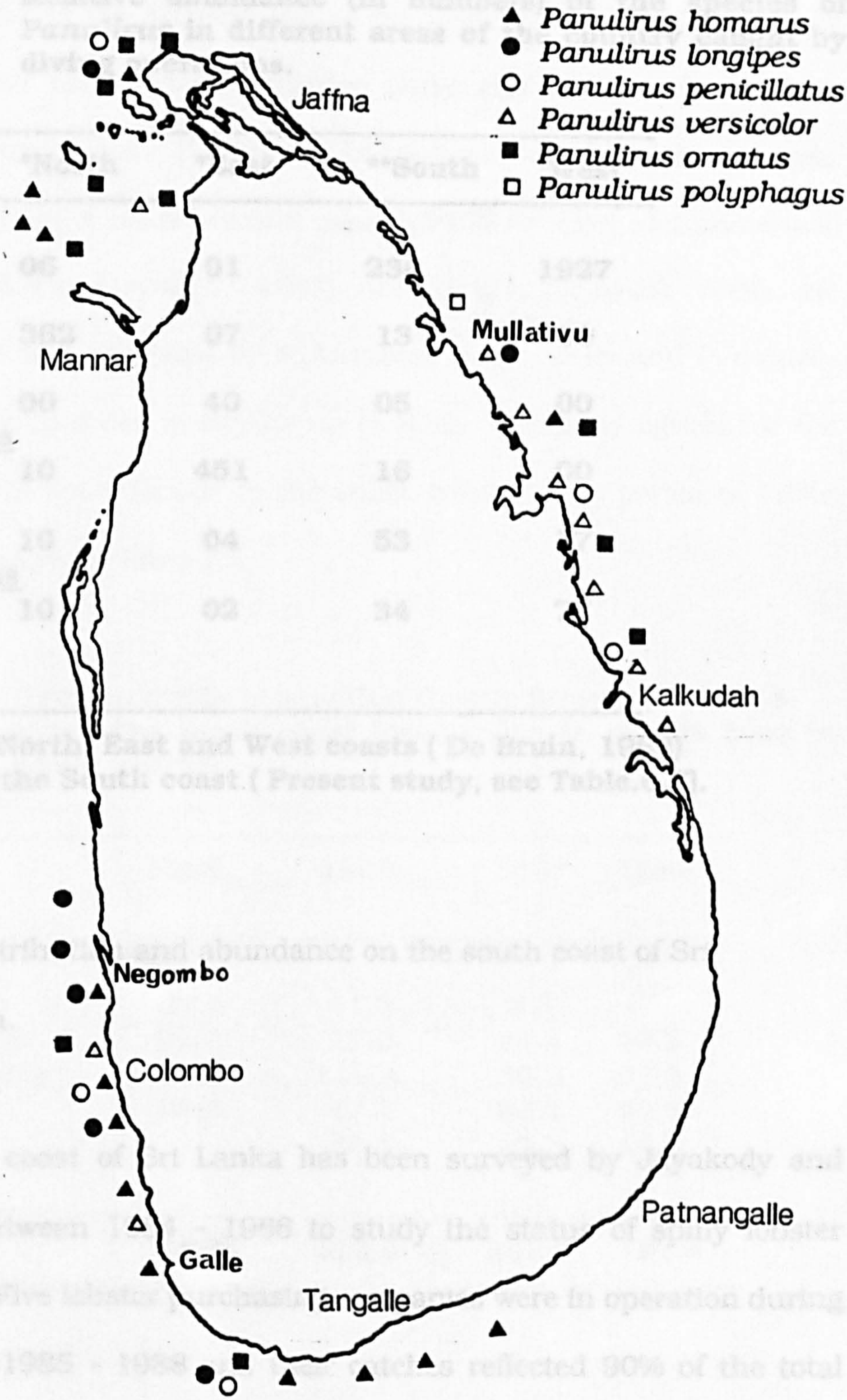


Fig. 1.2 Distribution of species of *Panulirus* around the coast of Sri Lanka (from De Bruin, 1962).

Table. 1.2 Relative abundance (in numbers) of the species of *Panulirus* in different areas of the country caught by diving operations.

	*North	*East	**South	*West
P. homarus	06	01	236	1927
P. ornatus	362	07	13	00
P. polyphagus	00	40	05	00
P. versicolor	10	451	16	00
P. penicillatus	10	04	53	17
P. longipes	10	02	34	77

*** Data for North, East and West coasts (De Bruin, 1962)**
****Data for the South coast (Present study, see Table.6.7).**

1.2.1.1 Distribution and abundance on the south coast of Sri Lanka.

The south coast of Sri Lanka has been surveyed by Jayakody and Kensler, between 1984 - 1986 to study the status of spiny lobster resources. Five lobster purchasing companies were in operation during the period 1985 - 1988 and their catches reflected 90% of the total production of the south coast. During the 1986-1987 period, a survey on spiny lobsters was carried out by Jayakody (1987) at Patnangalle area situated in the extreme end of the south coast (Fig. 1.2). All six spiny lobster species were recorded there and of them *P. homarus* dominated the catches. The maximum sustainable yield for the area was estimated using a catch per unit effort (CPUE) vs effort plot and found to be 11086.5 kg (Jayakody, 1987). According to De Bruin (1969), the south coast was inhabited by *P. homarus*, *P. versicolor* and *P. ornatus* and all were recorded in depths up to 60m. Company figures for the production of spiny lobster in the south coast for the period of 1985-1988 are shown in Table 1.3.

Table 1.3 Company wide production figures for spiny lobsters along the south coast (production in metric tons in whole weight).

COMPANY	1985	1986	1987	1988
EXPOCATE	27.4	11.2	6.3	-
SEA & LAND	25.6	17.6	31.4	20.3
AGROMARINE	170.0	110.4	50.3	37.3
ANDRIEZ	80.3	47.3	36.2	20.6
SRI MIC	-	26.3	40.0	54.6
TOTAL	303.3	212.8	158.2	132.8

1.2.2 Fishery for spiny lobsters in Sri Lanka.

There is no recorded literature on the initiation of the lobster fishery on a commercial basis in Sri Lanka. However it has developed rapidly during the last two decades. In Sri Lanka, particularly on the south coast, fishing is mainly done by non-mechanized outrigger wooden canoes ranging from 2.5 - 3 m in length. Some of these canoes are sail driven and the others are paddled by hand. The fishery is highly affected by the rough weather conditions caused by the south-west monsoon which prevails from April to August.

Spiny lobsters are caught through out the year, but the best season is from August to March during which time 90% of the annual catch is taken. Usually fishermen make daily fishing ventures. They set their nets in the evening and collect in the following morning. The total number of craft actually engaged in the fishery increased from 350 in 1985 to 560 in 1990. Although spiny lobsters are found throughout the Sri Lankan coast line, they are most abundant along the southern shore where the bottom is rocky and ledges are prominent.

At the beginning of the season, few fishermen enter into the fishery, but during November and December almost all the craft actively engage in the industry. Fishing activities are mostly restricted to local fishing grounds in coastal waters up to a depth of 30m. Area wise it extends to a maximum of 5 km from the coast line. By and large, the lobster fishery, because of its special and localised nature, mostly functions within the ways and means of local artisanal fishermen. Technological advance made no inroads into lobster fishing in Sri Lanka until 1985, after which several significant changes took place.

1.2.3 Recent changes in the spiny lobster fishery.

Until 1984 the exploitation pattern of the lobster fishery was more or less uniformed. Since 1985, there were several significant changes have taken place in the lobster fishery as a result of the high demand and attractive prices. The changes are as follows.

a) Fishing during the southwest monsoons: Due to the introduction of 6m mechanized out board engine boats the fishing effort during the southwest monsoons has increased progressively for the past 5 years.

b) Live lobster export industry: Since 1988 there is a growing demand for live lobsters for export. Higher prices are being paid for undamaged live lobsters. These lobsters are kept in aerated tanks until they are exported to the destination (Japan and Singapore). There is a particular demand from Japan for undamaged live berried females.

perhaps for aquaculture purposes.

c) Multi-day fishing ventures: Since 1989, fishermen of the southern coast started migrating to the extreme end of the coast where road access is lacking. They carry out fishing for 7 -10 days and the lobsters that are being caught are kept alive in submerged metal wire mesh cages (1m x 1m x 1m). These lobsters are fed with rotten fish, fish heads, cuttle fish and mussels.

d) Introduction of trammel nets: Since 1985, most of the usual 7.5 cm meshed bottom set nets are being replaced by trammel nets and this is the most destructive change which has taken place. These trammel nets are non-selective and a wider size range of lobsters are being entangled (see Table 6.2).

1.2.4 Spiny lobster production in Sri Lanka.

The annual production of spiny lobster in Sri Lanka from 1980 - 1990 is shown in Fig. 1.3 and Table 1.4. The area wise breakdown in production for 1985 - 1989 is given in Table 1.5 for available areas.

De Bruin (personal communication) reasoned that the changes in

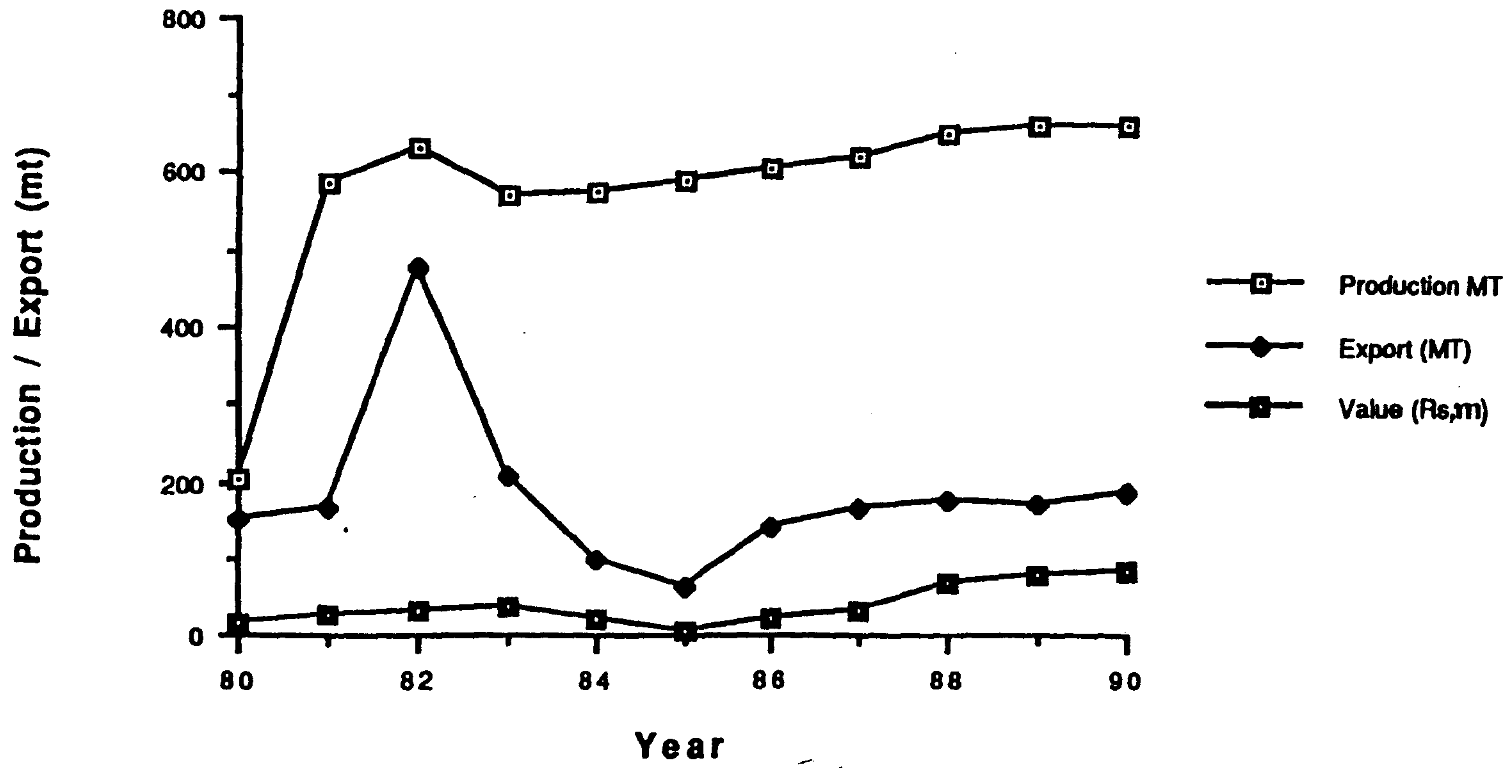


Fig. 1.3 **Production, export and earnings of the Sri Lankan spiny lobster industry during 1980-1990.**

annual production in Sri Lankan spiny lobsters cannot be considered as reflecting the abundance or year to year variability of lobsters. Catching methods have been uneven and the attempts sporadic. During the 1970s, a lack of proper and sustained demand discouraged fishermen as well as company owners from risking capital investment in suitable gear and sustained operations. The unsettled situation in the country for several years which discouraged lobster company owners from investing money etc. are additional reasons advanced to explain the discontinuity and unreliability of production figures. Fig. 1.4, has been prepared using the annual production figures obtained from the lobster companies (1970 - 1979) and also using the published data by the Ministry of Fisheries (1980 - 1989). In recent years the spiny lobster production has increased in almost all areas of the country except the south coast, where a very clear decline in production was observed. The total spiny lobster production in Sri Lanka has exceeded 600mt mark mostly since 1986.

Table 1.4 Annual Production of spiny lobsters from 1980 - 1990.

YEAR	PRODUCTION (MT)[a] (A)[*]	(B)[**]	EXPORT (MT)[b]	VALUE[*] Rs.M
1980	204	-	149.7	15.9
1981	589	-	167.9	25.5
1982	636	-	479.7	33.4
1983	571	-	206.0	38.3
1984	577	-	100.0	20.9
1985	592	(116)	64.0	6.4
1986	608	(408)	139.0	20.2
1987	625	(447)	168.0	31.1
1988	654	(471)	176.0	69.9
1989	663	(410)	174.0	75.8
1990	665	(401)	185.0	86.4

* Ministry of Fisheries (Sri Lanka) - Administrative Reports
** Lobster company statistics
a Production in whole weight of lobsters
b Export in tail weights

Table 1.5 Spiny lobster production figures (MT) by area for the period from 1985 - 1989.

AREA	1985	1986	1987	1988	1989
W. C.	13.3	17.1	30.6	20.3	19.2
SW. C.	12.1	25.1	34.2	44.9	32.4
S. C.	303.3	212.8	158.2	132.8	127.3
E. C.	0.0	12.0	36.3	52.6	34.4
NE. C.	14.1	44.0	91.1	70.4	94.4
N. C.	19.0	57.0	64.2	58.3	64.1
NW. C.	11.6	64.1	5.5	51.5	42.1
Total	373.4	432.1	420.1	430.8	412.9

SOURCE: Lobster companies of the respective areas.
W = West, SW = South west, S = South, E = East, NW = North West, N = North, NW = North west, C = Coast.

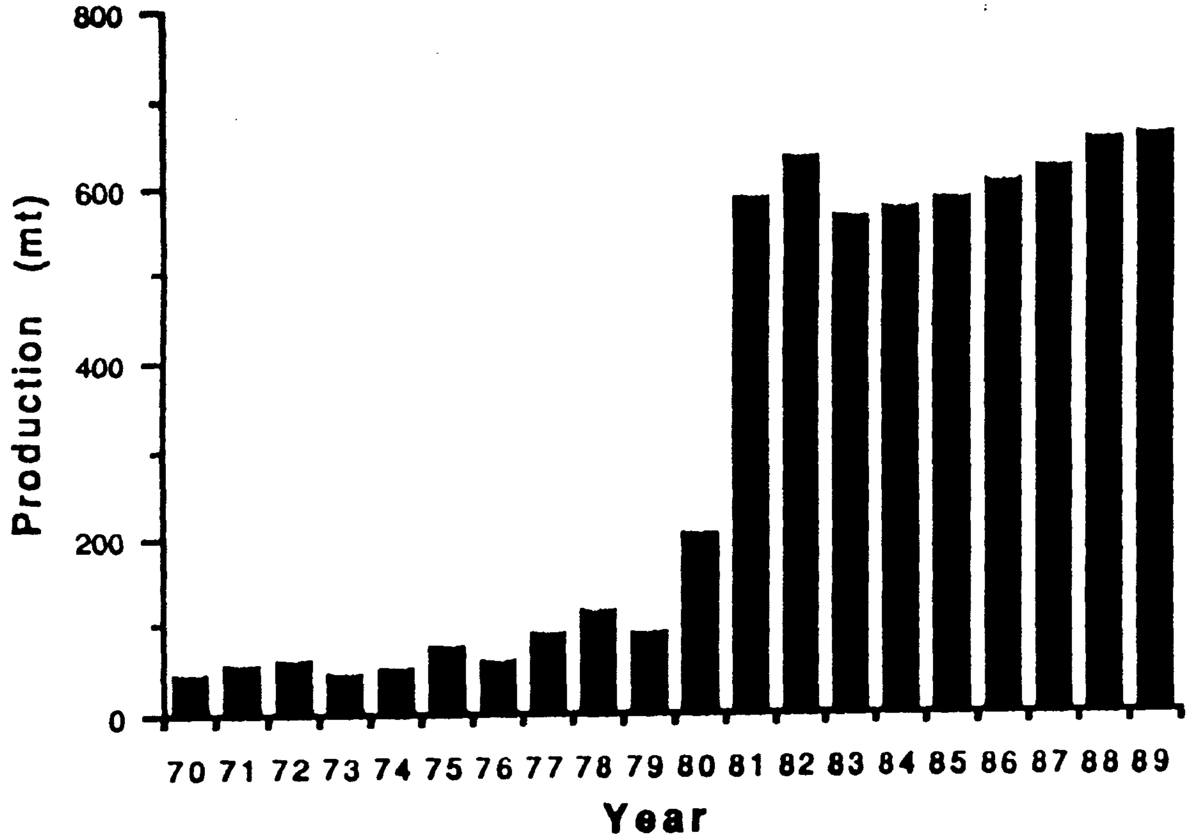


Fig. 1.4 Spiny lobster production figures of Sri Lanka from 1970-1989.
1970 - 1979 Lobster company data(1990 b)
1980 - 1989 Ministry of fisheries records(1990 a)

1.2.5 Utilization of spiny lobsters.

The domestic market for spiny lobsters in Sri Lanka is only a small fraction when compared to the export market. Over the last few years, earnings from sea food exports have shown a steady increase from Rs. 15.9 million in 1980 to Rs. 86.4 million in 1990 (Table 1.4). This increase is mainly due to an increase in the export prices, rather than an increase in the quantities exported. Even though the export earnings have increased several fold during 1986-1990 period the quantity of sea food exported has increased only by 30% during the same period. The major marine product exported from Sri Lanka are shrimp, accounting for nearly 65% of the exports, followed by crabs, lobsters, cuttlefish, ornamental fish, shell fish and shark fins. Sri Lanka's main spiny lobster buyer is Japan and a country-wide export breakdown for the year 1989 extracted from Subasinghe, Namaratne and Perera, (1990) and is given in Table 1.6.

Lobster exports have remained somewhat steady with a peak of 479.7 mt in 1982. The lowest export figure of 64mt was noted in 1985 (Table 1.4). During the past ten year period, the local price of lobsters has increased from SL Rs. 106 to Rs. 800 per kg (£ 1.4-11.4).

1.3 General life history - A review of literature.

1.3.1 Taxonomic status of *Panulirus* species.

Most of the information available on the general life history of *P. homarus* in Sri Lankan waters is the result of investigations carried out by De Bruin (1962, 1969). When the tropical region is considered, valuable contributions have been made by Heydorn (1969a) and Berry (1971b, 1974), especially on the life history and taxonomy of *P. homarus*.

Table 1.6 Country-wide export figures of Sri Lankan spiny lobsters.

Country	Quantity(MT)	Value(Rs.Million)
Japan	134.6	60.000
U.S.A	24.3	10.500
Hongkong	7.4	3.000
France	6.8	2.140
Singapore	1.4	0.140
Maldives	0.03	0.120
Australia	0.01	0.001
Total	174.54	75.901

The genus *Panulirus*, established in 1847 by White, contains those species of Palinuridae, in which the carapace has no rostrum, the pleopods and the second abdominal somite of the female differ greatly from the following pairs, and the antennular flagella are very long. This genus is represented by 17 species (De Man, 1916). The review by Holthuis (1946) made after the Snellius Expedition 1, provides basic distributional and taxonomical data for the species of Palinuridae.

The genus *Panulirus* has a wide Indo-Pacific distribution (Holthuis, 1946; Barnard, 1950; George and Holthuis, 1965). It appears that the species belonging to this genus are widely dispersed and exhibit a considerable degree of variation according to the location of occurrence. This has led to a certain amount of confusion with regard to their taxonomy. Much of the uncertainty was cleared up by the revision made by George and Holthuis (1965). The original list of the genera, species and varieties of Palinuridae given by De Man (1916) has been up dated by Holthuis (1946). The most updated taxonomic list of the living species of the family Palinuridae according to Phillips, Cobb and George, (1980), is as follows.

Palinuridae Gray, 1947

Genus	Species
1. *Palinustrus*	*mossambicus* Barnard (1926) *truncatus* A. Milne Edwards (1880) *waguensis* Kubo 1963
2. *Projasus*	*parkeri* Stebbing 1902 *bahamondi* George 1976
3. *Linuparus*	*trigonus* (von Siebold 1824) *sordidus* Bruce 1965 *somniosus* Berry and George 1972
4. *Puerulus*	*angulatus* Bate 1888 *carinatus* Borradaile 1910 *swelli* Ramadan 1938 *velutinus* Holthuis 1963
5. *Palinurus*	*elephas* Fabricius 1787 *gilchristi* Stebbing 1900 *mauritanicus* Gruvel 1911 *charlestoni* Forest and Postel 1964 *delagoae* Barnard 1926
6. *Jasus*	*lalandii* (H. Milne Edwards 1837) *verreauxi* (H. Milne Edwards 1851) *frontalis* (H. Milne Edwards 1837) *edwardsii* (Hutton, 1875) *paulensis* (Heller 1862) *novaehollandiae* Holthuis 1963 *tristani* Holthuis 1963
7. *Justitia*	*longimanus* (H. Milne Edwards 1837) *japonica* (Kubo 1955) *mauritiana* (Miers 1882)

8. *Panulirus*	*argus* Latreille, 1804
	echinatus Smith 1869
	homarus homarus (Linnaeus 1758)
	interruptus (Randall 1840)
	japonicus (von Siebold 1824)
	laevicauda (Latreille 1817)
	ornatus (Fabricius 1798)
	penicillatus (Oliver 1791)
	polyphagus (Herbst 1796)
	versicolor (Latreille 1804)
	guttatus (Latreille 1804)
	inflatus (Bouvier 1895)
	cygnus George 1962
	gracilis Streets 1871
	homarus megasculpta Pesta 1915
	homarus rubellus Berry 1974
	longipes femoristriga (von Martens 1872)
	pascuensis Reed 1954
	regius (de Brito Capella 1864)
	stimpsoni Holthuis 1963

A detailed examination was made by Prem-Kumar and Daniel (1975) on the material collected from the Zoological Survey of India. They cited 8 valid species of the genus *Panulirus*, White 1847, from the Indian Ocean which are:

P. japonicus, *P. longipes*, *P. penicillatus*, *P. cygnus*, *P. homarus*, *P. versicolor*, *P. ornatus* and *P. polyphagus*.

1.3.2 Races of *Panulirus homarus*

A review of the literature reveals that the identity of *Panulirus bugeri* (De Haan) and *Panulirus dasypus* (Latreille) has been doubted by many researchers in the field of *Panulirus* taxonomy. This was clarified by Gordon (1953) and the two species were assigned to a single species called *Panulirus homarus* (Linnaeus). A revision of the species *P. homarus* was made by Berry (1974), who also gave a detailed description of this species in the south-western Indian ocean. The distribution pattern of *P. homarus* in different regions has been documented by several workers, for instance De Bruin (1962) in Sri Lankan waters; Heydorn (1969a) and Berry (1971a) in South African waters; Batia (1974) in Thai waters; Prem-Kumar and Daniel (1975) in Indian waters and Schreiber and Cases (1985) in Philippine waters.

P. homarus is among the eight valid species of the Indian Ocean and also contributes considerably to the commercial spiny lobster production of the region (George, 1973; Prem-Kumar and Daniel, 1975; Schreiber and Cases, 1985). Colour and morphological differences of *P. homarus* have been reported by Berry (1974), and according to him there exists two forms (Fig. 1.5) of this species, namely;

A. Megasculpta form - this has been further divided into two of the following forms:

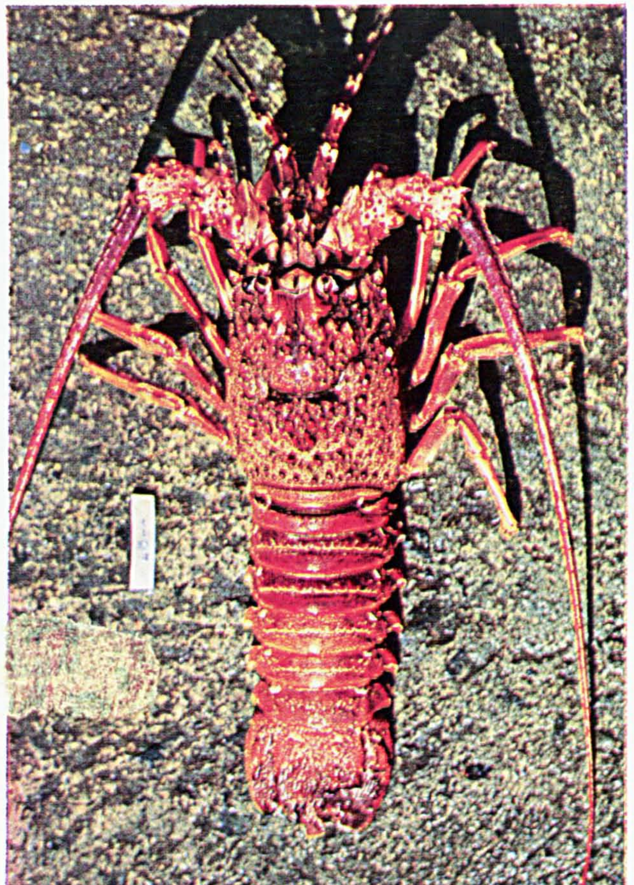
1) "Nothern megasculpta form" - North-western region of South Arabia, Somalia and south-west coast of India.

2)"Southern megasculpta form" - Confined to the south-east coast of Africa and Madagascar.

B. Microsculpta form - mainly in the eastern and northern Indian Ocean.

De Bruin's results have been subjected to analysis by Berry (1974), who concluded that the Sri Lankan *P. homarus* is the microsculpta form.

(A)



(B)

Fig. 1.5 Megasculpta (A) and Microsculpta (B) forms of Panulirus homarus (L.).
(from Berry, 1974)

1.3.3 Adult habitat.

The Palinuridae occupy a circumglobal band from approximately 45° N to 45° S latitude. Genera of Palinuridae have been grouped taxonomically by external morphology and also loosely correlated with latitude, water depth and temperature (George and Main, 1967). Adults have been recorded from depths ranging from 1 to > 100m but the majority prefer < 50m depths. Adult habitat preference varies among Palinuridae from the shallow intertidal surf zone to great ocean depths (Kanciruk, 1980). It is well known that spiny lobsters are invariably nocturnal in their habits, mostly for foraging. The animals spend the daylight hours by hiding in rock corners, crevices and cavelets between and below boulders, rocks, corals etc. and venture out only after dark.

De Bruin (1969), separated six species of the genus *Panulirus* inhabiting Sri Lankan waters into habitat types by considering the turbidity of sea water, bottom substrata, salinity, temperature, depth and calmness or agitation of the sea water. Berry (1971a), classified the *Panulirus* habitat along the west coast of South Africa by considering water temperature, turbidity, bottom type, depth, tidal range and geographic area. George (1974), described the habitat preference of several members of the genus *Panulirus* and according to him *P. penicillatus* inhabit the rock shelters characteristic of the outer shelf zone, *P. versicolor* resided in the delicate coral formations along the deeper reef face and *P. ornatus* occupied the long shore area. According to Berry (1971a), *P. homarus* inhabit the surf zone associated with surge - washed rocks. *P. longipes* was found adapted to a range of habitats from clear water reef areas to the turbid shallow waters. According to De Bruin (1969), *P. polyphagus* has been encountered only on a mud turbid substratum at moderate depths.

In Sri Lankan waters, the genus *Panulirus* is represented by six species as mentioned in section **1.2**. Their distribution is dependent on the type and availability of sea bed preferred by each species which is discussed in detail in section 6.4.

1.3.4 Eggs and spawning.

The age and size at which the female *P. homarus* reaches sexual maturity varies considerably in different areas.

Country	Size at spawning Carapace length (mm)	Reference
Sri Lanka	55 - 59	De Bruin, 1962
East Aden	60 - 70	George, 1963
South Africa	50	Heydorn, 1969a
South Africa	50 - 60	Berry, 1971b

The spawning season in different areas of the region varies considerably as shown below:

Country	Spawning season	Reference
Sri Lanka	Aug.-Mar.	De Bruin, 1962
South Africa	Nov.-Jan.	Heydorn, 1969a
South Africa	Nov.-Jan.	Berry, 1971b
Thailand	Jun.-Oct.	Rongmuangsart and Luvira, 1973

According to Heydorn (1969a), there was no indication of more than one spawning per year, while repetitive breeding in *P. homarus* was reported by Berry (1971b), Sanders and Bouhlel (1984).

Initially the ova are not spherical and their approximate diameter ranges from 0.07-0.15 mm, but at the time of spawning they are around 0.35-0.46 mm in diameter (Berry, 1971b). No one has so far recorded the actual process of egg deposition and attachment of eggs to the setae in *P. homarus*. The eggs are fastened to the ovigerous setae in bunches and the number of eggs in each bunch varies considerably. It is assumed that, once the eggs are released, they are fertilized externally and are driven backward against the pleopods by beating of the endopodites. Mostly, spiny lobsters lay their eggs during night time and egg laying lasts for 4 - 6 hours (Crawford and Smidt, 1922).

Newly spawned eggs are spherical in shape , orange in colour and about 0.54 mm in diameter. Embryonic development starts while the egg is still attached to the female. At the beginning the yolk material is dense and hence the eggs are opaque. Eye spots of the embryo can be seen after 7 days of incubation and by that time 5 pairs of appendages have developed. As the embryo develops, the colour of the egg changes gradually and turns to brown closer to hatching. Upon hatching the egg attains a size of 0.58 mm in diameter. The number of external eggs at spawning in *P. homarus* varies with the size of the female and in the range of 100,000 -700,000 (Berry, 1971b).

1.3.5 Life history.

The general life histories of Sri Lankan spiny lobsters has not so far been fully described. Several researchers working on *Panulirus* spp. in tropical waters have outlined the life history (Berry, 1971b, 1973; George, 1965) and assumed a similar pattern occurs in Sri Lankan waters. Generally the life cycle of most spiny and rock lobsters comprises two distinct phases,

a) Inshore phase - juveniles and adults

b) Oceanic phase - spawning, eggs and larvae

Males are attracted to sexually receptive females, possibly by means of a pheromone sex attractant. After a prolonged courtship the male deposits a putty-like spermatophoric mass on the female's sternum. This becomes hard and protects the spermatozoa until the female is ready to spawn, which may be within a period of 3 - 44 days (Berry, 1973).

The female *P. homarus* attains physical maturity at a carapace length of 59.5mm, by that time they are about 3 years old. During this stage, the majority of females bear eggs. The egg bearing females are available at any time of the year in tropical waters (Berry, 1973). In Sri Lankan waters the spawning season is protracted and extends from August to March (De Bruin, 1969). Most of the female spiny lobsters migrate into deep waters during spawning (Smith, 1958; Phillips et al. 1980).

Egg bearing is recorded throughout the year (Berry, 1973, this study), but most of the breeding activity was observed during August to March. *P.homarus* was found to breed repetitively throughout the year and females become capable of producing more broods as they increase in size. Between 100,000 to 700,000 eggs are laid depending on the size of the female and they are carried under the female's abdomen for 4 - 6 weeks until they are hatched (Berry, 1971b). The incubation period varies among Palinuridae from 3-8 weeks and as the embryo develops, there appears a gradual change in colour of the egg which ranges from orange to dark brown (Lyons, Barber, Foster, Kennedy and Millano, 1981).

The time for incubation was found to be strongly dependent on water temperature (Berry, 1973). Soon after hatching, the tiny larvae called phyllosomas rise to the surface and take up a planktonic life. A stage lasting for a very short period called "pre phyllosoma" was observed in *P. homarus* by Prasad and Tampi (1959) and Deshmukh (1968). After releasing the eggs the female lobsters begin to return to shallow waters. Phyllosomas go through a series of stages (1 - X1), during which time they are mostly non-swimming and planktonic. Early phyllosomas prefer to stay at the water surface, while later stages avoid sunlight during day time and are found in deeper waters (Fig. 1.6). Concentrations of late stage phyllosomas in some of the *Panulirus* species have been found in the waters off the edge of the continental shelf. The duration of the phyllosoma period ranges from 4-6 months for most of the tropical spiny lobsters (Berry, 1971b). The late stage phyllosomas which usually live in deeper waters close to the continental shelf show both a progression in development and an overall reduction in abundance. This overall reduction may possibly be due to heavy predation on them by Moray eels and Octopus etc. The late stage phyllosomas prefer a benthic life and metamorphosis takes place into a stage called " puerulus". This stage is

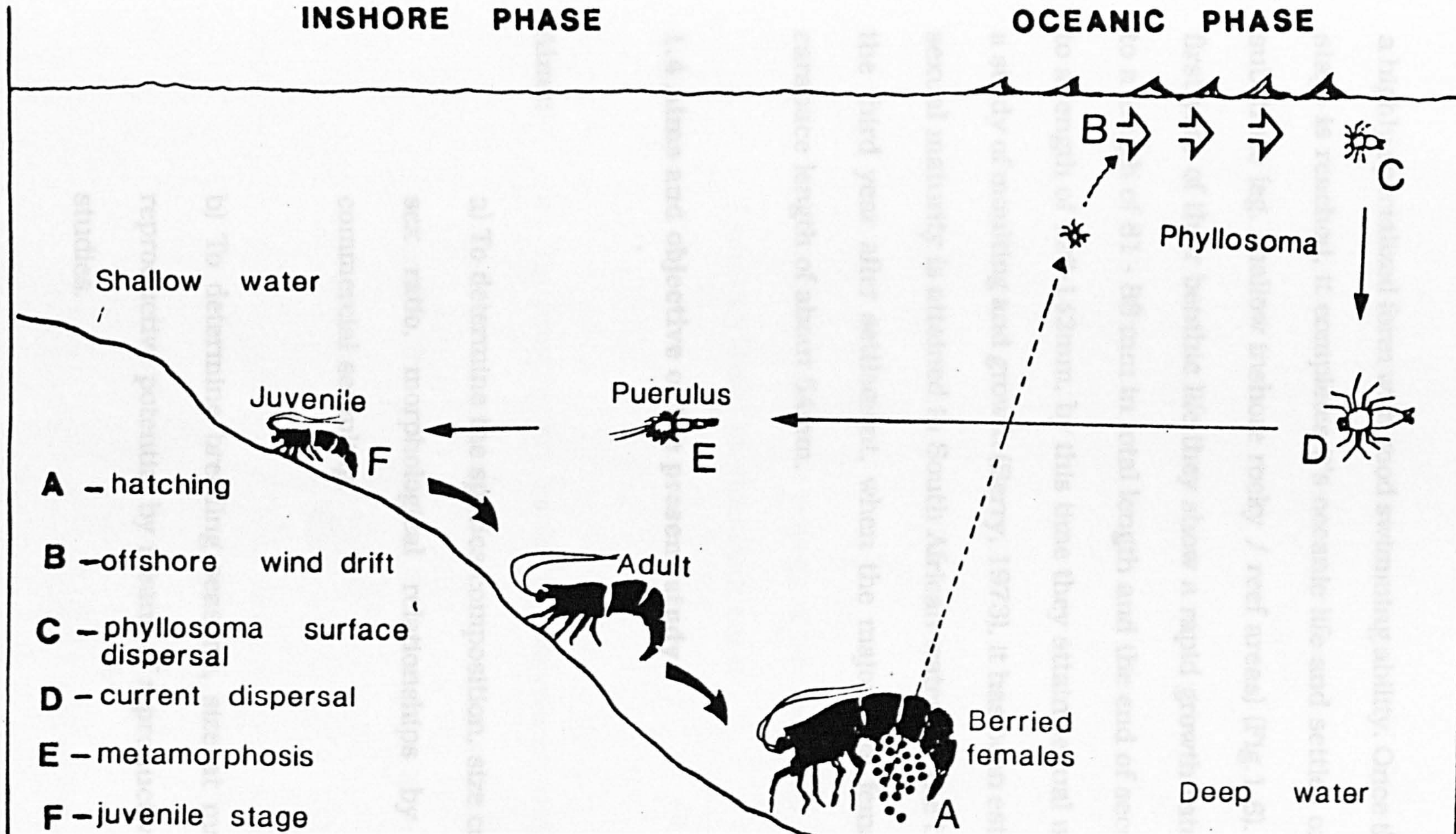


Fig. 1.6 Life cycle of spiny / rock lobster.

a highly specialized form with good swimming ability. Once the puerulus stage is reached, it completes it's oceanic life and settles on a suitable substrate (eg. shallow inshore rocky / reef areas) (Fig.1.6). During the first year of their benthic life they show a rapid growth rate increasing to a length of 81 - 88 mm in total length and the end of second year up to a length of 126-142mm, by this time they attain sexual maturity. In a study of moulting and growth (Berry, 1973), it has been estimated that sexual maturity is attained in South African waters at the beginning of the third year after settlement, when the majority of females have a carapace length of about 54mm.

1.4 Aims and objective of the present study.

Aims:

a) To determine the species composition, size composition, sex ratio, morphological relationships by means of commercial sampling.

b) To determine breeding seasons, size at maturity and reproductive potential by means of reproductive biological studies.

c) To determine the fishing effort expended on the fishery by means of number of fishing days (craft nights), number of crafts operated and type of gear used.

d) To determine maximum sustainable yield by means of catch/effort and catch per unit effort studies.

e) To assess the population parameters affecting the dynamics of *P. homarus* of the south coast.

f) To understand the ecology of the members of the genus *Panulirus* found on the south coast.

Objective:

a) To provide Sri Lankan government with sufficient scientific results to understand the status of the fishery and to enable the government to develop a rational national management plan.

1.5 Chapter summary.

Spiny lobsters (Family: Palinuridae) are one of the most valuable fisheries in the world and their present annual production is around 207949mt. In Sri Lanka the annual spiny lobster production fluctuates around 600 mt.

Due to heavy exploitation the lobster fisheries in certain parts of the world have collapsed. Of the eight valid species of spiny lobsters occur in the Indo-Pacific region, six species have been recorded from Sri Lankan waters.

Spiny lobsters are mainly caught in baited pots or tangled nets in many parts of the world. Trammel nets, bottom set gill nets and lobster rings are the fishing gear used by Sri Lankan fishermen for catching lobsters. In Sri Lanka spiny lobsters are mostly caught in coastal waters down to a depth of 30m. Different areas of the coast line are dominated by different spiny lobster species, *P. homarus* dominates along the south coast.

This fishery on the south coast is still carried out by fishermen using non-mechanized outrigger canoes. Fishing is affected by the rough weather conditions prevail during south-west monsoon and lobster season extends from August to March.

Although technical advances have not made any inroads to the fishery in Sri Lanka for the past 20 to 30 years, considerable changes in this fishery appeared during the past 4 to 5 years. 185 mt of spiny lobsters worth of Rs. Million 86.4 has been exported during the year 1990.

Life history includes a several months of planktonic and oceanic phase followed by an inshore phase during which they are caught by fishermen.

CHAPTER 2

2. Study area and sampling methods.

2.1 Study area

The area selected for the present study is the coastal stretch from Tangalle to Kirinda, situated close to the end of the south coast of Sri Lanka between 5^0 9'- 6^0 1' N and 80^0 40'- 80^0 70' E (Fig. 2.1). This stretch is approximately 110 Km long and 1 - 5 Km wide with an area of approximately 450 Km^2 and is also generally known as the most productive lobster fishing area of the south coast. The shallow coastal area up to 30 m depth is traditionally a good fishing ground for spiny lobsters (De Bruin, 1969) as well as for sardines and herrings. The deeper area is well known for several species of fish of the tuna group.

Along this region, three major rivers and several tributaries drain into the sea and therefore, in some localities, inshore waters are subjected to seasonal turbidity, particularly during the south west monsoon that prevails from May until August. During this time considerable quantities of silt enter these rivers and the rain water reduces estuarine salinity.

The coast line of the south coast is mostly low-lying and some parts are semi-arid with several small lagoons, some of which are used for solar salt production. The commercial fishery for spiny lobsters takes place along the area where the shelf slopes gradually down to 30 m averaging 3 km in width. The 30 m depth contour lies close to the coast where the lobster fishery is concentrated. Along the 30 m stretch, the bottom,

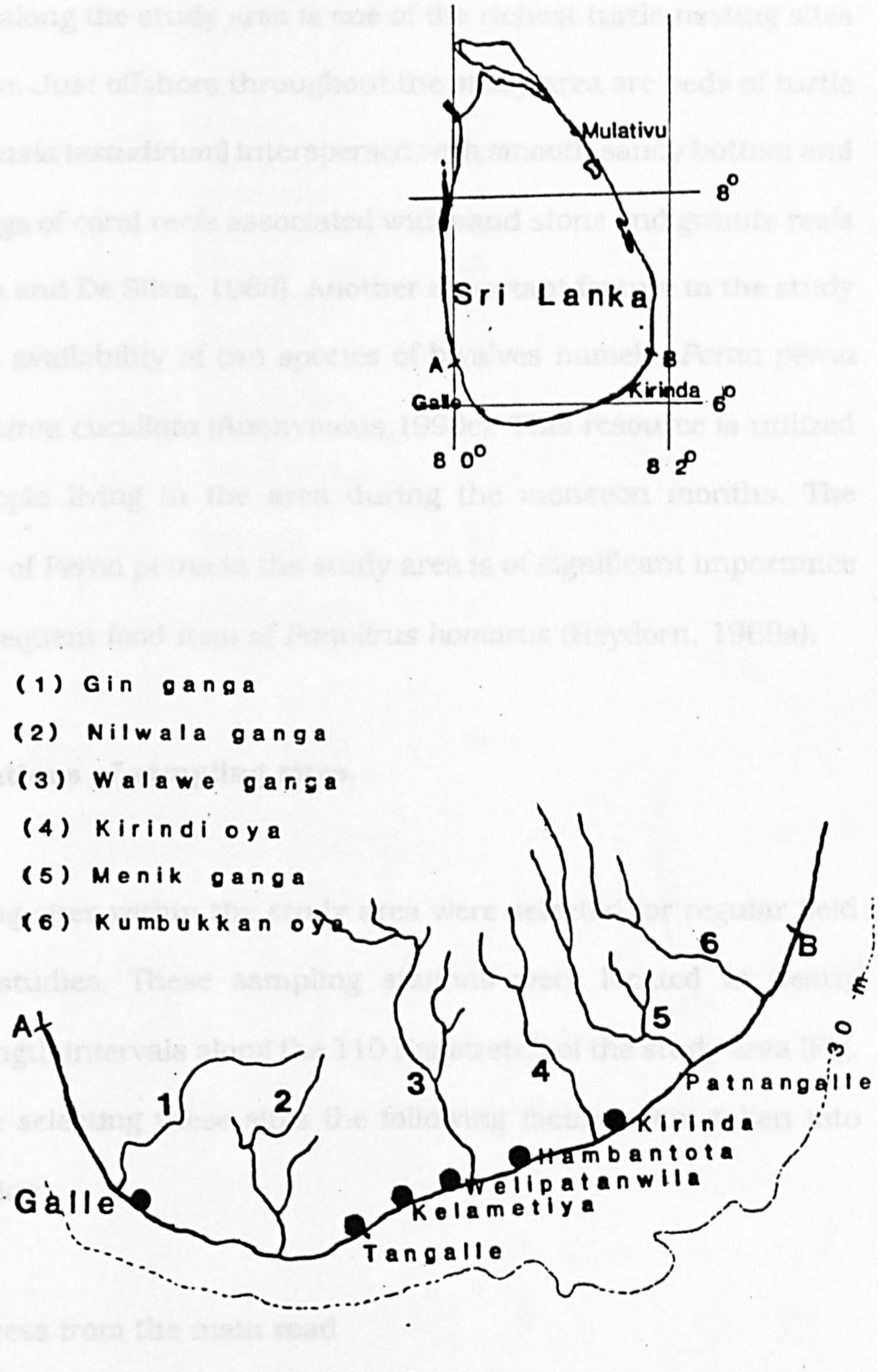


Fig. 2.1 South coast of Sri Lanka - Fishing area (A-B) and sampling stations (●).

except for few places is uneven and associated with rocks and reef areas. The beach along the study area is one of the richest turtle nesting sites of Sri Lanka. Just offshore throughout the study area are beds of turtle grass (*Thalasia testudinum*) interspersed with smooth sandy bottom and outcroppings of coral reefs associated with sand stone and granite reefs (Rajasuriya and De Silva, 1988). Another important feature in the study area is the availability of two species of bivalves namely, *Perna perna* and *Saccostrea cucullata* (Anonymous, 1990c). This resource is utilized by the people living in the area during the monsoon months. The availability of *Perna perna* in the study area is of significant importance as it is a frequent food item of *Panulirus homarus* (Heydorn, 1969a).

2.1.1 Locations of sampling sites.

Five landing sites within the study area were selected for regular field sampling studies. These sampling stations were located at nearly uniform length intervals along the 110 Km stretch of the study area (Fig. 2.2). While selecting these sites the following factors were taken into consideration:

a) easy access from the main road

b) number of craft operated

c) willingness of fishermen to cooperate in the study.

Fig. 2.2 **South coast showing landing sites, sampling stations and number of crafts.**

Landing site	Name	No. of crafts
1	Galle	26
2	Matara	17
3	Dondra	41
4	Dickwella	15
5	Gandara	12
6	Kottegoda	20
7	Mawella	14
8 *	Tangalle	41
9	Rekawa	10
10*	Kelametiya	54
11*	Welipatanwila	25
12*	Hambantota	76
13	Malala	23
14	Uraniya	40
15*	Kirinda	46
16	Palatupana	40
17	Patnangalle	60

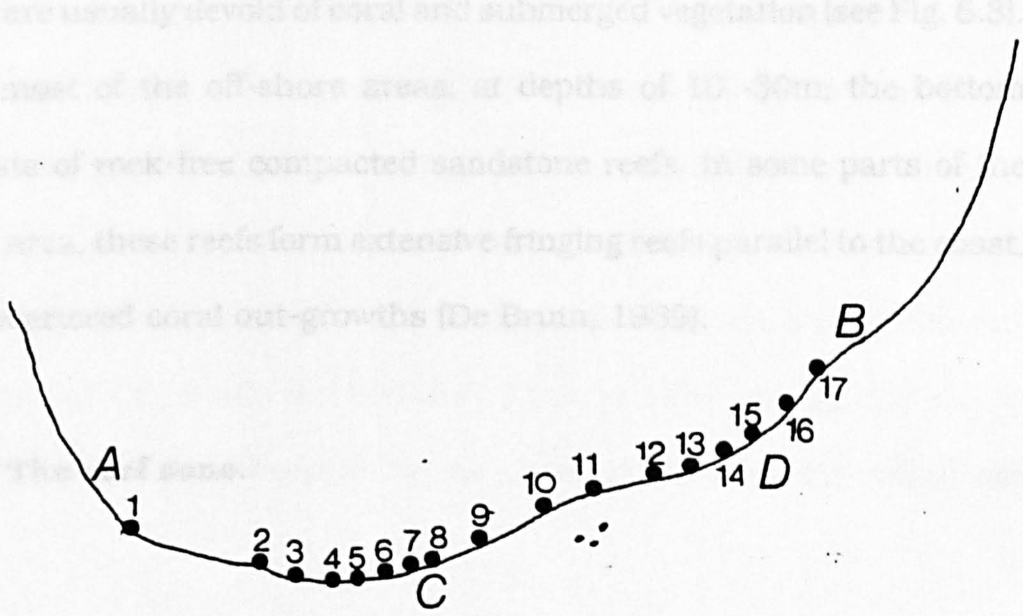
315 Craft

Total number of crafts 560

* Sampling stations

A - B South coast

C - D Study area (315 Craft)



The selected sampling sites and their locations are shown in Fig. 2.2.

2.1.2 Coast line and sublittoral topography.

The sublittoral substratum is one of the major factors influencing the distribution and abundance of spiny lobsters (George, 1963). Sandy beaches, coral reefs, limestone reefs, sandstone reefs associated with rocky bottom areas of varied origin are the dominant features along the south coast of Sri Lanka. In many parts of the study area, limestone and sandstone platforms are present interspersed with extensive white sand beaches.

The rivers and tributaries draining into the sea from the south coast add considerable quantities of silt to the coastal waters. During monsoonal months, some of these rivers are at times subjected to flash flooding and form sand bars and sandstone reefs closer to the river mouths. These areas are usually devoid of coral and submerged vegetation (see Fig. 6.3). Over most of the off-shore areas, at depths of 10 -30m, the bottom consists of rock-free compacted sandstone reefs. In some parts of the study area, these reefs form extensive fringing reefs parallel to the coast, with scattered coral out-growths (De Bruin, 1969).

2.1.3 The surf zone.

Along the south coast, in many places beaches are interrupted by rocky areas, coral reefs, limestone reefs and sandstone reefs (De Bruin, 1962). In most of these non-sandy areas rocks, corals, limestone and sandstone reefs are directly exposed to the wave action. Near shore areas of many sandy beaches consist of submerged rocks. In these areas water movement results mainly from wave action and circulation is dependent on the angle at which waves strike the shore. When wave approach is normal to the shore, "cells" of circulation are set up (Harris, Jordaan and Mcmurray, Verwey and Anserson, 1962) and the water is mostly saturated by oxygen (Table 6.1). This area is called the surf zone which provides different habitats for lobsters, crabs, mussels, sea urchins and star fish. This community structure can be observed in many places of the study area, namely, Tangalle harbour area, Kahandawa rocks, Kalametiya area, Hambantota area, Uraniya point and Kirinda area (Fig. 2.2).

2.1.4 Rainfall and temperature pattern.

The study area is generally categorized as one of the low rainfall zones of the country due to an annual rainfall of less than 1000 mm. Because of the low rainfall nature of the area Sri Lanka's most productive saltern is situated in Hambantota. The annual rainfall of the study area was recorded as 642.9 mm in 1988, 828.3 mm in 1989 and 1192.9 mm in 1990. A monthly breakdown for the period of 1988/89 extracted from the records of Department of Meteorology, Sri Lanka, is given in Appendix 2.1.

Temperature variation pattern of the study area was obtained from the records of the Department of Meteorology, Sri Lanka. The data indicate low temperatures during December to January and high temperature values during August to September. Monthly variations of temperature for the period of 1988 to 1990 are given in Appendix 2.2.

2.1.5 Inshore currents.

Around Sri Lanka, strong currents prevail as components of large current systems such as the Indian south-west monsoonal current, the Indian north east monsoonal current and circulations of the Bay of Bengal (Anonymous, 1986). During May to September of each year, there is a current from the Persian Gulf region passing clock wise through the Arabian sea, west coast of Pakistan and India and turning towards the southern part of Sri Lanka and moving further towards the easterly direction. This is an extension of the north-east setting Somali Current (Anonymous, 1986), which is well known for its high nutrient content.

During October to November, the current pattern changes with currents turning towards a westerly or north westerly direction with subsequent Indian north east monsoonal current. These two major current systems change from one to the other during the months of April and October (Anonymous, 1986).

2.2 Sampling methods.

2.2.1 Introduction.

Every sampling system is used to obtain estimates of certain properties of the population studied. Spiny lobster population studies involve the measurement and analysis of many quantities -eg. age composition, growth rates - few of which can be measured exactly, either because of their variability or the difficulty of measurement.

Most of these quantities involved in lobster population studies cannot also be obtained or measured throughout the whole population. A section or sample of the whole population is therefore examined for the attributes concerned. An estimate may be made of the true value in the population on the assumption that this sample is representative of the whole population.

Information on commercial catches is of great importance in any study of exploited lobster populations. Even when the catch is far from representative of the natural population, information on the age and length composition etc. of the catch is of great importance as these are lobsters that are actually being removed from the stock (Gulland, 1966). It is also most important in being one of the best sources of data on the lobster population itself.

The most extensive sampling work in fishery research is concerned with determining the size and age composition of the catches. The sampling procedure adopted in this study can be divided into two sections as recognised by Gulland (1966).

a) A thorough and precise examination and measurements, of several characteristics (fecundity, gonad weight, maturity, etc.) of relatively few specimens, done under laboratory conditions.

b) Sampling for a single rapidly determined measure, such as length, sex ratio etc. for a large number of specimens, at the landing sites.

2.2.2 Spiny lobster sampling along the south coast.

2.2.2.1 Collection of data.

Field visits were made during the first and last weeks in each month to the south coast for the period of May 1989 to April 1991. Each visit lasted for five days. During field visits lobster landing sites and lobster processing companies were visited for the collection of statistics.

2.2.2.2 Biological aspects.

Sampling for various biological aspects were made during the whole sampling period of two years. This included two consecutive lobster seasons. In each visit around 50 lobsters taken at random were used for biological studies. Lobsters were handled fresh. The first 15 lobsters measured in each half cm group were sexed. When there were less than 15 lobsters in a length group, all lobsters were sexed. The first five males and first five females in each half cm group were used for detailed analysis. In cases where there were less than five lobsters of a particular sex, within a length group, all were examined. This ensured that all size groups present in a sample were examined for various aspects of maturity and reproduction. A note was made of those individuals carrying spermatophores, ovigerous setae, berried or non berried and of the colour and state of development of eggs from the external appearance.

For reproductive biological studies carapace length, total body length and total weight measurements were made in the field. Carapace length measurements were made using a calliper and a divider. The weight measurements were made using a field balance (Ohaus CT 600) with an accuracy of one gram. Samples collected for ova counts and maturity studies were immediately emerged in ice. Berried females used for fecundity studies collected from diver catches were kept in separate polythene bags and were housed in an ice cool container. Usually in a particular field sampling trip, the final day was used for the collection of these samples. As soon as sample collection was over, they were brought to the laboratory of the National Aquatic Resources Agency (NARA), to carryout further studies.

Berried females for the fecundity studies were obtained from the experimental fishing and diving operations. Thirty five females of ovary stage five and sixty five females in berried were used for the estimates. Divers were instructed to bring all lobsters that they catch without selecting larger animals to avoid any size selectivity influence. The lobsters were selected to cover as wide a range of carapace lengths as possible, as well as being more or less equally divided between newly spawned (orange eggs) and late stage (brown eggs), at which time embryonic development is almost completed (Lyons et. al.,1981).

For fecundity studies, all female lobsters were handled fresh and were dissected by making a cut along the mid-dorsal line. The complete ovary of the stage five lobsters were removed and weighed to the nearest mg using a Mettler H 10T type balance. After weighing, three 1g samples of eggs were taken for manual counting. For the ovigerous females, the complete egg mass were removed and weighed and immersed in 96% methanol for two days. Later the egg mass was dried in an oven at approximately 100°C for 2 to 5 hours. After drying the egg mass was rubbed over a 1mm screen to break up egg clusters and separate from the pleopods and any other non-egg material. The dried eggs were then weighed to the nearest mg on a Mettler H 10T balance. After weighing, three 1g samples of eggs were taken and counted manually. Three counts of eggs in 1g samples taken from the same animals were made with newly spawned eggs and late spawned eggs separately. For the late stage eggs, the number of infertile eggs were also noted. Detailed treatments of these samples for the various requirements is given in relevant sections.

2.2.2.3 Catch and effort statistics

Information on catch and effort statistics were mainly collected at the landing sites. On each sampling day, the total number of craft operating was noted. A systematic random number chart was used each day and selected craft according to their landing time were used to gather detailed information. The data were collected in two ways.

A) Fishermen from the selected craft were interviewed for the following information.

a) Time of departure.
b) Time of setting and hauling the nets.
c) Area and depth of fishing.

d) Number of net pieces used.

B) The entire lobster catch of selected craft were sampled for the following.

a) Total lobster catch - Weight and Number

b) Species composition.

c) Sex ratio.

d) Percentage of berried females.

e) Total length, carapace length and weight measurements.

f) Percentage of females with ovigerous setae.

g) Percentage of females with spermatophores.

h) The number of the crew involved was also noted.

2.2.2.4 Morphological parameters.

Total length was measured from the base of the rostral horns to the end of the telson along the mid dorsal line using a measuring board. Carapace length was measured from the base of the rostral horns to the posterior end of the carapace along the mid dorsal line using a divider and a calliper (Fig 2.3). Fresh weight of the lobsters were measured at the landing sites by using a portable field balance (Ohaus CT 600). Before weighing, excess water and sand particles were removed using blotting tissues.

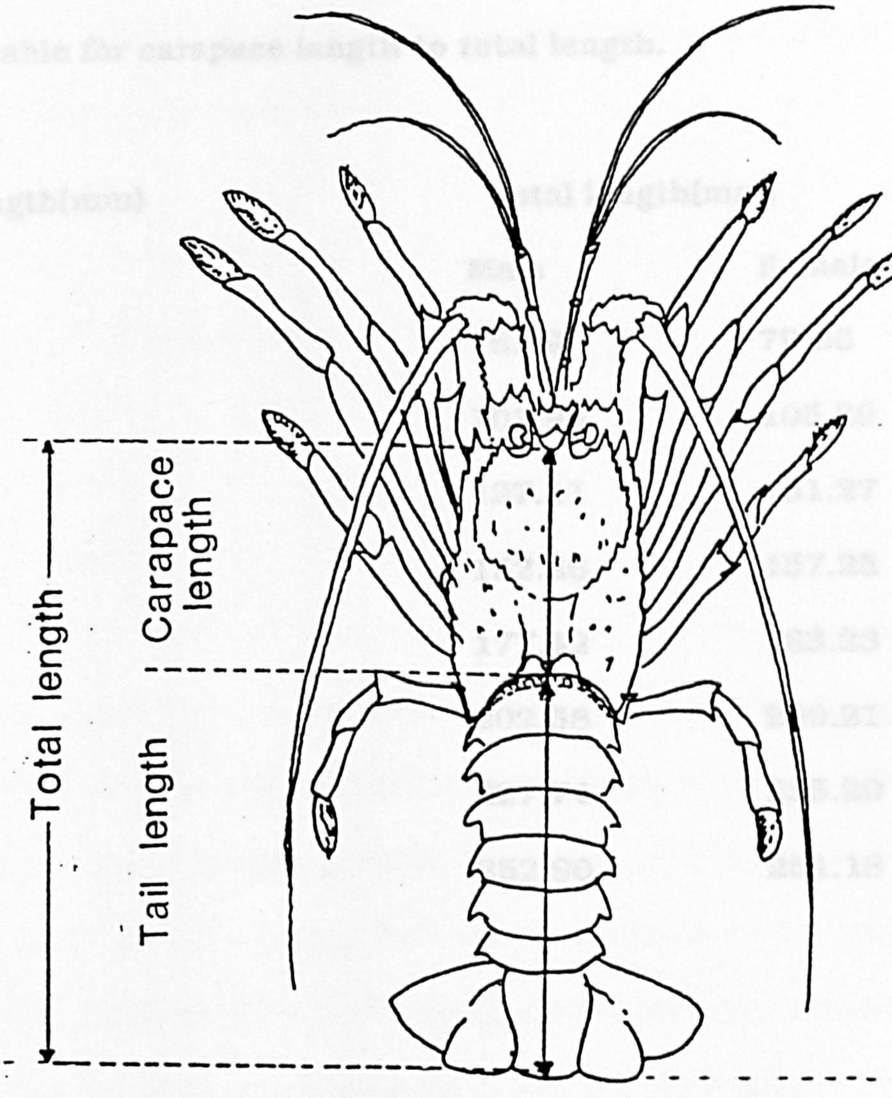


Fig. 2.3 **Length dimensions of *Panulirus homarus* measured during the study period.**

Carapace length-total length relationships for *P. homarus*

Male $Y = 1.3146 + 2.5158\ X$

Female $Y = 1.3582 + 2.5982\ X$

Immature male/ female $Y = 0.2353 + 1.7657\ X$

Y = Total length X = Carapace length

Fig. 2.3 contd.

Conversion table for carapace length to total length.

Carapace length(mm)	Total length(mm)	
	Male	Female
30	76.79	79.26
40	101.95	105.29
50	127.11	131.27
60	152.26	157.25
70	177.42	183.23
80	202.58	209.21
90	227.74	235.20
100	252.90	261.18

2.2.2.5 Hydrological parameters.

On each field sampling visit made to the study area, the following hydrological parameters were collected,

a) surface sea water temperature

b) bottom sea water temperature

c) dissolved oxygen

d) sea water salinity

e) sea water turbidity.

Surface and bottom water temperatures were measured by using a laboratory thermometer and a Nansen bottle respectively. Dissolved oxygen was measured using a portable oxygen meter (Jenway Portlab 9070) of 0 to 19.9 mg/L range. This has a resolution of 0.1 mg/L. Salinity measurements were made using a refractometer (American Opticals), while turbidity was measured by using a sechi disc.

2.2.2.6 Lunar phase.

Daily catch per craft values of Sri Mic Lobster Company at Tangalle from January to December 1990 have been used to determine its variation with the lunar cycle.

2.3 Experimental fishing and diving operations.

2.3.1 Introduction.

In the study area fishermen use mainly trammel nets for lobster fishing. In addition, 7.5 cm stretched mesh bottom set nets and lobster rings are also in practice. It has been observed that in addition to catching legal size lobsters, fishermen collect considerable quantities of sub-legal lobsters by their fishing nets (Jayakody and Kensler, 1986). Recently, trammel nets became more popular among lobstermen, and it was assumed that the use of trammel nets is the main way of catching illegal lobster. Experimental fishing trials were carried out with trammel nets along with bottom set gill nets with different mesh sizes and lobster rings to select the best fishing gear for the fishery.

Along the coast line of Sri Lanka, many areas except the south coast, are inhabited with only two or three species of spiny lobsters (De Bruin, 1962), whereas along the south coast all six species are recorded in a relatively small area of 110km coast line (Jayakody and Kensler, 1986). It was thus of interest to study the sub- strata and hydrological parameters of the sea water of the area to understand the reason/s for this uncommon distribution pattern.

2.3.2 Survey design.

The length of the fishing ground of the south coast exploited by the traditional craft and the area studied in this survey was approximately 110 Km and the breadth up to the 30m isobath, was approximately 3 Km. The survey area was divided latitudinally into 5 transects which in turn was divided longitudinally into 3 stripes at depths 0 - 10m, 11 - 20m and 21 - 30m respectively, thus making 15 "rectangles" (Fig.6.3). These latitudinal divisions and longitudinal stripes were labelled A - E from west to east and 1 - 3 according to the depth ranges respectively. Twenty five trials of fishing operations were made during the months of November and December 1990. In each fishing day, before sunset all three types of nets were taken into the fishing grounds and were set at places of the preselected depth range. The 3 types of gear were operated in close proximity to each other in order to provide uniformity of the bottom type for the gears. The following morning the nets were collected and taken back to the coast for clearing and making records of the catch.

2.3.2.1 Fishing gear

A trammel net, bottom set gill net and lobster rings were used for sampling. The specifications of the fishing gear are as follows.

Gear	Total length (m)	Total width (m)	Mesh size (SP)	Mesh size (cm)
Trammel net	100	5	3.75 cm	7.5*
B.S.G	100	5	-	7.5
Lobster ring	50** no^s	-	-	7.5

B.S.G = Bottom set gill net SP = side panel * Middle panel

** 50 numbers of lobster rings cover almost the same area as that is covered by 100m of trammel nets or 100m of bottom set gill nets.

2.3.2.2 Craft

A commercial wooden boat with a crew of three was employed for experimental fishing trials. The specifications of the vessel are as follows.

Overall length - 8.48m

Beam - 3.00m

Gross tonnage - 3.50

Engine power - 30.00 HP

Maximum speed -4.30 Knots

2.3.2.3 Recording of data

The catch was sorted into different species and the number in each gear type and the berried females were recorded. Their lengths were measured to the nearest mm as explained in chapter 3. Salinity, dissolved oxygen and turbidity values of the fishing places were recorded according to the method explained in 2.2.2.5.

2.3.3 Diving operations

During November and December 1990, diving operations were arranged to carryout with two skin divers and two SCUBA divers at a selected 2km x 2km area at Tangalle (Fig. 6.3). Twenty five diving operations were conducted during this period each lasting for three hours (total of 300 diving hours). In a particular diving operation, a selected area was covered (coral, sand stone, lime stone, rocky bottom or muddy bottom) and the information on the following was recorded.

a) Detailed nature of the sea bottom

b) Total number of spiny lobsters available

c) The living pattern of lobsters - single or groups

d) Species composition

e) Size of spiny lobsters

f) Number of dens, caves or crevices (hiding places) available

g) Turbidity of the sea water

h) Temperature of the sea water

i) Dissolved oxygen concentration

j) Nature of the bottom sea water (turbulent/ calm / agitated etc.)

2.3.4 Statistical analysis

For analysis of variance estimations, STATGRAPHICS Statistical Graphics System , Educational Institution Edition, Version 3.0 was used.

2.4 Chapter summary

The 110Km long coastal stretch from Tangalle to Kirinda in Hambantota district of the south coast of Sri Lanka was selected for the present study. This area is geographically situated in the arid zone and traditionally reputed as a good lobster fishing coast of the country.

Coast line of this area is varied in origin where sandstone, coral, rocky bottom ,limestone and muddy bottom areas are available.

Five landing sites were selected for regular sampling for a period for two years from May 1989 to April 1991. Twice monthly visits were made to the landing sites for data collection.

During field visits lobster catch, effort, morphological data, length distribution and information on reproductive biology were collected.

Experimental fishing trials were carriedout during the period from Nov.-Dec. 1990, during which, information on species distribution in the study area and catchability of different gear types were tested.

Diving operations were conducted during the same period at a selected small area at Tangalle to understand the habitat preference by the six species of spiny lobsters which occur along the south coast.

CHAPTER 3

3. Reproductive biology.

3.1 Introduction.

One feature that is common to both clawed and spiny or rock lobsters is the reproductive system about which surprisingly little is known (Aiken and Waddy, 1980). In contrast to other biological parameters such as moulting and growth, the reproductive biology has been largely ignored (Aiken and Waddy, 1980). An understanding of the reproductive behaviour of the spiny lobster species is important in population studies of that species and is also relevant to future management of the fishery in any given area. As far as Sri Lankan waters are concerned the work done on reproductive biology is very much limited. Certain principal aspects of the reproductive biology of the spiny lobster *P. homarus* of the south coast of Sri Lanka such as maturity, spawning season, length and age at first sexual maturity and breeding, sex ratio, fecundity, reproductive potential and egg loss during incubation were examined in the present study.

3.2 Materials and Methods.

Spiny lobsters were collected each month for a period of two years (May 1989 to April 1991) from the south coast spiny lobster fishery. A twice monthly sampling programme was attempted during this period.

Detailed description of the methodology of sampling procedures for estimating size at maturity, age at maturity, spawning season, sex ratio, fecundity, reproductive potential and egg loss estimates have been given elsewhere (see section 2.2.2).

3.3 Determination of gonad maturity stages.

As the males are easily distinguished from females by the prominent mating organ associated with the gonopore on the basal segment of the fifth pereiopods, sexing externally was not difficult. As gonads were readily visible, a cut along the mid dorsal line was made in each case to open the body cavity. The ovaries resembled an elongated " H " shape with the vertical lobes joined by a transverse bridge just anterior to the heart.

Ovaries were removed from the thorax and their colour was recorded. Ova from females in different stages of maturity were examined microscopically to determine whether clearly differentiated stages of development could be distinguished.

Diameters of ten eggs per specimen were measured under magnification (X10) on a transparent mm grid and mean ova diameters were obtained from 10 specimens.

Various arbitrary classifications of maturity have been used in the study of seasonal changes of gonad condition in spiny lobsters. These have used features such as colour, size and shape of the gonad in relation to the body cavity, condition of contents, the ratio of gonad weight to body weight or the diameter of the oocyte. To obtain detailed description of the state of maturity, a series of numbered stages were used, from the immature lobsters to the spent.

A six stage classification of gonad maturity (immature, inactive to active, active, active to ripe, ripe and spent) was used by Heydorn (1969a) and Berry (1971b) for *P. homarus* in South African waters. Squires and Rveros (1978) determined the condition of maturity of female *Panulirus argus* in four stages (immature, maturing, mature, spent-recovering) and in males in three stages (immature, maturing and mature). A five point scale was used by Thomas (1964), for *Nephrops norvegicus*.

The classification used in the present study is that used by Heydorn (1969a). The criteria for the different stages are as follows:

Female maturity stages	Description
(1) Immature	Ovaries white; No discrete ova; Ovaries flattened and strap-like; Immature ova can be seen with a hand lens; Ova diameters range from 0.08-0.13mm.
(2) Inactive to active	Ovaries light pink in colour; Beginning to swell; Ova not uniform in nature; Smaller ones white and larger ones pale pink; Ova diameter range from 0.08 - 0.23mm.
(3) Active	Ovaries pink - orange in colour; Slightly swollen; Ova appear clearly round; Ova can be clearly seen by a hand lens; Diameter range from 0.24-0.31mm.
(4) Active to ripe	Ovaries orange in colour; Fill most of the cephalothoracic cavity; Ova can be seen by the naked eye; Ova

	diameter range from 0.30 - 0.41mm.
(5) Ripe	Ovaries bright orange in colour; Fill the complete cephalothoracic cavity; Ova ready to be released; Ova diameter range from 0.36-0.48.
(6) Spent	Ovaries collapsed; Cream in colour; Almost same as stage two with few residual ova in the ovary lobes and in oviduct.

Male maturity stages	**Description**
(1) Undeveloped	Vasa deferentia not visible to the naked eye.
(2) Developing	Vasa deferentia just visible.
(3) Developed	Vasa deferentia well developed.
(4) Advanced	Vasa deferentia prominent; White to cream in colour; Full of seminal fluid.
(5) Spent	Vasa deferentia flaccid and shrunken.

3.4 Maturity indices.

For each lobster whose gonad was weighed, a gonad : body weight ratio was calculated and expressed as a percentage.

$$\text{Maturity Index} = \frac{\text{Gonad Weight}}{\text{Body Weight}} \times 100$$

In the case of smaller immature lobsters, an accurate dissection and weighing of minute gonads was not attempted.

The following calculations were made:

(a) Individual maturity indices
(b) Mean maturity indices per gonad stage and standard deviation of the means per monthly sample
(c) Gonad mean maturity indices per gonad stage and standard deviation for the means for all data from the different months combined.

Lobsters at different stages of gonad maturity were taken together during a number of months (due to the protracted spawning season). The mean maturity index of the catch during any one month was therefore not a good measure of the pattern of spawning activity in the lobster population. However, maturity indices were used to support the reliability of visual determination of the stages of gonad maturity especially at gonad stages 4 and 5.

Lobsters of the one sex at the same stage of maturity from different months were combined to provide the information in Table. 3.1. Fig. 3.1 is based on information in Table. 3.1 and shows that the mean maturity index for females increases gradually, reaching a maximum for ripe (stage 5) lobsters and then drops when the lobsters become spent. A similar pattern was observed in males (Table 3.2 and Fig. 3.2) where gonad maturity index shows a maximum value of 4.36 in stage 4 lobsters and drops as they become spent.

The seasonal changes in mean maturity index for the females is plotted in Fig. 3.3. High values obtained from August to April correlate with the spawning activities of the lobsters during this period.

Table 3.1. Mean maturity indices, standard deviations of means and number in sample by sex and gonad stage for female lobsters.

Stage of maturity	Mean maturity Index	Standard deviation from the mean	No. Of lobsters
(1)	0.82	0.81	78
(2)	1.63	0.45	57
(3)	2.62	0.78	54
(4)	4.73	1.12	64
(5)	6.54	0.84	46
(6)	2.10	0.54	26

Table 3.2 Mean maturity indices, standard deviations of means and number in sample by sex and gonad stage for male lobsters.

Stage of Maturity	Mean maturity Index	Standard deviation From mean	Number Of lobsters
(1)	0.64	0.61	36
(2)	1.11	0.46	31
(3)	2.41	0.94	47
(4)	4.36	1.15	53
(5)	0.71	1.11	37

3.5 Spawning season.

3.5.1 Introduction.

Elder (1976), stated that the spawning season of a stock can be

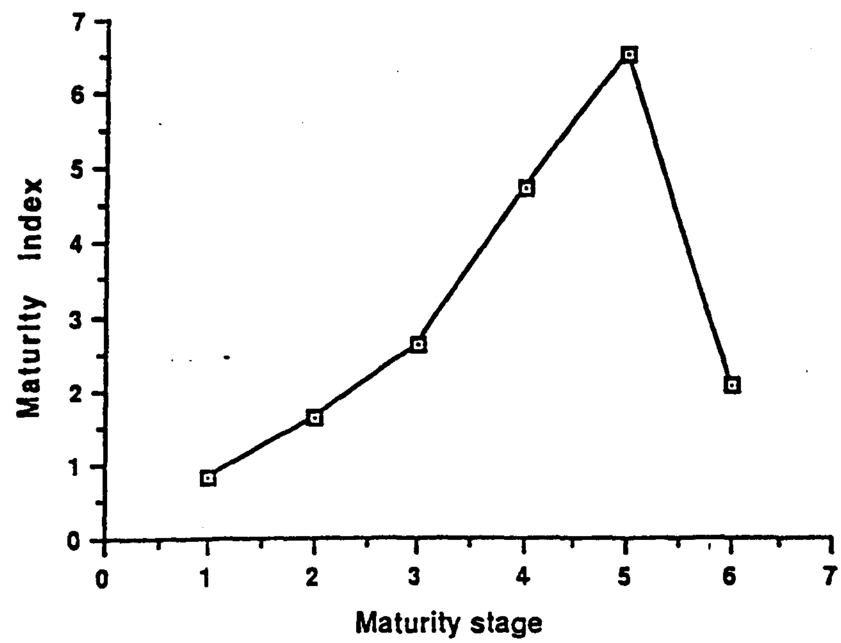


Fig. 3.1 Relation between maturity index and gonad maturity stage in female *Panulirus homarus*.

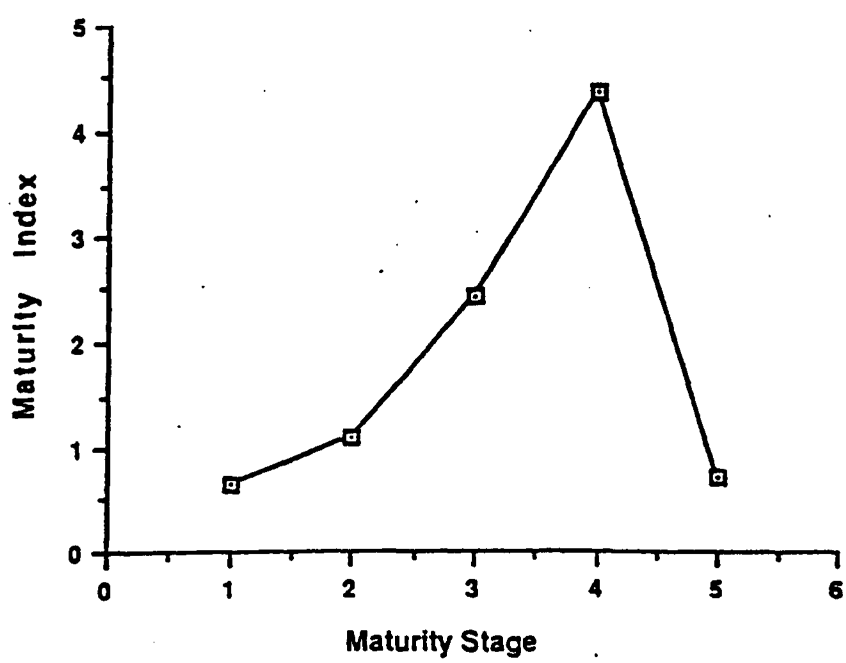


Fig. 3.2 Relation between maturity index and gonad maturity stage in male *Panulirus homarus*.

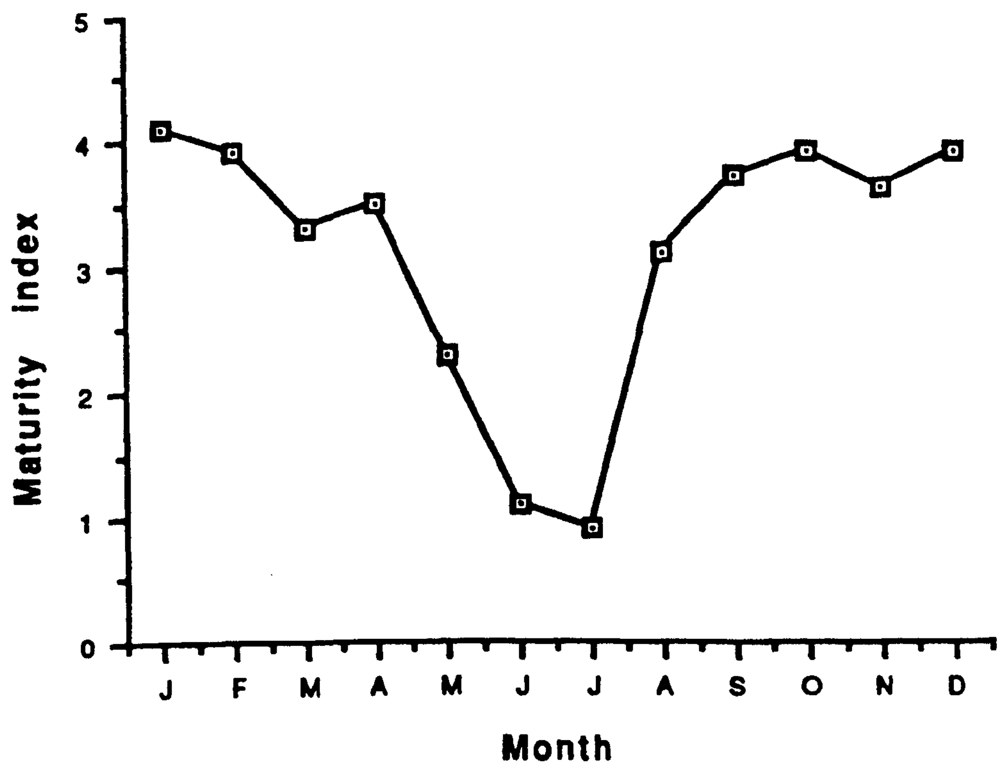


Fig. 3.3 **Monthly variation pattern in gonad maturity index in female *Panulirus homarus* (combined data for 1989/90 and 1990/91 lobster seasons).**

determined by a study of the seasonal occurrence of spawning fish in the catches from the stock. Spawning season was determined for long rough dab (Bagenal, 1957) from the disappearance of the mature fish from the samples and their replacement by spent females and also by the appearance of eggs in the plankton.

Kohler (1967) and Olsen (1961) used the assigned maturity stages to determine the spawning seasons of fish species. The seasonal distribution of nearly ripe, spawning and recently spent animals can be used to make some conclusions regarding spawning time. The appearance of ripe and spent females in the catches indicates that spawning has begun. Similarly, a preponderance of spent lobsters may indicate that peak spawning activity is over. However, Olsen (1961), stated that care must be taken when using gonad maturity stages to determine spawning season. The gear used in sampling could also influence the final outcome of maturity studies.

3.5.2 Results and analysis.

The spawning season of *P. homarus* on the south coast of Sri Lanka in the present investigation was determined from the assigned maturity stages assigned to the lobsters sampled on a twice monthly basis. Appendices 3.1 and 3.2 list the percentage of *P. homarus* in the various maturity stages by month for the entire period sampled. Table. 3.3 has been prepared based on the data in Appendix 3.1 for females. Stages 4 and 5 occurred right through the year with peaks from August to February (Fig. 3.4). This was confirmed by the presence of berried females in high percentages after 1 to 2 months from the occurrence of mature females in the fishery (Table. 3.4, Fig. 3.5). It could be assumed (from the presence of spawning lobsters in high percentages during August) that spawning had begun by late July or early August.

Table 3.3. Gonad maturity stages of female *P. homarus*. Pooled data for 1989/90 and 1990/91 fishing seasons.

Month	Gonad State	
	1 and 2 (%)	4 and 5 (%)
Jan.	18.0	60.0
Feb.	24.0	53.0
Mar.	33.0	24.1
Apr.	33.3	20.8
May.	40.0	30.1
Jun.	13.3	46.7*
Jul.	34.2	44.7*
Aug.	13.0	61.0
Sep.	33.1	41.0
Oct.	25.0	51.0
Nov.	24.0	46.0
Dec.	23.0	58.0

* Estimates based on few individuals.

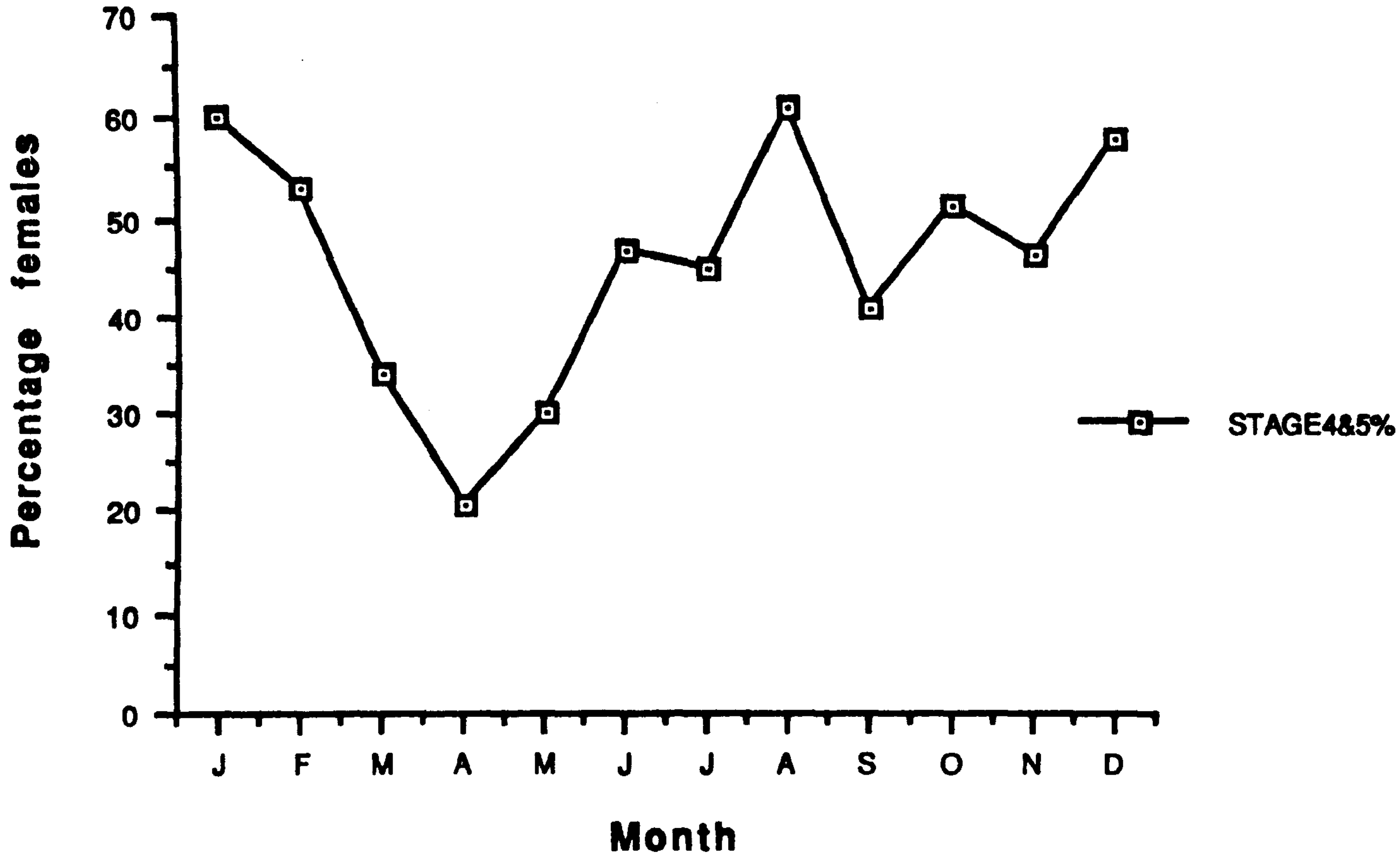


Fig. 3.4 **Occurrence of mature female *Panulirus homarus* (ovary stage 4 & 5) during the study period (combined data for 1989 /90 and 1990 /91 lobster seasons).**

Table 3.4 Percentage of female *P. homarus* carrying eggs during 1989/90 and 1990/91 fishing seasons.

Month	No. females observed	Number Berried	Percentage Berried
Jan.	190	91	47.89
Feb.	160	90	56.25
Mar.	216	145	67.13
Apr.	314	96	30.57
May	21	4	19.05
Jun.	41	7	17.07
Jul.	91	16	17.58
Aug.	170	100	58.82
Sep.	280	169	60.36
Oct.	174	93	63.45
Nov.	265	115	43.40
Dec.	249	123	49.40

Increasing numbers of spent lobsters were taken in November/ December and again in March periods, indicating that spawning is protracted with two peaks. The period August to March could be regarded as the spawning season for *P. homarus* of the south coast. It is difficult to pick up a peak within the spawning period from the data presented in Tables. 3.3 and 3.4 but it could be assumed to be in the period of August to March.

For both sexes, all lobsters assigned to gonad stage 1 were immature and most of them were sampled in the period of March to September. Stage 2 lobsters were a mixture of adults and recovered spent lobsters. The recovered spent lobsters made up a good portion of stage 2 lobsters

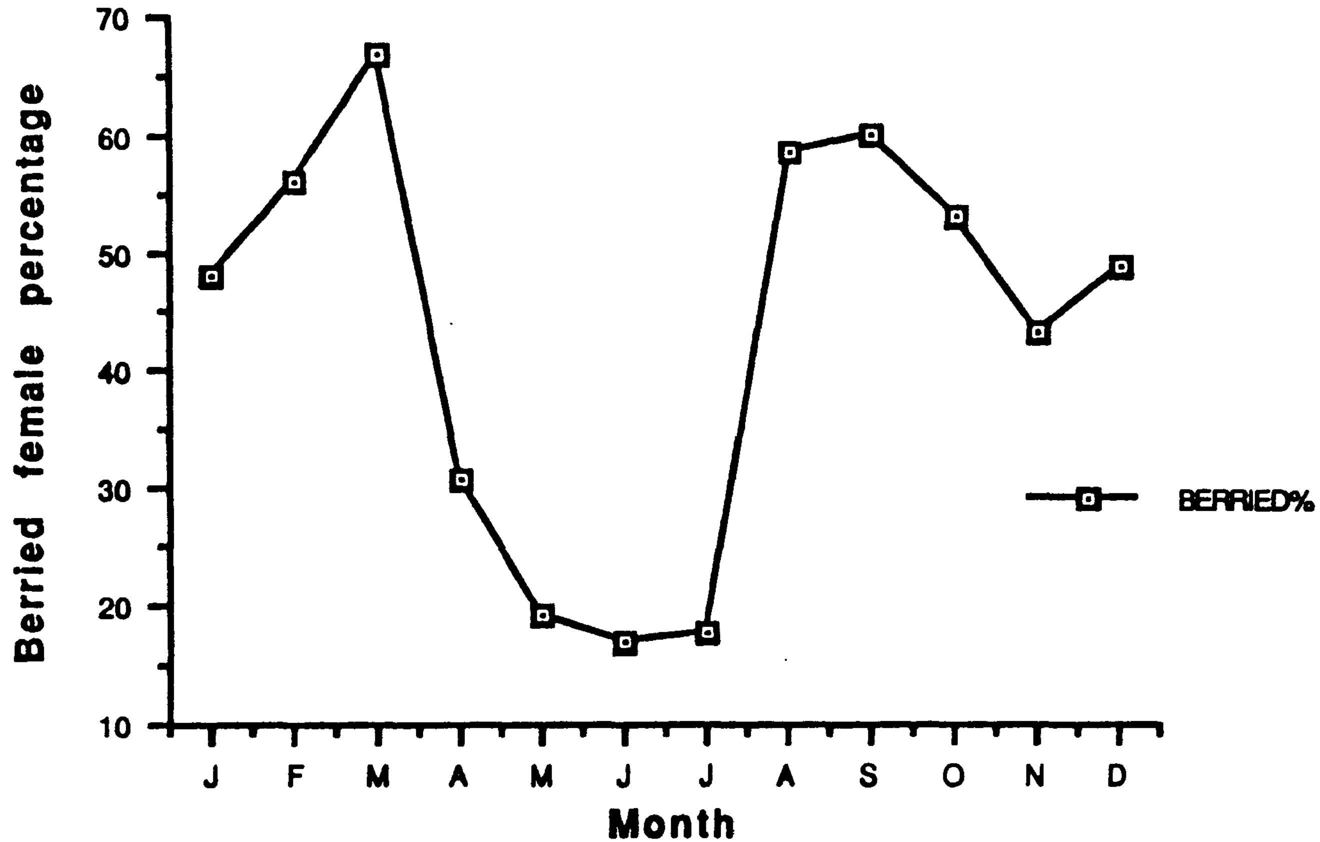


Fig. 3.5 **Occurrence of berried females of *Panulirus homarus* during the entire study period (1989/90 and 1990/91 fishing seasons).**

sampled in most of the months except June (Appendix 3.1).

3.5.3 Comparison with previous work.

De Bruin (1962) studied the breeding cycle of species of *Panulirus* from the presence of berried females in samples obtained throughout the year from the West coast of Sri Lanka. Over 50% of the females of *P. dasypus* (= *P. homarus*) were seen to be berried during the months of August to March - with a peak in December. Jayakody and Kensler (1986) recorded high percentages of berried females during July, August and September. During this period over 50% females were recorded as ovigerous. Jayakody (1987) found high percentages of ovigerous females during February and March at Patnangalle. According to Table 3.4, around 50% of the females are berried during August-March. In April the percentage dropped to 30.57 and during May to July, it was around 17.90%. It is clear, therefore, that breeding is cyclical and ceases during the South-west monsoon which commences in April and ends in August. This cessation of breeding during the monsoon is possibly due to the continuous swell.

The spawning season of some of the other spiny lobster species in different regions of the world is given in Table 3.5. It ranges from a few months to year round. Spawners with a protracted spawning period such as *P. polyphagus* in Thai waters and *P. homarus* in South African waters have a spawning peak limited to a few months.

In south Indian waters, even though the peak spawning is limited to a few months (Nov. and Dec.) berried females were recorded during the latter part of the fishing season (Jan.-April)in low percentages. The spawning pattern of *P. homarus* in Sri Lankan waters is similar to that described by Sanders and Bouhlel (1984) in Yemen waters, ie, females with eggs and spent females are present within the population throughout all the fishing season. Fig. 3.4 and 3.5 indicate a delay of one to two months between the appearance of stage 4 and 5 ova and ova extrusion (berry).

Table 3.5 Spawning seasons of some spiny lobster species.

Species	Source	Region	Spawning season
P. homarus	Heydorn (1969)[a]	East coast S. Africa.	Nov.-Jan. Peak in Jan.
P. homarus	Berry (1971)[b]	East coast S. Africa	During summer Dec.-Jan.
P. homarus	George (1965)	South west coast, India	Nov.-Dec.
P. versicolor	MacDonald (1982).	Western Caroline Is.	Throughout the year.
Palinurus elephas	Hepper (1977)	Cornwall area	Mid-summer to autumn.
P. polyphagus	Rongmuangsant and Luvira (1973).	West coast of Thailand	June-Oct. peak in Aug.
Palinurus gischristi	Pollock and Augustyn(1982)	East coast S. Africa	Throughout the Year
P. marginatus	Mac Donald and Thompson (1987)	Midway Is. (Hawiian Is)	April to Oct. (Summer)
P. homarus	Sanders and Bouhlel (1984)	Republic of Yamen	Oct. - Apr. (Through out fishing season)
P. homarus	This study	Sri Lanka	August - March

P = Panulirus

3.6 Length and age at maturity.

3.6.1 Criteria for maturity.

The onset of sexual maturity is an important threshold in the life cycle of female lobsters because from that time on energy must be shared between growth and reproduction. In studying the length and / or age at which *P. homarus* becomes sexually mature for the first time, it is first necessary to establish criteria for maturity.

Many authors have used the " 50% maturity level" (ie, the smallest carapace length at which 50% of a population bears eggs) as an index of maturity and breeding. The onset of sexual maturity in female spiny lobsters can be determined by the presence of several externally visible features. Street (1969), Pollock and Augustyn (1982) considered lobsters bearing well developed pleopod endopodal setae as mature. Munro (1974) and Morizur (1983) regarded a lobster as mature if it had externally attached eggs. Both, Fielder (1964) and Morizur (1983) considered the state of ovary development as a feature of maturity, while Templeman (1935; 1944) demonstrated that abdomen width in female homarid lobsters increased relative to body length at sexual maturity. George and Morgan (1979) noted external elongation of the anterior pair of walking legs of *P. versicolor* corresponding with onset of maturity.

Chittleborough (1976) working on *Panulirus longipes cygnus* and Booth (1984) working on *Jasus verreauxi* demonstrated a delay between the appearance of pleopod setae and spawning. It appears in *P. homarus* that at least two inter-connected physiological changes govern the changes associated with sexual maturity and the onset of oviposition (spawning). Hence, the 50% maturity criterion itself can be misleading unless size at spawning is also considered.

3.6.2 Estimation of size at maturity.

Carapace length values were plotted against the respective tail length values and the resulting plots were examined visually for discontinuities in the slopes of the regressions. The steps used in this analysis were the same as those used by George and Morgan (1979), Grey (1979) in their intersect analysis. Least square regressions were fitted separately to immature male and females, mature males and mature females. Students t-test was used to determine the validity of the slopes of regression lines. This method was compared with the observations made on gonad developmental stages as discussed in section 3.3.

Females assigned to maturity stages 1 to 3 and males to maturity stages 1 and 2 were considered immature, while those assigned to maturity stages 4 to 6 in females and 3 to 5 in males were considered as mature. Size at spawning was estimated by considering the externally visible eggs. Ovigerous females encountered during the study period are shown in Appendix 3.3.

Based on the data in Appendix 3.3, Table. 3.6 was prepared and the percentage ovigerous values were plotted against the mid length values of the each carapace length group in the form of a smoothed curve is shown in Fig. 3.6. Percentage ovigerous values were plotted against the respective carapace length values as explained by Wenner, Fusaro and Oaten (1974) and the resultant plot is shown in Fig. 3.7.

Table 3.6. ***P. homarus*** **- summary of percentage ovigerous values of female in each 5mm carapace length class. C.M.L = Carapace Mid Length (mm).**

Carapace mid length(mm)	Percentage
42	1.5
47	3.6
52	12.4
57	40.5
62	63.3
67	71.3
72	80.7
77	86.0
82	86.0
87	88.0
92	95.1
97	96.1

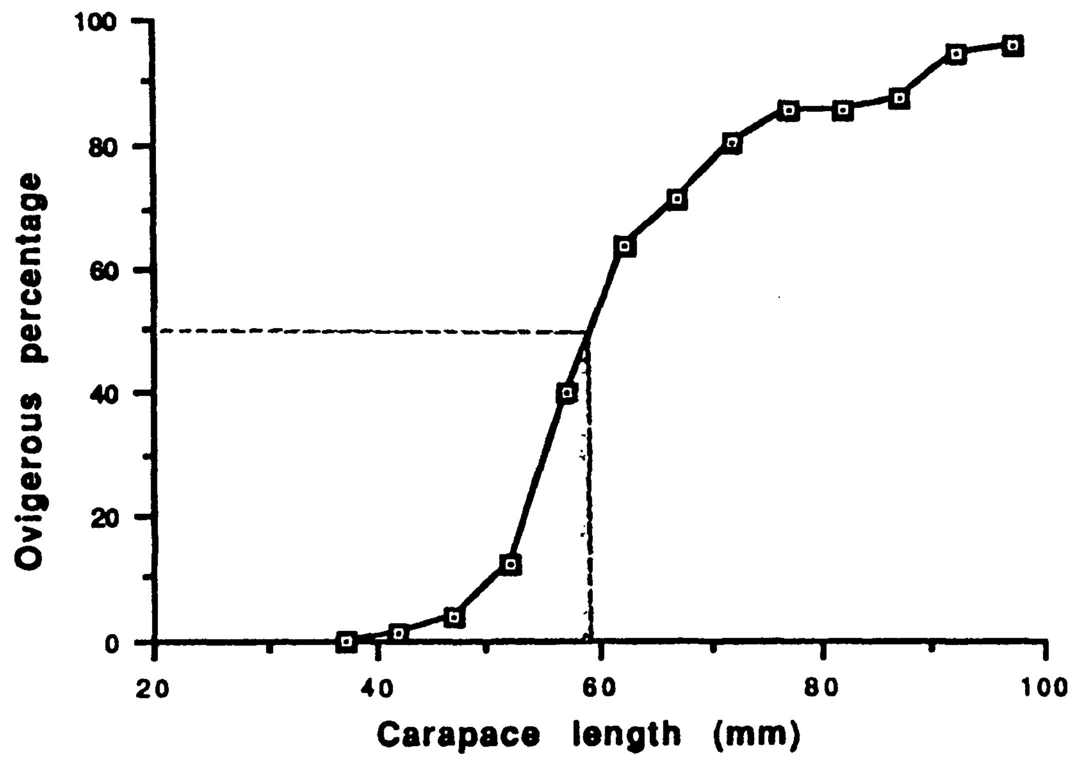


Fig. 3.6 ***Panulirus homarus*** **- length at first functional maturity estimated using a smoothed curve.**

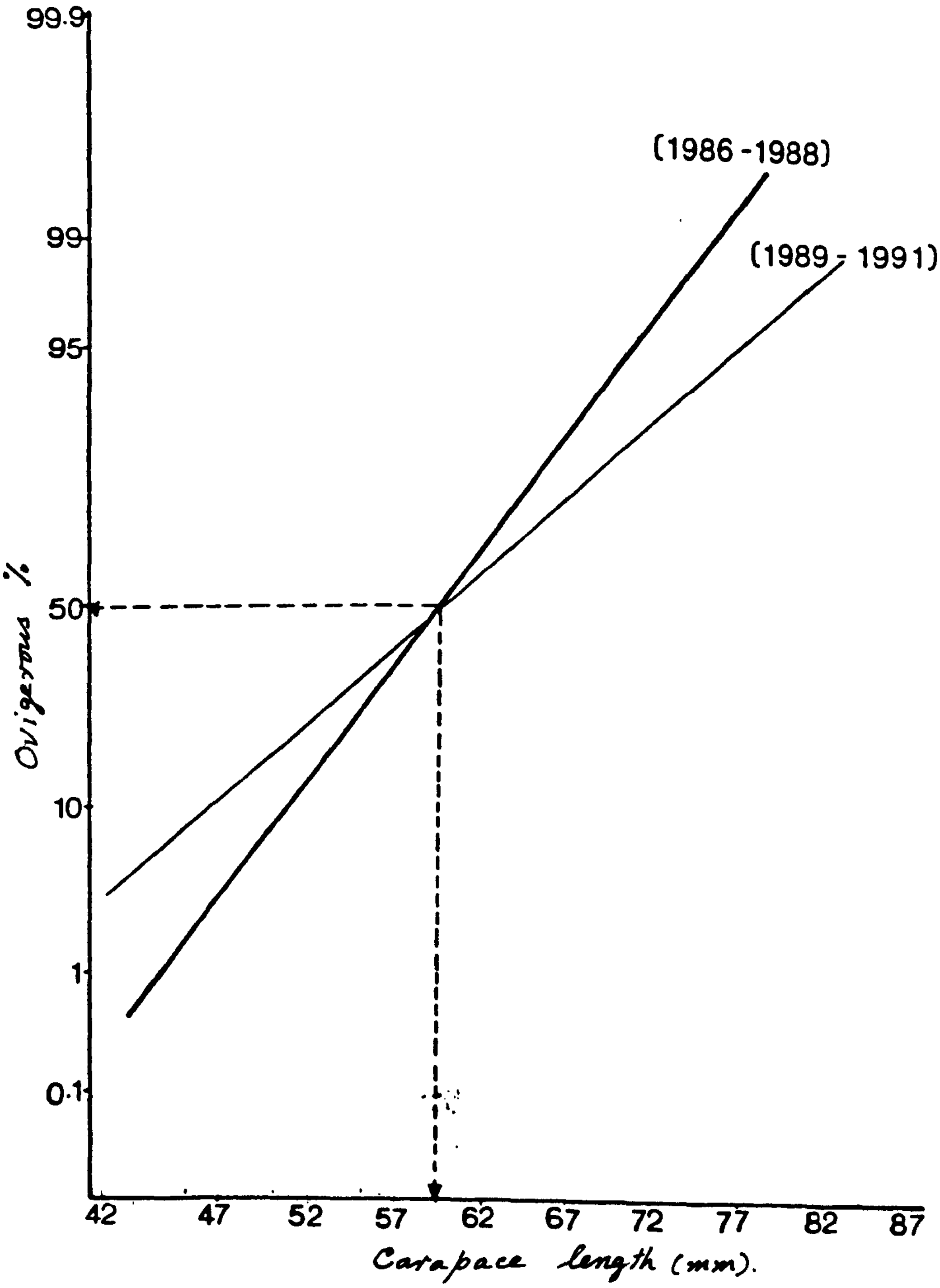


Fig. 3.7 ***Panulirus homarus*** **- estimation of length at first functional maturity using probability paper technique.**

3.6.3 Results and analysis.

3.6.3.1 Length at maturity.

Fig. 3.8 shows the results of the intersect analysis made as explained by George and Morgan (1979), Grey (1979). The results indicate that female lobsters start to show longer tails than male above a size of about 32mm in carapace length. It is seen from the present study that the graphs for males and females (Fig. 3.8) overlap up to 32mm carapace length, after which there is a distinct separation of regression lines. It should be noted that the smallest ovigerous females were recorded within the 40 - 44mm carapace length group (Appendix 3.3). The separation of the two graphs after 32mm carapace length on the other hand might be due to a differential relative growth pattern between the two sexes.

Tables 3.7A and 3.7B gives the numbers of lobsters in each length group and in different maturity stages for the whole period for the two sexes separately (based on Appendix 3.1 & 3.2). These numbers have been converted to percentages in Tables 3.8A and 3.8B for females and males respectively. The total percentage of mature lobsters (stages 4 to 6 in females and 3 to 5 in males) in each length group is also given in the Table. These values are shown in Fig. 3.9 in the form of smoothed curves. Comparison of data for males and females show that the former

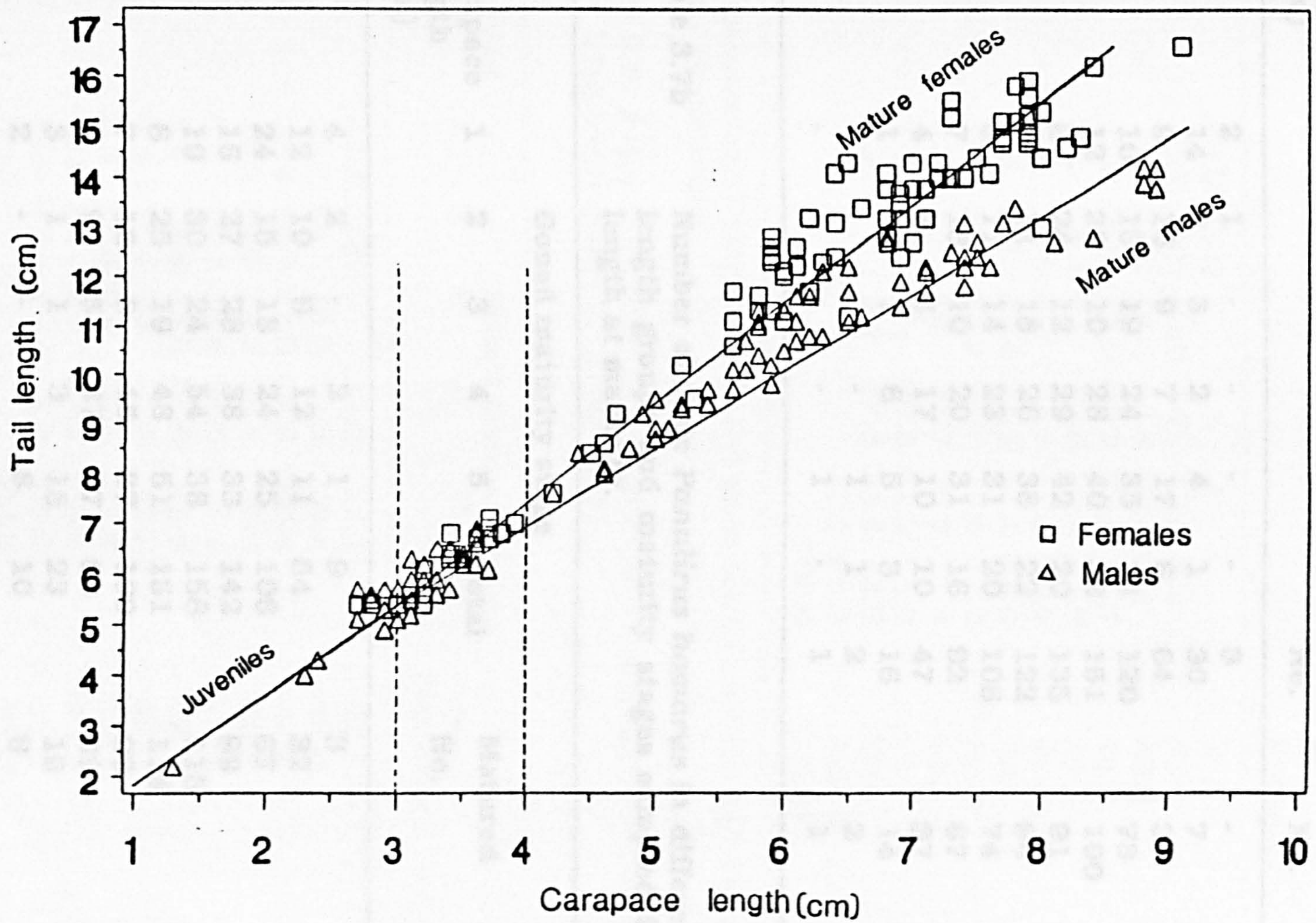


Fig. 3.8 *Panulirus homarus* - fitted regresssion lines for carapace length and tail length values of female (□) and male (Δ). Dotted lines show the intersect area.

Table 3.7a Number of female *Panulirus homarus* in different 5mm length groups and maturity stages sampled for length at maturity estimates.

Carapace mid-length (mm)	Gonad maturity stage 1	2	3	4	5	6	Total No.	Matured No.
37	2	1	-	-	-	-	3	-
42	14	6	3	2	4	1	30	7
47	9	16	9	7	17	6	64	30
52	10	18	19	24	35	14	120	73
57	12	29	10	28	40	32	151	100
62	8	24	12	29	42	20	135	91
67	8	11	18	26	38	22	122	86
72	8	11	14	23	31	20	106	74
77	7	13	10	20	31	16	92	67
82	4	2	4	17	10	10	47	37
87	1	-	1	6	5	3	16	14
92	-	-	-	-	1	1	2	2
97	-	-	-	-	1	-	1	1

Table 3.7b Number of male *Panulirus homarus* in different 5mm length groups and maturity stages sampled for length at maturity.

Carapace mid-length (mm)	Gonad maturity stage 1	2	3	4	5	Total No.	Matured No.
37	4	2	-	2	1	9	3
42	12	10	9	12	11	54	32
47	24	15	18	24	25	106	67
52	16	27	28	38	33	142	99
57	10	30	24	54	38	156	116
62	8	25	19	48	51	151	118
67	7	12	8	45	37	109	90
72	5	9	5	27	37	83	69
82	3	1	1	3	15	23	19
87	2	-	-	-	8	10	8
92	-	-	-	-	4	4	4
97	-	-	-	-	2	2	2

Table 3.8a Percentage distribution of female *Panulirus homarus* by length and gonad maturity stage.

mid- Carapace Length (mm)	Gonad maturity stage 1	2	3	4	5	6	% maturity
37	66.6	33.3	-	-	-	-	0.0
42	46.7	20.0	10.0	6.7	13.3	3.3	23.3
47	14.1	25.0	14.1	10.9	26.6	9.4	46.9
52	8.3	15.0	15.9	20.0	29.2	11.7	60.9
57	8.0	19.2	6.6	18.5	26.5	21.2	66.2
62	5.9	17.8	8.9	21.5	31.1	14.8	67.4
67	6.6	9.0	14.8	21.3	31.1	18.0	70.4
72	7.6	10.4	13.2	21.7	29.3	18.9	70.2
77	7.6	14.1	10.9	21.7	33.7	17.4	72.8
82	8.5	4.3	8.5	36.2	21.3	21.3	78.8
87	6.3	-	6.3	37.5	31.3	18.8	87.8
92	-	-	-	-	50.0	50.0	100.0
97	-	-	-	-	-	100.0	100.0

* Gonad maturity stages 4,5 and 6 were considered for percentage maturity estimates.

Table 3.8b Percentage distribution of male *Panulirus homarus* by length and gonad maturity stage.

mid- Carapace length (mm)	Gonad maturity stage 1	2	3	4	5	% maturity
37	44.4	22.2	-	22.2	11.1	33.3
42	22.2	18.5	16.7	22.2	20.4	59.3
47	22.6	14.2	17.0	22.6	23.6	63.2
52	11.3	19.0	19.7	26.8	32.2	69.7
57	6.4	19.2	15.4	34.6	24.4	74.4
62	5.3	16.6	12.6	31.8	33.8	78.2
67	6.4	11.0	7.3	41.3	33.9	82.5
72	6.0	10.8	6.0	32.5	44.6	83.1
77	12.9	6.5	6.5	27.4	46.8	80.7
82	13.0	4.4	4.4	13.0	65.2	82.6
87	20.0	-	-	-	80.0	80.0
92	-	-	-	-	100.0	100.0
97	-	-	-	-	100.0	100.0

* Gonad maturity stages 3,4 and 5 were considered for percentage maturity estimates.

matured at smaller length than the latter. The 50% maturity point (sexual or physiological) was approximately 40 mm in carapace length for males and 48 mm for females.

3.6.3.2 Age at maturity.

It was not possible to make a reliable estimation on the age at first maturity of *P. homarus* of the South coast. A direct estimation of the age of individual lobster could not be done as they do not have hard parts of the body except the shell which is cast off in each moulting. However, the von Bertalanffy (1938) growth formula was used to estimate the probable age corresponding to the size at maturity levels. Details of this estimate are shown in Table 3.9 (see chapter 5).

Since males have been shown to reach 50% maturity at a carapace length of 40 mm, it is reasonable to assume that a high percentage of males (more than 50%) reach sexual maturity at the age of 1.5 years. Although females attain sexual maturity at a comparatively larger length (48 mm), due to their almost similar fast growth pattern (See section 5.3.1) they also attain sexual maturity at a similar age. It is therefore reasonably safe to assume that both male and female *P. homarus* reach sexual maturity (physiological maturity) at an age between 1.5 to 2.0 years. As the 50% ovigerous level is around 59.5 mm carapace length, it is possible to assume that the age of spawning (functional maturity)

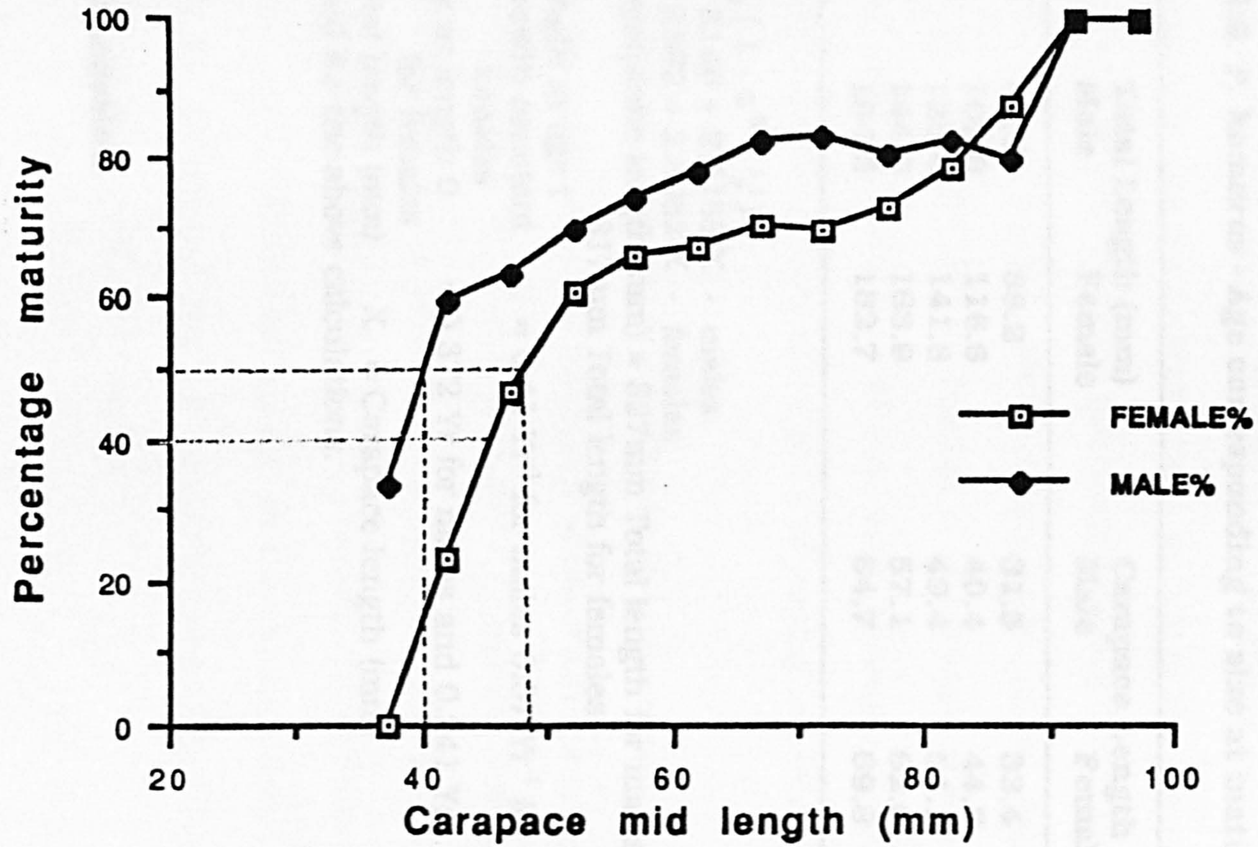


Fig. 3.9 ***Panulirus homarus*** **- length at first sexual (physiological) maturity estimated using a smoothed curve.**

should be around 2.5 years for both sexes.

Table 3.9. *P. homarus* - Age corresponding to size at maturity.

Age (Yrs)	Total Length (mm) Male	Total Length (mm) Female	Carapace Length (mm) Male	Carapace Length (mm) Female
1.0	80.5	88.2	31.5	33.4
1.5	103.0	116.6	40.4	44.3
2.0	125.6	141.8	49.4	54.1
2.5	144.9	163.9	57.1	62.6
3.0	164.2	182.7	64.7	69.8

$L_t = L_\infty (1 - e^{-K(t-t_0)})$

$Y = 1.3146 + 2.5158\,X$ - males

$Y = 1.3582 + 2.5982\,X$ - females

L_∞ = Asymptotic length (mm) = 327mm Total length for males
317mm Total length for females

L_t = Length at age t

K = Growth constant = 0.41 Yr^{-1} for males 0.37 Yr^{-1} for females

t_0 = Age at length 0 = 0.372 Yr for males and 0.241 Yr for females

Y = Total length (mm) X = Carapace length (mm)

were used for the above calculations.

3.6.4 Discussion.

Heydorn (1969a) could find no particular size for the attainment of sexual maturity of *P. homarus*. Based on 293 observations he illustrated the relationship between the development of the vasa deferentia and the mating organs at various carapace lengths. The first macroscopic signs of development of the mating organs were observed at a carapace length of 34 mm and of the vasa deferentia at a carapace length of 41 mm. According to Heydorn (1969a), both are fully developed at a carapace length of 59 mm. Based on these results he assumed that sexual maturity is attained during the final stages of development of both the vasa deferentia and the mating organs, ie, within the carapace length range of 50 - 59 mm. This was confirmed by Berry (1971b) working on 209 specimens of male *P. homarus* from Natal waters, South Africa. According to Berry (1971b), seminal fluid revealed the presence of spermatozoa in animals from 47 mm carapace length upwards and it was concluded that males are capable of mating between a carapace length of 50 - 59 mm.

It is reasonable to assume that the female *P. homarus* population in the Transkeian waters of South Africa as a whole attain sexual maturity at a carapace length of 50 mm and more (Heydorn, 1969a). Female *P.homarus* population in Natal waters appears to attain sexual maturity at a slightly larger size (Berry, 1971b). Breeding also appears to start at a smaller size in Transkeian waters, as the smallest berried females recorded had a carapace length of 43 mm as opposed to 50 mm, which was the smallest recorded in Natal.

De Bruin (1962) estimated that in Sri Lanka *P. homarus* attains sexual maturity at a carapace length of between 55 and 59 mm as the same as for the Natal population. George (1963), working on the East Aden *P. homarus* population had insufficient data to make an accurate assessment, but suggested that sexual maturity might be attained between a carapace length of 60 and 70 mm. According to the results of the present study female *P.homarus* in Sri Lanka waters attain sexual (gonad) maturity at a carapace length between 35 and 50 mm, and the size at the onset of oviposition (spawning) was estimated as 59.5 mm carapace length.

Researchers on other spiny lobster species generally estimate maturity using only females since the male lobsters do not posses satisfactory indicators of sexual maturity. The largest size at maturity for female *Homarus americanus* occurs among the off shore lobsters of southern Georges Bank (Perkins and Skud, 1966), and the inshore lobsters of Bay of Fundy - Grand Manan area (Templeman, 1936; Wilder, 1954; Groom, 1977). There the smallest ovigerous females are close to 90 mm carapace length and 50% maturity is reached between 110 - 120mm carapace length. These data suggest that the Bay of Fundy is one area where a maximum size limit might help preserve reproduction potential (Aiken and Waddy, 1980). It has been shown by several workers from Bay of Fundy, that the size at onset of maturity decreases along the coast in both directions. To the south, 50% maturity drops to 70 - 74mm in CL in extreme southern areas (Thomas, 1973) and from the Bay of Fundy north wards, smallest ovigerous females of 59mm CL were recorded in Canadian waters (Templeman, 1936; 1944). Several hypotheses have been put forward to explain why the size at maturity changes from area to area. One of the most important explanations is their high exploitation rates in the commercial fishery combined with legal size limits below mean maximum size at maturity exert genetic pressure for maturation at a smaller size. Another suggestion is that exposure to the continental slope results in larger minimum size at maturity because of the genetic influence from offshore stocks, both through larval drift and direct movement of adults. The most plausible explanation appears to be that first advanced by Templeman (1936), who contended that high summer temperature favours early maturity in female lobsters, whereas the very cold water of the Bay of Fundy retard reproductive maturation. In later studies, this hypothesis was supported by Kurata (1962) and Smith (1977), as explaining that a progressive decrease in mean size of ovigerous lobsters from the eastern (coldest) towards the western (warmest) end of the Long Island Sound area. This phenomena was also observed by Simpson (1961) for *Homarus vulgaris* along the coast of North Wales.

Considerable variation in size at maturity also seems to occur among the members of the genus *Nephrops* (Thomas, 1964; Figueiredo and Thomas, 1967; Morizur, 1983) and also among some spiny lobster species. Female *Jasus* lalandii , for example, mature at 45mm CL in south west Africa and at 55 - 59 mm CL in south Africa (Matthews, 1962; Heydorn, 1965). In New Zealand, Bradstok(1950) found that female *Jasus edwardsii* matured between 70 - 79mm CL in the Wellinton area, whereas 50%

maturity values of 80mm, 110mm and 120mm CL for the same species have been recorded by Street (1969) for other areas of New Zealand. In contrast, information from Heydorn (1969a) and Berry (1971b) for *P. homarus* indicated the opposite trend, with smaller size at maturity occurring in colder waters. Several researchers have reported similar variation in size at first maturity from different parts of the world,eg. for *Jasus verreauxi* in New Zealand waters (Kensler, 1967b); for *Panulirus cygnus* in Australian waters (Chittleborough, 1976); for *Jasus lalandii* in South African waters (Newman and Pollock, 1974); for *Jasus edwardsii* in New Zealand waters (Annala et al. 1980). Annala et al., (1980) working on *Jasus edwardsii* reported that size at onset of maturity shows an inverse relationship with water temperature and supported the hypotheses put forward by Templeman (1936). Further more, the size at which the female becomes sexually mature is a result of differential growth of the ovary and the remainder of body and the high summer temperatures are favourable for growth in length, but even more favourable for ovarian development. As a result the lobsters mature at a smaller size and an earlier age in areas with high summer temperatures than in areas with low summer temperatures. Chittleborough (1976), working on *P. cygnus* in Australian waters rejected the idea that variation in size at maturity ,is due to differences in water temperature and suggested the phenomenon of density dependence. According to him, high density resulting in retarded growth and consequent small size at first breeding. Further to him there is no evidence to suggest that breeding commences at an earlier age in areas where the size at first breeding was small. According to Newman and Pollock (1974), the onset of maturity of female *Jasus lalandii* at early sizes in some areas of the west coast of South Africa can be correlated with the faster growth rate of male lobsters.

3.7 Sex ratio.

3.7.1 Data and analysis.

Sex was recorded for all of the mature lobsters and for all immature lobsters for a period of two years. Thus, a total of 6747 lobsters have been sexed during this study. The ratio of male: female obtained (3416:3331) is consistent with the hypothesis that the ratio of male to female is 1:1 ($P > 0.05$) for the whole study period. This consistency was obtained by the log likelihood ratio test. As there was no statistical difference between the two years sampled, the numbers of the respective months were pooled and the results are shown in Fig. 3.10, in the form of percentage of female lobsters sampled each month. The distribution by size of male and female lobsters sampled along the South coast for the whole period is shown in Fig. 3.11 and Table. 3.10. The number of males exceeds that of females in the smaller size groups while the number of females exceeds that of males in the larger size groups.

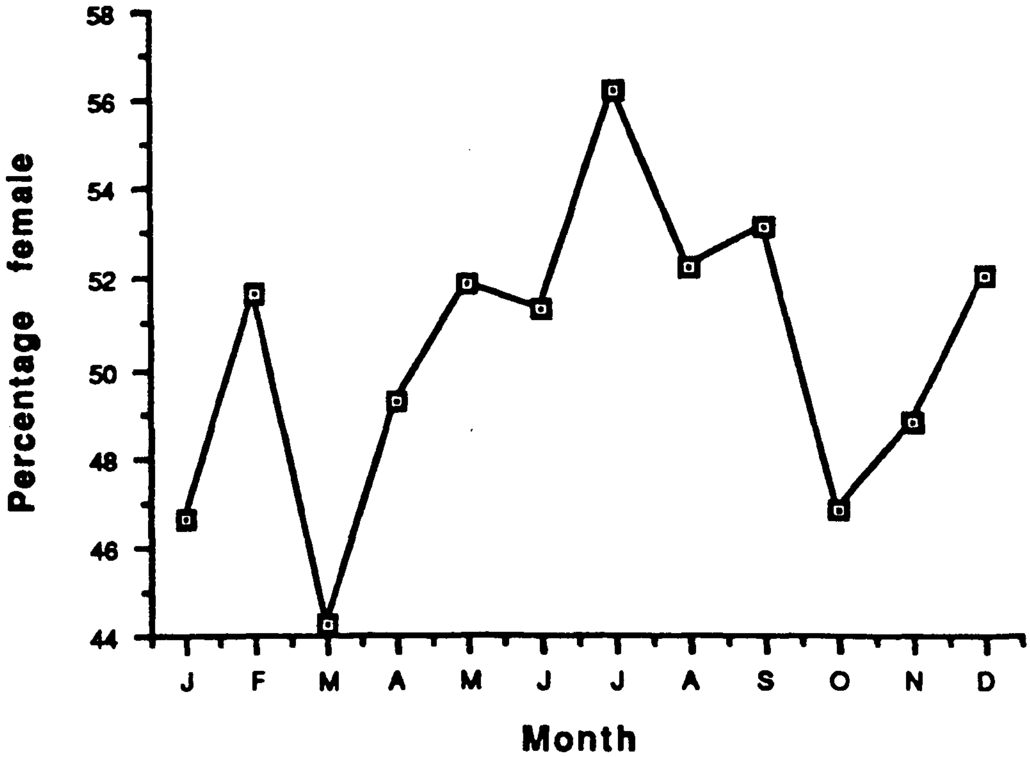


Fig. 3.10 **The monthly sex ratio in the two year period sampled as percentage female.**

Table 3.10 Size distribution of male and female *Panulirus homarus* in the commercial catch during the study period.

Total length(mm)	Number male	Number female
35	2	2
45	6	10
55	12	7
65	8	15
75	17	16
85	39	32
95	70	65
105	114	102
115	243	155
125	381	289
135	704	434
145	766	636
155	834	567
165	794	601
175	746	596
185	810	731
195	849	778
205	733	752
215	693	694
225	485	579
235	349	418
245	179	340
255	76	199
265	52	102
275	17	80
285	14	44
295	10	3
305	2	1
Total	3416	3331

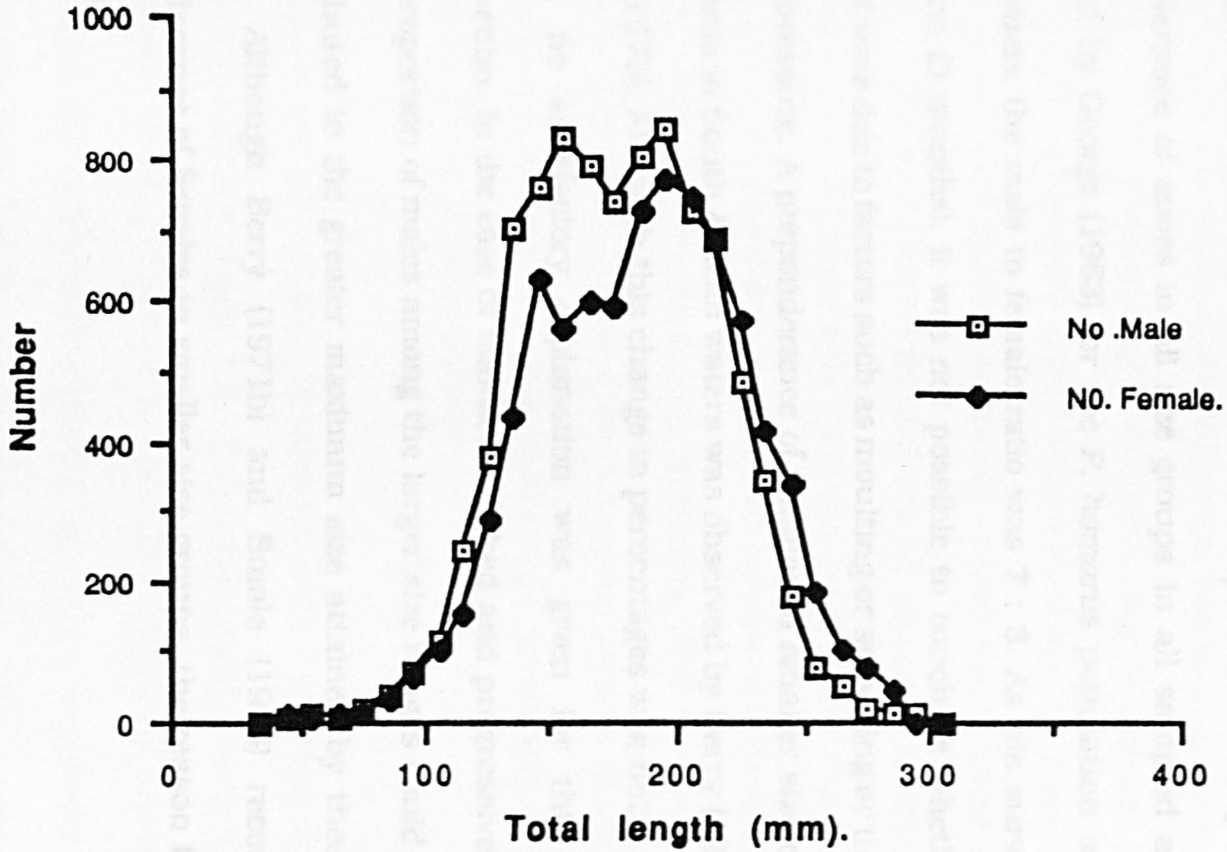


Fig. 3.11 **Size distribution of male and female *Panulirus homarus* during the study period.**

3.7.2 Discussion.

According to Heydorn (1969a), in all length classes of *P. homarus*, except the largest and smallest, the sexes are represented fairly evenly. A preponderance of males in all size groups in all sampled areas was observed by George (1963) for the *P. homarus* population in eastern Aden, where the male to female ratio was 7 : 3. As his survey was a short one (3 months), it was not possible to conclude whether these changes were due to factors such as moulting or spawning or to selective fishing pressure. A preponderance of females in smaller size classes in *P. homarus* in South African waters was observed by Berry (1971b) and Smale (1978). Although this change in percentages was not a sampling artifact, no satisfactory explanation was given for this puzzling phenomenon. In the case of males, a marked and progressive increase in the proportion of males among the larger size ranges could probably be attributed to the greater maximum size attained by them (Berry, 1971b). Although Berry (1971b) and Smale (1978) recorded the preponderance of females in smaller size groups, the reason for this is obscure.

The particular gear used and the time of capture can also influence the sex ratio of the catches. De Bruin (1962) recorded a high percentage of males collected from traps, but a 1:1 ratio was observed for samples collected by diving. He suggested that a greater proportion of males in samples collected by traps may be attributed to the greater foraging activity among males.

The gradual drop in the percentage of male lobsters in larger size groups as observed in this study agrees with what has been observed for most fish species. The gradual drop in the percentage of males in larger size groups (larger age groups) is well known in many fish populations but as yet remains unexplained. As juvenile males and females, immature animals, adults and berried females are all taken by different types of gear operated in the same area , the sex ratio differences observed in this study cannot be related to any of the behavioural patterns such as moulting migration or spawning migration. The preponderance of females in larger size groups observed in the present study could be suggested as an adaptation to maintain a high reproductive potential for the better survival of the population.

As the males grow faster than females (K = .41 / year for males and K = .37 for females, see section 5.3.1), the differential growth rates could also influence for the preponderance of males in the large size categories. According to Sri Lanka's spiny lobster regulations (Appendix 3.4), it is prohibited to catch berried females but this may act to maintain a high proportion of females in the larger size groups of the population. The faster growth rate combined with the high natural mortality rate of males as observed in this study (M=.98 for males and 0.69 for females, see Chapter 5.5.2) perhaps could be the reason for the lesser males in larger size groups. Due to the nature of hiding of lobsters in burrows during the breeding period this could make them less vulnerable to fishing as observed by Chapman and Rice (1971) in *Nephrops norvegicus* is also a possible reason for the higher percentages of females in larger size groups.

3.8 Fecundity.

3.8.1 Introduction.

Bagenal (1968) defined fecundity as the number of ripening eggs in the female fish prior to the next spawning season. Cushing (1977), remarked that one of the most striking characteristics of fishes was their high fecundity.

Knowledge of the fecundity of a species is an important factor in lobster stock assessment. It is used to calculate the reproductive potential of a stock and the survival from egg to recruitment, on which, a judgement of minimum adult stock necessary to maintain recruitment can be made. Knowledge of fecundity and the sex ratio of the adult stock are also needed to calculate the size of the stock from estimates of annual egg production. Fecundity studies also provide data related to population stability and to year class fluctuations. These fluctuations can reach extreme proportions in some species becoming a major factor determining variations in production from year to year.

Estimating fecundity depends upon evaluating the following factors:

1) The absolute number of ova produced

2) Whether the species is a total or a partial spawner

3) On the degree of differentiation between size of eggs which will be spawned in that season and any immature eggs present which will be carried over to the next spawning season.

Fecundity in spiny lobsters can be estimated either by considering the number of matured oocyte in the ovary or by counting the number of eggs attached to the ventral side of the abdomen. Increasing attention is being given to the number of ova developing in a female before spawning each year and survival of the early stages after hatching.

It has been commonly found that a very large proportion of population production in fish and lobsters occur in the early stages of their life history. To obtain a complete picture of population production, MacKay and Mann (1969) stressed the importance of discovering as much as possible about egg production and growth and survival of the young stages.

A number of workers have realised the value of fecundity studies in population estimations. Among them, Buchanan-Wollaston (1926) attempted to estimate the total number of spawning plaice in the North Sea from the abundance of eggs in plankton samples. Walford (1938) made a similar estimate with Georges Bank haddock. Simpson (1951), MacGregor (1957) and Nagasaki (1968) were all interested in fecundity studies for such population estimates. Other possible interests in fecundity estimates are for taxonomic and racial studies.

Fecundity in this study refers to the reproductive potential of a female spiny lobster as estimated by number of potential progeny , that is the total number of final stage ova developing in the ovary just before spawning.

3.8.2 Materials and methods.

During this investigation, fecundity values were estimated by considering three different stages, ie,

a) counting the final stage (stage 5) ova in the ovary
b) counting the newly spawned eggs (orange colour eggs)
c) counting the late spawned eggs (brown colour eggs).

As documented by Morgan (1972), it is possible to fit regression lines for fecundity values estimated based on ova counts, newly spawned eggs and late spawned eggs. Based on the regression lines, egg loss corresponding to carapace length values can therefore be calculated. Three regression lines were fitted separately to each of the above mentioned stages and from them, egg-loss percentages were estimated.

3.8.2.1 Counting preserved eggs.

Numerous methods have been used to estimate fecundity in spiny lobsters (Hickman, 1946; Bradstock, 1950; Matthews, 1962). Some workers have counted all the eggs of ovary or egg mass, mostly in the case of less fecund lobsters, whereas the others have counted ova or eggs in a series of replicate sub samples to yield more constant and reliable results. Most fecundity estimates have been based on counts from small egg samples, adjusted to total number for individual lobster by the ratio of weight or volume of the sample. Descriptions of variations on the gravimetric and volumetric sub-sampling procedures are numerous in the literature.

Volumetric sampling as its name implies is based on counting eggs in a fixed volume of the sample. Volumetric sub-sampling is usually carried out with wet eggs and has been attempted for American lobster *Homarus americanus* by several researchers e.g. (Herrick, 1909; Squires, 1970).

Early records of the volumetric sub-sampling used to count lobster eggs goes back to Herrick (1909), who estimated the fecundity of *Homarus americanus*. Squires (1970) estimated fecundity of female *H. americanus* in Newfoundland waters using the volumetric technique.

A comparatively recent variation of the volumetric method (Hodder, 1963; Pitt, 1964) is based on the use of the "Whirling vessel" originally designed for sampling plankton. Recently, Corey (1987) used the volume of the egg mass and the area of the ventral aspect of the abdomen for his fecundity studies in crayfish species from Canadian waters.

Gravimetric sampling as its name implies is based on weighing the eggs. Sub-sampling can be carried out using either dry or wet eggs. For counting lobster eggs, many researchers have used the gravimetric method (Thomas, 1964; Kensler, 1967a, 1968; Berry, 1971b; Morgan, 1972; Hepper and Gough, 1978; Abello and Sarda, 1982; MacFarlane and Moore, 1986).

In his fecundity studies on *Jasus verreauxi* and *J. edwardsii*, Kensler (1967a, 1968) removed the total egg mass and squeezed it on a fine plankton netting to separate the eggs. Three 1g samples of eggs were used for manual counting and the total number then calculated from the total weight of the egg mass. Abello and Sarda (1982), used the gravimetric sub-sampling method to estimate fecundity of *Nephrops* *norvegicus*. If the number of eggs did not exceed 1000, all were counted individually. In other cases, the number was estimated from the dry weight of a sub-sample of fifty eggs referred to the dry weight of the whole sample. The maximum error in the calculations was found to be less than 3%. Hepper and Gough (1978) also adopted a similar procedure to count the total number of eggs of *Homarus gammarus*, but the estimate was regarded as the minimum value considering the egg-loss during handling by fisherman and merchants.

Honda (1980) obtained estimates of *Panulirus marginatus* eggs based on sub-samples of 0.125g from each pleopod to makes up a sample of 1g. The method used by Thomas (1964) to obtain numbers was little different. The whole ovary was dissected out and weighed. Two portions, together representing between one-quarter and one-half of the whole ovary were broken off and weighed. The eggs in these portions were then counted and from this a calculation was made for the total number of eggs.

A few workers have made comparisons of different methods used in fecundity estimations. Thomas (1964), tested the dependability of estimates based on ovarian counts and egg counts. Although only undamaged specimens were used, estimates of the number of eggs carried by *Nephrops norvegicus* in berry showed a lower average than the estimates based on the ova counts. Although, comparison of the estimates from volumetric and gravimetric methods for spiny lobsters are not found to be in the literature, such comparisons have been made for some fish species. Wolfert (1969), tested the dependability of the above two methods for estimating egg production of walleyes from Lake Erie. He observed less variability in his results with the gravimetric method than the volumetric method. The errors ranged from -1.3 to 2.8% with the gravimetric estimate and -15.0 to 4.7% with the volumetric estimate. The present study has thus adopted the gravimetric approach.

3.8.3 Results and analysis.

The results of the fecundity estimates based on ova and egg counts are shown in Table 3.11. The fecundity values of *P. homarus* based on ova counts have been related to carapace length, total weight and age. To estimate length-age relationships, the von Bertalanffy (1938) growth formula was used (see chapter 5). While preparing the Table 3.12, the present study results were also compared with the age values for *P. homarus* given by other workers (Mohamad and George, 1968; Berry, 1971b; Joseph, 1971). Considering the number of females, number of spawners, and their fecundity values in different length groups a measure of total reproductive potential of the population was also estimated.

3.8.4 Relationship of fecundity to other parameters

3.8.4.1 Fecundity related to carapace length.

From the scatter diagram of fecundity against carapace length (Fig. 3.12), it is apparent that fecundity increases in direct proportion to increase in carapace length. The relationship of ova number to carapace length is given by the equation:

$$Y = 9301.3X - 351040 \quad (r = 0.92;\ N = 35).$$

(where, Y = fecundity and X = carapace length in mm).

The data given in Table. 3.11 also indicate that for any one length of the lobster, the fecundity varies between wide limits. It has been pointed out by Raitt (1933), Simpson (1951) and others that the relationship between body length and fecundity of fish is best expressed by an equation of the type:

$$F = c L^n$$

(where, F = fecundity, L = total length, c = a constant and n = an exponent usually with a value of 3).

Several researchers working on lobsters documented the relationship between fecundity and length as linear (Berry, 1971b; Hepper and Gough, 1978; Honda, 1980; Mac Farlane and Moore, 1986). In this

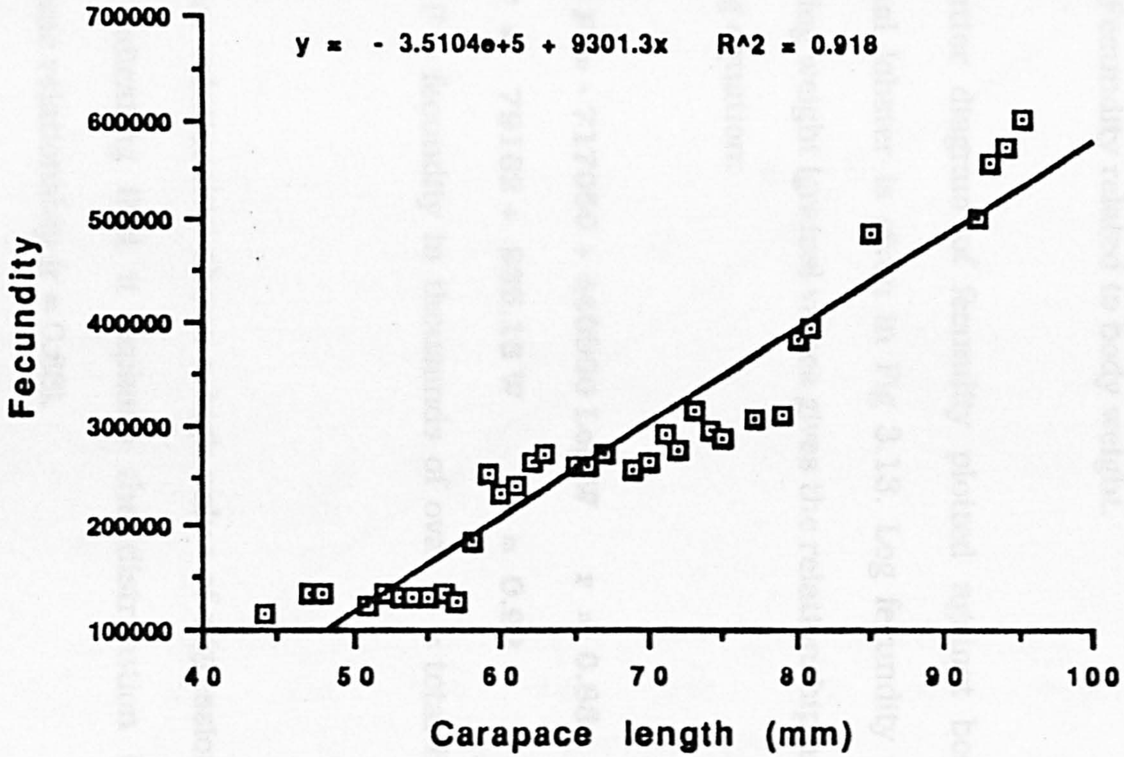


Fig. 3.12 Scatter diagram of fecundity (No. of ova) against carapace length for female *Panulirus homarus*.

study, it was found that linear relationship between carapace length and egg number gave a slightly higher coefficient of determination than a logarithmic relationship, with values of r^2 (the proportion of variation explain by the regression) - Linear = 0.92: Log = 0.88, suggesting that a linear equation gives the better description of the relationship.

3.8.4.2 Fecundity related to body weight.

The scatter diagram of fecundity plotted against body weights of individual lobster is given in Fig 3.13. Log fecundity values plotted against log weight (grams) values gives the relationship as shown in the following equation:

$$\mathbf{Log\ F = -7.17050 + 4.40990\ Log\ W \qquad r = 0.88}$$

$$\mathbf{F = 79162 + 935.16\ W \qquad r = 0.92}$$

(where, F = fecundity in thousands of ova; W = total body weight in grams).

The linear relationship shows a high value of regression coefficient (r =0.92), indicating that it explains the distribution better than a logarithmic relationship (r = 0.88).

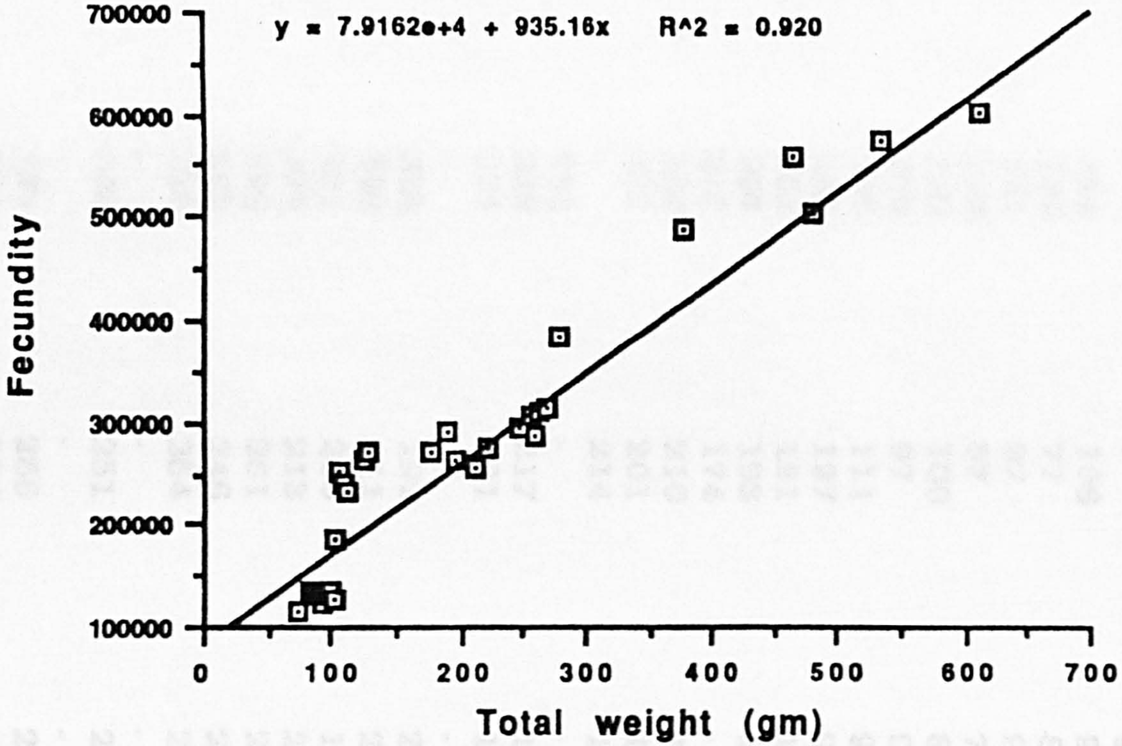


Fig. 3.13 Scatter diagram of fecundity (No. of ova) against body weight of female *Panulirus homarus*.

Table 3.11 Fecundity estimates made based on ova counts (A), newly spawned eggs (B) and late spawned eggs (C).

Carapace length (mm)	A x 10^3	B x 10^3	C x 10^3
44	116	-	-
45	-	-	-
46	-	-	-
47	137	102	94
48	134	96	100
49	-	106	-
50	-	-	96
51	124	106	99
52	136	77	81
53	131	97	98
54	130	87	79
55	130	100	87
56	136	97	96
57	127	111	93
58	184	127	91
59	252	181	127
60	234	193	153
61	241	174	-
62	262	210	106
63	271	201	174
64	-	214	166
65	261	-	-
66	258	217	154
67	271	201	168
68	-	-	-
69	256	191	203
70	262	211	209
71	291	206	199
72	274	213	211
73	316	261	227
74	295	246	249
75	286	254	209
76	-	-	-
77	306	251	254
78	-	-	-
79	309	286	258
80	384	294	268
81	396	301	294
82	-	-	-
83	-	-	-
84	-	309	-
85	491	-	291

Table 3.11 contd.

86	-	-	-
87	-	-	-
88	-	-	-
89	-	-	-
90	-	-	-
91	-	-	-
92	506	-	406
93	561	417	367
94	577	401	-
95	601	-	-

3.8.4.3 Fecundity related to age.

Fecundity values estimated in the present study were related to their respective ages and are shown in Table 3.12. The scatter diagram on Fig 3.14 of fecundity plotted against age shows that it varies widely within an age class and there is a considerable degree of overlapping in fecundity ranges between age classes. Spiny lobsters of age above 5 years have not been considered due to heavy overlapping of age classes with length. This is mainly because of the very slow growth in older size classes. The relationship of fecundity to age among fish as traditionally been described in terms of the general allometry equation, ie, by converting both fecundity and age to logarithms (Bagenal, 1957; Nagasaki, 1968; Hodder, 1963; Pitt, 1964). Despite the inadequacy of the age data, there is a definite positive linear relationship between fecundity and age. It is :

$$F = -74486 + 115620\,t \qquad r^2 = 0.92$$

(where, F = fecundity in thousands of ova and t = age in years).

The high correlation coefficient value indicates that, although there is a high overlapping in fecundity values, it increases with increasing age.

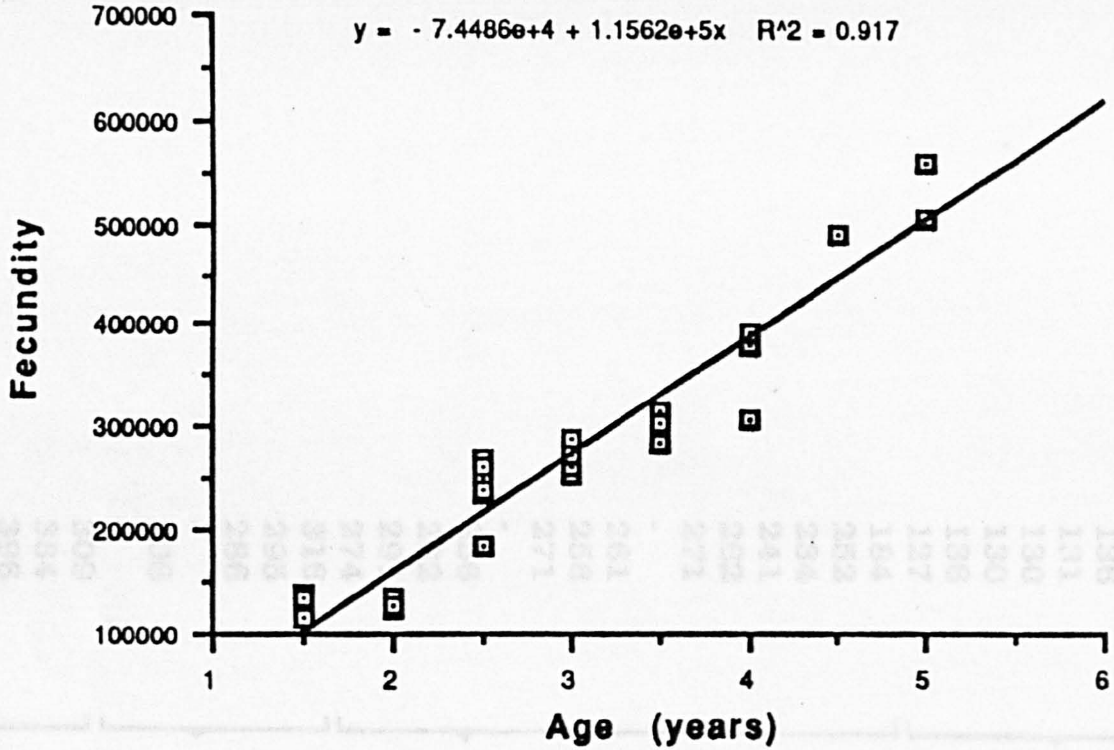


Fig. 3.14 **Scatter diagram of fecundity (No. of ova) against age for female *Panulirus homarus*.**

Table 3.12 Fecundity of *Panulirus homarus* related to age.

Carapace length (mm)	Fecundity(x 1000)	Age
44	116	
45	-	1.5 Years
46	-	
47	137	
48	134	
49	-	
50	-	
51	124	
52	136	
53	131	2.0 Years
54	130	
55	130	
56	136	
57	127	
58	184	
59	252	
60	234	
61	241	2.5 Years
62	262	
63	271	
64	-	
65	261	
66	258	
67	271	
68	-	
69	256	3.0 Years
70	262	
71	291	
72	274	
73	316	
74	295	
75	286	
76	-	3.5 Years
77	306	
78	-	
79	309	
80	384	
81	396	
82	-	4.0 Years
83	-	
84	-	
85	491	
86	-	

87	-	4.5 Years
88	-	
89	-	
90	-	
91	-	5.0 Years
92	506	
93	561	
94	577	
95	601	

3.8.5 Reproductive potential

The reproductive potential of a lobster population per breeding season is related to (a) female egg carrying capacity (b) the propensity of females to carry eggs and (c) the female size frequency, where (a) and (b) can vary with the size of the female. By combining the fecundity values of different size groups with the percentage of individuals of these length groups and the number of broods produced in a particular season, a measure of total reproductive potential of different size classes was calculated. This was shown in Table. 3.13 as the " relative fecundity" (percentage of total fecundity) and the calculation procedures are also shown in Table. 3.13. It was assumed that all females produce an average of two broods per season, but it does not take into account any reduction that may occur in terms of fecundity in the second spawning. According to the results given in Table. 3.14 and Figure 3.15, females in the carapace length range of 60 - 79 mm contributed the most (62.05 %) to total egg production.

Table 3.13 Estimation of relative fecundity for each size class in the female *Panulirus homarus* population.

Size class (mm) carapace length	Percentage of females (A)	No. of eggs produced x 10^{-3} (B)	Average no. of broods /season (C)	Total fecundity AxBxC	Relative fecundity
35 - 39	0.00	-	-	-	-
40 - 44	1.20	116.0	2	278.4	0.57
45 - 49	5.15	135.5	2	1395.7	2.88
50 - 54	12.54	130.3	2	3267.9	6.75
55 - 59	17.18	165.8	2	5696.9	11.76
60 - 64	15.64	253.1	2	7916.9	16.35
65 - 69	14.78	262.7	2	7765.4	16.04
70 - 74	12.71	287.6	2	7310.8	15.10
75 - 79	11.51	300.3	2	6948.9	14.35
80 - 84	6.36	390.0	2	4960.8	10.24
85 - 89	2.41	491.0	2	2366.6	4.89
90 - 94	0.34	548.0	2	372.6	0.76
95 - 99	0.17	601.0	2	204.3	0.34

Table 3.14 Length frequency of mature *Panulirus homarus* in the population and associated relative reproductive potential.

length group (mm) carapace length	No. of mature females (A) (stages 4/5/6)	Mean fecundity value x 10^3 (B)	No. of broods (C)	Reproductive potential x 10^5 (A)x(B)x(C)
35 - 39	-	-	-	-
40 - 44	7	116.00	2	16.22
45 - 49	30	135.50	2	81.30
50 - 54	73	130.25	2	190.20
55 - 59	100	165.80	2	331.60
60 - 64	91	253.25	2	460.80
65 - 69	86	262.67	2	450.60
70 - 74	74	287.60	2	425.60
75 - 79	67	300.33	2	402.40
80 - 84	37	390.00	2	288.60
85 - 89	14	491.00	2	137.50
90 - 94	2	548.00	2	21.92

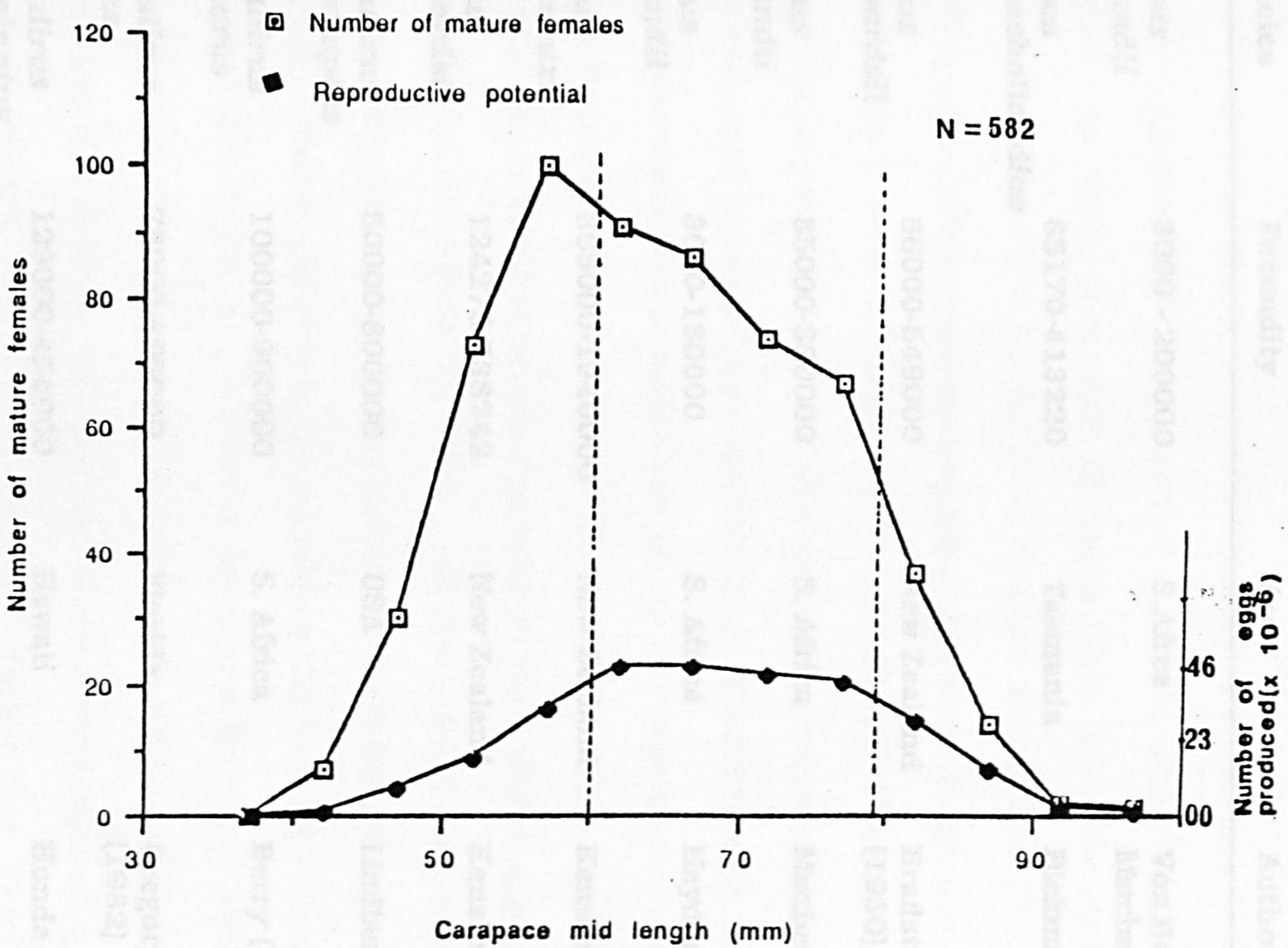


Fig.3.15 Length frequency of mature female *Panulirus homarus* and associated relative reproductive potential.

Table 3.15. Comparison of fecundity levels of the members of Palinuridae.

Species	Fecundity	Area	Author
Jasus lalandii	3000 - 200000	S.Afrca	Von Bonde and Marchand (1935)
Jasus novaehollandiae	65170-413220	Tasmania	Hickman (1946)
Jasus edwardsii	86000-549000	New Zealand	Bradstock (1950)
Jasus lalandii	85000-330000	S. Africa	Matthews (1962)
Jasus lalandii	3000-180000	S. Africa	Heydorn (1965)
Jasus verreauxi	385000-1940000	New Zealand	Kensler (1967a)
Jasus edwardsii	124278-538242	New Zealand	Kensler (1968)
Panulirus inturruptus	50000-800000	USA	Lindberg (1955)
Panulirus homarus	100000-900000	S. Africa	Berry (1971) b
Panulirus argus	75000-690000	Florida	Gregory et., al (1982)
Panulirus marginatus	129000-454000	Hawaii	Honda (1980)
Panulirus ornatus	225000-840000	Papua New Guinea	Mac Farlane and Moore(1986)
Panulirus homarus	116000-601000	Sri Lanka	(present study)

3.8.6 Discussion.

Fecundity levels estimated for several members of Palinuridae having important fisheries in different parts of the world and the results obtained from the present study shown in Table. 3.15. The results indicate that fecundity of the female *P. homarus* ranges from 116000 ova of a lobster of 44mm carapace length and 74 g weight to a maximum of 601000 for a lobster of 95mm carapace length and 465 g weight. Although these observations are in close association with the fecundity values estimated for related species (Table. 3.15), it is important to note that present estimates were made based on ova counts as against many other workers. According to Morgan (1980), fecundity is high among all species of Palinuridae and usually ranges up to some 700000 eggs per spawning. It is clear from the Table. 3.15, that among Palinuridae, members of the genus *Jasus* appear to be less fecund than members of the genus *Panulirus*. In most cases, the relationship between carapace length and fecundity among lobsters is generally a linear one (Berry, 1971b; Morgan,1972; Hepper and Gough, 1978; Honda, 1980; Mac Farlane and Moore, 1986), although several researchers reported it as logarithmic (Herrick, 1909; Saila, Flowers and Hughes 1969; Perkins, 1971).

Some authors believe that *P. homarus* spawns more than once per season. According to Berry (1971b), large females of *P. homarus* produce even up to four broods per year, whereas according to Heydorn (1969a), there is no indication of more than one spawning per year. During the present study, some large females were observed bearing both fragmental spermatophores and recently deposited ones indicating the possibility of having more than one broods per year.

In the case of small females, high ova-loss (section 3.9.3) also provides reasonable clues about a second spawning. Apart from Berry's data, several other workers also reported the phenomenon of repetitive breeding among the members of the genus *Panulirus* (Chitty, 1973).

Fecundity of *P. homarus* in the present study increased at a rate linear to the carapace length. The loose relationship of fecundity and age is also linear, but the variability is larger. The relationship of fecundity to weight is also linear. When all these relationships are taken together, the following pattern has been found correct for *P. homarus*:

Fecundity $\propto$ Length $\propto$ Weight $\propto$ Age

Beverton and Holt (1957) observed that if the ovary were growing isometrically and size of eggs did not vary with the size of the fish (lobster), egg number would be proportional to the area of the germinal epithelium and thus to the 2/3 power of weight. They also pointed out, however, that the germinal epithelium is so convoluted that it completely fills the ovary, thus fecundity should be proportional to body weight itself. The results of the present study confirm this conclusion.

3.9. Ova-loss and egg-loss estimates.

3.9.1 Criteria for ova-loss and egg-loss estimates.

It has been shown by several researchers that there is an egg-loss during the process of incubation (Perkins, 1971; Morgan, 1972; Morizur, 1979;). As demonstrated by Morgan (1972), it is possible to fit regression lines for fecundity values estimated based on ova counts, newly spawned egg counts (orange colour eggs) and late spawned egg counts (brown colour eggs) (Fig. 3.16) and based on the regression equations percentage egg-loss can be calculated.

3.9.2 Results and analysis.

Table. 3.11 shows fecundity values estimated from ovary counts, newly spawned eggs and late spawned eggs. In Fig. 3.17, the number of ova in the ovaries, newly spawned eggs (orange colour) and late spawned eggs (brown colour) are plotted against respective carapace length values. The

A

B

Fig. 3.16 *Panulirus homarus* - A : Newly spawned (orange colour) and B : late stage (brown colour) eggs.

regression equations for each of the cases are shown in Table. 3.16.

Based on the regression equations given in Table 3.16, the egg-loss percentages were calculated from,

a) ovary eggs to newly spawned eggs ----------------- (A - B)

b) ovary eggs to late spawned eggs ----------------- (A - C)

c) newly spawned eggs to late spawned eggs ---------- (B - C)

The results are shown in Table 3.17.

Table 3.16. Regression equations and relevant "r" values for the ova, newly spawned eggs and late spawned eggs of female *P. homarus*.

	Number observed	r	Regression equation
A Ovary counts	35	0.96	Y= 9301.3 X - 351040.0
B Newly spawned eggs	33	0.97	Y= 6948.9 X - 260940.0
C Late spawned eggs	32	0.97	Y= 6793.7 X - 271190.0

Y = total number of eggs, X = carapace length (mm).

Table 3.17. Ova loss and egg loss percentages for female *P. homarus.*

Carapace length (mm)	Ova A	Newly spawned B	Late spawned C	% egg loss A-B	% egg loss A-C	% egg loss B-C
44	58217	34562	27732	40.6	52.4	198
60*	207038	145744	136432	29.6	34.1	6.3
79*	383763	277773	265512	27.6	30.8	4.4
95	532584	399205	374212	25.0	29.7	6.2

*** The carapace length range having the highest reproductive potential**

According to the results there is a considerable ova-loss (25 - 30%), during the process of ova extrusion, which was very prominent among large size classes. The egg-loss percentage between newly spawned and late spawned animals seems to high among small size groups (19.8%) whereas it is comparatively low among large size classes (6.26%). The carapace length range of 60mm-79mm, having the highest reproductive potential shows the highest ova loss during the process of spawning. This may be due to one or combination of several of the following factors.

a) large females do not release all the final stage ova in a single extrusion.

b) a large percentage of ova fail to adhere to the pleopods soon after

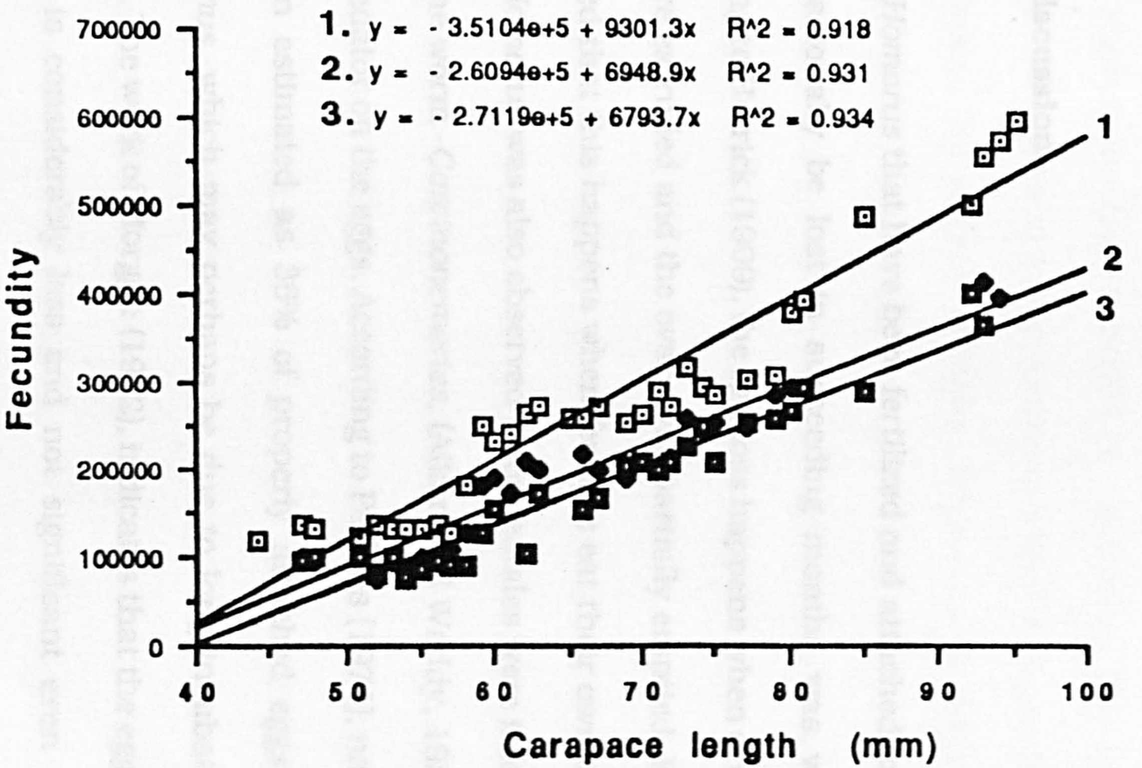


Fig. 3.17 **Relation between total number of ovary ova and eggs carried with carapace length for ovary ova (⊡) newly spawned eggs (■) and late spawned eggs (◘) in *Panulirus homarus*.**

fertilization.

c) considerable predation takes place on the recently deposited eggs (especially among small females).

d) considerable amount of egg-loss takes place in newly attached eggs during the process of capture or handling (specially among small females).

3.9.3 Discussion.

Eggs of *Homarus* that have been fertilized and attached to the pleopods will occasionally be lost in succeeding months was well observed. According to Herrick (1909), the egg-loss happens when unusually small eggs were extruded and the ovary was partially emptied. Knight (1919), suggested that this happens when females eat their own eggs. High egg loss of *Homarus* was also observed when females were infested with the nemertine worm -*Carcinonemertes*, (Aiken and Waddy, 1980) which is a micropredator on the eggs. According to Perkins (1971), natural egg loss has been estimated as 36% of properly attached eggs in *Homarus americanus*, which may perhaps be due to long incubation period (9 months). The work of Morgan (1972), indicates that the egg loss in spiny lobsters is considerably less and not significant even at 10% level because of their comparatively shorter incubation period (3.5 - 8 weeks). High egg loss of *Nephrops norvegicus* was observed by Morizur, Conan, Guenole and Omnes (1981). It was high among smaller females (45%), and according to these authors it is mainly due to predation by fish. Mac Farlane and Moore (1986), working on *P. ornatus* did not detect any significant egg-loss during incubation.

It is well known that most of the Homarid lobsters in cold waters show a longer incubation period (9-11 months), while those in tropical waters show a shorter incubation period (4 - 6 weeks). The high ova - loss observed in the present study contrasts with the observations made by other workers for tropical lobsters. According to Berry (1971b), the incubation period of *P. homarus* ranges from 4 - 6 weeks. It is reasonable to assume that one possible reason for high egg loss in Homarid lobsters is their longer incubation period.

The results of the present study indicate an ova-loss of 25 - 30% during the process of extrusion which may possibly be attributed to the partial spawning activity among larger females. Out of their mature eggs they may release the first batch during February/ March period and the rest in a later time. Perhaps this may be the reason for having spawning lobsters at any time of the year even during the monsoon months when low percentages of mature females are present. The release of eggs in two batches may be a mechanism to ensure a high percentage of survival. The repetitive breeding among *P. homarus* is a phenomenon which was also observed by Berry (1971b). According to him some larger females of *P. homarus* make up to as high as four broods within a spawning season.

3.10 Chapter summary.

Based on the observations on samples of the south coast spiny lobsters it is considered that sexual maturity is attained by the majority of males at a carapace length of about 40mm and females at 48mm, by this time they are about 1.5 to 2 years old. The main spawning takes place when the females are of about 59mm in carapace length and by this time they are around 2.5 years old.

Sex ratio studies indicated a preponderance of males in smaller size groups while high percentage of females in older size groups. Egg bearing was recorded throughout the year, but maximum breeding activity was recorded during September to March. Larger females appear to spawn at the beginning of the season (August / September), and the first time spawners appear to lay their eggs during the latter part of the season (March/ April). Signs of repetitive breeding were observed, which was clear among larger females.

Ova counts were made on 35 randomly selected females, over the sexually mature size range. The smallest ovigerous female

observed had a carapace length of 44mm and carried 116000 ova. The largest berried female was of 95mm carapace length and had 601,000 ova.

Although berried females were observed from 40-44mm carapace length group onwards, highest reproductive potential was contributed by the 60-79mm carapace length range.

Estimates made on ova and egg counts indicated a 25-30% ova loss among larger females during the process of egg extrusion. This high ova loss may perhaps be attributed to a true one or most probably be due to retention of eggs to release in a later time. A higher egg-loss was also observed among smaller females (19.8%), when compared to larger ones (6.26%).

CHAPTER 4

Fig. 4.1 Out-rigger dug-out canoes. Fishermen clearing lobsters from trammel nets.

4. Fishery

4.1 Introduction

The history of the spiny lobster fishery along the south coast was traced briefly in Section 1.2.1.1 together with comments showing this is one of the main lobster producing areas in Sri Lanka at present.

Materials for the present part of the study were collected during the twice monthly field visits made to the south coast from May 1989 to April 1991. In addition to the above, results of the spiny lobster fishery survey of the National Aquatic Resources Agency (NARA) from 1986 - 1988 are also incorporated. Methods of data collection were discussed in Chapter.2.

4.2 Fishing craft and gear.

The present fishing fleet within the study area consists of a maximum of 315 small outrigger canoes. All of these are wooden dug-out canoes (Fig. 4.1), of which some are driven using a sail while the majority are driven by paddling. The length of these canoes ranges from 2.5m - 3.0m and usually two people are involved in all fishing activities including of paddling, shooting the net and hauling.

Spiny lobsters are fished in the study area by using four different methods. These are,

a) trammel nets

b) 7.5 cm stretched mesh bottom set nets

c) lobster rings, and,

d) diving

a) Trammel nets:

These nets consist of three net panels made out of fine nylon threads (Fig. 4.2a). The mesh sizes of the three panels differ from each other and usually the middle panel holds the largest mesh. The middle net is usually a 7.5 cm meshed net while the mesh sizes of two side nets varies from 3.13 cm to 3.75 cm under stretched condition. Most of the fishermen also use these nets to catch prawns in lagoon areas during the non lobster season. A variety of small fish as well as lobsters of all sizes are usually caught by these nets. From the fishermen's point of view, these nets are highly productive, but the major drawback is that it takes a long time to clear and take undamaged lobsters. Quite often, fishermen are forced to cut these nets in many places to clear animals and hence the nets do not last long. Lobsters caught by trammel nets are very often badly injured and are categorized as low grade and fetch a low price. Along with lobsters, several fish and crustacean species are

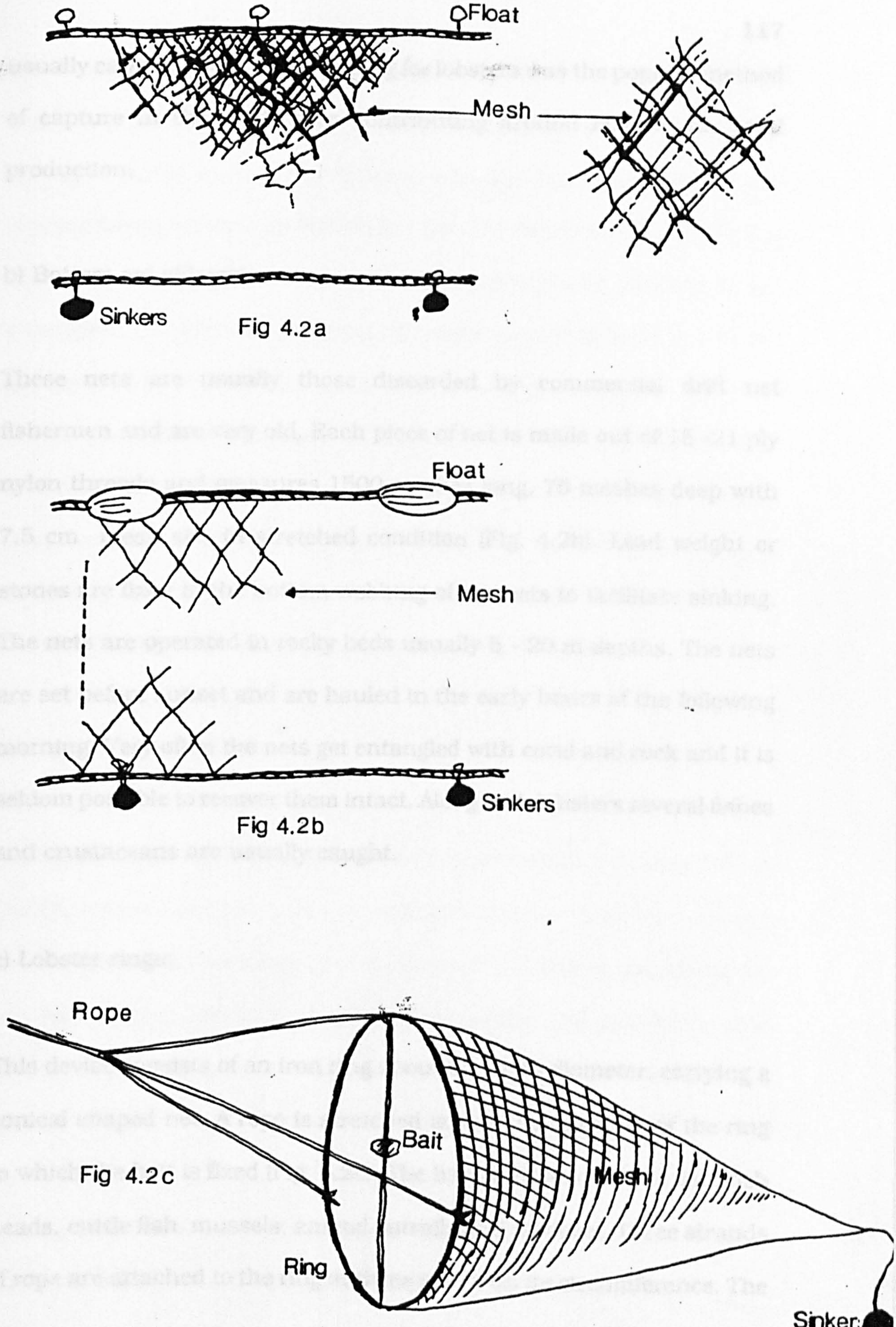


Fig. 4.2 Fishing gear used for catching lobsters in the study area.

usually caught. Trammel net fishing for lobsters was the popular method of capture in the study area contributing around 80% to the total production.

b) Bottom set gill nets:

These nets are usually those discarded by commercial drift net fishermen and are very old. Each piece of net is made out of 15 -21 ply nylon threads and measures 1500 meshes long, 75 meshes deep with 7.5 cm mesh size in stretched condition (Fig. 4.2b). Lead weight or stones are fixed to the bottom webbing of the nets to facilitate sinking. The nets are operated in rocky beds usually 5 - 20 m depths. The nets are set before sunset and are hauled in the early hours of the following morning. Very often the nets get entangled with coral and rock and it is seldom possible to recover them intact. Along with lobsters several fishes and crustaceans are usually caught.

c) Lobster rings:

This device consists of an iron ring about 90 cm in diameter, carrying a conical shaped net. A rope is stretched across the diameter of the ring to which the bait is fixed (Fig. 4.2c). The bait consists of whole fish, fish heads, cuttle fish, mussels, animal entrails and raw beef. Three strands of rope are attached to the ring at three points on its circumference. The free ends of these strands are joined to a single rope to which a float is attached. On an average 50 of these structures are carried by an outrigger canoe unit of two fishermen to the fishing grounds in the evening where lobsters are known to exist. The fishermen set these rings about 10 - 15 m apart and leave them overnight for lobsters to get entangled. The following morning, the same ground is located with the guidance of shore bearings and traps are hauled one by one using the floats. They are taken back to the shore for clearing lobsters and rebating. This gear appear to be a better device for catching lobsters than trammel nets and bottom set gill nets as the probability of obtaining undamaged live lobsters is high. Apart from lobsters, few other animals (mainly fish and crabs) are caught by these nets.

d) Skin diving:

This is the least important lobster catching method in the study area. A few fishermen carry out diving operations on certain days when the sea is clear and calm. The majority of the divers of the fishing community do not have any under water breathing apparatus and only basic skin diving equipment is used, viz; mask, snorkel, flippers, weight belt and gloves.

Among all these methods trammel net fishing dominates with a contribution of around 80%, followed by 7.5 cm bottom set nets and lobster rings. Diving for spiny lobsters along the study area is the least important method. The contribution of each fishing gear and method to the total production on a monthly basis during the study period is given in Table 4.1.

During the south west monsoon period, the intensity of the use of trammel nets is reduced and it is replaced by lobster rings (Table. 4.1). Fishermen who use trammel nets are reluctant to use them during the south-west monsoon period as many of the nets entangle heavily with adjacent corals and rocks due to rough sea conditions and it becomes difficult to locate them.

All the different fishing methods used for lobster fishing in the study area are conducted during night time, whereas diving operations are conducted at night as well as during the day time. Except diving, all other methods are passive and hence they have to be operated at times where the lobsters are active. Usually spiny lobsters are nocturnal and are entangled in these gear when they move out of their hiding places in search of food mainly during dusk and dawn (Casterlin and Reynolds, 1979, Cobb, 1981).

4.3 Fishing time and measurement of fishing effort

The following factors were considered in determining the best measure

Table 4.1 Percentage contribution of each fishing gear and method by weight to the total lobster production during the study period (pooled data for the two years).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T.N.	76.2	81.6	92.3	84.4	70.2	64.3	70.3	86.3	86.2	84.3	84.7	79.5
B.S.G	12.3	10.3	6.0	8.6	6.3	4.3	3.9	7.2	8.5	11.6	8.6	11.3
Rings	10.3	4.6	0.5	3.2	23.5	31.4	25.8	6.5	4.3	3.3	5.3	8.2
Diving	1.2	3.5	1.2	3.8	-	-	-	-	1.0	1.8	1.4	1.0

T.N.: Trammel Nets. B.S.G: Bottom Set Gill nets. -: No diving.

of fishing time in the study area.

a) Fishing is done at night. Craft leave in the evening to reach fishing grounds at sun set. The paddling (or sailing) time to the fishing grounds is normally 45 to 60 minutes. The last 15 to 30 minutes of this is spent in locating a suitable place for setting the nets/rings.

b) The setting of nets usually takes place in about 30 minutes. This has to be added to searching time to obtain total time spent on fishing related activities.

c) It takes around 30 minutes for the return trip after setting the nets/rings.

d) On the following morning around 6 a.m. the fishermen reach the lobster grounds and locate their fishing gear based on land bearings and floats. It takes nearly 45 to 60 minutes to collect the nets and the time required for return is approximately the same.

In addition to the data collected on catch and effort based on field sampling visits, an attempt was made to collect daily information from the fishermen by using a data sheet shown in Appendix 4.1. The attempt that was made to obtain precise information on the time of departure and arrival and their earnings by using the data sheet was not successful since they are not used to keeping proper records and are reluctant to declare their earnings. Even though the number of hours spent on fishing activities is the best measurement of the effective fishing effort, it was decided to consider "craft night" as the unit of the measurement of fishing effort mainly due to the reasons given above.

Fishing is done on all days except those with a full moon. Thus the number of actual fishing days per month varies around 28-30, depending on the month. Fishing is highly affected by the lunar cycle and fishing intensity is very much reduced on and around full moon days. Fishermen through their experience know that catches are poor due to high light intensity in full moon nights. As mentioned in chapter 1, fishing is highly controlled by the monsoon. In addition, even within the non-monsoonal period daily fishing ventures are very much weather dependent. Weather patterns, full moon days and lunar cycle to a large extent determine the number of days that fishermen actively conduct fishing operations.

The maximum number of fishing days recorded by a fishing craft in one month during the fishing season was 21, while the minimum was as low as 11 days. During monsoon months each year, around 90% of the fishing crafts are laid up for repairs and maintenance work. This 4 - 5 month period therefore records the lowest number of fishing days on a monthly basis.

On account of the limitations in handling small canoes in off-shore areas during rough sea conditions, the rings and set nets are very often set near to the shore in fairly shallow grounds and as a result the area of operation on such days (or weeks) is very limited.

4.4 Composition of the total catch

Besides spiny lobsters, a few other species of lesser commercial value are also brought up in lobster nets. Fishermen use these fish and crustaceans for their domestic consumption and if they are in excess, they make dry fish out of them. These incidental varieties include,

a) *Portunus pelagicus* - Sea crab

b) *Leiognathus fasciatus* - Pony fish

c) *Penaeus indicus* - Milk prawn (= Indian prawn)

d) *Epinephelus* spp - Rock fish

e) *Lactarius lactarius*

Table 4.2, and Fig. 4.3 were prepared by using the data collected from trammel net catches during the study period. Table 4.2 shows that the spiny lobsters are the principal species exploited in the fishery, forming

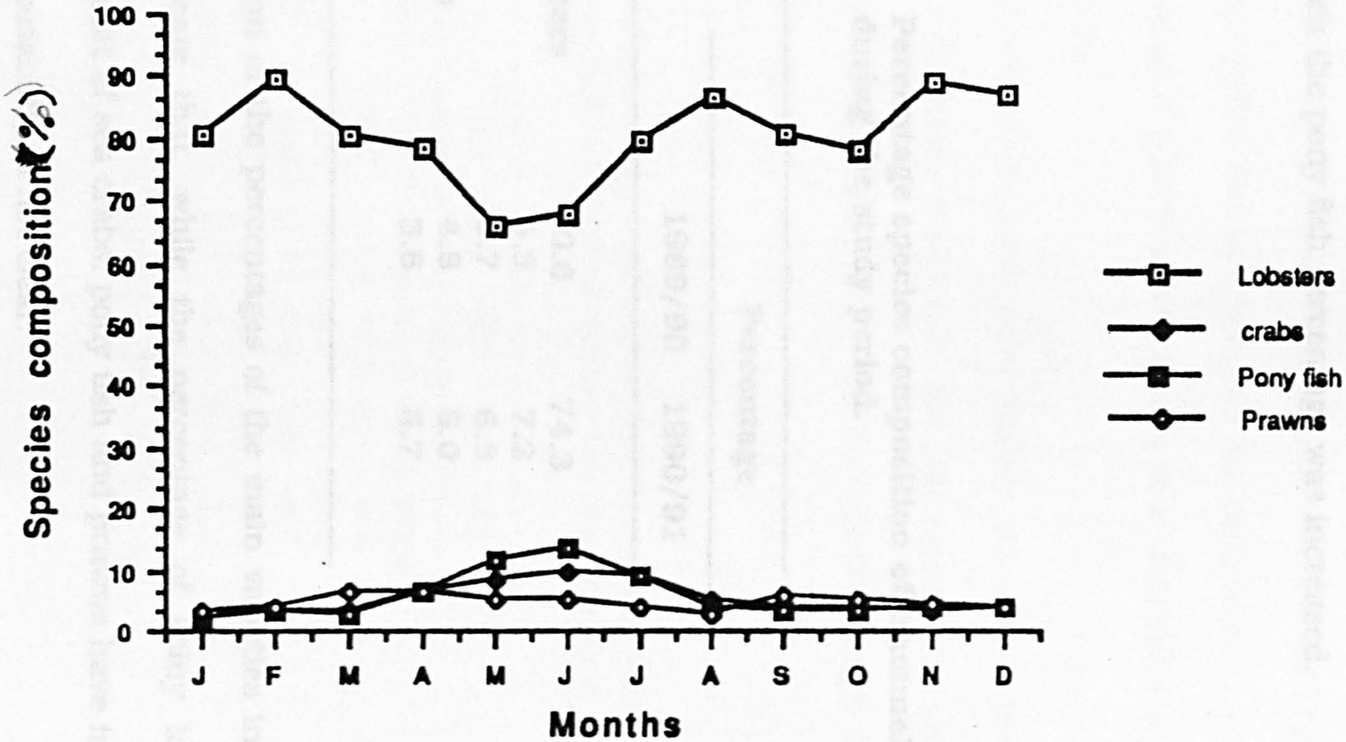


Fig. 4.3 **Species composition of the trammel net catches during the study period (combined data for 1989/90 and 1990/91).**

around 77% of the catch. According to Fig. 4.3, spiny lobsters dominate the trammel net catches throughout the year. A slight drop in the percentages of spiny lobsters was observed during monsoonal months, during which the pony fish percentage was increased.

Table 4.2 Percentage species composition of trammel nets during the study period.

Variety	Percentage	
	1989/90	1990/91
Spiny lobsters	80.6	74.3
Sea crabs	5.3	7.2
Pony fish	5.7	6.8
Sea prawns	4.8	6.0
Others	3.6	5.7

A comparison of the percentages of the main varieties in the study period indicate that, while the percentage of spiny lobsters has decreased, that of sea crabs, pony fish and prawns have increased for which the variability is not clear.

4.5 Species composition of spiny lobsters.

Six species of spiny lobsters are found in the south coast, confirming the earlier records given by Jayakody and Kensler (1986). All six species were recorded throughout the year with varying percentages. Table 4.3 shows the abundance of the six species in all sampling stations. *P. homarus* dominated the catches and its contribution ranged from a minimum value of 61.6% at Kelametiya to a maximum value of 85.9% at Hambantota.

P. polyphagus was the least recorded species with a contribution of around 1% - 2% to the total catch. Possible reasons for the presence of all six species in the south coast with varying percentages are discussed in detail in Chapter 6.

Table. 4.3 Percentage species composition of spiny lobsters in each sampling station during the study period.

Species	(A)	(B)	(C)	(D)	(E)
P. homarus	79.7	61.6	66.0	85.9	78.6
P. penicil	5.5	16.6	10.0	3.1	6.6
P. ornatus	5.9	8.1	9.3	2.4	2.3
P. longipes	3.6	5.1	6.4	2.3	4.1
P. versicolor	3.1	6.5	6.6	3.9	6.4
P. polyphagus	2.2	2.1	1.7	2.4	2.0

(A) - Tangalle, (B) - Kalametiya, (C) - Welipatanwila, (D) - Hambantota, (E) - Kirinda.

4.6 Disposal of catch.

All spiny lobsters caught are brought to the landing sites during the early hours. At the landing sites, fishermen start cleaning the nets while clearing the lobsters. It is easy to remove lobsters in an undamaged stage if they are lightly entangled. Usually, the fishermen who use 7.5 cm stretched mesh bottom set nets and lobster rings clear their nets within 0.5 -1.0 hours time depending on the other things entangled in the net (pieces of coral, sea weeds, crabs and fish etc.). Fishermen who use trammel nets usually take 1.0 - 1.5 hours to clear lobsters from their nets. According to the design of the trammel net, lobsters get thoroughly entangled and most of the animals are not in a good condition at the time they are cleared. All of the marketable size as well as under size lobsters are taken to companies alive for processing. Under sized lobsters are processed separately to serve the local tourist hotels.

4.7 Analysis of the catch in recent years.

Analysis of catch data available for the spiny lobster fishery has been attempted in two parts. Firstly due to the paucity of information, a simple measure has been used to analyse catch data for the period 1986 - 1988. In the second part, catch data for the periods of present investigation has been analysed more precisely due to the higher accuracy of the data available.

Commercial fishing for spiny lobsters in the south coast probably commenced in mid 1960s, and fishing was conducted on a highly

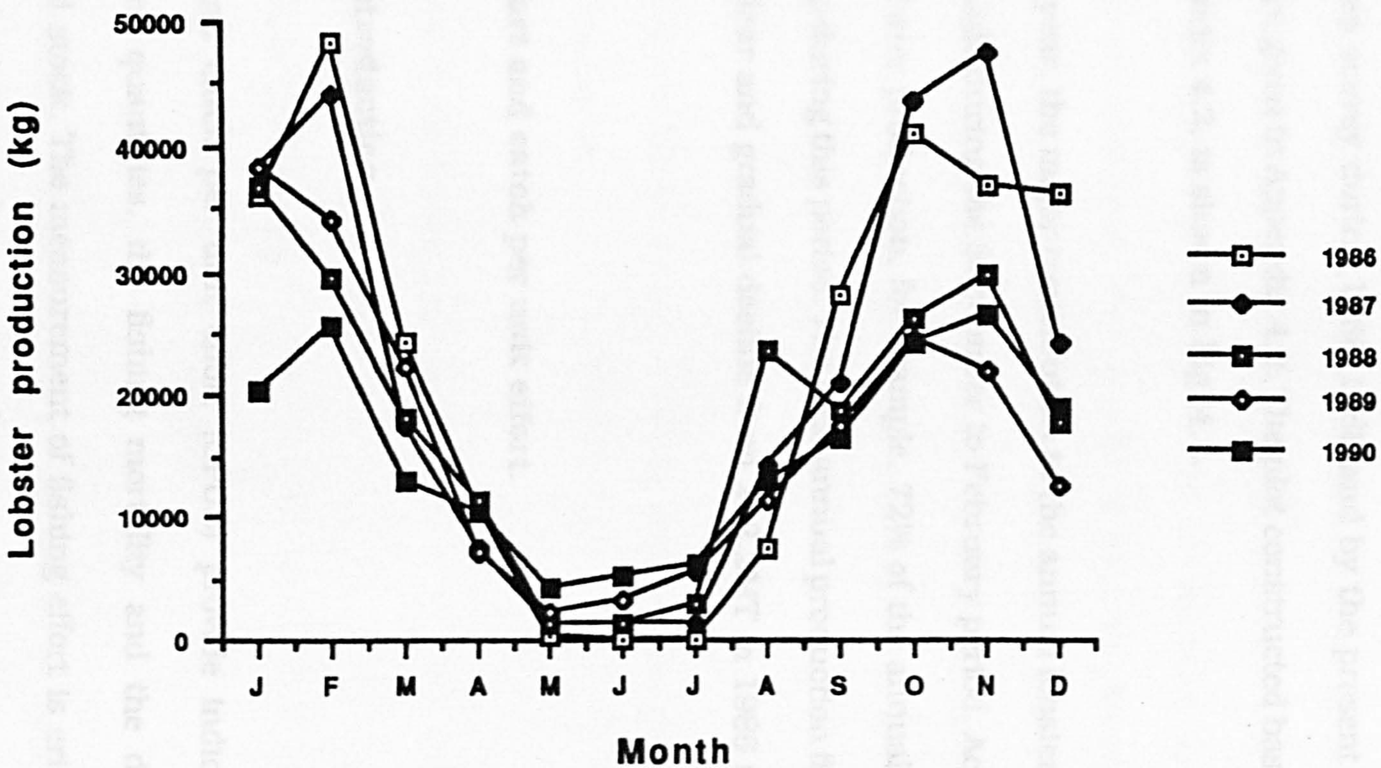


Fig. 4.4 **Monthly lobster production figures for the period 1986 - 1990 (based on Appendix 4.2).**

seasonal basis solely by the nearby villagers, for which period records of lobster production are lacking. Estimates on total lobster production of the south coast on a monthly basis made by NARA spiny lobster resources survey during 1986-1988 and by the present study (1988 - 1991) are given in Appendix 4.2. The plot constructed based on the data of Appendix 4.2, is shown in Fig. 4.4.

In each year, the major contribution to the annual lobster production is being made during the September to February period. According to the 1990 lobster production, for example, 72% of the annual production is taken up during this period. The total annual production figures indicate a very clear and gradual decline from 272.2MT in 1986 to 184.7MT in 1990.

4.8. Effort and catch per unit effort.

4.8.1 Introduction.

Effort and catch per unit effort (CPUE) provide indices related to important quantities, the fishing mortality and the density of the exploited stock. The measurement of fishing effort is critical for stock assessment. It is also critical from the point of view of fishery management, as management often involves allocation of effort.

The classical method of monitoring changes in stock abundance has been the use of catch and effort statistics from the commercial fishery. CPUE will rarely be exactly proportional to the stock density. However, as it is often desirable to have some measure of the stock, the CPUE will nearly always be the best available. The uncritical use of commercial CPUE data can give misleading results. On the other hand, if properly collected and analysed, the use of this data will be one of the most important methods of monitoring the abundance of major lobster stocks. While it is relatively easy to measure catch, the measurement of effort is often more complex and one of the most important and difficult tasks in fishery research.

The quantity of lobsters which a fishing craft catches per craft night will depend mainly on,

a) the type of the fishing gear used
a) the place of setting the nets
b) activity of the lobsters
c) number of net pieces and rings used,

but not on the size of the vessel, its capacity, skill of the crew, catchability of the craft etc. which are normally the factors affecting most other fisheries.

Within a given lobster fishery, weather conditions and the behaviour of lobsters are among the factors influencing the CPUE. Phase of the moon, for instance, can affect the catches (Section 4.14). Standardization of the fishing effort depends on determining whether there are appreciable variations in effective fishing time, fishing power etc. These problems when using catch and effort data for studying stock abundance have been reviewed in Anonymous (1976).

4.8.2 Catch per unit effort in trammel net fishery.

In many countries, entangling types of fishing gear such as trammel nets and bottom set gill nets are used to catch spiny lobsters (Miyamoto and Sheriff, 1961,George, 1967, Phillips, Cobb and George, 1980). In such fisheries CPUE is influenced mainly by the behaviour of lobsters and the area covered by the nets. As the trammel net comprises several overlying nets with different mesh sizes, the entanglement is assumed to be equal for smaller as well as larger lobsters. As the lobsters are nocturnal, CPUE in this type of fisheries is very sensitive to the time of the day fishing is carried out.

However, if the fishery is being conducted using only one type of gear, the efficiency of which is unlikely to change much over the years the fishing effort could be expressed as the number of units of gear used or the total number of operations such as the number of net nights. As trammel net is the widely used fishing gear in the study area, "craft night", was considered as the measure of fishing effort.

4.8.3 Analysis of effort in recent years

Monthly fishing effort values obtained for the period of 1986-1988 by the NARA spiny lobster fishery survey and also the fishing effort values estimated for the present study period are shown in Appendix 4.3. To understand the changes in fishing effort over the years, Figure 4.5 was constructed based on the data in Appendix 4.3. The results indicate low fishing effort values during March to August period which coincides with the south-west monsoon. In recent years, an increasing fishing effort during monsoonal months was also noted. According to De Bruin (pers. comm.), during the early 1980s, no spiny lobster fishing existed along the south coast during the south-west monsoonal months. The total annual fishing effort shows erratic fluctuations from year to year and ranges from 82,396 - 106,126 craft nights.

4.8.4 Analysis of catch and effort data of the study period.

Monthly catch and effort data during the present study period are given together with the data collected in previous years (January 1986 to April 1989) in Appendices 4.2 and 4.3. Annual estimates of catch, effort and catch per unit effort (CPUE) data during the study period are shown in

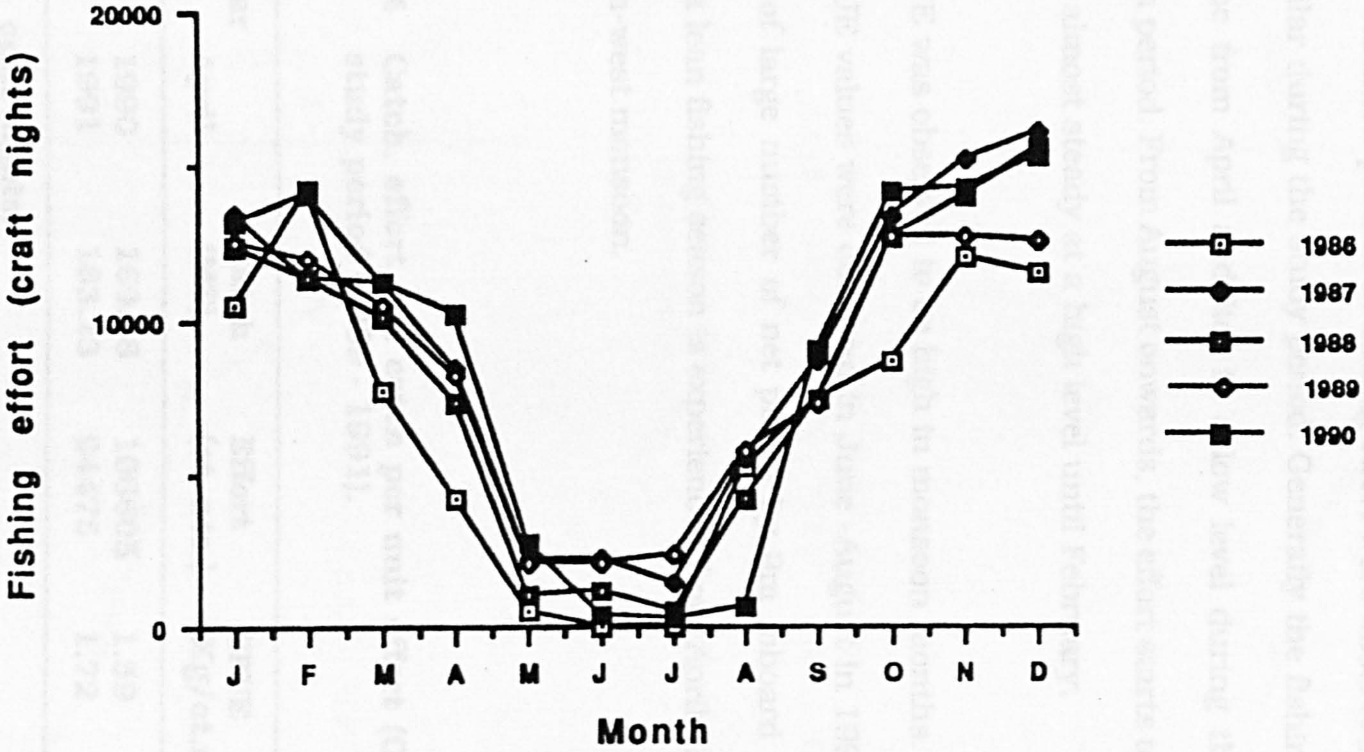


Fig. 4.5 **Monthly fishing effort values expended on the spiny lobster fishery during the period of 1986 - 1990 (based on Appendix 4.3).**

Table 4.4. Monthly CPUE data for this period are given in Table 4.6.

Monthly variation pattern in fishing effort were observed to be more or less similar during the study period. Generally the fishing effort starts to decline from April and lies in a low level during the south west monsoon period. From August onwards, the effort starts to increase and remains almost steady at a high level until February.

The CPUE was observed to be high in monsoon months. Exceptionally high CPUE values were observed in June -August in 1990, because of the use of large number of net pieces by 9m inboard engine boats. Usually a lean fishing season is experienced from April - August due to the south-west monsoon.

Table 4.4 Catch, effort and catch per unit effort (CPUE) for the study period (1989 - 1991).

Year		Catch	Effort	CPUE
May	April	(MT)	(ct. nts.)	(Kg/ct.nts)
1989	1990	169.56	106605	1.59
1990	1991	163.23	94475	1.72

ct. nts. - craft nights.

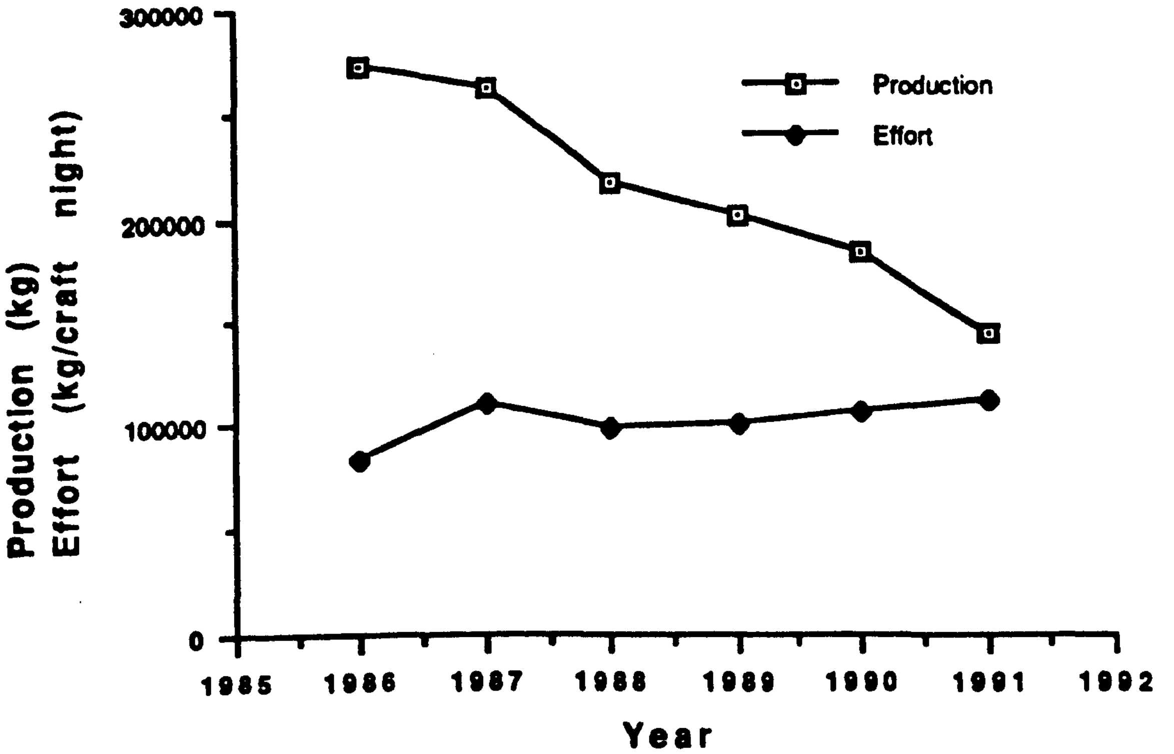


Fig. 4.6 Variation pattern of catch and effort from 1986 - 1991 in the study area.

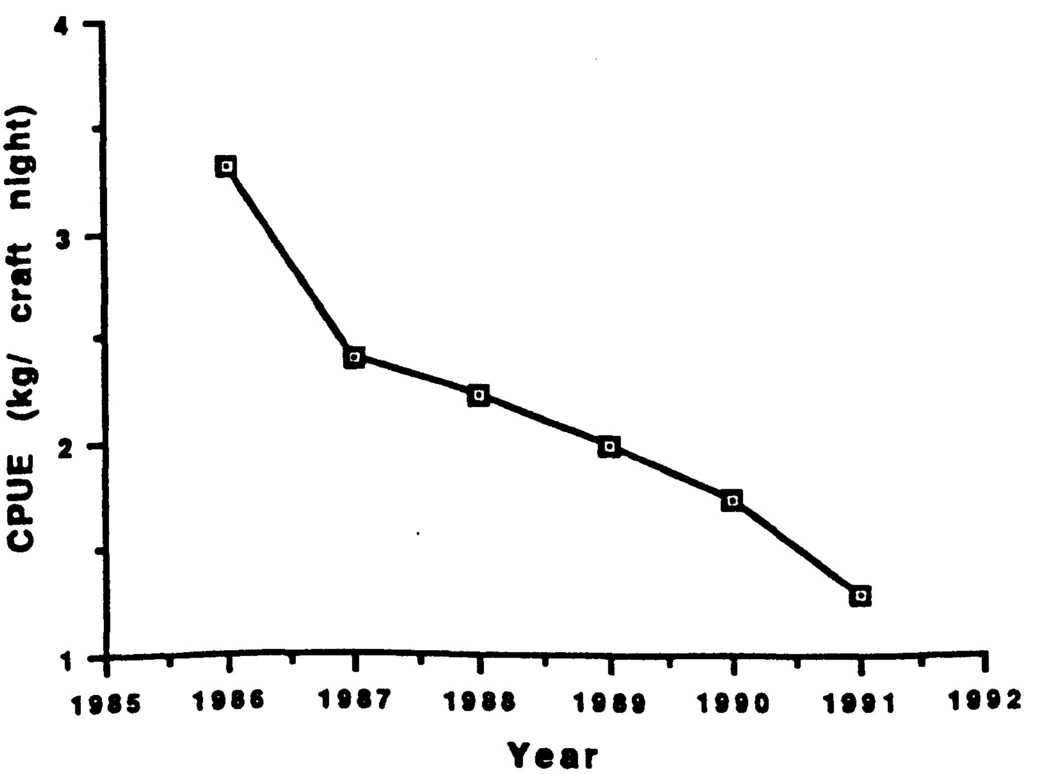


Fig. 4.7 Variation pattern of catch per unit effort from 1986 - 1991 in the study area.

4.8.5 Catch per craft night.

Catch and effort data for the period from 1986-1991 have been analysed to understand the variation pattern and is shown in Figures 4.6 and 4.7, based on the data in Appendices 4.2 and 4.3, indicates that the CPUE value of 3.03 kg/ craft night in 1986 has dropped to 1.99 kg/ craft night in 1991. Monthly CPUE data for the study period (Table 4.6) show high values during the peak south-west monsoonal months in both sampling years.

4.9 Maximum sustainable yield (MSY).

MSY was estimated for the spiny lobster fishery using 6 years data from 1986 - 1991. CPUE values were plotted against relevant effort values according to the Schaefer (1954) model and against Ln CPUE values according to the Fox (1970) model. The results indicate MSY estimates of 201.56 MT and 196.39 MT according to the Schaefer and the Fox models respectively. The methodologies of the above estimates are given in Table 4.5. The results in Table.4.5 indicate a maximum sustainable yield of 196395 - 201559 Kg from the study area on an annual basis. The optimum fishing effort on an annual basis to obtain MSY is estimated as 82659 craft nights.

Table 4.5 Results of the analysis of catch per unit effort and effort using Schaefer and Fox models.

Year	Yield (Kg)	Effort (ct.nts)	S. Model CPUE	F. Model Ln CPUE
1986	272235	82396	3.304	1.195
1987	262330	109669	2.392	0.872
1988	217229	98294	2.210	0.793
1989	201281	101146	1.990	0.688
1990	184659	106126	1.740	0.554
1991	145083	111602	1.300	0.262*
Mean	213802.8	101538.8	2.156	0.727
SD	47978.16	10635.23	0.680	0.314
Intercept (a)			4.8769	-2.0057
Slope (b)			-0.0000296	-0.0000139
r			-0.9693	-0.9905
P			0.05	0.05

Calculation procedure:

Schaefer model: $$MSY = \frac{-a^2}{(4b)} = 201559.30 \text{ kg.}$$

Fox model: $$MSY = -\left(\frac{1}{b}\right) \exp(a-1) = 196394.90.$$

Optimum fishing effort = 82659 Craft nights

*** Calculated based on 4 months data; S = Shaefer ; F = Fox**

CPUE = Catch per unit effort CPUE is given in Kg/ craft nights

4.10 Rainfall and monsoonal effect on CPUE.

Generally from May to August each year, the coastal areas of the south coast receive high rainfall due to the south-west monsoons and around

November (November-March) due to the north - east monsoon. Results in Table 4.6 indicate that during south - west monsoon period CPUE increases with increasing rainfall. However such increase in CPUE was not observed during north-east monsoonal months.

The results of the ANOVA performed for the values of CPUE at different levels of rainfall and also with south-west and north-east monsoonal months indicate no significant difference ($P > 0.05$) (Tables 4.7 and 4.8).

4.11 Influence of sea water temperature on CPUE.

During the study period, the sea water temperature at 10m depth ranged from 26.4°C to 30.3°C (Table 4.6). Generally the temperature was high during the months of July - September and low during November to February. Four temperature ranges were selected to test its effect on the CPUE and the results indicated no significant influence ($P > 0.05$) (Table 4.9).

Table 4.6 **Variation pattern of monthly catch per unit effort (CPUE) with rainfall, sea water temperature, salinity and turbidity.**

Month	CPUE Ct/nts	Rain. (mm)	Temp.* °C	Sali. (ppt)	Turb.** (m)
1989					
May	1.02	63.4	28.0	30.9	5.9
June	1.55	26.4	28.1	31.4	6.4
July	2.33	146.8	29.6	32.3	5.0
Aug.	2.03	96.5	28.7	31.4	5.3
Sep.	2.45	25.0	28.4	31.7	5.6
Oct.	1.94	69.3	27.3	32.3	6.1
Nov.	1.70	123.1	26.4	31.4	5.3
Dec.	0.99	24.4	27.4	31.6	5.8
1990					
Jan.	1.56	59.9	27.1	30.4	6.0
Feb.	1.81	21.5	26.5	30.3	6.7
Mar.	1.15	97.0	27.8	32.3	7.5
Apr.	1.03	27.9	28.4	32.7	8.0
May	1.55	152.7	28.8	30.4	6.4
June	12.49	105.3	29.0	30.1	3.9
July	19.49	11.5	29.3	29.3	4.2
Aug.	21.58	0.4	29.6	29.1	6.2
Sep.	1.81	12.8	30.3	29.3	7.2
Oct.	1.70	190.3	29.5	31.1	8.3
Nov.	1.84	270.8	29.5	30.1	3.0
Dec.	1.24	242.8	27.1	29.3	3.2
1991					
Jan.	1.24	45.4	28.1	28.4	3.8
Feb.	1.45	60.2	27.1	29.5	6.2
Mar.	1.29	24.1	28.1	30.4	6.7
Apr.	1.16	33.3	28.4	30.7	6.0

* Temperature at 10m depth
** Sechi depth
Rain. = Rainfall Temp. = Temperature Sali. = Salinity Turb. = Turbidity

Table 4.7 Summary of the analysis of variance for the catch per unit effort (CPUE) at levels of rainfall.

1. Source of variation

Source of variation	S.S.	D.F.	M.S.	F.	P.
Group	132.1602	3	44.0534	0.745	> 0.05
Error	1242.4780	21	59.1656		
Total	1374.6382	24			

Level of rainfall:

0.0-50.0mm	51.0-100.0mm	101.0-150.0mm	151.0-200.0mm
X CPUE			
12.4846	13.4429	10.9233	18.5225

2. Conclusions from multiple range analysis.

Method: 95% Confidence interval.

Level	Count	Average	Homogeneous Groups
151-200mm	4	18.5225	*
101-150mm	3	10.9233	*
51-100mm	7	13.4429	*
0- 50mm	11	12.4845	*

Table 4.8 Summary of the analysis of variance for the catch per unit effort (CPUE) during south-west and north - east monsoonal current period.

1. Source of

Varieties	S.S.	D.F.	M.S.	F.	P.
Group	178.0418	1	178.0418	5.306	> 0.05
Error	536.8746	16	33.5547		
Total	714.9164	17			

2. Conclusions from multiple range analysis.

Method: 95% confidence interval.

Level	Count	Average	Homogeneous Groups
NE	10	1.4270	*
SW	8	7.7563	*

NE = North East monsoonal current period
SE = South West monsoonal current period

Table 4.9 Summary of the analysis of variance for the catch per unit effort (CPUE) at different levels of sea water temperature at 10m depth.

1. Source of variation	S.S.	D.F.	M.S.	F.	P.
Group	115.3803	3	38.4601	1.222	> 0.05
Error	629.2811	20	31.4641		
Total	744.6614	23			

Level of temperature:

	26.4-27.3°C	27.4-28.3°C	28.4-29.3°C	29.4-30.3
X CPUE	1.6167	1.2067	5.7429	5.8480

2. Conclusions from multiple range analysis.

Method: 95% confidence interval.

Level	Count	Average	Homogeneous Groups
29.4-30.3°C	5	5.8480	*
28.4-29.3°C	7	5.7429	*
27.4-28.3°C	6	1.2066	*
26.4-27.3°C	6	1.6167	*

4.12 Influence of salinity on CPUE.

During the study period the sea water salinity at 10m depth ranged from 28.4 ppt to 32.7 ppt. Generally the salinity was observed low one or two months after heavy rainfalls (Table 4.6). Three salinity groups were selected for the ANOVA and the results indicated no significant influence ($P > 0.05$) of salinity on CPUE (Table 4.10).

4.13 Influence of turbidity on CPUE.

The study area received heavy rainfalls during the months of July, August and November in 1989 and May, June, October, November and December in 1990. These rainfall values were considerably high (mostly more than 100mm per month), for an arid zone of the country which includes the study area (Table 4.6). As the heavy rains add vast quantities of silt to the coastal waters, high turbidity values (low sechi depth values) were observed in respective months. Three sechi depth groups were considered to analyse the influence of turbidity on CPUE and the results indicated no significant difference ($P > 0.05$) (Table 4.11).

4.14 Influence of lunar cycle on CPUE.

In addition to the environmental factors that influence on fisheries conducted in the day time, fisheries conducted in the night are

Table 4.10 Summary of the analysis of variance for the catch per unit effort (CPUE) at different levels of salinity.

1. Source of variation	S.S.	D.F.	M.S.	F.	P.
Group	145.986	2	72.9927	2.557	> 0.05
Error	599.394	21	28.5426		
Total	745.380	23			

Level of salinity	28.0-29.5 (ppt)	29.6-31.1 (ppt)	31.2-32.7 (ppt)
X CPUE	7.8017	2.7133	1.6856

2. Conclusions from multiple range analysis.

Method: 95% confidence interval.

Level	Count	Average	Homogeneous Groups
31.2-32.7	9	1.6856	*
29.6-31.1	9	2.7133	*
28.0-29.5	6	7.8017	*

Table 4.11 Summary of the analysis of variance for the catch per unit effort (CPUE) at different levels of turbidity.

1. Source of variation	S.S.	D.F.	M.S.	F.	P.
Group	72.2473	2	36.1237	1.127	>0.05
Error	673.1329	21	32.0540		
Total	745.3802	23			

Level of turbidity:	3.1-5.0m	5.1-7.0m	7.1-9.0m
X CPUE	6.4383	3.0057	1.4225

2. Conclusions from multiple range analysis.

Method: 95 % confidence interval.

Level	Count	Average	Homogeneous Groups
7.1-9.0	4	1.4225	*
5.1-7.0	14	3.0057	*
3.1-5.0	6	6.1383	*

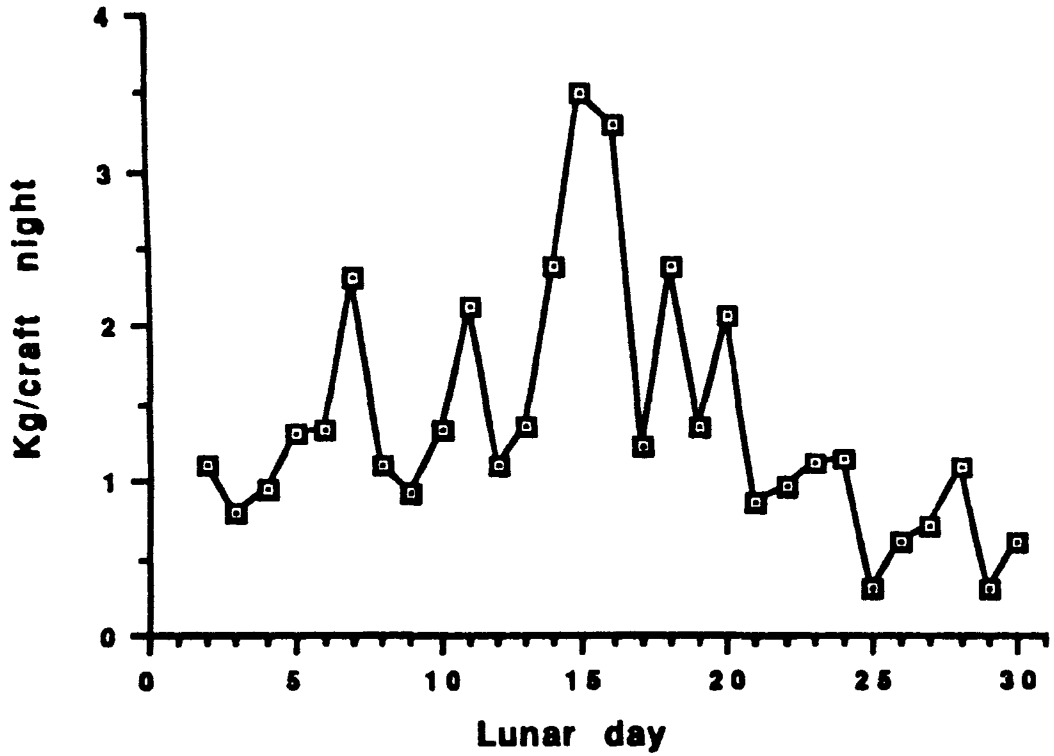


Fig. 4.8 **Variation pattern of catch per unit effort with lunar cycle (Data during 1990 Jan. - Dec.).**

Table 4.12 Summary of analysis of variance for the catch per unit effort (CPUE) at three different types of moonphase.

Source of variation	S.S.	D.F.	M.S.	F.	P.
Group	36.087	2	18.043	76.469	< 0.05
Error	10.618	45	0.236		
Total	46.705	47			

Moon phase:	New moon	Quarter moon	Full moon
X CPUE	2.7416	1.4275	0.2925

2. Conclusions from multiple range analysis.

Method: 95% confidence level.

Level	Count	Average	Homogeneous Groups
FM	12	0.2925	*
QM	24	1.4275	*
NM	12	2.7416	*

$X_{new\ moon} \neq X_{quarter\ moon} \neq X_{full\ moon}$

FM = Full Moon; QM = Quarter Moon; NM = New Moon.

influenced by the lunar cycle. Daily catches obtained from the Sri Mic lobster processing company during 1990 were used to obtain a mean daily catch per craft night to observe its variation with the lunar cycle. The full moon day in each month was assigned day one in the lunar cycle and the corresponding calender days were assigned to appropriate lunar days. The mean catches per craft night observed for the different lunar days have been listed in Appendix 4.4. According to the plot (Fig. 4.8) made on the data in Appendix 4.4, a very clear difference was observed in CPUE values calculated during full moon period and the other days, indicating that the lunar cycle has a noticeable influence on the daily catches of spiny lobsters.

Results of the ANOVA and multiple range analysis performed on the CPUE values calculated for full moon, quarter moon and new moon days indicated that the CPUE during the full moon is significantly lower ($P<0.05$) than the CPUE values obtained during quarter moon and new moon days (Table 4.12). Similarly it also indicated a significant difference ($P< 0.05$) in CPUE values between quarter moon and new moon days where new moon days recorded the highest CPUE values.

4. 15 Discussion.

The total annual yield of spiny lobsters during 1986 - 1991 period and the number of craft nights spent in each year indicates a gradual drop in yield during 1986 - 1991 period. The effort values show erratic fluctuations from year to year. The peak effort in 1987 can be correlated to the swarming back of fishermen from areas where there were communal disturbances. The CPUE has dropped from 3.3 Kg/craft night in 1986 to 1.3 Kg/craft night in 1991. The fishing effort showed a gradual increase from 1986 onwards, but the CPUE declined (Figure 4.7). The increasing effort with a decreasing CPUE could be correlated to a several fold increase in price paid to lobster fishermen (see section 1.2.5).

As far as the 1989-1991 study period is concerned, the total production of 115.34 mt in the first year (May - April) has dropped to 95.15 mt in the second year indicating a 17.51% drop in production. A parallel drop in fishing effort was also observed during the same period from 71095 craft nights in the first year to 59463 craft nights in the second year.

During the study period, the monthly CPUE was high during May to July of the south-west monsoonal period (Table 4.6). The monthly effort was low during this period due to the difficulties in handling small canoes in rough weather conditions. The highest lobster production was recorded from August/September - February/March period and this is considered as the best fishing season for the spiny lobster fishery along the south coast. During this period, although CPUE was low (around 1.5 kg/ craft night) the overall monthly production was at a very high level due to the high fishing pressure involved under favourable weather conditions.

McLeese and Wilder (1958) reported that the activity levels of spiny lobsters are temperature dependent so that the catch rates varies seasonally. However, the insignificant ($P > 0.05$) difference between the CPUE and sea water temperature observed in the present study may be due to the narrow fluctuations of temperature in sea water (Table 4.6) of the study area.

There are five rivers and several tributaries which drain into the south coast, enriching the coastal waters of this region with their outfalls. During the monsoonal rains, the flooded rivers pour down their nutrient rich waters increasing the primary production in coastal waters. Legare (1957) has observed a similar phenomenon in the Strait of Georgia in Canada. In the west coast of Sri Lanka, Karunasinghe (1990) observed an increasing aggregation of *Sardinella sirm* particularly during the south-west monsoonal period and correlated this to the increase in primary production.

According to a NARA report (Anonymous, 1990c), considerable quantities of molluscs are available during the south-west monsoon months in many coastal areas of Sri Lanka. Among them, the availability of *Perna perna* along the south coast is of special significance since that it is one of the frequent food items of *P. homarus* (Berry, 1971b). It was observed in the present study that partially digested molluscs were among the gut contents of *P. homarus*. However, a systematic study on the gut analysis was not carried out during the present study. The abundance of *Perna perna* may be a reason for the increase in CPUE during south-west monsoons.

During the heavy rains in May, due to operational difficulties of craft and gear the CPUE reduces, but recovers again as the intensity of the rain decreases in June to August. The north-east monsoon which prevails from November to February brings some rain to the south coast during November and December but does not adversely affect fishing activities.

The diurnal tidal variation indicates that the peak tidal heights are observed around 02.00 hrs. and 14.00 hrs. on full moon and new moon days and around 06.00 hrs. and 18.00 hrs. on quarter moon days. The fishing operation for spiny lobsters is most often carried out between 18.00 - 06.00 hrs. During full moon and new moon days the peak tidal hight occurs during the hours of lobster fishing operations. On the other hand, on quarter moon days fishing time does not overlap with the peak tide but instead overlaps with the least tide.

The results of ANOVA and Scheffe's multiple contrast procedure indicates that highest CPUEs were observed on new moon days, whereas on quarter moon days and full moon days the CPUEs were significantly lower. When quarter moon and full moon days are compared, the CPUE was significantly higher on quarter moon days. A similar trend was observed by Sutcliffe (1956) for *P. argus* that these lobsters are active throughout the dark period and is generally depressed at times of greater nocturnal illumination such as full moon. This indicates that the light penetration into the sea water has a definite influence on the behaviour of spiny lobsters. The lunar differences in CPUE may be attributed to the movement pattern of lobsters associated with their nocturnal feeding behaviour. Many authors have reported the nocturnal habits of lobsters. The expression of locomotor activity appears to be strongly controlled by the light cycle in many lobster species eg. *J. lalandii* (Fielder, 1965), *H. americanus* (Cobb, 1969), *N. norvegicus* (Chapman and Rice, 1971; Hammond and Naylor, 1979), *P. argus* (Kanciruk and Herrnkind, 1973; Herrnkind, van Derwalker and Barr, 1975, Casterlin and Reynolds, 1979) and *P. cygnus* (Jernakoff, Phillips and Maller 1987).

An analysis of variance (ANOVA) indicated that there is no statistically significant difference (P> 0.05) in CPUE with different levels of rainfall. Although the ANOVA did not indicate a significant difference in CPUE during the south-west monsoonal current period and north-east monsoonal current periods (Table 4.8), the CPUE distribution during the study period indicates that the highest values of CPUE are observed during June to August. This shows that the change in CPUE is not solely dependent on moon phase but also on certain predetermined factors such as the ocean current system around the island (see section 2.1.5). The months from May to September produce sudden peaks which can be correlated to this changing current system. The period with high CPUE values coincide with the Indian south-west monsoonal current period. From November through March which coincides with Indian North-east monsoon currents, the observed CPUE values were poor but very high monthly production values occurred due to the large number of craft operating. It is also a general view that in the northern hemisphere due to Coriolis effect the west coasts of continents are more productive than the respective east coasts (Pond and Pickard, 1983). Therefore, the west coast of India may be more productive than the east coast of India and when the south-west monsoonal current passes through this coast it may bring in nutrients from that region towards Sri Lanka. The north-east monsoonal current, however, does not pass through such a productive region before reaching Sri Lanka (Anonymous 1986).

According to the results of the spiny lobster resources survey carried out by NARA, and the present study, the lobster stocks of the study area is being exploiting at or beyond its maximum sustainable level. The declining CPUE values over the years and existing low CPUE levels indicate the impossibility of expanding the fishery. The optimum effort for the fishery was estimated as 82659 craft nights per year. If 275 active fishing days per year (craft nights) is considered, the number of craft that can operate to obtain MSY is 300. This suggests a reduction of 15 fishing craft in the study area to maintain the MSY.

4. 16 Chapter summary

Although the spiny lobster fishery along the south coast is a commercial fishery, it could be considered as a small scale artisonal fishery due to its,

a) shallow water coastal nature, and,
b) use of non-mechanized traditional crafts.

Rough sea and strong winds during the south-west monsoon period which prevails during April-August act as a natural barrier for fishermen entering into the fishery. The north-east monsoon which prevails during November to February generally does not make adverse effects on the south coast spiny lobster fishery.

The period from September to March, during which the sea is calm is the lobster fishing season of the south coast. The peak fishing months are November, December and January.

Fishing is done during the night time and fishermen use bottom set gill nets, trammel nets and lobster rings to catch lobsters. Diving is the least employed method in the study area. Except diving all the other lobster catching techniques involve passive processes where lobsters are entangled when they step into the nets in search of food during the night time.

A significant inverse relationship was observed between the lunar cycle and the catch per unit effort, where catch per unit effort was tend to be high towards the new moon when the light intensity was low.

No significant correlations were observed between the monthly catch per unit effort values and monthly rainfall, sea water temperature, sea water salinity and sea water turbidity.

The maximum sustainable yield estimated for the fishery indicated an annual value of 196395 - 201539 Kg. The annual optimum effort was estimated as 82659 craft nights. The analysis of lobster production figures in recent years indicated a gradual decline. A decrease in catch per unit effort was observed in certain years with an increase in fishing effort indicating signs of overfishing.

CHAPTER 5

5. Population Dynamics.

5.1. Introduction.

An increasing awareness of the need to manage Palinurid fisheries in recent years has provided an impetus to the study of the ecology and population dynamics of the adult stocks in several areas (Morgan, 1980). Because of this motivation, the aspects that have received attention have usually been those that are directly concerned with the estimation of yield curves, the establishment of optimum size at first capture and other fisheries oriented problems. These aspects include, studies of growth rates, total mortality rates, fishing mortality rates, survival rates, exploitation rates, recruitment pattern, management of abundance and measurement of fishing effort etc. Various methods employed in different regions of the world to measure these population parameters include: examination of length frequency distribution, tagging and recapture studies, and experimental fishing. In addition, the commercial fisheries based on several species of spiny lobsters have also proved valuable in providing data, particularly on mortality rates (Morgan, 1980). Although there are limitations and problems, studies on population dynamics of lobsters generally rely on the inherent assumption that the population as a single entity contains no subgroups within the population and behaves as a "unit stock".

So far, few attempts have been made to measure the absolute abundance of wild adult spiny lobster populations (Peacock, 1974; Morgan, 1974), although relative abundance has been estimated from the information based on catch rates in most species that support commercial fisheries, eg, *P. argus* (Munro, 1974); *P. cygnus* (Bowen and Chittleborough, 1966); *J. lalandii* (Heydorn, Newman and Rossouw, 1968) and *J. edwardsii* (Street, 1970).

Knowledge of mortality rates (total, fishing and natural) is important for an understanding of the dynamics of exploited populations. Total and fishing mortality rates are usually estimated from either an analysis of the age distribution of the catch or landings, or by the analysis of tag return data, or by some combination of the two. The estimation of natural and fishing mortality rates in Palinurids usually relies on data from the operations of commercial fisheries. Since not all species of the Palinuridae are commercially exploited, and since very few of the exploited species have adequate commercial statistics available, the information on mortality rates is necessarily sparse. Due to the problems that are associated with the inability of determining age for any of the Palinurid species, the method of comparing the abundance of successive year classes (commonly used in the studies of fish populations) cannot be used. All of the available methods of mortality rate estimation, therefore, rely on some knowledge of the length distribution of the species in question, rather than the age.

In exploited populations, the total instantaneous mortality rate (**Z**) will consist of combinations from both fishing mortality rate (**F**) and the natural mortality rate (**M**). Bowen and Chittleborough (1966), used the decline in catch per unit effort (CPUE) during a season to calculate total mortality for *P. cygnus* in western Australia. According to Morgan (1980) the method given by Bowen and Chittleborough (1966) suffers from a major disadvantage by assuming that the CPUE is proportional to the abundance of spiny lobsters at all times throughout the fishing season, which certainly is not the case for many lobster populations. According to Morgan (1980), the use of CPUE data particularly within a fishing season will therefore be unlikely to provide realistic estimates of total mortality for exploited spiny lobster populations. The equation derived by Beverton and Holt (1956), based on length composition data is probably the most fruitful approach for the estimation of total mortality in the Palinuridae (Morgan, 1980).

The separation of total mortality into its components of fishing and natural mortality may be achieved either by examining the changes of **Z** over a wide range of effort and thereby estimating **M** or by estimating **F** directly from tagging experiments. The first approach requires good data not only on **Z**, but also on the effort expended on the fishery over a number of years, which generally are not available in most of the developing countries. The tagging experiments which are usually used for the estimation of growth and movement of lobsters can also be used for the estimation of fishing mortality (Ricker, 1975). This method has been used for several species to estimate fishing mortality rates including *J. lalandii* in South African waters (Newman, 1972); *P. cygnus* in Western Australia (Morgan, 1977); *H. americanus* in Canadian waters (Ennis, 1979) and in *H. americanus* in the United States (Briggs and Mushacke, 1984).

The natural mortality (**M**) rate of an exploited population is more difficult to estimate and usually requires detailed information on catch and effort data (Annala, 1980). Munro (1974), using data on the average carapace length of the population together with data on the growth parameters, utilized the method of Beverton and Holt (1956), to estimate total and natural mortality rates of various populations of *P. argus*. He calculated annual values of **M** of 0.52 for an unexploited stock, 0.23 for a moderately exploited stock and 0.14 for a heavily exploited stock. According to Munro (1974), natural mortality is highly affected by predation and the relationship of mortality and predation has the form of ,

$$\mathbf{M = gP + Mo}$$

where, **g** is the mortality generated by the prey species by one unit of biomass of predators, **P** is the biomass of predators and **Mo** is the mortality caused by other factors (eg. age etc.) which is probably negligible. Several researchers have calculated **M** for *P. cygnus* using catch and effort statistics in different regions and arrived at values ranging from 0.592 - 2.083 (Bowen and Chittleborough, 1966).

Where population dynamics models are concerned there are two types applicable to the study of spiny lobster populations, namely empirical and conceptual. Empirical models, which involve fitting relationships to observed data on yield and one or more variables, have not been used in spiny lobster fisheries. There are two types of conceptual models, namely surplus yield models and dynamic pool models which are commonly in use to explain how a particular lobster population reacts to the changes in fishing effort in terms of changing biomass. Different surplus yield models namely, Schaefer model (Schaefer, 1957), Genpord model (Pella and Thomlinson, 1969), Prodfit model (Fox, 1975) and Delayed recruitment model (Marchesseault and Saila, 1976) are widely in use among Palinurid population dynamicists. Where dynamic pool models are concerned, those proposed by Beverton and Holt (1957) and Ricker (1975) are widely used. Both models essentially the same relationship in expressing the yield in weight for any fishing mortality rate as a simple function of,

a) the number of recruits entering the fishable stock,

b) the fishing mortality rate,

c) the natural mortality rate,

d) the age at first capture and

e) the von Bertalanffy growth parameters - growth rate (**K**), asymptotic weight (**W_{∞}**) and the age at which the length is zero (**t_0**).

All these population parameters can be calculated except the precise number of recruits, which can only be overcome by the introduction of the concept of "yield per recruit". According to Morgan (1980), as the surplus yield models require a minimum of data, they are biologically more reasonable for spiny lobsters than dynamic pool models, which need more information. In the surplus yield models, CPUE is used as an index of population abundance and the limitations of the index have been discussed by Munro (1974). Since the possibility of ageing spiny lobsters is remote, length related cohort analysis (Jones, 1974), can be used for the estimation of population size, which has already been successfully tested for several crustacean populations (Morgan, 1980). According to Saila, Annala, McKoy and Booth (1979), the yield per recruit model based on the empirical growth formula is more realistic to spiny lobsters than the Beverton and Holt (1957) yield per recruit model.

5.2 Length-weight relationship and relative condition.

5.2.1 Introduction.

Length-weight data of lobsters are commonly analysed to yield biological information, and Le Cren (1951) identified the two main objectives of such studies as:

a) to obtain a mathematical relationship between length and weight so that one may be converted to the other, and,

b) to measure the variation from the expected weight for length of individual lobster or groups of lobsters as indications of general well-being or fitness.

The mathematical relationship between length and weight of most lobsters has been described by a formula of the type:

$$\mathbf{W} = \mathbf{a}\,\mathbf{L}^{\mathbf{b}}$$

where, **W** = weight, **L** = length and **a** and **b** are constants. For ease of analysis by regression methods, the equation can be transformed into its logarithmic form:

$$\text{Log}\,\mathbf{W} = \text{Log}\,\mathbf{a} + \mathbf{b}\,\text{Log}\,\mathbf{L}$$

where, **b** represents the slope of the regression line and Log **a** its intercept on the ordinate (Log W) axis.

The value of '**b**' is 3 for an ideal fish which maintains the same shape. However, the cube law ($\mathbf{W} = \mathbf{L}^3$) has not been obeyed by most species whose length-weight relationships have been calculated. It is generally agreed that most lobsters change their shape as they grow mainly due to allometric growth of some parts of the body (eg. 1st and 2nd pereiopods) and a cubic relationship between length and weight could hardly be expected.

The value of **b** usually lies between 2 and 4 for most fish and crustaceans. The different conditions under which it can vary for the same species of fish have been listed by Le Cren (1951) and Bagenal (1968). These include locality, sex, growth stanza or stage (larval, immature or mature) and time of day (changes in stomach fullness). Such reasons for the variation of '**b**' value for spiny lobsters have not been fully described in the literature.

Individual variations from the general length-weight relationship have been frequently studied under the general name 'condition'. Changes in condition are analysed by means of a condition factor, a coefficient of condition or a ponderal index. It is used to compare the condition or the well-being of the lobster, based on the assumption that the heavier lobsters of a given length are in better condition.

The condition factor is calculated as the ratio between observed weight and that expected from its observed length. Differences in condition factor have been interpreted as measuring the fatness and suitability of environment or gonad development. However, the condition factor can be influenced by a number of variables as discussed in Le Cren (1951), who advocated calculating a relative factor $\bar{K}$ based on the calculated length-weight relationship. The relative condition factor is given by the formula:

$$\bar{K} = \frac{W}{aL^b} = \frac{W}{\hat{W}}$$

where, **W** is the observed weight and $\hat{W}$ is the expected weight derived from the calculated relationship $W = aL^b$.

In view of the widely different factors that affect the condition factor, interpretation of $\bar{K}$ is difficult, often leading to error (Le Cren, 1951).

5.2.2 Analysis of data.

5.2.2.1 Length-weight relationship.

Length and weight data recorded for 1020 lobsters (567 males and 453 females) have been used in this analysis. These were the lobsters sampled for maturity studies and their size distribution on a monthly basis is given in Appendices. 3.1 & 3.2.

Length-weight data obtained for the entire study period was analysed by regression method for males and females separately. Fig. 5.1 & 5.2 are

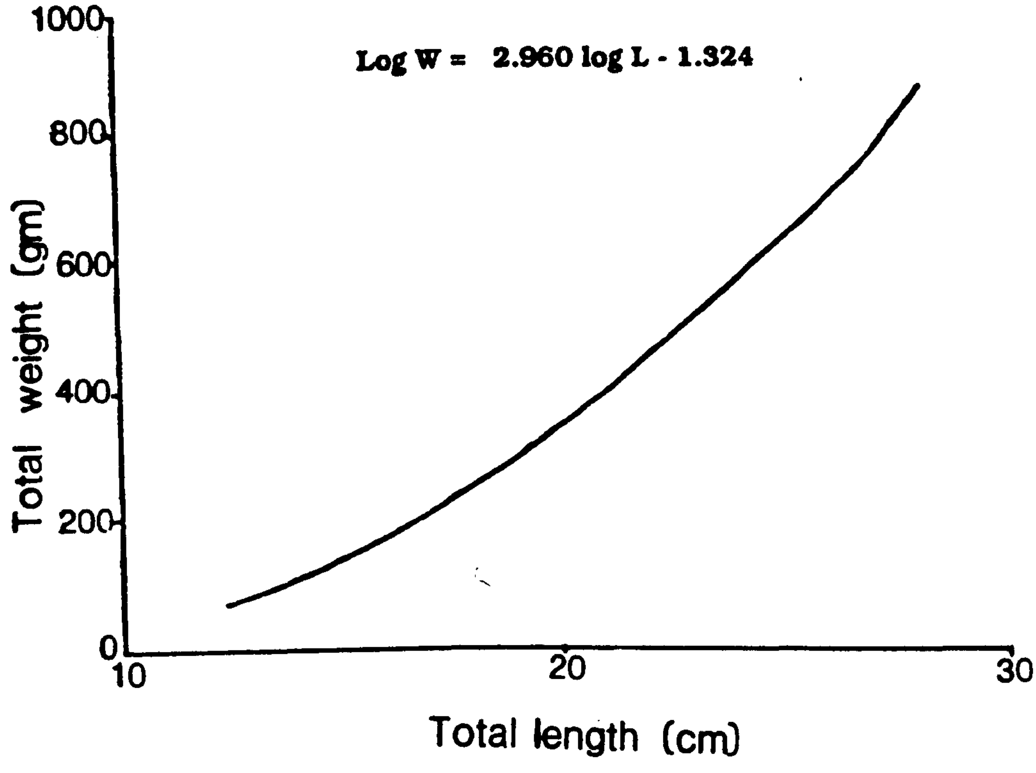


Fig. 5.1 **Length - weight relationship for male *Panulirus homarus*.**

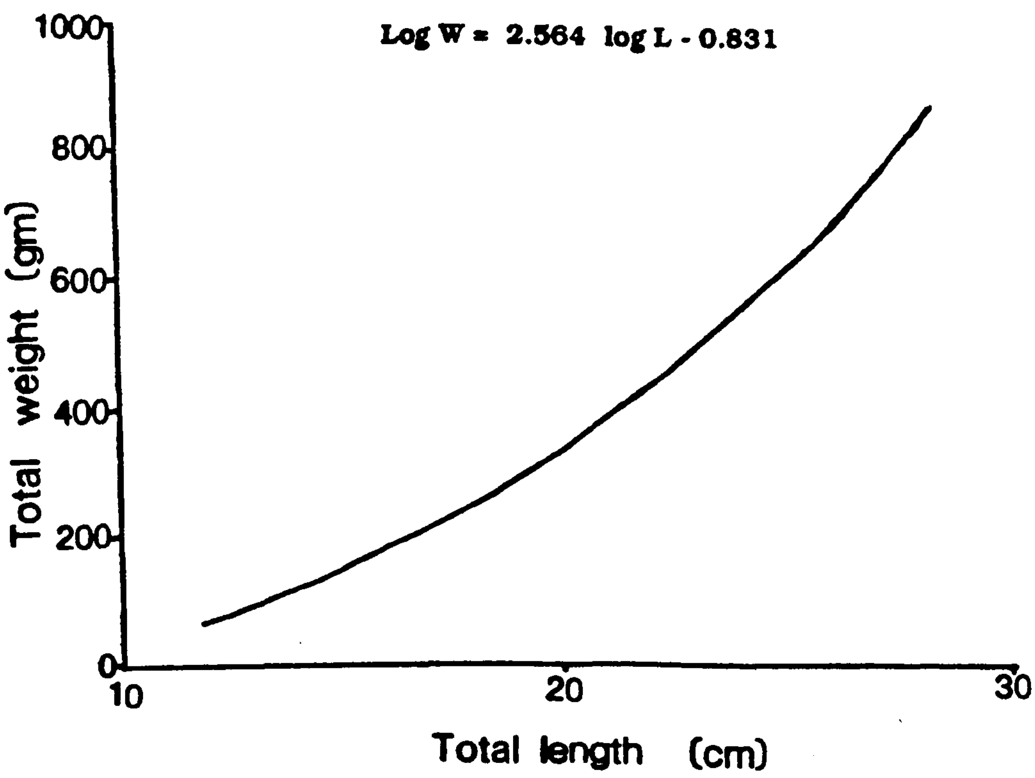


Fig. 5.2 **Length - weight relationship for female *Panulirus homarus*.**

line diagrams of the length values plotted against respective weight values for males and females seperately for the whole study period. The following regression relationships were calculated from the length-weight values:

a) for all lobsters, both sex combined

b) for all lobsters, sexes separate

c) for juvenile lobsters (lobsters below a length of 13.0 cm) sexes combined.

The results of the various regression analysis are listed in Table. 5.1. The common regression equation for all length-weight data is:

$$\text{Log } W = 2.817 \text{ Log } L - 1.147$$

or

$$W = 0.07129\, L^{2.817}$$

Table. 5.1 Results of regression analysis of length and weight relationships.

	No. of lobsters	Intercept (a)	Slope (b)	Regression coefficient
Males	474	-1.324	2.960	0.849
Females	504	-0.831	2.564	0.974
Juveniles	42	-1.226	2.839	0.993
All lobsters	1020	-1.147	2.817	0.884

5.2.2.2 Condition factor ($\bar{K}$).

A relative condition factor was calculated for each lobster using the formula:

$$\bar{K} = \frac{W}{\hat{W}} = \frac{W}{aL^b}$$

$$= \frac{\textbf{Observed weight}}{0.07129\ L^{2.817}}$$

where, **L** is the total length of the lobster in cm and the values of the constants **a** and **b** are those calculated for the common regression for all length-weight data.

Monthly mean values of $\bar{K}$ were then calculated for each sex together with standard deviations and these are given in Appendix 5.1. The relative condition factor has an expectation of 1, which makes higher and lower values of condition easily identified. Both sexes follow a similar trend in Figs. 5.3 & 5.4.

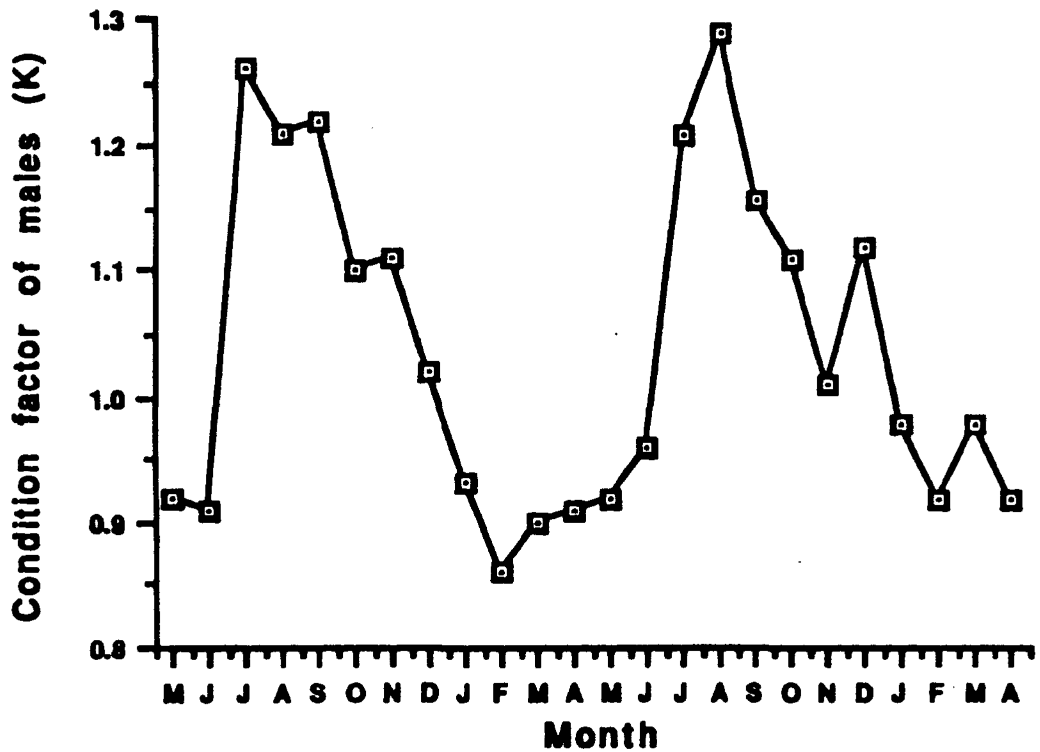


Fig. 5.3 **Variation pattern of the condition factor of male *Panulirus homarus*.**

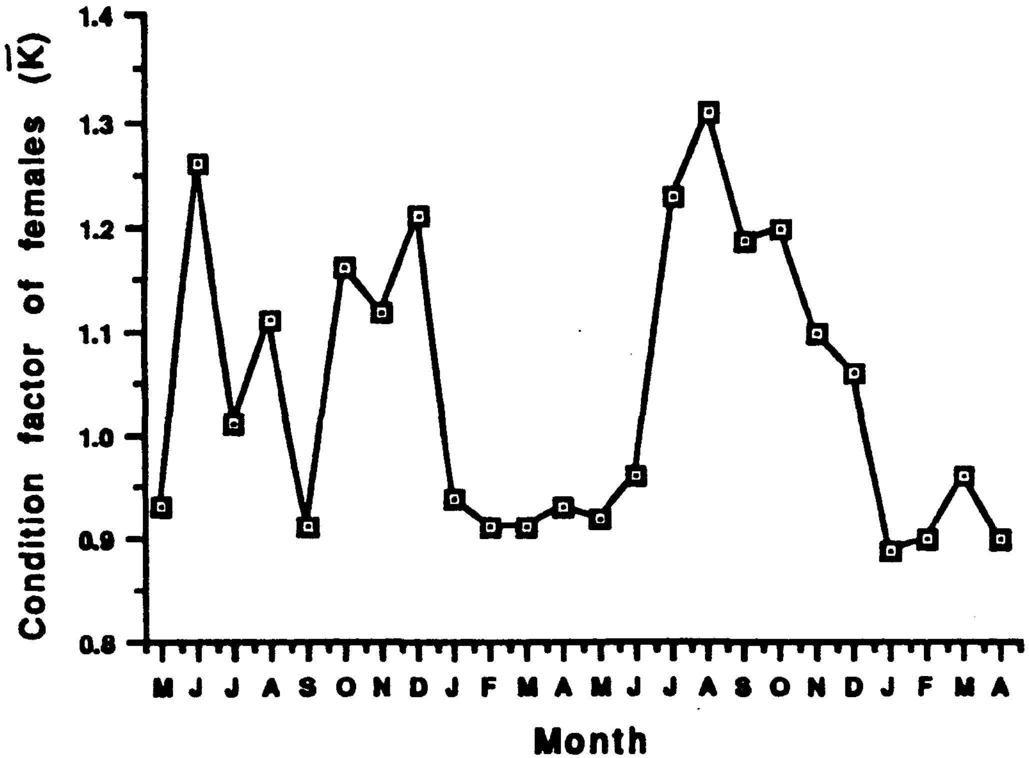


Fig. 5.4 **Variation pattern of the condition factor of female *Panulirus homarus.***

The condition factor was low during the months of January to June and was high during the months of July to December. This pattern was very clear for the two sexes for both study years.

5.3 Estimation of growth parameters.

There are three general approaches to estimate lobster growth i.e., mark and recapture methods, age reading from the seasonal marks on the hard parts, and analysis of length frequency data. The mark and recapture method is practically difficult and time consuming and there were no clear hard parts except the exoskeleton which is shed from time to time during the process of growth. Therefore length-based methods were used in this analysis.

5.3.1 Estimation of growth parameters using ELEFAN method.

Monthly length frequency samples were analysed using the " Compleat ELEFAN " version 1.11 software package (Gayanilo, Soriano and Pauly, 1989). For growth studies, length measurements of *P. homarus* were grouped into one cm classes and summarized on a monthly basis.

In the ELEFAN 1 technique, the von Bertalanffy growth function modified for seasonal oscillations in growth (Pauly and Gaschutz, 1979) is used which is in the following form:

$$L_t = L_{00} (1 - \exp \{-[K (t - t_0) + CK / 2 \ \sin 2 \ (t - t_s)]\})$$

where, L_{oo} = asymptotic length

K = growth constant

L_t = length at age t

t_o = theoretical age at length zero

C = constant expressing the amplitude of growth oscillation

t_s = starting point of oscillation with respect to $t=0$

When $C = 0$, this equation reduces to the usual von Bertalanffy (1938) function of the following form:

$$L_t = L_{00} \{ 1 - \exp [-K (t - t_0)]\}$$

This growth equation (isometric growth) was fitted to the restructured length frequency samples of *P. homarus* in the study area. The optimum combination of **K** and L_{00} was chosen through maximization of the **Rn** value (i.e., goodness of fit) which can range from 0 to 1. The ratio between the sum of peaks through which a single curve passes (the " explained sum of peaks " or ESP) and the maximum sum of peaks available in the set of length frequency samples which can possibly be accumulated by a single growth curve (the " available sum of peaks " or ASP) is the basis of the definition of **Rn** value ($Rn = (10^{ESP/ASP}) / 10$).

The step - wise procedure of estimation of growth parameters is as follows:

Step 1. Obtaining preliminary estimates of growth parameters by ELEFAN 1. depending on the initial value of L_{∞} estimated by the Wetherall method (Wetherall, 1986).

Step 2. Estimating probabilities of capture of similar size classes via detailed analysis of the left, ascending part of the catch curve by constructing a selection curve using **Z** and natural mortality (**M**) values estimated from the preliminary estimates of L_{∞} and **K** (see below for further details on the theory and computation procedure of catch curve).

Step 3. Correcting the original length frequency data using probabilities of capture (Pauly, 1986b).

Step 4. Obtaining the improved estimates of L_{∞} and **K** from the corrected length frequency data by means of ELEFAN 1.

5.3.1.1 Restructuring of length frequency data.

The length frequency data files were restructured by ELEFAN 1

before estimating growth parameters. Restructuring of the length frequency samples is done to arrive at an objective identification of the peaks corresponding to "cohorts", independently of the height of the peaks themselves and without any assumption about the shape of the length frequency distribution within a single cohort. The computation is described in detail by Brey, Soriano and Pauly (1988). Briefly this procedure consists of the following major steps:

a) computation of the moving average over the length classes

b) computation of adjusted frequency, dividing frequency by moving average

c) computation of relative adjusted frequency, dividing adjusted frequency by mean value of adjusted frequency and subtraction of 1 to identify the peaks (relative adjusted frequencies greater than zero) and troughs (relative adjusted frequencies less than zero).

In the restructuring procedure, some other techniques are also incorporated for adjustment of peaks for zero frequencies, reduction of influence of low frequency values etc.

This improved method of estimation of growth parameters using ELEFAN 1 as suggested by Pauly (1986b, 1987) is important to obtain more precise values because in this method, smaller lobsters are given more emphasis in estimating growth parameters. Usually more accurate fitting of von Bertalanffy growth formula is possible for smaller size classes.

Monthly length frequency distributions of *P. homarus* in the study area appeared to follow closely similar yearly patterns of recruitment and growth i.e., peak size classes are similar in the corresponding months of each year(Appendix 5.2a, 5.2b, 5.2c, 5.2d). Therefore the length frequency data of corresponding months in the two years were pooled and a series of length frequency samples covering from January to December was obtained to construct a "mean" (artificial) year for *P. homarus* and to estimate growth parameters according to the step -wise procedure described above.

The length frequency distribution of *P. homarus* for the study period is shown in Appendix 5.2a, 5.2b, 5.2c and 5.2d. Based on the pooled data of the respective months for males and females separately, the best growth curves were estimated by "Compleat ELEFAN" and are shown in Fig. 5.5 and 5.6. The values for asymptotic total lengths were estimated as 32.7 cm for males and 31.7 cm for females. Growth constant values were estimated as 0.415 yr^{-1} for males and 0.370 yr^{-1} for females.

5.3.2 Growth performance index (ϕ).

5.3.2.1 Theory of growth performance index.

In fish and invertebrates whose growth can be described by the von Bertalanffy growth function, the comparison of growth performance is

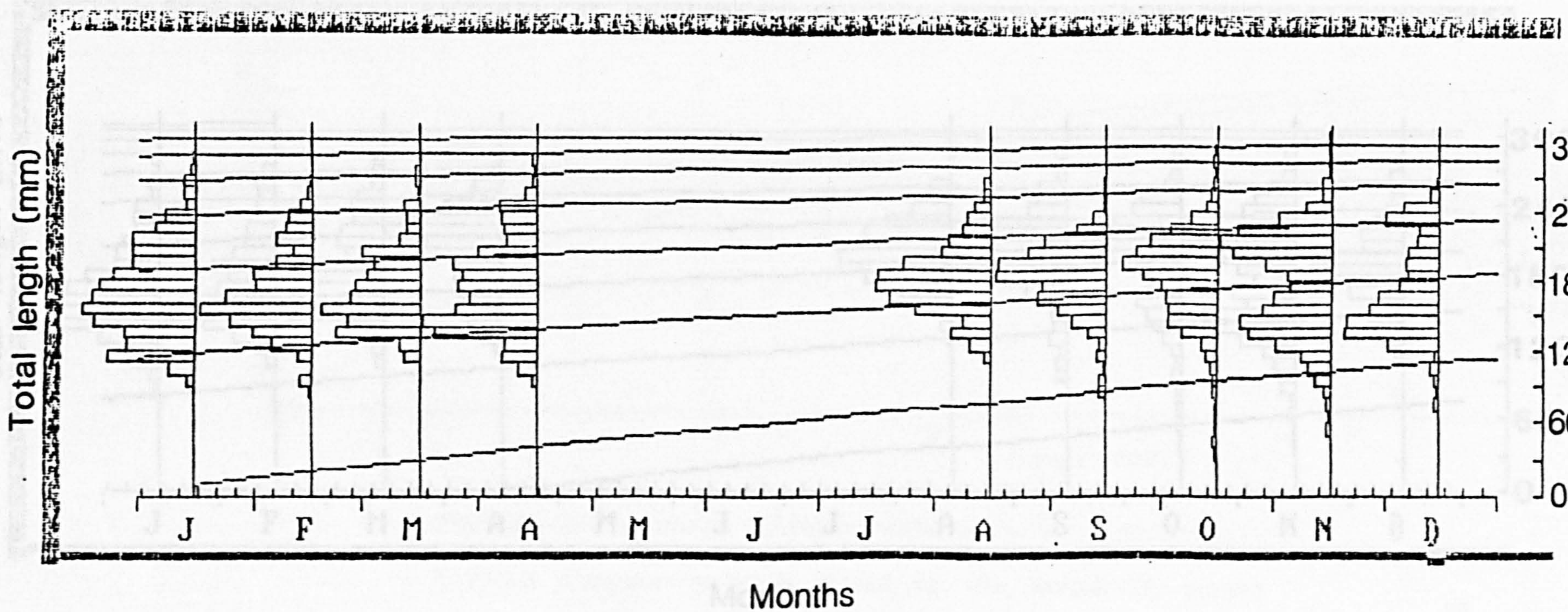


Fig. 5.5 Growth curve for male *Panulirus homarus* traced from ELEFAN 1 computer program.

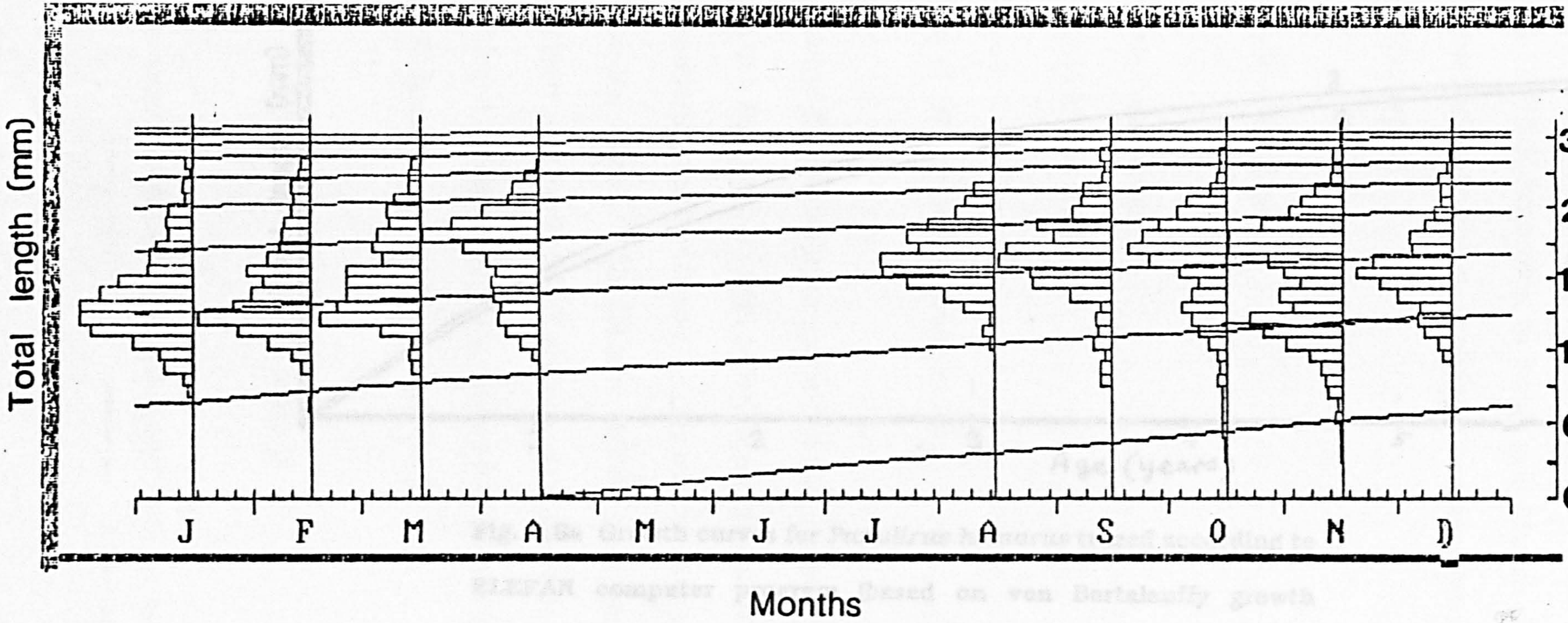


Fig. 5.6 Growth curve for female *Panulirus homarus* traced from ELEFAN 1 computer program.

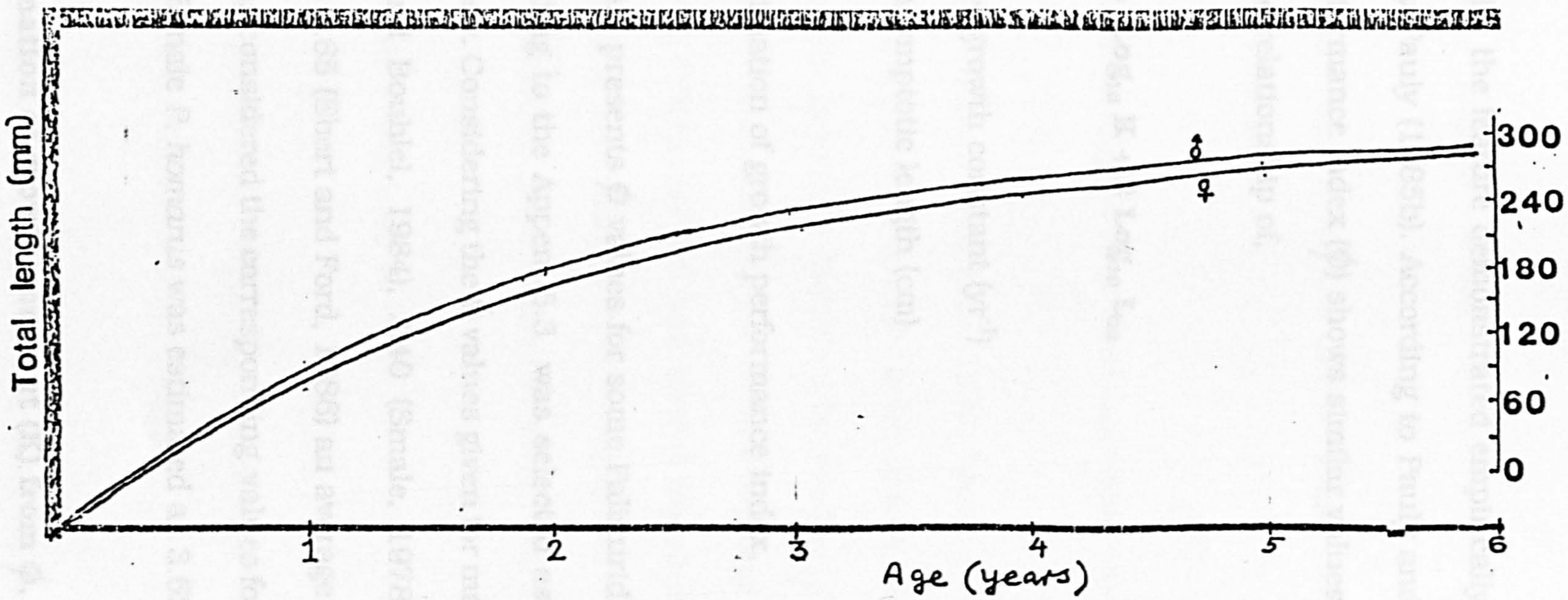


Fig. 5.6a Growth curves for *Panulirus homarus* traced according to ELEFAN computer program (based on von Bertalanffy growth equation).

facilitated by the feature demonstrated empirically and on theoretical grounds by Pauly (1985b). According to Pauly and Munro (1984), the growth performance index (ϕ) shows similar values for related animals and has the relationship of,

$$\phi = \mathrm{Log}_{10} K + 2\,\mathrm{Log}_{10} L_{\infty}$$

where, **K** = growth constant (yr^{-1})

L_{∞} = asymptotic length (cm)

5.3.2.2 Estimation of growth performance index.

Appendix 5.3 presents ϕ values for some Palinurids. An average value of ϕ according to the Appen. 5.3 was selected as reasonable for the present study. Considering the ϕ values given for male *P. homarus*: 3.93 (Sanders and Bouhlel, 1984), 3.40 (Smale, 1978); and for male *P. penicillatus* 3.65 (Ebert and Ford, 1986) an average value was taken as 3.56. Having considered the corresponding values for females (Appendix 5.3), ϕ for female *P. homarus* was estimated as 3.62.

5.3.3 Estimation of growth constant (K) from ϕ.

By substituting the values of ϕ (3.56 for males and 3.62 for females) in the equation:

$$\phi = \text{Log}_{10} K + 2 \text{Log}_{10} L_{00}$$

an approximate value for **K** was estimated as 0.214 yr^{-1} for males and 0.269 yr^{-1} for females.

5.3.4 Estimation of growth parameters using the Wetherall method.

The Wetherall method (Wetherall, 1986; Pauly, 1986a) is based on the assumption that lobster populations are stable, with constant annual recruitment, the growth is described by von Bertalanffy (1938) model, and that continuous mortality occurs at a uniform instantaneous rate. The Wetherall (1986) method was derived from the Beverton and Holt (1956) method of estimating **Z/K** (**Z** = instantaneous total mortality; **K** = growth constant) as given in the following form:

$$Z/K = (L_{00} - \bar{L}) / (\bar{L} - L_c)$$

where, L_{00} = asymptotic length; L_c = knife-edge selection length; $\bar{L}$ = mean length of the lobsters larger than L_c.

Wetherall (1986) has shown that $\bar{L}$ is a linear function of the knife-edge selection length,

$$\bar{L} = L_{00} / [1 + (Z/K)] + L_c / [1 + (Z/K)]$$

In the fully recruited phase of the sample (above L_c), for a series of arbitrary cut-off lengths (L'), corresponding $\bar{L}$ can be calculated. A positive linear relationship occurs between L' and $\bar{L}$ ($\bar{L}$ = mL' + C) and slope (m) and intercept (C) of the relationship are given as follows:

$$m = L_{\infty} / [1 + (Z/K)]$$

$$C = 1 / [1 + (Z/K)]$$

As such, from **m** and **C** of the relationship, L_{∞} and **Z/K** values can be obtained.

$$L_{\infty} = C / (1-m),$$

$$Z/K = m / (1-m).$$

Pauly (1986a) has suggested a modification to this method. According to this method, instead of plotting the successive mean lengths ($\bar{L}$) against their corresponding cut-off lengths (L'), a plot of ($\bar{L}$-L') against L' can be used for estimating L_{∞} and **Z/K**. This gives $\bar{L} - L' = a - bL'$ where, $L_{\infty} = a / -b$ and

$$Z/K = (1 + b) / -b.$$

L_{∞} and **Z/K** were calculated by the modified Wetherall plot (Pauly, 1986a) as implemented in the "Compleat ELEFAN" soft- ware package.

According to the method, L_∞ was estimated as 32.21 cm for males and 31.59 cm for females. The plots made on $\bar{L}$ - L' and L' are shown in Figs. 5.7 & 5.8.

5.4 Recruitment pattern.

Since it is the pulsed nature of annual recruitment into a population which generates the peaks and troughs in length frequency data, the converse also applies that, given a set of length frequency data and growth parameters, one should be able to recover the pulsing of annual recruitment. A routine which performs this task was incorporated into ELEFAN 11, it produces that are called "recruitment patterns", i.e., graphic descriptions of the recruitment process that generated the length frequency data available. The recruitment pattern of *P. homarus* to the fishery based on the length frequency data is given in Appendices. 5.2a, 5.2b, 5.2c and 5.2d (using pooled data for two years for males and females separately). The recruitment pattern was estimated by using the ELEFAN 11 programme (Gayanilo et. at., 1989) and the results are shown in Figs. 5.9 & 5.10. The results indicate two recruitment peaks each year. Out of these two peaks, the first one is smaller in magnitude while the second peak seems to be the one which contributes greatly to the fishery.

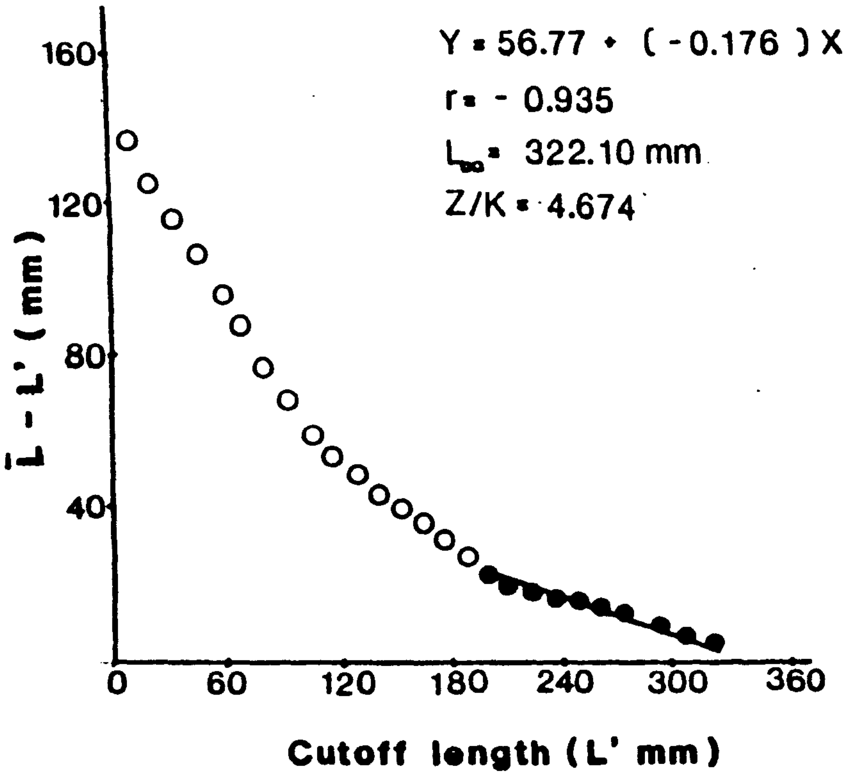


Fig. 5.7 Modified Wetherall plot for male *Panulirus homarus*.

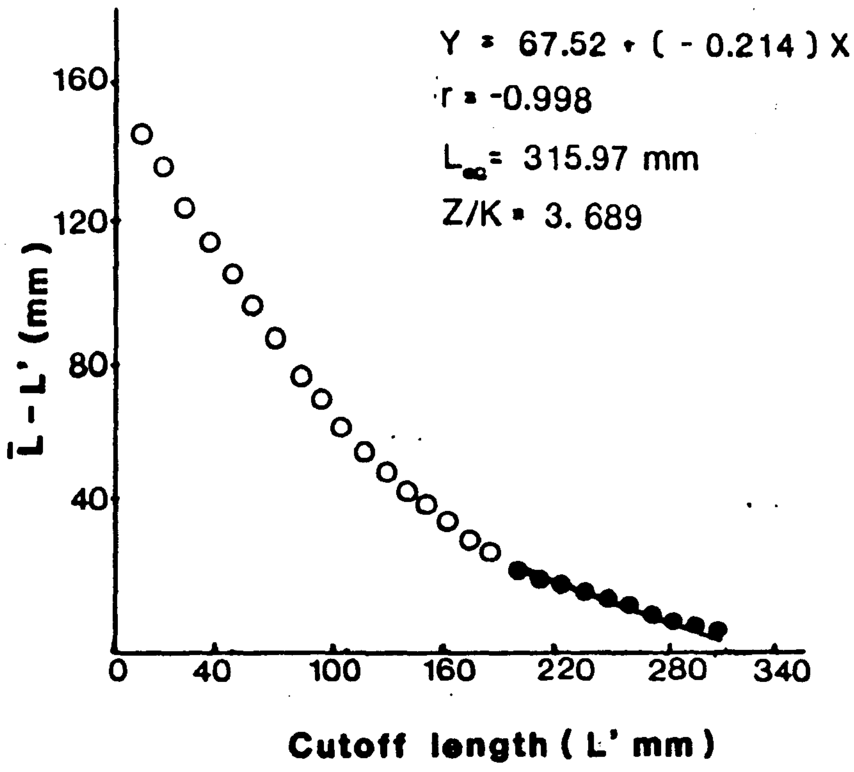


Fig. 5.8 Modified Wetherall plot for female *Panulirus homarus*.

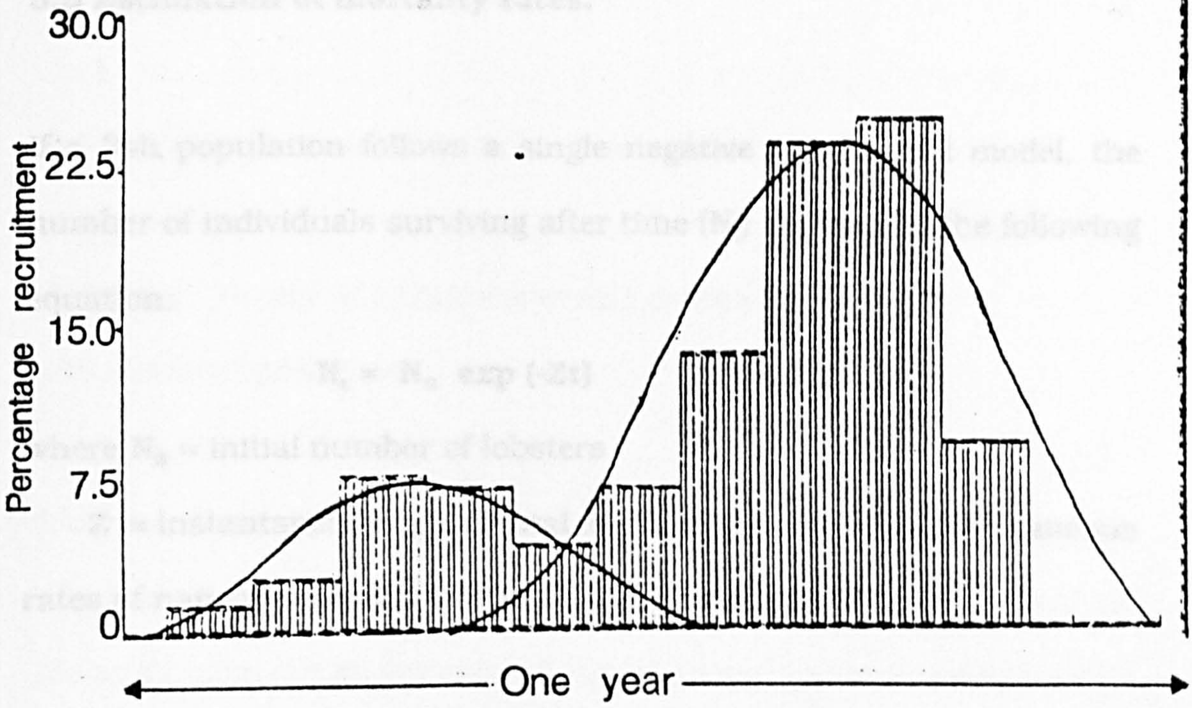


Fig. 5.9 Recruitment pattern for male *Panulirus homarus* constructed using ELEFAN program.

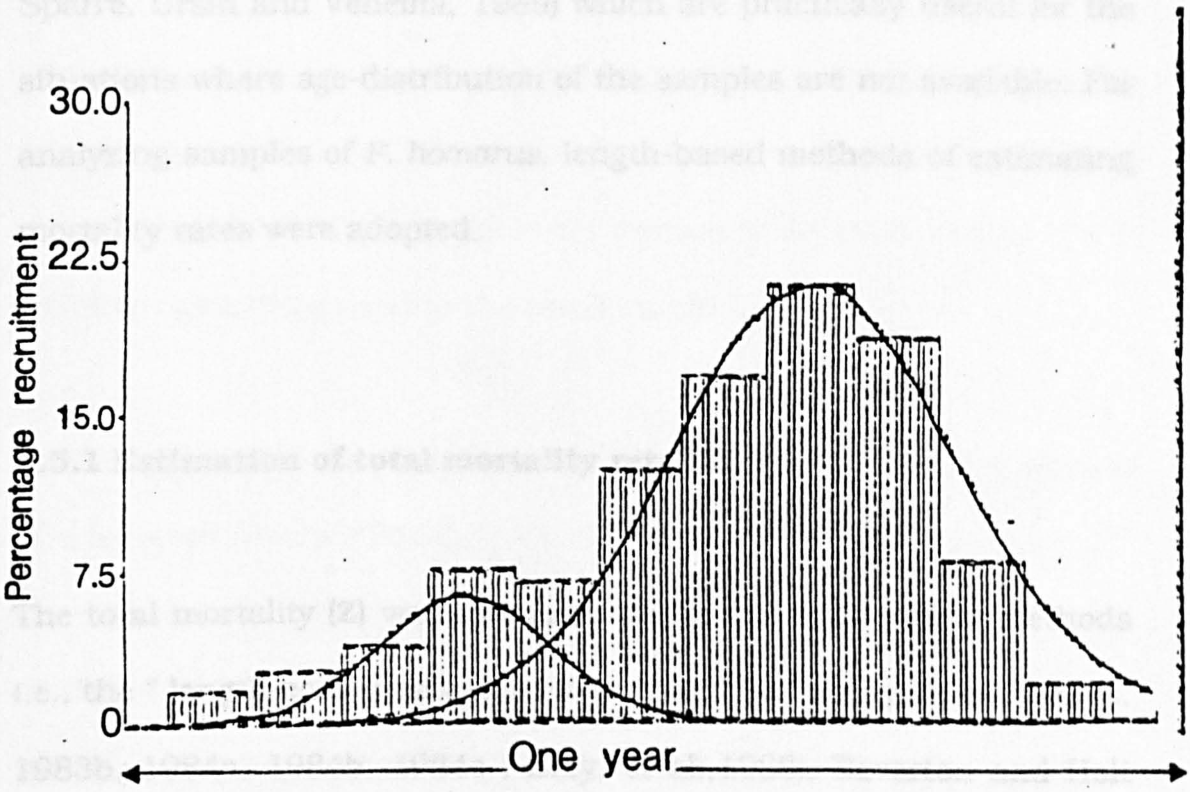


Fig. 5.10 Recruitment pattern for female *Panulirus homarus* constructed using ELEFAN program.

5.5 Estimation of mortality rates.

If a fish population follows a single negative exponential model, the number of individuals surviving after time (N_t) is given by the following equation:

$$N_t = N_0 \exp(-Zt)$$

where N_0 = initial number of lobsters

Z = instantaneous rate of total mortality i.e., sum of instantaneous rates of natural mortality (**M**) and fishing mortality (**F**).

A wide array of length-based methodologies to estimate mortality rates is now available (Pauly, 1984a; Pauly and Morgan, 1987; Sparre, 1987; Sparre, Ursin and Venema, 1989) which are practically useful for the situations where age-distribution of the samples are not available. For analyzing samples of *P. homarus*, length-based methods of estimating mortality rates were adopted.

5.5.1 Estimation of total mortality rate (Z).

The total mortality (Z) was estimated using three alternative methods i.e., the " length-converted catch curve " method (Pauly, 1982, 1983a, 1983b, 1984a, 1984b, 1984c ; Brey, et al., 1988), Beverton and Holt (1956) method and **Z/K** estimates made by the modified Wetherall plot

(Wetherall, 1986; Pauly, 1986a).

5.5.1.1 Length-converted catch curve method.

5.5.1.1.1 Theory of length-converted catch curve and computation procedure.

Length converted catch curve is a length-based version of the age-structured catch curve which essentially consists of a plot of logarithmic form of a negative exponential of the following equation (Ricker, 1975).

$$\mathbf{Ln\ N_t = a + bt}$$

Z is estimated from the slope **b** (with sign changed) of the descending right arm of the plot. Since the **Z** value is independent of age **t**, knowledge about absolute age is not necessary. As such, setting $\mathbf{t_0 = 0}$, relative age can be used in the catch curve.

In the catch curve methods for estimating **Z**, the following assumptions are involved (Pauly, 1984a).

a) **Z** is the same in all age groups used in the plot,

b) all age groups used in the plot were recruited with the same abundance (or the recruitment fluctuations have been small and random in character),

c) all age groups used in the plots are equally vulnerable to the gear used for sampling and

d) the sample used is large enough and covers enough age groups to effectively represent the average population structure over the period of time considered.

The length-converted catch curve method involves the following steps:

a) pooling length frequency samples to obtain a single, large length frequency sample representative of the population for the period under consideration,

b) construction of a catch curve using the pooled length frequency sample and growth parameters,

c) estimation of **Z** from the descending part of the catch curve.

Pooling of length frequency samples is done to reduce the effect of seasonal recruitment pulses on the population structure. Also, the various samples are given the same weight by conversion to percent length frequency samples (when samples have roughly similar sizes and are evenly spaced in time) or by conversion to percent of square root of sample total (when the samples have dissimilar sizes) to minimise the effect of different sample sizes on the pooled samples.

When length frequency is converted to age distribution using von Bertalanffy growth parameters, due to non-linear growth of lobsters, distortion of the catch curve occurs because a size interval of larger lobsters will include a wider age range that the same size interval of smaller lobsters. As such, a length-converted catch curve of the following form is suggested by Pauly (1982, 1983b).

$$Ln\ (N_i/\triangle t_i) = a - bt_i$$

Where, N_i = the number of lobsters in length class i,

$\triangle t_i$ = the time needed by the lobster to go through length class i,

t_i = relative age of the mid point of length class i.

Here, t_i and $\triangle t_i$ are estimated as follows:

$$t_i = (1/K)\ \{Ln\ [L_{00}/\ (L_{00} - L_i)]\} + t_0$$

Where, L_{00}, K and t_0 are von Bertalanffy growth parameters and L_i is the mid point of the length class i. Setting $t_0 = 0$, relative age of the mid point of length class can be obtained. Similarly,

$$\triangle t_i = \{Ln\ [(L_{00} - L_1)/(L_{00} - L_2)]\}\ /\ K$$

where L_1 and L_2 are lower and upper limits of length class **i** respectively. The slope of this length-converted catch curve (**b**) with sign changed gives an estimate of **Z**. In "Compleat ELEFAN" software package, the following iteration equation is used to correct the estimate of **Z = - b** of the regression line for the non-linearity of the growth model and for the reason that some mortality occurs within each length class.

$$\mathbf{Ln\ \{N_i / [1 - exp\ (- Z_i \Delta t_i)]\} = a - Z_i \Delta t_i}$$

Where, N_i and Z_i are the number of lobsters and total mortality of length class **i** respectively. Δt_i is the age interval of upper and lower limits of length class **i** (Gayanilo et. al., 1989).

5.5.1.1.2 Estimation of total mortality rate (**Z**) using length - converted catch curve.

Using the estimated growth parameters of *P. homarus* and its length frequency data, **Z** values were calculated by the length-converted catch curve method as implemented in ELEFAN 11 of the software package.

The points belonging to the ascending, left arm of the catch curve which represent lobsters that are not fully selected by the gear and the highest point which is still affected by incomplete selection and recruitment were disregarded in estimating **Z**. The points corresponding to lengths very close to L_{∞} were also excluded from the computation of **Z** since they would affect the estimate of **Z** dramatically (Gayanilo et. al., 1989). The relationship of $\ln(\%N/\Delta t) = a - bt$ was fitted to the descending arm of the curve since it represents those lobsters that are fully vulnerable to the fishing gear. Using the preliminary estimate of **Z** from the slope of the relationship, a corrected estimate of **Z** was obtained from the iteration procedure described above, as implemented in ELEFAN 11. Straight line regressions were fitted to the right hand limbs of the two catch curves for males and females and the slopes of the lines were estimated as 1.966 for males and 1.538 for females (Figs. 5.11 & 5.12).

5.5.1.2 Beverton and Holt method.

As given earlier, the Beverton and Holt (1956) formula for estimating **Z** is as follows:

$$Z = K(L_{\infty} - \bar{L}) / (\bar{L} - L')$$

Hence, using the mean length of lobsters ($\bar{L}$) above the fully vulnerable length of lobsters to the fishing gear (L'), an estimate of **Z** was obtained for *P. homarus* males and females separately.

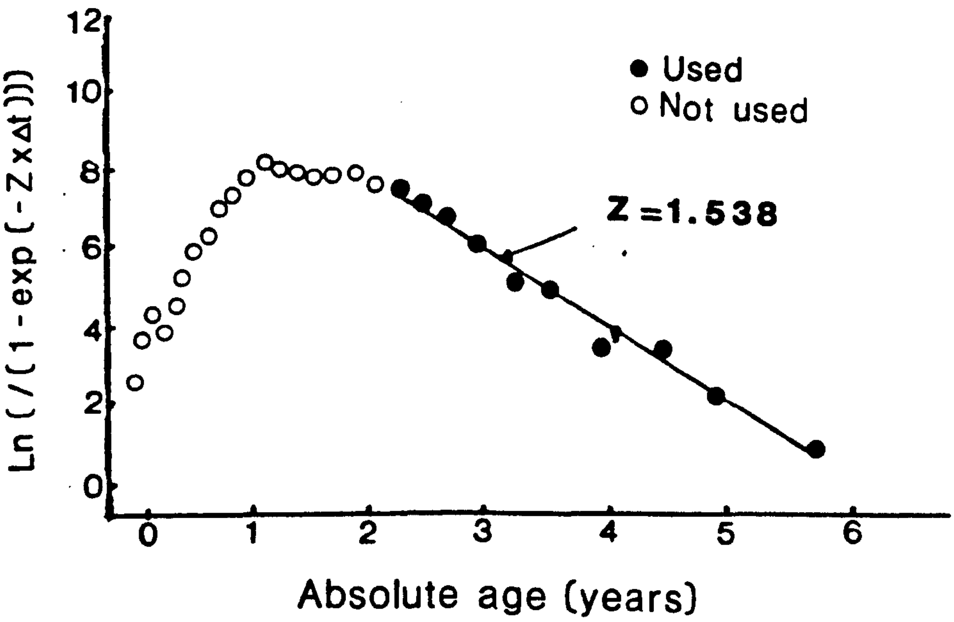
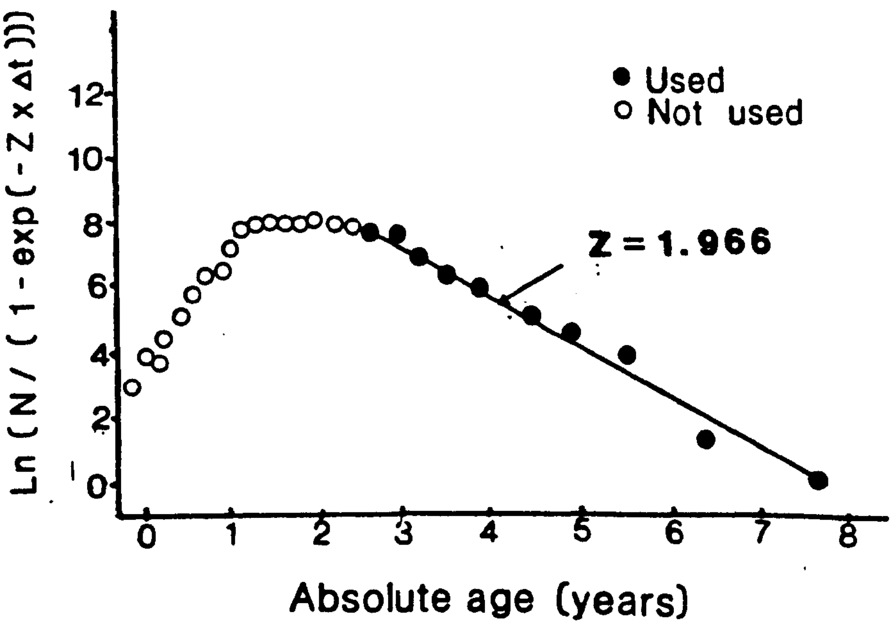


Fig. 5.11 Catch curve for male *Panulirus homarus.*

Fig. 5.12 Catch curve for female *Panulirus homarus.*



Males	Females
L_{00} = 32.70 cm	31.70 cm
$\bar{L}$ = 21.59 cm	22.59 cm
L' = 19.00 cm	20.00 cm
K = 0.41 yr^{-1}	0.37 yr^{-1}

Substituting these values in the above equation, **Z** was estimated as 1.759 for males and 1.301 for females.

5.5.2 Estimation of natural mortality rate (M).

5.5.2.1 Pauly's formula.

In the present study, time series data of fishing effort and **Z** are not available, so that to estimate the natural mortality rate (**M**) of *P. homarus* in the study area, the empirical relationship derived by Pauly (1980) expressing **M** as a function of the von Bertalanffy growth parameters and temperature has been used. The relationship is:

$$\mathbf{Log_{10}\, M = -\,0.006 - 0.279\, Log_{10}\, L_{00} + 0.6543\, Log_{10}\, K + 0.4634\, Log_{10} T}$$

Where, L_{00} = asymptotic total length in cm,

K = growth constant ($year^{-1}$),

T = mean annual sea water temperature (^{0}C).

Since Pauly (1980) has used the above units in the derivation of the multiple regression equation using data of 175 fish stocks, the parameters with the same units and L_{∞} expressed in total length were used in the empirical equation.

Using the above formula and the following values of L_{∞}, **K** and **T**,

Male	**Female**
K = 0.214 yr^{-1}	**K = 0.269 yr^{-1}**
L_{∞} = 32.2 cm	**L_{∞} = 31.6 cm**
T = 28.27 °C	**T = 28.27 °C**

natural mortality value was estimated as 0.980 for males and 0.920 for females.

5.5.2.2. Rikhter and Efanov method

The method developed by Rikhter and Efanov (1976), was also used for estimating the natural mortality coefficient (**M**). It requires a knowledge of the age at first sexual maturity, which has a relationship with **M** according to the following equation,

$$M = 1.521 / (t_m)^{0.720} - 0.155$$

The estimates made on the age at first maturity of *P. homarus* (see section 3.6.3.2) was taken as 2.0 years for males and 2.5 years for females. From which, the natural mortality rates were calculated as 0.77 for males and 0.63 for females.

5.5.3 Estimation of fishing mortality (F).

The estimates for fishing mortality (**F**) of *P. homarus* in the study area were obtained by subtracting the estimated **M** values from their corresponding **Z** values. Hence, **Z** and **M** are known, **F** was calculated using the following relationship:

$$F = Z - M$$

$$F = 1.966 - 0.980 = 0.986 \text{ (for males)}$$

$$F = 1.538 - 0.920 = 0.618 \text{ (for females)}$$

5.6 Estimation of survival rates (S).

The relationship between survival rate (**S**) (the fraction of an age-group surviving from one year to the other) and **Z** (the total mortality coefficient) is given by the relationship:

$$Z = \log_e 1/S$$

To estimate **S**, this relationship can be transformed as follows:

$$S = e^{-Z}$$

from which survival rates were estimated as 0.140 for males and 0.215 for females respectively.

5.7 Exploitation rate (E).

Exploitation rate was calculated using the relationship:

$$E = \frac{F}{Z}$$

from this **E** was calculated as 0.502 for males and 0.402 for females. When the population as a whole is considered, an exploitation rate value of 0.50 could be reasonable.

5.8 Estimating stock numbers and fishing mortality using Virtual Population Analysis (VPA).

5.8.1 Length-structured Virtual Population Analysis (VPA 11).

By VPA or Cohort Analysis, historical data could be analysed for estimation of population parameters. Jones (1976, 1984) has introduced a method for dealing with the situations where only length composition data for the total fishing are available. In this method of analysis, real cohorts are not considered and dynamics of all size classes caught during one year are assumed to be equal to dynamics of a cohort. Length-structured VPA is analogous to Jones length cohort analysis (Jones, 1974, 1976, 1984; Sparre et. al., 1989).

5.8.1.1 Computation procedure in length-structured VPA (VPA 11)

The length-structured VPA (Pauly, 1984a) is derived from the following version of the catch equation of Beverton and Holt (1957).

$$N_i/C_i = (Z_i \exp - Z_i) / [F_i (1 - \exp - Z_i)]$$

where,

N_i = population size at the beginning of the ith time period,

C_i = catch from the population during the ith time period,

F_i = fishing mortality in the ith period,

Z_i = total mortality in the ith period.

This equation can be generalised for any time interval Δt as follows:

$$N_i \Delta t/C_i = [Z_i \exp (-Z_i \Delta t)] / \{F_i [1- \exp (-Z_i \Delta t)]\}$$

or

$$C_i = N_{i\ t} (F_i/Z_i) [\exp (Z_i \Delta t) -1]$$

The length groups of the catch samples can be converted into age classes by inverse von Bertalanffy equation.

$$t_i = t_0 - \{(1/K) \, Ln \, [1 - (L_i / L_{00})]\}$$

and $$\Delta t = 1/K \, Ln \, [(L_{00} - L_1) \, / \, (L_{00} - L_2)]$$

where, the symbols are given in the section 5.5.1.1.1. This Δt can be substituted to the above generalised catch equation.

Therefore, using these equations, starting from a guessed terminal fishing mortality of the largest length group, the number of lobsters in the smaller size classes and the fishing mortalities affecting them can be calculated from catch-at-length data of a steady state population. This length-structured VPA is implemented as VPA 11 in "Compleat ELEFAN" software package (Gayanilo et. al., 1989).

Using the mean annual catch, and catches in different size classes, stock numbers and fishing mortality in each length class can be calculated from the length frequency data collected over a long period of time and their corresponding total catches. In this computation, coefficients of length-weight relationship ($W = a \, L^b$) are also needed to estimate sample weights using the method of Beyer (1987) for raising samples to the total catch. In the "Compleat ELEFAN" package, the following procedure is used for estimating catch numbers.

a) Calculation of adjusted catch (C_{adj}) using the equation,

C_{adj} = (monthly catch x mean annual catch) / total sample catches

b) Calculation of raising factor (RF) using the equation,

RF = C_{adj}/ sample weight.

c) Calculation of catch numbers (C_N) in each size class from,

C_N = frequency x **RF**

5.8.1.2 Estimating stock numbers and fishing mortality using VPA 11.

Monthly length frequency data and total landings of *P. homarus* in the study area were analysed using the length-structured VPA, implemented as VPA 11 in "Compleat ELEFAN" package. The estimated values of von Bertalanffy growth parameters (**L_{∞}** and **K**) and natural mortality (**M**) were used in this analysis.

Different terminal **F** values were tested in the iteration and the **F** value that gave consistency (**F** = 0.2) in estimating of **M** in different size classes were selected as the terminal **F**. From this analysis, number of survivors, number of fish died of natural causes and fishing, and fishing mortality in different size classes were estimated, and the results are shown in Tables 5.2a, 5.2b and Fig. 5.13.

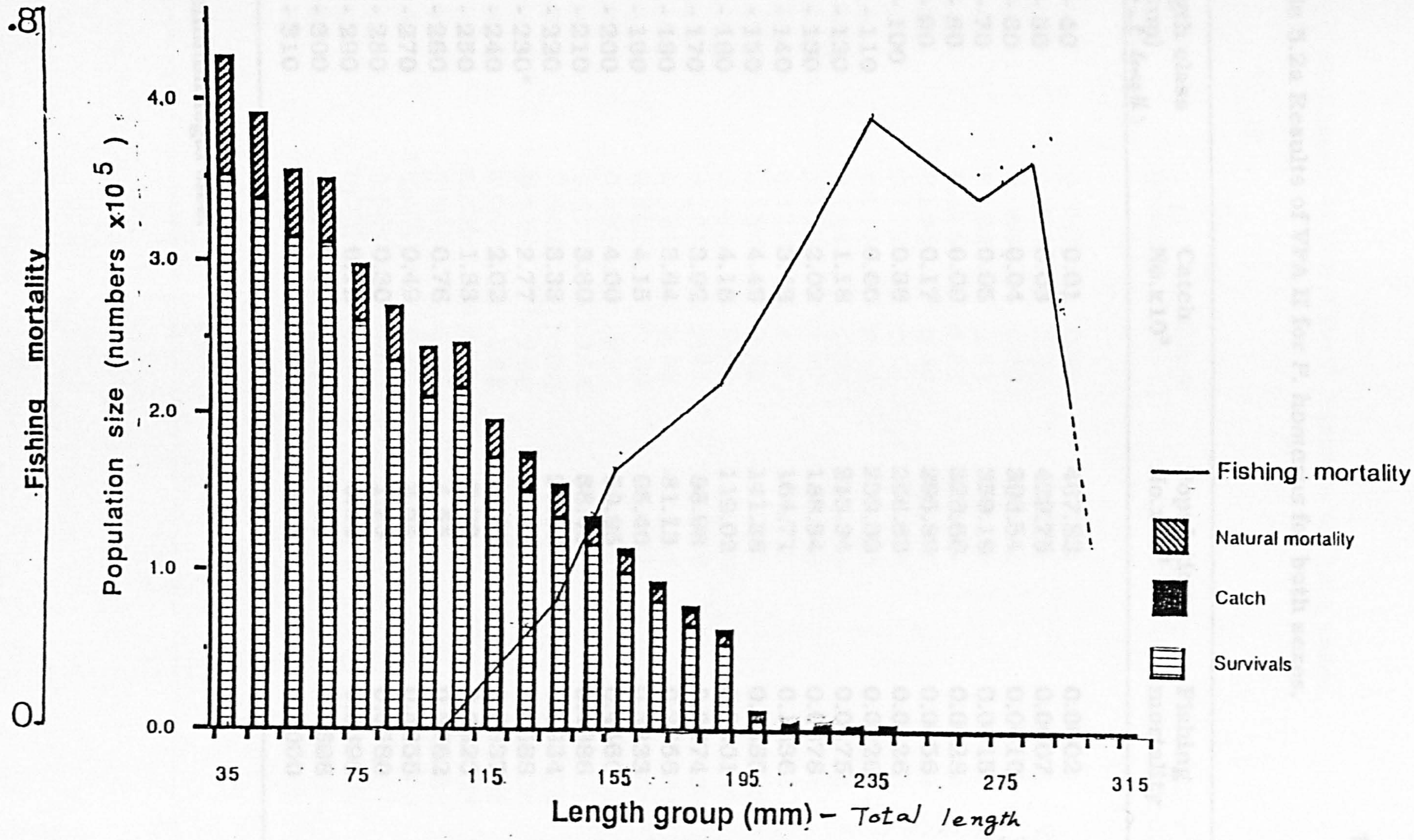


Fig. 5.13 **Results of the VPA 11 obtained from ELEFAN for** ***Panulirus homarus.***

Table 5.2a Results of VPA II for *P. homarus* for both sexes.

Length class (mm) (Total length)	Catch No.x10³	Population No.x10³	Fishing mortality
30 - 40	0.01	467.83	0.0002
40 - 50	0.03	429.75	0.0007
50 - 60	0.04	393.54	0.0010
60 - 70	0.05	359.19	0.0015
70 - 80	0.09	326.66	0.0028
80 - 90	0.17	295.89	0.0056
90 - 100	0.36	266.82	0.0126
100 - 110	0.60	239.33	0.0226
110 - 120	1.18	213.34	0.0475
120 - 130	2.02	188.54	0.0878
130 - 140	3.43	164.71	0.1636
140 - 150	4.49	141.38	0.2385
150 - 160	4.18	119.02	0.2501
160 - 170	3.92	98.98	0.2674
170 - 180	3.64	81.13	0.2856
180 - 190	4.15	65.40	0.3833
190 - 200	4.00	50.95	0.4460
200 - 210	3.60	38.42	0.4986
210 - 220	3.33	27.97	0.5934
220 - 230*	2.77	19.32	0.6588
230 - 240	2.02	12.62	0.6837
240 - 250	1.33	7.79	0.6623
250 - 260	0.76	4.55	0.5762
260 - 270	0.49	2.54	0.5955
270 - 280	0.30	1.26	0.6580
280 - 290	0.12	0.52	0.5395
290 - 300	0.03	0.19	0.2698
300 - 310	0.01	0.06	0.2000

* Minimum legal size.

Table 5.2b Results of VPA II for *P. homarus* for both sexes.

Mid-length (mm) (Total length)	Δt (years)	Catch (tons.)	Steady-state biomass	Cumulative biomass tons
35.00	0.089	0.00	137.29	137.29
45.00	0.093	0.00	243.19	380.40
55.00	0.096	0.00	378.39	758.79
65.00	0.100	0.01	529.72	1288.51
75.00	0.104	0.02	692.33	1980.84
85.00	0.108	0.05	858.47	2839.31
95.00	0.113	0.15	1011.54	2850.85
105.00	0.111	0.34	1151.35	5002.20
115.00	0.124	0.87	1261.55	6263.74
125.00	0.130	1.87	1344.66	7608.41
135.00	0.137	3.95	1384.31	8992.72
145.00	0.145	6.32	1372.81	10365.53
155.00	0.154	7.09	1312.80	11678.33
165.00	0.163	7.94	1230.06	12908.39
175.00	0.174	8.70	1114.65	14023.04
185.00	0.187	11.61	977.60	15000.64
195.00	0.202	12.97	817.73	15818.37
205.00	0.219	13.44	654.94	16473.31
215.00	0.240	14.20	497.42	16970.74
225.00	0.265	13.30	353.63	17324.36
235.00	0.295	11.08	234.58	17558.95
245.00	0.333	8.21	144.31	17703.26
255.00	0.383	5.25	82.03	17785.29
265.00	0.451	3.77	43.24	17828.53
275.00	0.548	2.58	19.47	17848.21
285.00	0.697	1.16	7.09	17855.30
295.00	0.961	0.29	2.01	17857.30
305.00	1.554	0.11	0.42	17857.73
Total	-	135.29	17857.73	-

5.9 Yield-per-recruit analysis.

Pauly and Soriano (1986) have stated that the length-structured version of yield-per-recruit model developed by Beverton and Holt (1966) is ideally suited for use in data-sparse, tropical situations.

5.9.1 Assumptions behind the yield-per-recruit analysis.

As in the age-structured version of the yield-per-recruit model of Beverton and Holt (1957), the length-structured relative yield-per-recruit model (Beverton and Holt, 1966; Pauly and Soriano, 1986) is based on the following assumptions.

a) Lobsters exhibit isometric von Bertalanffy growth pattern.

b) Natural, fishing and total mortality rates are expressed by negative exponential curves.

c) All lobsters of a given cohort enter the fishing ground and become catchable by the gear at the same ages through knife-edge recruitment and selection.

The relative yield-per-recruit (**Y/R**) model is given by the following formula.

$$Y/R = E(1-C)^{M/K}\{1 - [3(1-C)/(1+((1-E)/(M/K)))] + [(3(1-C)^2)/(1+((2(1-E))/(M/K)))] - [(1-C)^3/(1+((3(1-E))/(M/K)))]\}.$$

Where, **E** = **F/Z**; **C** = L_c / L_{∞} in which L_c is the length at first capture. In this model, t_0 is set at zero.

However, the assumption of knife-edge selection is valid in many species in the case of long-lived tropical fish species (Pauly and Soriano, 1986). Pauly and Soriano (1986) suggested an expression of **Y/R** model to compensate for the effect of wide selection range.

5.9.2 Computation of relative yield-per-recruit values.

Using the estimated values of L_{∞}, **K**, **M**, L_c and probabilities of capture of different length classes, relative yield-per-recruit values (**Y/R**) for various exploitation rates (**E**) were calculated for *P. homarus* both sexes combined. **Y/R** values as a function of **E** were computed for the present level of L_c (L_c level was considered as 100mm in total length based on experimental fishing. See chapter 6). The resultant plot of relative yield per recruit and relative biomass per recruit against respective exploitation rates constructed from "Compleat ELEFAN 111" are shown in Fig. 5.14.

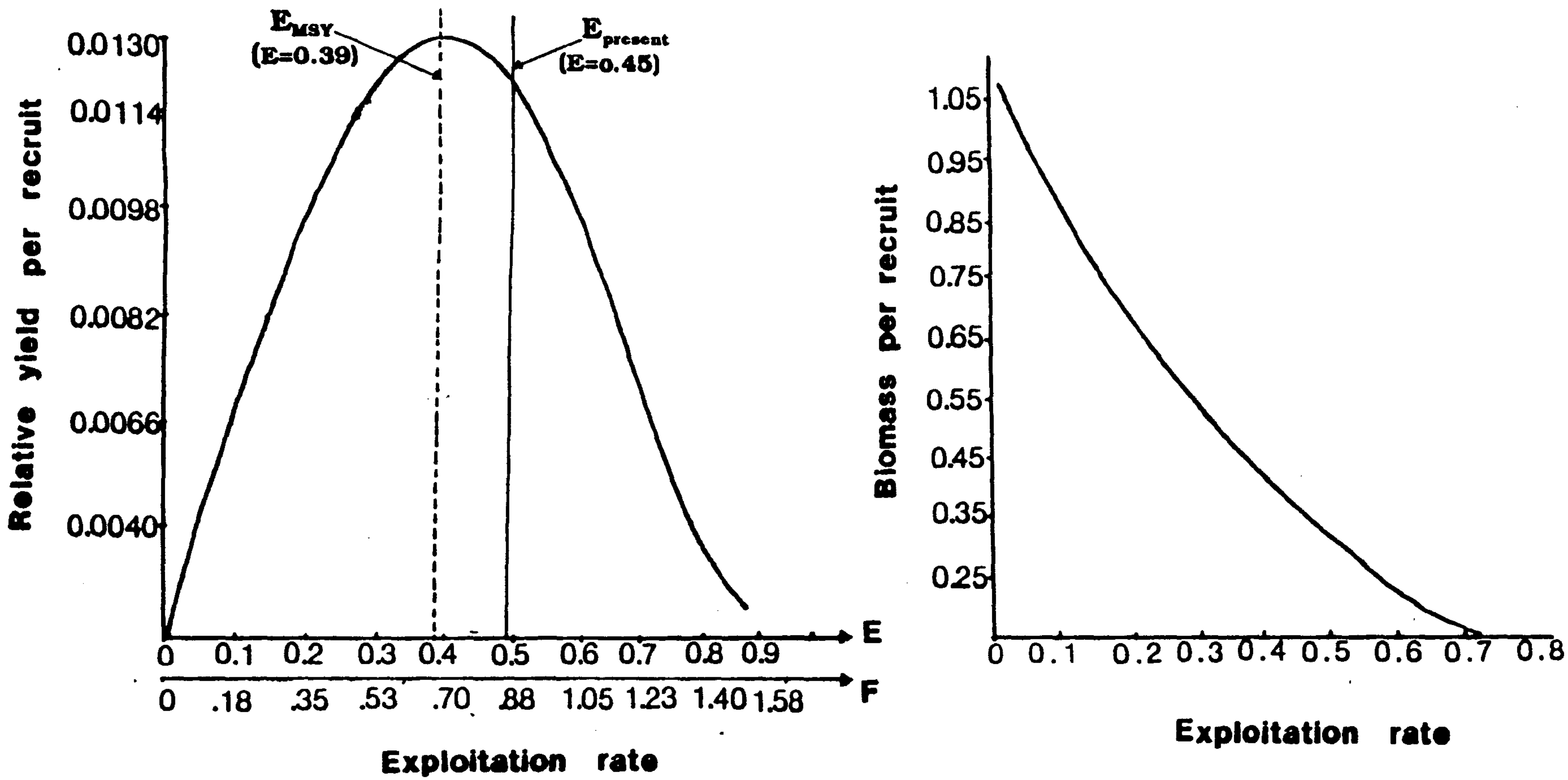


Fig. 5.14 **Relative yield per recruit and biomass per recruit values as functions of exploitation rates (E) and Fishing mortality values (F) for *Panulirus homarus*.**
(E_{MSY} = 0.39, M = 0.95, K = 0.39, L_c / L_∞ = 0.11, M/K = 2.41).

5.10 Discussion.

The length-weight relationship of the form of $W = aL^b$ where 'b' value ranges between 2 - 4 for most fish species seems to hold true for *P. homarus* where the 'b' value in the present investigation was 2.960 for males and 2.564 for females. For the population as a whole (including juveniles), 'b' value was estimated as 2.817. According to the available literature, the 'b' value of Palinurids shows a variation from 2.525 to 2.859, e.g. 2.765 for male and 2.717 for female *P. homarus* (Sanders and Bouhlel, 1984); 2.625 for male and 2.195 for female *P. marginatus* (Uchida, Uchiyama, Humphreys and Tagami, 1980); 2.525 for male and 2.676 for female *P. polyphagus* (Rongmuangsart and Luvira, 1973); 2.788 for both sexes of *P. argus* (Olsen and Koblic, 1975) and 2.777 for male and 2.859 for female *P. homarus* (Berry, 1971b).

The estimates made on condition factor ($\bar{K}$) for both sexes during the study period showed an increasing trend during the months of July to December. The reproductive biology studies (see chapter 3) indicate this period as the pre-spawning and spawning period for the majority of lobsters, thus the increase in the value of $\bar{K}$ is expected.

The estimation of spiny lobster growth in nature by any of the presently known methods is difficult. The adequacy of the von Bertalanffy (1938) growth function as a realistic description of the growth process in

Palinurids depends on the main assumption that the growth rate is constant throughout any one year. This is obviously not the case in the Palinuridae, where the moult frequency varies seasonally. Although temperature changes are not prominent in tropical waters, monsoonal changes can create seasonal variations which may directly or indirectly influence on growth. The effects of these seasonal changes in the growth rate in the form of the growth curve have not been examined properly for spiny lobsters (Morgan, 1980).

The measurement of the growth rate of an individual lobster is important in establishing a mean growth curve applicable to the population as a whole. It is the "population growth curve" that forms a vital part of the description of the population dynamics of the species in question, as well as forming part of the yield assessment models for several species of the Palinuridae. The most adequate description of the growth curve has been provided by the von Bertalanffy (1938) growth function, although variation around the curve is generally high (Morgan, 1980).

In the present analysis, it is assumed that the growth of spiny lobsters follows the von Bertalanffy type of growth. The $\mathbf{L_{\infty}}$ and **K** values estimated by ELEFAN 1 in the present study, are questionable because of the low values of **Rn** (**Rn** = 0.57). Still it produces estimates ($\mathbf{L_{\infty}}$ = 32.7 cm, **K** = 0.415 for males and $\mathbf{L_{\infty}}$ = 31.7, **K** = 0.370 for females), which are in agreement with Sanders and Bouhlel (1984). As the ELEFAN estimates of L_{∞} and **K** are not exact values, an attempt was made to estimate these parameters through the modified Wetherall plot (Wetherall, 1986; Pauly, 1986a). The results of this plot produce estimates (L_{∞} = 32.2 cm for males and 31.6 cm for females) closed to the values estimated from ELEFAN 1.

In addition to the above methods, an attempt was also made to estimate **K** through the ϕ and the results obtained from these methods were given below.

Method	Male		Female	
	L_{∞} (cm)	K (yr^{-1})	L_{∞} (cm)	K (yr^{-1})
ELEFAN 1	32.70	0.415	31.70	0.370
ϕ index	-	0.214	-	0.269
M.W.P	32.20	0.510	31.59	0.680

M.W.P = Modified Wetherall Plot (Wetherall, 1986;Pauly,1986a).

The slow growth rate values implied by low **K** (0.214 yr^{-1} and 0.269 yr^{-1}) given by the ϕ index estimates are not comparable to the results available in the literature (Appendix 5.3).

The asymptotic lengths (L_{∞}), calculated from data collected during the present study (327mm total length = 129.5mm carapace length for males and 317mm total length = 121.5mm carapace length for females) indicate that males grow larger than females. This results correlates well with the maximum sizes attained in the wild for *P. homarus* in other areas, eg., 127mm carapace length in male and 102mm carapace length in female in South African waters (Berry, 1971b) and 120mm carapace length in male and 90.2mm carapace length in female *P. homarus* in the same region (Smale, 1978). The results of the present study fit very well with the maximum sizes reported for *P. homarus* by Mohamad and George (1968) in Indian waters (312.7mm total length for males and 303.2mm total length for females) and Jayawickrama (1991) (287mm in total length for both sexes) in the west coast of Sri Lanka. Probably the higher ambient sea water temperatures in the Indian region and associated higher metabolic rates may cause this difference from South African waters.

Faster growth rate of male *P. homarus* (**K** = 0.415 yr^{-1} for male and 0.370 yr^{-1} for female) observed during the present study is contradictory to Smale (1978); according to him a fast growth rate was observed in female *P. homarus* in South African waters (**K** = 0.177 yr^{-1} for males and 0.337 yr^{-1} for females). Berry (1971b) working on the growth of *P. homarus* reported growth patterns of both sexes as similar until they reach sexual maturity and afterwards growth was faster in males. Growth rates calculated in the present study from ELEFAN 1 seem to show a better fit (**K** = 0.415 yr^{-1} for male and 0.370 yr^{-1} for female) than those estimates made through the ϕ index ($\mathbf{K}$ = 0.214 yr^{-1} for males and 0.269 yr^{-1} for females) with the high **K** values given by Mohamad and George (1968) where **K** was 0.717 yr^{-1} for males and 0.601 yr^{-1} for females. Considering the strong recommendation of *P. homarus* as a suitable candidate for aquaculture purposes (Smale, 1978) mainly due to its fast growth rate, the comparatively low **K** values estimated through ϕ must be considered a limitation. Consideration of average **K** value of 0.39 yr^{-1} for both sexes of *P. homarus* was also supported by Jayawickrama (1991), where **K** of *P. homarus* of the west coast of Sri Lanka was estimated as 0.43 yr^{-1} for both sexes combined.

Since, not all populations of the Palinuridae are commercially exploited and a very few of the exploited tropical stocks have adequate statistics available, the information on mortality rates in the literature is necessarily sparse. Due to the common problem of inability of determining age of crustaceans, all the available methods of mortality rate estimation rely on some knowledge of length frequency data rather than age. In the present study, the total mortality rate (**Z**) estimates were made using three different methods and they are:

a) Length-converted catch curve technique (Pauly, 1983b, 1984b)

b) using Beverton and Holt method (1956) and

c) substituting **K** value estimated by ϕ index to the **Z/K** estimates obtained by the modified Wetherall plot.

The **Z** values estimated according to the above methods are as follows:

Method	Male	Female
a)	1.966	1.538
b)	1.783	1.364
c)	0.730	1.000

According to the literature, **Z** values for Palinurids range from 0.3 to 2.4 (see Appendix 5.3). When *P. homarus* is concerned, **Z** values show a range from 2.0 - 2.3 (Sanders and Bouhlel, 1984) and 1.04 (Jayawickrama, 1991). It also appears from the results that the **Z** value shows some degree of flexibility depending on the method used in its calculation, and also to the changes in availability from year to year. Such effects of availability could also be age - specific. Although Morgan (1980) described the Beverton and Holt (1956) method as the best method for estimating **Z** , the determination of $\bar{L}$ and L' for entangling type of net (eg. Trammel net) catches seems to be highly questionable. Hence the estimates made based on the catch curve was considered reasonable, and the estimate made from the Beverton and Holt (1956) method treated with reservation. The disadvantages of using the Beverton and Holt (1956) method for spiny lobsters arises from their decreasing vulnerability to capture (by baited traps) with increasing size (Newman, 1972 and Morgan, 1979).

Although there are several methods available to estimate natural mortality (**M**), most of them need some knowledge of age or several years data on **Z** (Rikhter and Efanov, 1976; Sanders, 1977; Sanders and Kedidi, 1983; Munro, 1984). As two years data was used for this analysis, Pauly's empirical formula was used (Pauly, 1980) and **M** was estimated as 0.98 for males and 0.92 for females. These results are in agreement with values estimated for *P. homarus* by Jayawickrama (1991) for *P. homarus* in the west coast of Sri Lanka as 1.04 for both sexes combined. The estimates made on **M** by Sanders and Bouhlel (1984), for *P. homarus* is lower than the present values (**M** = 0.85 for both sexes). This may be attributed to the fact that the mean annual environmental temperature of Sri Lankan waters (28.7°C) is higher than that in Yemen, which has been taken as 20°C - 25°C. Gulland (1969) stated that a fish with a high value of **K** (in the von Bertalanffy growth equation) is likely to have a high **M** and vice versa. High **K** and **M** values observed in this study support such a relationship for *P. homarus*. According to the empirical formula of Pauly (1980), which was used to calculate **M**, a lower estimate of L_{oo} resulted in a higher value of **M**. It is therefore important to note that the selection of a proper value of L_{oo} is extremely necessary when using this formula for mortality estimates. The available literature on natural mortality estimates for *P. homarus* is sparse and the results given by Sanders and Bouhlel (1984) are also based on the above two methods. Natural mortality estimates available in the literature for other Palinurids indicate a range from 0.92 - 2.10,(see Appendix 5.3). It is also important to note that the estimates made on natural mortality may arise due to changes in the catchability coefficient, or otherwise, they may be due to age specific changes in natural mortality. It should also be noted that the application of both the Pauly's formula and (Pauly, 1980) and Rikhter and Efanov (1976) method for estimation of natural mortality is not strictly correct as they were originally developed for fish populations. According to Sanders and Bouhlel (1984), estimates based on these methods should be treated with reservation.

Figs.5.9 & 5.10 shows the recruitment patterns obtained by means of ELEFAN 11 software package. This shows a continuous pattern of recruitment with two peaks. The second recruitment peak seems to be high in magnitude in both males and females and contributes significantly to the total recruitment. Although it is impossible to correlate these peaks with exact months of the year, it can be presumed that these pulses should show some sort of relationship with the two monsoons. It is also important to note the overall agreement of shapes with the availability of spawning females (Fig.3.5) suggestive of two spawning seasons. It has to be noted that in recruitment patterns the absolute time scale of recruitment is unknown (Pauly and Ingles, 1981). According to some researchers, this method suggests useful information from which legitimate inferences on the dynamics of fish and invertebrate stocks can be drawn (Pauly and Navaluna, 1983).

The survival rates of *P. homarus* estimated in the present study (0.140

for males and 0.215 for females) seem to be very low and reflect the high total mortality values exerted by the fishery. The exploitation rates estimated during the study period were 0.502 for males and 0.402 for females and indicate considerably high exploitation pattern of the resource. These results are also in agreement with the results obtained from Schaefer's surplus production model Schaefer (1954), which indicated that a reduction of 15 fishing craft from the study area is necessary to maintain the MSY level. As the surplus production model was applied only for a few years of data, the results from exploitation rate seems to be much more reliable.

The VPA 11 results shown in the Tables 5.2a, 5.2b and Fig. 5.13 indicate that the population size is considerably reduced from 160 - 170 mm length class onwards to which high fishing mortality is exerted. The results further indicate that when compared to the existing spiny lobster regulations in Sri Lanka, (minimum legal length = 218.2 mm total length), 78.51% of the total production could be considered as illegal. The "yield-per-recruit curve" often has a maximum the " maximum sustainable yield" for the age or size at entry used. The yields are " sustainable", because higher yields can be obtained only temporarily by a sudden increase of effort (Sparre et al., 1989). According to the Figure 5.14, MSY can be obtained for an exploitation rate of 0.338 ($\mathbf{E}_{max}$ = 0.388). The present **E** of 0.50 for both sexes combined is in the descending arm of the yield-per-recruit curve and is almost 25% higher than the level it should be to obtain the maximum yield-per-recruit. This curve suggests that a reduction of the exploitation level from 0.5 to 0.388 (or reduction of **F** from 0.88 to 0.77) will increase the yield-per-recruit resulting in a higher production.

"Compleat ELEFAN" version 1.11 (Gayanilo et al., 1989; which has been used for the estimation of growth parameters of *P. homarus* in the south coast, is an improved version in which the issues raised at an international conference on the theory and application of length based methods for stock assessment have been incorporated. As such, erroneous results due to the weakness of ELEFAN technique are very unlikely. Pauly (1986c) warned that the application of ELEFAN technique should be done after checking whether the assumptions behind the method are met. In the present study, when analysis of length frequency data of *P. homarus*, these aspects were taken into consideration.

5.11 Chapter summary.

The length-weight relationship of *P. homarus* for the total population is in the form of **W = 0.0712 L** $^{2.817}$ and agreeable with the general pattern of **W** = aL^b where 'b' mostly varies between 2 - 4. Observations were made on the condition factor for 24 consecutive monthly samples for both sexes, and the results indicate a clear increase during July to December, which are the pre-spawning to spawning period for majority of lobsters.

The growth of *P. homarus* is high and shows values of **K** ranging from 0.370 - 0.415 yr^{-1}. An estimate of asymptotic length was made by two different methods and the final value was approximated to 327 mm for males and 317 mm for females in total length.

The total mortality coefficients ranged from 1.538 - 1.996 while that of natural mortality ranged from 0.92 - 0.98 for males and females respectively. Knowing the values of fishing and total mortality exerted on the fishery, an estimate of 0.5 for the exploitation rate was calculated for both sexes. Survival rates of *P.homarus* was very low (0.14 for males and 0.215 for females) and reflects the high total mortality of the fishery.

The total population size was estimated using the virtual population analysis method as 4047.71 x 10^3, with the majority represented by small length classes. The low numbers in larger size groups may be due to the high fishing pressure exerted on them (F = 0.50 - 0.66) and in addition to their high natural mortality. It was also found that a reduction of the present fishing effort by about 20.5% is required to put back the fishery to an equilibrium level.

The results of the yield per recruit analysis and the high exploitation rates estimated suggest the need for a proper management strategy for the sustainable utilization of this resource.

CHAPTER 6

6. Co-occurring *Panulirus* species.

6.1 Introduction.

As a tropical country lying close to the equator, the coasts of Sri Lanka represent an important biological margin of the south-Indian ocean and offer an exceptionally wide range of coastal environmental conditions related to monsoons and associated current circulations. The coastal waters of southern Sri Lanka are influenced by the Indian south-west monsoonal current, Indian north-west monsoonal current, circulations of the Bay of Bengal, the entry of numerous rivers to the sea, a number of estuarine systems representing important nursery areas and pronounced seasonal fluctuations due to south-west monsoon.

The occurrence of spiny lobsters in Sri Lankan coastal waters has been recorded for some time (De Bruin, 1962). Apart from the basic habitat investigations carried out by De Bruin (1969), no proper ecological study has been conducted. Considerable research on the distribution of clawed lobsters and the factors affecting their catchability has been carried out in European waters (Jensen, 1967; Atkinson, 1974; Farmer, 1974; Chapman, 1979; Bagge and Munch-Petersen, 1979 and Howard, 1982). The distribution and ecology of Indo-Pacific spiny lobsters has been studied by George (1968, 1974), De Bruin (1969), Heydorn (1971) and Batia (1974). George concluded that oceanic spiny lobsters (*Panulirus* *penicillatus*) required "clean" oceanic waters uncontaminated by land run-off. He noted that the coral spiny lobsters, *P. longipes* and *P. versicolor* inhabit waters where little or no land detrital run-off occurs. By comparison, he observed that the continental spiny lobsters, *P. ornatus, P. polyphagus* and *P. homarus* occur in coastal regions where water quality is dominated by land climatic conditions.

Along with *P. homarus* five other species belonging to the genus *Panulirus* have been recorded from Sri Lankan waters. They are *P. longipes, P. penicillatus, P. ornatus, P. versicolor* and *P. polyphagus* (De Bruin, 1962)(Fig. 6.1a - 6.1e). Of the six species, De Bruin (1969) recorded only three species (*P. homarus, P. versicolor* and *P. ornatus*) from the south coast but Jayakody and Kensler (1986) recorded all six species (Fig. 6.1a to 6.1e). The fluctuating pattern of rainfall, air temperature, sea water temperature, turbidity and the nature of the sea bed of the area where commercial fishery takes place are discussed in Capter 4.

All six species of spiny lobster mentioned above are captured by the fishermen and their species composition was discussed in chapter 4.9. The presence of the six species of spiny lobsters in the study area suggests that along this coast suitable habitats are available for all these species. The distributional pattern and the preferred habitats of spiny lobsters (Palinuridae) in the south coast is considered in this chapter in relation to environmental parameters which appear to limit their distribution.

6.2 Other *Panulirus* species

P. homarus has been described in detail in Chapter 1 and the descriptions of the other five species are given below.

6.2.1 *Panulirus longipes* (A. Milne Edwards 1868) (Fig. 6.1a).

In early literature this species has been referred as *Panulirus japonicus* by some workers (Barnard, 1950; De Bruin, 1962). According to George (1958), *P. longipes* has two colour patterns, namely "Red" and "White". George and Holthuis (1965) in their revision of the *P. japonicus* group have shown that the specimen referred to by Barnard (1950) was the spotted legged subspecies, *P. longipes longipes*. Considering the wide geographical distribution of *P. longipes*, George (1968), concluded this species as the second most abundant spiny lobster species in the Indo-Pacific region. It occurs seasonally in Western Australian waters during November and December and shows no extensive migration (Bell, Channells, Mac Farlane, Moore and Phillips, 1987). In Natal waters of South Africa, this species was found to be abundant on offshore reef areas where it was recorded up to a depth of 18m (Berry, 1971a). This species prefers clear water but can tolerate slightly turbid conditions and inhabits protected areas not subjected to strong wave action (Berry, 1971a; Batia, 1974). This species contributes considerably to the total lobster catch in some parts of the south coast of Sri Lanka (Galle area) (Fig. 2.1), but as far as the study area as a whole is concerned it's contribution ranged from 2.3 - 6.4% (see section 4.5).

6.2.2 *Panulirus penicillatus* (Oliver 1791) (Fig. 6.1b).

This is the most widely distributed member of the genus *Panulirus* and occurs from the Red Sea (30^0 E) to the Galapagos islands (90^0 W) (George, 1968). *P. penicillatus* is characterised by the antennular somites armed with four spines; a semicircular blue patch at the base of the second antennae; cephalothorax with a anterior spiny region and posterior relatively unarmed area. The walking legs are dark olive green in colour with pale yellow stripes running along their length. Their abdominal segments are transversely grooved and these grooves are uninterrupted on all six somites.

This species has been reported from a wide range of habitats such as reefs and rocky reef fronts (De Bruin, 1962; Berry, 1971a) seaward reef edges (George, 1968) and rocky areas devoid of corals (Charbonnier and Crosnier, 1961) at very shallow depths (1 - 4m). According to Charbonnier and Crosnier (1961), *P. penicillatus* in Madagascar waters contributes considerably to the commercial fishery along with *P. homarus*.

Fig. 6.1a Panulirus longipes

Fig. 6.1b Panulirus penicillatus

P. penicillatus bear extremely robust legs which are thought to be an adaptation for clinging to rocks in turbulent waters (Berry, 1971a). In Thai waters it is the biggest among all spiny lobsters and inhabits rocky habitats at 1 - 10m depths with strong turbulence (Batia, 1974). This species has also been recorded from northern Zululand and southern Mozambique coasts occurring on reef in the surf zone. According to Jayakody and Kensler (1986), it's contribution to the total spiny lobster production of the south coast of Sri Lanka was around 4%. The present study indicated that it's contribution ranged from 3.1 -16.6% depending on the locations.

6.2.3 *Panulirus ornatus* (Fabricius 1798) (Fig. 6.1c).

P. ornatus has been recorded for several countries of the Indo-Pacific region, namely India, Sri Lanka, Maldives, Thailand, Papua New Guinea, Australia and South Africa. It's occurrence in the Indian region has been documented by, Chopra (1939) and Prem-Kumar and Daniel (1975). According to Prem-Kumar and Daniel (1975), it contributes to a lucrative fishery in south east coast of India during December to April. In the African region, specially in east African waters, it contributes to the bulk of the spiny lobster production (Hall, 1960). The occurrence of the large number of puerulus stage of *P. ornatus* in South African waters has also been recorded by Berry (1971a). *P. ornatus* has been recorded from coral reefs (Charbonnier and Crosnier, 1961) and among rock piles on muddy or sandy substratum at depths up to 2m (George, 1968) or sometimes down to 8m under turbid conditions (Berry, 1971a). In the waters of Papua New Guinea, mating and oviposition of *P. ornatus* takes place during the period of migration (Mac Farlane and Moore, 1986). According to them there is a marked segregation of sexes after migration where males enter shallow waters (< 3m) and females prefer deeper waters (3-15m). In Sri Lanka among spiny lobsters, *P. ornatus* dominates the northern coast (De Bruin, 1962). According to Jayakody and Kensler (1986), *P. ornatus* grows to the largest size of the six species and the recorded maximum size was 42.4 cm in total length. It's contribution to the total lobster production of the south coast was around 4%(Jayakody and Kensler, 1986). According to the present study it's contribution ranged from 2.3 - 9.3% depending on the sampling area (see section 4.5).

6.2.4 *Panulirus versicolor* (Latrielle 1804) (Fig. 6.1d).

This species was recorded originally by Latrielle (1804) under the genus *Palinurus*, includes the synonym *Palinurus fasciatus* De Haan (1841) and *Panulirus ornatus taeniatus* Gruvel (1911). De Man (1916), working on the decapoda of the Siboga Expedition included this species under *Panulirus versicolor*. It is one of the rare species along the Indian coast (Chhapgar and Deshmukh, 1961; Prem-Kumar and Daniel, 1975). It occurs from October to February along the west coast of India and

Fig. 6.1c Panulirus ornatus

Fig. 6.1d Panulirus versicolor

during February to April in the Andaman and Nicobar group of islands. It is a rare species on the coasts of South Africa (Berry, 1971a), but contributes considerably to the fishery around Adong and Muk islands in Thai waters (Batia, 1974). *P. versicolor* is readily distinguished by the characteristic colour pattern of the carapace and the pink base of the antennae.

This species has been previously recorded from rocky slopes (Berry, 1971a), on substrates of fine sediments (George, 1968) and from coral reefs (Batia, 1974) at depths of 3 - 6m (Berry, 1971a) or beyond (De Bruin, 1962). The size at first maturity has been estimated by George and Morgan (1979) using the intersect analysis and according to them males attain sexual maturity at a larger size than females. According to De Bruin (1962), this species is extremely gregarious and never enter lobster traps. During the day time it inhabits 6 - 10m depths and migrates shorewards to a depth of around 1m during night time (Batia, 1974). According to Jayakody and Kensler (1986), it's contribution towards south coast spiny lobster production was around 4%. The present study revealed that it's contribution is around 3.1 - 6.6% to the total spiny lobster production.

6.2.5 *Panulirus polyphagus* (Herbst 1793) (Fig. 6.1e).

This species has been frequently referred to as *Panulirus fasciatus*

Fig.6.1e Panulirus polyphagus

(Fabr.). It occurs all along the north-west and north-east coast of India, Sri Lanka, Thailand, South Africa, Mauritius, Gulf of Aden, Baluchistan, Malacca Strait and Singapore. According to Chhapgar and Deshmukh (1961), *P. polyphagus* constitutes 99% of the total spiny lobster production of the Bombay area in India. Unlike other species of spiny lobsters, *P. polyphagus* is found only in habitats with muddy bottom (De Bruin, 1962; Rongmuangsart and Luvira, 1973). In Thai waters, this species is caught in small numbers throughout the year with a peak during the south-west monsoon period (May - September). According to De Bruin (1962), *P. polyphagus* is not found in any other parts of Sri Lanka except the north-east coast. Jayakody and Kensler (1986), recorded this species from the south coast of Sri Lanka, but according to them it's contribution to the commercial fishery is almost negligible. The present study shows that it contributes around 2% to the total spiny lobster production of the study area (see section 4.5).

6.3 Experimental fishing.

Twenty five experimental fishing operations were carried out during 1st November - 31st December 1990 period. During these operations the entire study area was covered and three net types were tested for the catchability of spiny lobsters. Environmental parameters such as sea water turbidity, salinity and the sea water temperature were measured to examine their relationship to the availability of spiny lobsters and are discussed in chapter 4.

6.3.1 Results of the fishing trials

The results of the twenty five experimental fishing operations conducted during 1st November to 31st December 1990 are given in Table 6.1. The length distribution of *P. homarus* caught during the experimental fishing operations by each gear type is given in Table 6.2. The results indicate that around 82% of the trammel net catch consisted of undersized lobsters. The median total lengths of the lobster catches caught by the three different gears indicated that the lobster ring is the only gear that catch low percentage of sub-legal lobsters (Fig. 6.2). The experimental fishing trials revealed the abundance of *P. homarus* in shallow depth ranges. The occurrence of high abundance in A1 -E1 blocks (Fig. 6.3) indicated the shallow water nature of this species. The results of the one-way ANOVA for the availability of *P. homarus* in different depth ranges, turbidity levels, and in different oxygen concentrations observed during the experimental fishing period are also included in Tables 6.3, 6.4 and 6.5. The results show that there is a significant correlation between the availability of *P. homarus* with depth ($P < 0.001$) and turbidity ($P < 0.05$) but no correlation was observed for different levels of oxygen. The one-way ANOVA done for the availability of berried females in different depth ranges indicated that the abundance in the 0 - 10.0m depth range is significantly different from the other two depth

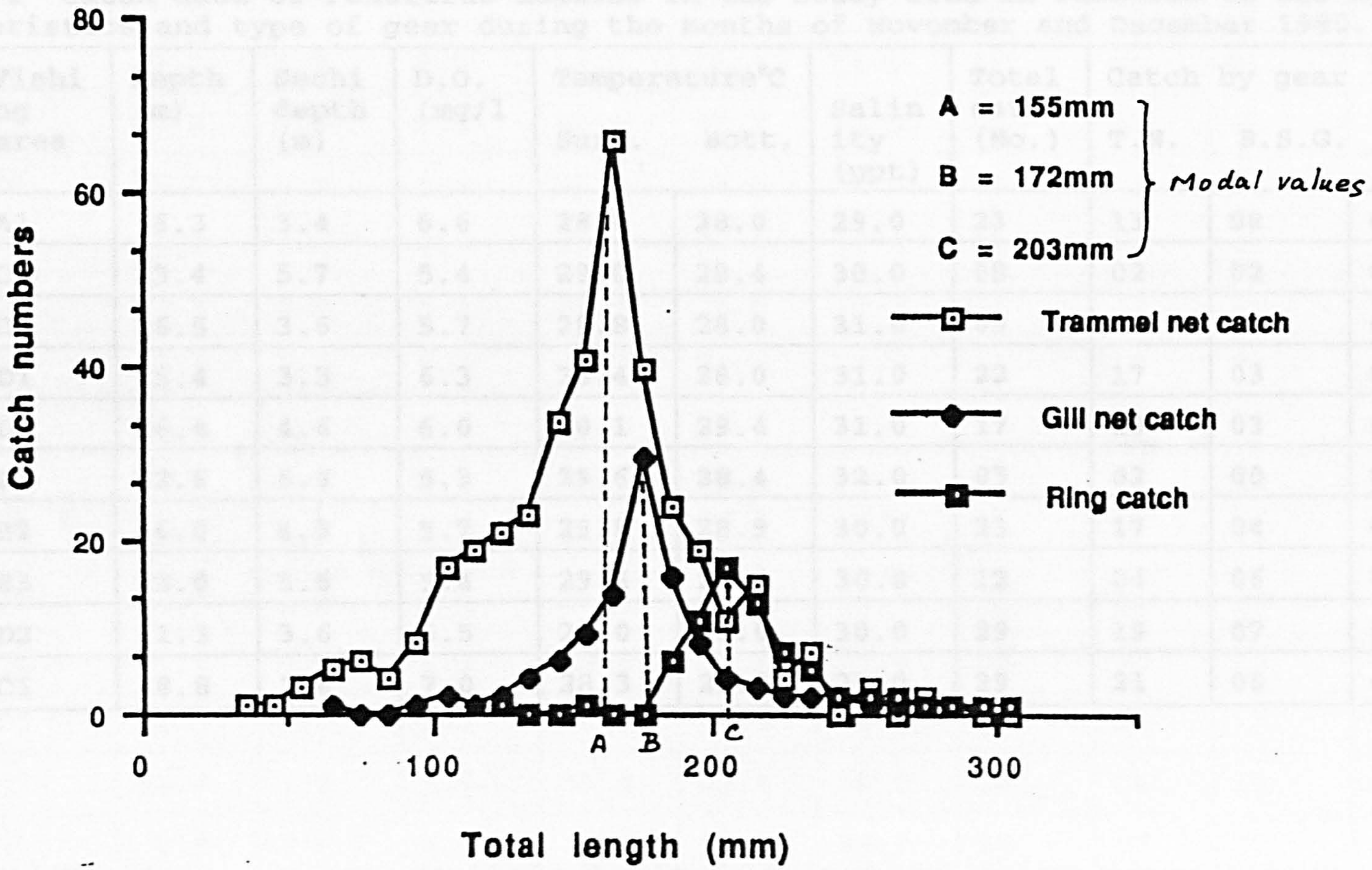


Fig. 6.2 Size composition of *Panulirus homarus* caught in different net types during the experimental fishing operations.

Table.6.1 Catch data of *Panulirus homarus* in the study area in relation to the hydrological characteristics and type of gear during the months of November and December 1990.

Operational day	Fishing area	Depth (m)	Sechi depth (m)	D.O. (mg/l	Temperature°C Surf.	Bott.	Salinity (ppt)	Total catch (No.)	Catch by gear (No.) T.N.	B.S.G.	L.R.	No. berried
01	A1	6.3	3.4	6.6	28.6	28.0	29.0	23	13	08	02	02
02	C3	23.4	5.7	5.4	29.0	28.4	30.0	08	02	02	04	01
03	C2	16.5	3.6	5.7	28.8	28.0	31.0	09	06	02	01	01
04	D1	5.4	3.3	6.3	28.4	28.0	31.0	22	17	03	02	03
05	D2	16.4	4.6	6.0	30.1	29.4	31.0	17	10	03	04	02
06	D3	22.6	5.6	5.3	29.6	28.4	32.0	03	02	00	01	02
07	E2	16.0	4.9	5.7	29.8	28.9	30.0	23	17	04	02	04
08	E3	28.0	5.6	5.4	29.3	28.5	30.0	12	04	06	02	01
09	D2	11.3	3.6	5.5	29.0	28.6	30.0	29	19	07	03	03
10	C1	8.8	2.6	7.0	28.3	28.0	29.0	29	21	06	02	02

Table 6.1 contd.

11	B1	6.5	2.5	6.8	29.0	28.6	29.0	27	24	02	01	04
12	A2	13.3	3.0	6.0	29.0	28.7	29.0	18	07	07	04	03
13	A3	26.5	4.6	5.5	30.0	28.6	33.0	03	02	01	00	01
14	B3	27.1	5.1	5.9	30.2	28.9	31.0	05	02	02	01	01
15	B2	14.4	4.6	5.9	29.6	28.6	30.0	22	14	06	02	02
16	C2	17.6	4.6	6.1	29.1	29.0	30.0	20	19	00	01	02
17	D1	5.8	3.0	6.7	29.0	28.6	28.0	25	18	04	03	03
18	E1	6.9	3.3	6.1	29.1	29.0	28.0	36	27	04	05	04
19	E1	8.4	4.0	5.9	29.6	29.2	30.0	52	41	05	06	07
20	E2	16.3	4.6	5.8	30.0	29.0	30.0	21	16	04	01	02
21	C1	6.7	3.3	6.2	28.6	28.0	28.0	36	24	08	04	04
22	B2	17.6	4.6	6.1	30.0	29.1	30.0	05	01	03	01	00
23	B1	3.3	3.0	5.9	30.3	30.0	28.0	46	29	13	04	04
24	A2	16.6	4.6	5.8	30.6	29.4	29.0	18	14	02	02	00
25	A1	8.9	3.6	6.2	30.1	29.0	30.0	36	26	07	03	02

D.O. - Dissolved oxygen T.N. - Trammel net B.S.G. - Bottom set gill net L.R. - Lobster ring ranges (Table 6.6). Based on the sea bottom observations made during the experimental fishing, the nature of the sea bottom of the study area was mapped and is shown in Figure 6.3. It shows extensive sand stone reef in shallow waters (< 10m) lying parrel to the coast line. Based on the results obtained during the experimental fishing survey along with the experience gained during two year sampling programme, the species distribution of the study area was mapped and is shown in Fig. 6.4.

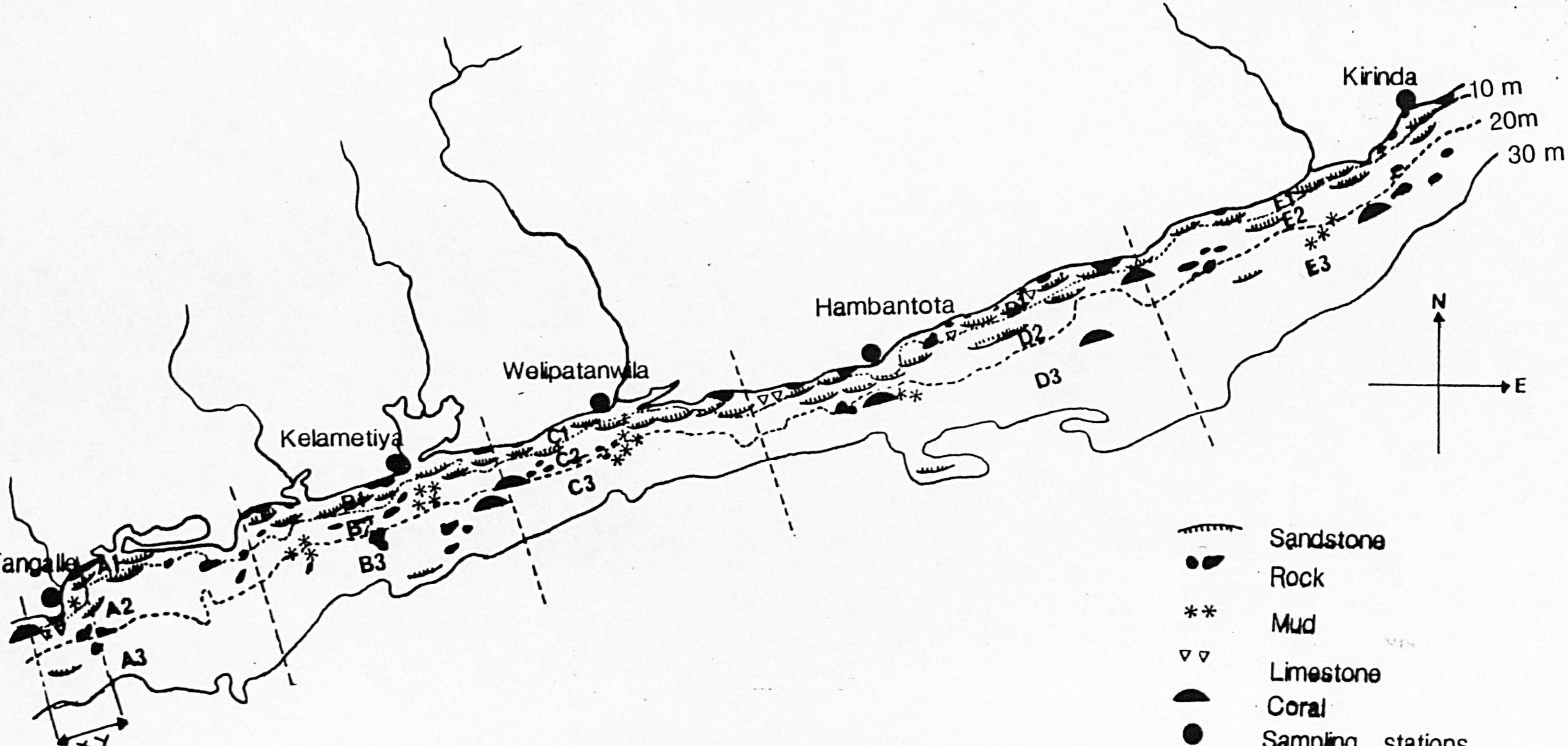


Fig. 6.3 **Map of the study area showing the sub-littoral topography and related information.**

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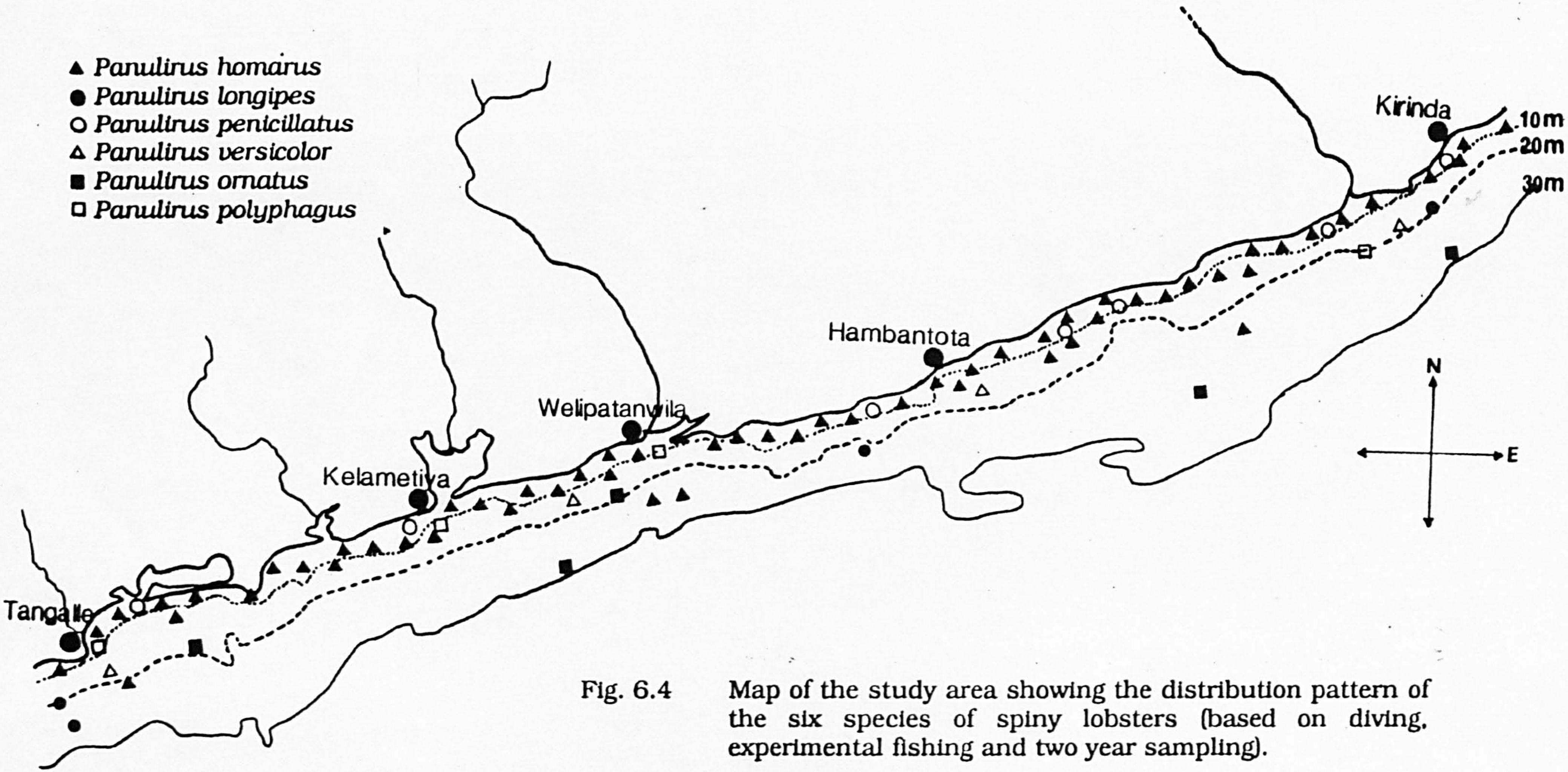

Fig. 6.4 Map of the study area showing the distribution pattern of the six species of spiny lobsters (based on diving, experimental fishing and two year sampling).

Table. 6.2 Length distribution of *Panulirus homarus* caught during experimental fishing operations.

(Total length) Mid length (mm)	Gear type: Trammel net	Gear type: Bottom set gill net	Gear type: Lobster ring
35	1.00		
45	1.00		
55	3.00		
65	5.00	1.00	
75	6.00	0.00	
85	4.00	0.00	
95	8.00	1.00	
105	17.00	2.00	
115	19.00	1.00	
125	21.00	2.00	1.00
135	23.00	4.00	0.00
145	34.00	6.00	0.00
155	41.00	9.00	1.00
165	66.00	14.00	0.00
175	40.00	30.00	0.00
185	24.00	16.00	6.00
195	19.00	8.00	11.00
205	11.00	4.00	17.00
215	15.00	3.00	13.00
225	4.00	2.00	7.00
235	7.00	2.00	5.00
245	0.00	2.00	2.00
255	3.00	1.00	2.00
265	0.00	1.00	2.00
275	2.00	0.00	1.00
285	1.00		1.00
295			1.00
305			1.00
Total	375.00	109.00	71.0

Table 6.3 Catch in numbers of *Panulirus homarus* for different depth ranges in twenty five fishing trials.

Catch in numbers		
0 - 10m depth	**11 - 20m depth**	**21 - 30m depth**
23	09	03
22	17	12
29	23	03
27	29	05
25	22	08
36	18	
52	20	
36	21	
46	05	
36	18	

Summary of Analysis of Variance for occurrence of *Panulirus homarus* at three different depth ranges.

Source of variation	Sums of squares	d.f.	Mean squares	F	P
Between groups	2446.00	02	1323.00	21.12	<0.001
Within groups	1378.00	22	62.63		
Total	4024.00	24			

Multiple range analysis for depth ranges.

Method: 95% confidence intervals

Depth range	Count	Average	Homogeneous groups
21 - 30m	5	0.800	*
11 - 20m	10	1.700	* *
00 - 10m	11	3.364	*

Table 6.4 Catch numbers of *Panulirus homarus* for different levels of turbidity.

Turbidity level (Sechi depth)		
2 - 3.4m	**3.5 - 4.9m**	**5.0 - 6.4m**
23	09	08
22	17	03
29	23	12
27	29	05
18	03	
25	22	
36	20	
36	52	
46	21	
	05	
	18	
	36	

Summary of Analysis of Variance for catch numbers of *Panulirus homarus* at three different turbidity levels.

Source of variation	Sums of squares	d.f.	M.S.	F.	P.
Between groups	1360.86	02	680.43	5.621	< 0.05
Within groups	2663.14	22	121.05		
Total	4024.00	24			

Multiple range analysis for turbidity ranges.

Method: 95% confidence intervals

Sechi depth	Count	Average	Homogeneous groups
5.0 - 6.4m	4	7.00	*
3.5 - 4.9m	12	21.25	* *
2.0 - 3.4m	9	29.11	*

Table 6.5 Catch numbers of *Panulirus homarus* for different levels of dissolved oxygen.

Dissolved oxygen level (mg/l)	
5.0 - 6.0	**6.1 - 7.0**
08	23
09	22
17	29
03	27
23	20
12	25
29	36
18	36
03	05
05	36
22	
52	
21	
46	
18	

Summary of Analysis of Variance for catch numbers of *P. homarus* at two levels of dissolved oxygen.

Source of variation	S.S.	d.f.	M.S.	F.	P.
Between groups	280.17	01	280.17	1.721	>.05
Within groups	3743.83	23	162.78		
Total	4024.00	24			

Multiple range analysis for dissolved oxygen ranges.

Method: 95% confidence intervals.

D.O. level	Count	Average	Homogeneous groups
5.0-6.0 mg/l	15	19.067	*
6.1-7.0 mg/l	10	25.900	*

Table 6.6 Catch numbers of berried females of *Panulirus homarus* in different depth ranges.

Depth range (m)		
0.0 - 10.0	11.0 - 20.0	21.0 - 30.0
02	01	01
03	02	02
02	04	01
04	00	01
03	03	01
04	02	
07	02	
04	02	
04	00	
02	00	

Summary of the Analysis of Variance for catch numbers of berried females of *Panulirus homarus* at three different depth ranges.

Source of variation	S.S.	d.f.	M.S.	F.	P.
Between groups	25.340	02	12.670	7.394	<.05
Within groups	37.700	22	1.714		
Total	63.040	24			

Multiple range analysis for berried females at different depth ranges.

Method: 95% confidence intervals

Depth range	Count	Average	Homogeneous groups
21-30m	05	1.20	*
11-20m	10	1.60	*
00-10m	10	3.50	*

6.4 Habitat investigations

6.4.1 Diving site

The reef area lying beyond and south of Tangalle harbour (6^0 01' N - 80^0 47' E) with an average depth of 10m was chosen for detailed observations as it consists of several different habitats(Fig. 6.3 - XY area). The chosen study site has a surface area of 4 km^2 and consisted of several different habitats inhabited by lobsters. This area contains coral reef, lime stone reef, sand stone reef and rocky bottom places interspersed with patches of sand and rock rubbles. The main habitat features of the reefs are the reeftops, reef face (reef fronts), caves and ledges. Immediately before the reef front is the surf zone where the wave break takes place. The reef area west of Tangalle harbour is between 200 to 500m from the shore and the reef mainly consists of fine or coarse sand. The landward edge of the reef rises steeply to a height of around 3m from the sea bottom and lies 0.5 - 1.0m under water at high tide. At low tide the reef is uncovered at some places. Near this edge of the reef are found scattered boulders of dead and live coral. The reef front generally slopes seawards, forming almost a plateau for a distance of around 1000m. The first 20 - 50m of this plateau is covered by rock but the main plateau itself is sandstone and is characterised by pot-holes apparently formed by the action of sea-urchins and star fish species. Many places of the plateau are about 1.5 - 2.0m in depth from the sea surface after which there is a steep drop to 3 - 5m. The sea bottom here is deeply fissured granite rock with scattered coral outgrowths. This type of rocky bottom extends from the edge of the plateau to about 1 Km seawards after which the sea bottom consists of fine sand and some places with silty mud. Many places of the reef area are covered by sea grass types (eg. *Sargassum* sp., *Hypnea* sp. and *Ulva* sp.). The occurrence of these algal types along the coast line of Sri Lanka has been listed by Durairatnam (1961).

6.4.2 Results of the diving operations.

The number in each species of spiny lobsters caught in 25 diving operations conducted during 1st November -31st December period is listed in Appendix 6.1. Based on the data in Appendix 6.1, Table 6.7 was prepared and it shows the habitat preference by the six species of the genus *Panulirus*.

Fig. 6.5 is based on the observations made during the diving operations to show the exact habitat and the distribution pattern of the six species of spiny lobsters.

In the selected area, *P. homarus* was mostly found in the dens/caves or crevices of sand stone reefs at a depth of 2 - 10 m (Fig. 6.5a). A few were recorded in deep waters up to a maximum depth of 25m. A lesser percentages were recorded in lime stone reefs and fewer from rocky

Table. 6.7 Number of *Panulirus homarus* collected from various sea bottom types in the study area by 25 diving operations.

Species	Coral	Sand stone	Lime stone	Rocky bottom	Muddy bottom
P. homarus	04	146	74	11	01
P. longipes	17	00	11	06	00
P. penicillatus	01	07	01	44	00
P. ornatus	03	01	02	01	06
P. versicolor	11	02	02	01	00
P. polyphagus	00	01	01	00	03
Total	36	157	91	63	10

bottom, coral reef and muddy bottom areas. During the day time operations it was observed that *P. homarus* is mostly hidden in dens, crevices and caves with antennae projecting outside. During most diving operations *P. homarus* was observed in single, but when in groups, they were usually different in sizes, ranging from 83 - 268mm in total length. Five groups of *P. homarus* were observed in a total of 25 diving operations and these groups consisted of 3, 3, 5, 4 and 3 individuals.

No evidence was found of discrete dens beyond 30m depth. 90% of the dens/caves and crevices were concentrated in the 0 - 10m depth range. On many occasions, density of the hiding places showed a decrease with increasing depth. The density of the dens/caves and crevices ranged from 1 - 3 m^2. In the vicinity of the sand stone areas there were many small burrows which provided shelter for 7 - 12 different types of fish species. *Perna perna* and tubes of Nereid worms were observed in association with the hiding places of *P. homarus*.

P. longipes was mostly observed in association with dead coral formations. Few individuals were recorded in sand stone and rocky bottom areas and none in muddy bottom places. All specimens were observed at night time, hence this could be considered as a highly nocturnal species. During most of the diving operations, this species was observed on the sea-ward side of the coral reef at a depth of 6 - 16m (Fig. 6.5b).

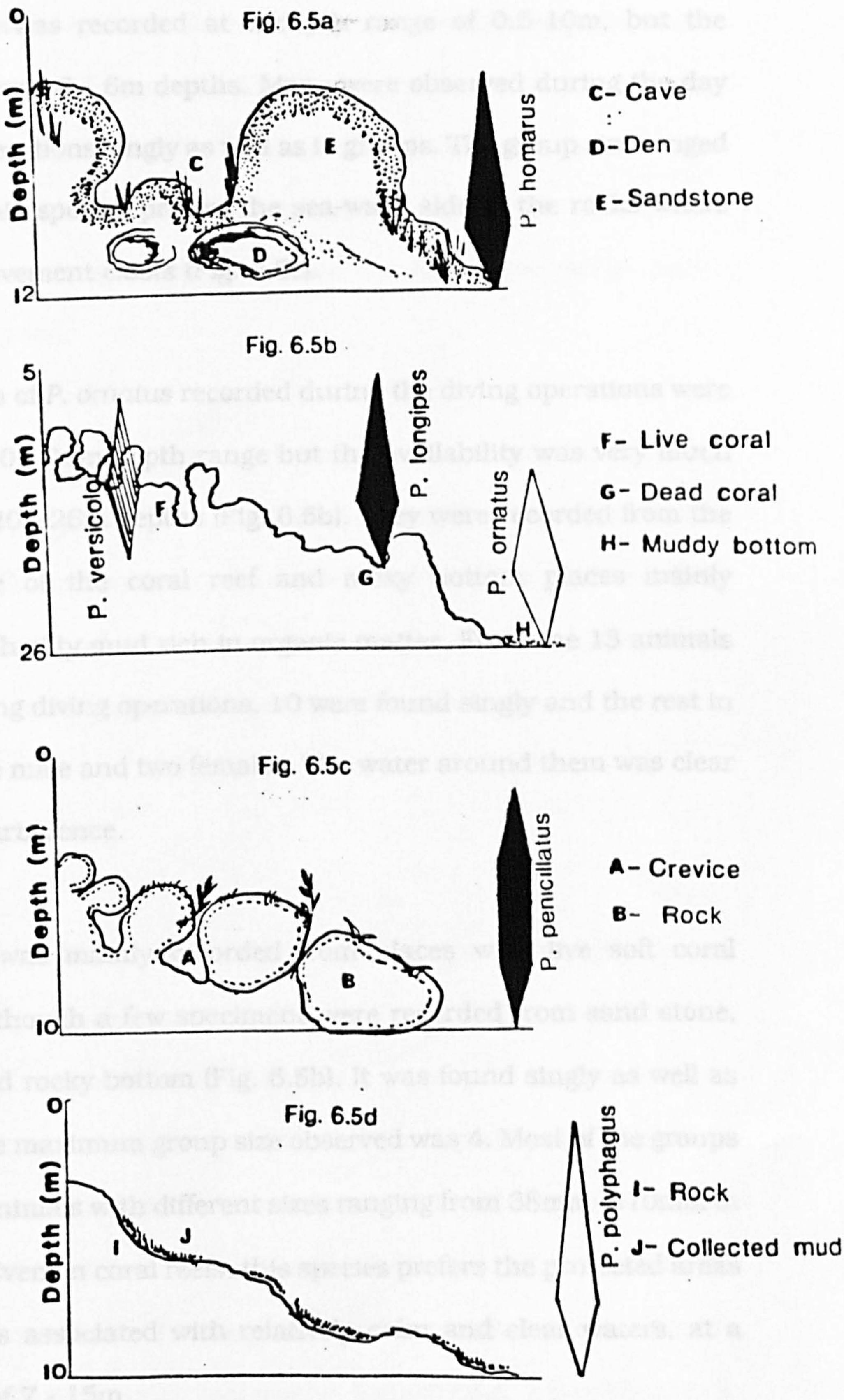

Fig. 6.5 **Schematic diagram showing main habitat features in the diving area at Tangalle.**

P. penicillatus was recorded at a depth range of 0.5-10m, but the majority preferred 3 - 6m depths. Many were observed during the day time diving operations singly as well as in groups. The group size ranged from 2 - 4. This species prefers the sea-ward side of the rocks where high water movement exists (Fig. 6.5c).

The specimens of *P. ornatus* recorded during the diving operations were restricted to 10 - 26m depth range but the availability was very much less between 20 - 26m depths (Fig. 6.5b). They were recorded from the sea-ward side of the coral reef and rocky bottom places mainly associated with silty mud rich in organic matter. From the 13 animals collected during diving operations, 10 were found singly and the rest in a group of one male and two females. The water around them was clear and of high turbulence.

P. versicolor was mainly recorded from places with live soft coral formations although a few specimens were recorded from sand stone, lime stone and rocky bottom (Fig. 6.5b). It was found singly as well as in groups. The maximum group size observed was 4. Most of the groups consisted of animals with different sizes ranging from 38mm -210mm in total length. Even on coral reefs, this species prefers the protected areas such as caves associated with relatively calm and clear waters, at a depth range of 7 - 15m.

P. polyphagus was the least observed species during diving operations hence considered as the rarest. All specimens were restricted to muddy bottom places associated with high concentrations of organic matter (Fig. 6.5d). They were recorded at a depth range of 0.5 - 10m. Two specimens were recorded from sand stone and lime stone reef places at depths of 6 and 9m.

Table 6.8 was prepared based on the results of both diving and experimental fishing operations conducted during the survey period. The results indicate the occurrence of the six *Panulirus* species, their preferred habitats and environmental parameters, which summarises the position of each species in the study site.

6.4.3 Analysis of data

The data in the Table 6.7 was analysed by using two-way ANOVA and the results are presented in Table. 6.9. The results show that there is a highly significant interaction ($P < 0.001$) between the species and the habitats. The mean plot based on the data in Appendix 6.1 is given in Fig. 6.6. It shows that sand stone reef and lime stone reef areas are highly preferred by *P. homarus* and rocky bottoms by *P. penicillatus* as found in high numbers. *P. longipes* and *P. versicolor* and *P. ornatus* prefer coral reefs and muddy bottoms respectively but this preference is not markedly indicated as in the case of *P. homarus* and *P. penicillatus*.

Table. 6.8 Habitat preference of different *Panulirus* species of the study area.

	Species					
Environmental factor	**A**	**B**	**C**	**D**	**E**	**F**
Sand stone	+++++	+	+	++	+	-
Lime stone	+	+	+	-	+	-
Rocky bottom	+	+	+++	+	+	-
Muddy bottom	+	-	-	+	-	+++++
Live coral	+	+	+	++	+++++	-
Dead coral	+	++	+	+++	+	-
High turbulence	+++	+	+++++	+	-	-
Low turbulence	++++	+++	+	++	++++	+
High turbidity	++++	+	++++	+++	+	++++
Low turbidity	+	++++	+	+++	++++	+
High salinity	++	++++	++	++++	++++	++
Low salinity	+++	+	+++	+	+	+++
Shallow waters	++++	+	++++	+	+++	++++
Deep waters	+	++++	+	++++	++	+
High oxygen	+++	+++	++++	+++	+++	++
Low oxygen	++	++	+	++	++	+++
Total + points	37	30	34	31	35	26
Total - points	00	01	01	01	02	06

(more + points indicates increasing tendency of occurrence in the factor considered)

A - *P. homarus* B - *P. longipes* C - *P. penicillatus*
D - *P. ornatus* E - *P. versicolor* F - *P. polyphagus*

Table 6.9 Summary of analysis of variance (two-way) for catch numbers of different species of the genus *Panulirus* given in Table 6.7

Source of	S.S.	d.f.	M.S.	F.	P.
Main effects	1978.90	9	219.81	94.91	<0.001
Habitats	426.84	4	106.71	46.06	<0.001
Species	1552.06	5	310.41	133.99	<0.001
2-factor interactions	3078.44	20	153.92	66.44	<0.001
Habitat species	3078.44	20	153.92	66.44	<0.001
Residuals	278.00	120	2.32		
Total (corr.)	5335.34	149			

Results of multiple range analysis for catch numbers by habitats.

Method: 95% confidence intervals

Habitat	Count	Average	Homogeneous groups
Mud	30	0.333	*
Coral	30	1.200	* *
Rock	30	2.100	* *
Lime	30	3.033	*
Sand	30	5.233	*

Results of the multiple range analysis for catch numbers by species.

Method: 95% confidence intervals

Species	Count	Average	Homogeneous groups
P. polyphagus	25	0.200	*
P. ornatus	25	0.520	* *
P. versicolor	25	0.640	* *
P. longipes	25	1.440	* *
P. penicillatus	25	2.040	*
P. homarus	25	9.440	*

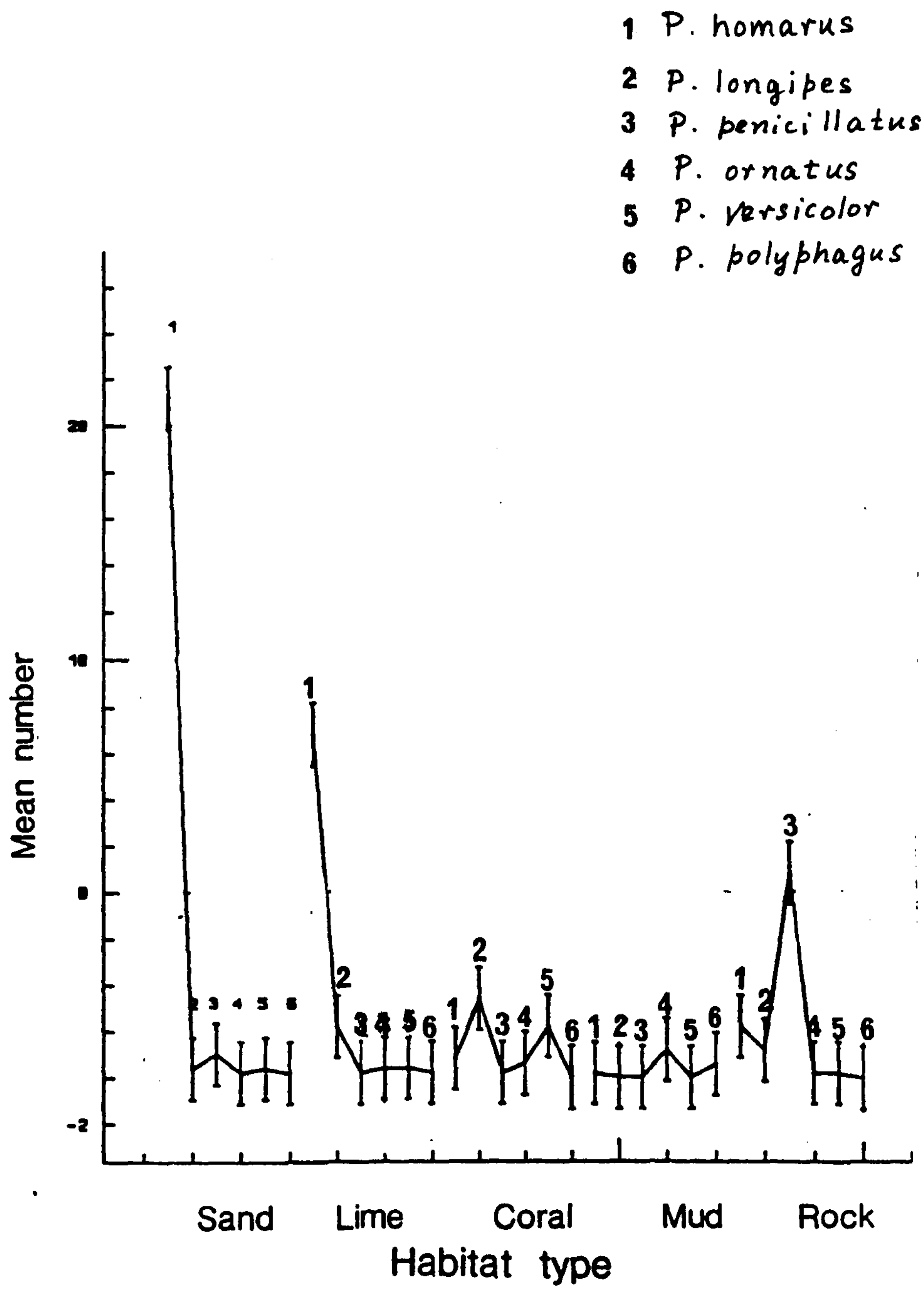

Fig. 6.6 Mean plot constructed to show the habitat preference of six species of spiny lobsters.

6.5 Discussion.

George (1968) considered that turbidity of the water might be an important factor governing the ecological separation of spiny lobsters. De Bruin (1969) reported that in Sri Lankan waters, turbidity in coastal waters is related to proximity to river mouths and the monsoons. Further to him turbidity in Sri Lankan coastal waters has a seasonal variation in extent and depth. The distribution of the members of the genus *Panulirus* appears to be governed by a combination of factors and out of them factors such as temperature, tidal range and turbidity are of particular importance (Berry, 1971a). According to Heydorn (1978), *P. homarus* in South African waters becomes reduced in numbers northwards along the northern Natal and southern Mosambique coasts probably due to the increased tidal range and reduction of a localised zone. Further to him, temperature probably limits its southward range. In the present survey area the maximum tidal range was less than 1m (Meterological Department, Sri Lanka) and the maximum sea bottom temperature variation within any one year of the whole study period was mostly less than 3°C (see Table 4.6) and thus these two cannot be limiting factors for distribution. However, according to De Bruin (1969), turbidity is an unimportant factor since all species tolerate wide ranges in turbidity and clarity of water for quite long periods of time. He also stated that turbidity, especially caused by rivers, might have an indirect effect on the ecological separation through its inhibition of the growth of coral. In the present investigation the ANOVA made for 3 turbidity ranges and catch numbers indicated a significant variation, with more lobsters caught in places with high turbidity. The high turbidity values were obtained for the lowest depth range (0 - 10m) studied. This could be attributed to the surface runoff during heavy rains in the survey months (see Table 4.6) and greater turbulence than the deeper depth ranges due to wave action. The south coast of Sri Lanka is also characterised by a relatively small tidal range, tropical inshore water temperatures with very little fluctuations, clear water conditions except for localised turbidity in areas of river inflow, narrow intertidal zone and continuous surf action which is strong during monsoonal months.

The morphological and geographical distinctions, and its occurrence as the dominant species along the south coast of Sri Lanka indicates that *P. homarus* is ecologically adapted to the environmental conditions which characterise this region. The localised dominance of *P. homarus* along the south coast is probably due to its ecological requirements being met by the environmental conditions available around the coastal waters of southern Sri Lanka. The other five species of the genus *Panulirus* are not as abundant as *P. homarus* in the study area but occur in small and constant numbers ranging from 1% - 6%. They, therefore could be regarded as representatives of an intrusive Indo-Pacific element, living under sub-optimal conditions and probably do not make a significant reproductive contribution. A similar situation in east coast of South

Africa was discussed by Heydorn (1978).

An ANOVA done for the 3 depth ranges (0 -10, 11- 20 & 21 - 30m) of the present survey indicated that the lobster catch is inversely related to the depth ($P < 0.05$). Of the three depth ranges considered, there observed a significant difference was observed in the distribution of lobsters in 0-10m and 21-30m depth ranges with high abundance being observed in the shallower depth (Table 6.3). According to Kanciruk (1980), there is a variation in depth distribution of lobsters that is mainly due to the fluctuations in the physical environment. The shallow water nature of *P. homarus* was also documented by George (1963) from Aden waters. However the main investigation carried out during the 2 year period showed that the CPUE of lobsters is always higher ($P < 0.05$) in low depth ranges and no significant difference was found for different turbidity levels ($P > 0.05$). Hence, the significant variation of the experimental lobster catches in different turbidity levels at different depth ranges may be a coincidence rather than a contributing factor. This supports the findings of De Bruin (1969). George (1974) identified species of reef-dwelling *Panulirus* species in the Indo-West Pacific region according to habitat preference. He concluded that four habitats could be distinguished and they are:

Species	Habitat
P. penicillatus	Rock shelters/ outer reef zone
P. versicolor	Delicate coral formation/ protected lagoon waters/ deeper reef face
P. ornatus	Long shore areas
P. cygnus	Coral crevices in the reef flats and seaward reef face

In the southern sectors of Sri Lanka, there is comparatively poor coral growth (Rajasuriya and De Silva, 1988) owing to the heavy outflow of silt and fresh water during the south-west monsoon (De Bruin, 1969). During the monsoons, coral growth is minimal and part of the living coral reefs die out (De Bruin, 1969). It was observed during the present investigations and also reported by De Bruin (1969) that sand stone reefs formed of compact sand are most extensive in the south coast where they formed fringing reefs parallel to the coast. In association with the sand stone reefs there are ample hiding places for marine organisms. Around 70% of *P. homarus* collected during this investigation were from the sand stone reefs in shallow waters (Fig. 6.4). The results of the present survey suggests, that the concentrated nature of the sand stone reefs in the southern coast may be one of the main reasons for the higher abundance of *P. homarus* compared to other coastal areas of Sri Lanka. According to Berry (1971b), the distributional pattern of *P. homarus* is governed not by the substrate, but by the availability of its frequent food item - the brown mussel (*Perna perna*). In East African waters, the distribution and abundance of *P. homarus* indicates that this species occurs optimally in subtropical waters with a temperature below 24°C (Berry, 1971b). Further to him, perhaps a factor more important than temperature in determining it's distribution and abundance may be tidal range.

The ecological separation of the six species of *Panulirus* recorded off the south-west coast of Sri Lanka is summarised below in terms of water quality, depth, substratum and wave action.

The results are mostly in agreement with the observations made by several other researchers in different parts of the tropical and sub-tropical belt (Berry, 1971a; De Bruin, 1969; George, 1968,1974; Batia, 1974).

There were no appreciable temperature differences between the surface and bottom because the main lobster grounds were located in a fairly shallow depths (0 - 10m), and mixing of the entire water column occurred due to the wave action (Table 6.1). The maximum temperature difference between surface and bottom (at 10m depth) during the survey period was 1.4°C. The lowest surface temperature was recorded in shallow rectangles and the lowest (28.3°C) was recorded in rectangles C_1, which is adjacent to the Walawe ganga river mouth. This is presumably due to an influx of cold water from the Walawe ganga. The bottom salinity in this region (0 - 10m) was also observed to be relatively low (29 ppt) probably for the same reason. Other regions away from the river mouths of the study area were outside the influence of land runoff, and recorded considerably higher values of bottom salinities ranging from 30 - 33 ppt (Table 6.1). The ANOVA on the abundance of berried females at different depth ranges show that the availability at 0 - 10.0m depth range is significantly ($P < 0.05$) higher than at other depth ranges. This could be attributed to the high abundance of hiding places such as caves, crevices and dens at the depth range of 0 - 10.0m. The living pattern of ovigerous females mainly concealed to their hiding places was recorded for *N. norvegicus* by Rice and Chapman (1971). The tendency of higher numbers of berried spiny lobsters to occur in deeper waters has been documented by several researchers (Herrnkind, 1980; Mac Farlane and Moore, 1986). Perhaps this is true for some oceanic species such as *P. argus* where larval dispersal may need current systems. The occurrence in aggregations of berried females of continental spiny lobsters such as *P. ornatus* in shallow waters (1 - 5m) has been recorded from Queensland waters, Australia (Bell et al., 1987). Perhaps this may hold good for continental spiny lobster species as observed for *P. homarus* in the present study. It was also found that there is no significant ($P > 0.05$) difference between the availability of *P. homarus* and different dissolved oxygen regimes. This may be due to their bottom living nature. Hence, dissolved oxygen level is not behaving as a limiting factor.

In support of the widely accepted view of substrata specificity, large numbers of lobsters were recorded during the present survey from sand stone, lime stone and rocky bottom areas. Even though turbidity is generally regarded as a criterion for the abundance of lobsters, it was considered to be a secondary factor. No lobsters were found in sandy ground or open plateau areas. Their distribution is limited to the sand stone, lime stone, rocky bottom and coral reef areas. Out of the six species found during the survey *P. homarus* was the most dominant and *P. polyphagus* was extremely scarce. All species of spiny lobsters inhabit reef rocky areas which afford cover. At day time, especially when the water is clear, all these species lie hidden in crevices or under boulders. The only indication of their presence is the pair of antennae projecting from under ledges.

The multiple occupancy of several species of spiny lobsters in a small area as observed in this study can be explained by assuming the following options,

(a) even though the area is small, it contains various microhabitats preferred by the six species of spiny lobsters

(b) the six species of spiny lobsters considered in this study can tolerate a wide range of environmental conditions which enable them to exist even though they are not optimal.

The results of the present investigation indicates that the survival of all six species of spiny lobsters along the south coast of Sri Lanka might be attributed to the combined effect of both the above mentioned options. Based on the results of this investigation, it is possible to conclude that although some spiny lobster species prefer special habitats, many of them can tolerate a wide range of environmental parameters which are readily available in tropical nearshore areas such as the south coast of Sri Lanka.

6.6 Chapter summary

The five species of spiny lobsters which occur with *P. homarus* are *P. longipes*, *P. penicillatus*, *P. ornatus*, *P. versicolor* and *P. polyphagus*. In the study area the species composition fluctuated among sampling stations. It was found that *P. polyphagus* was the least abundant species in the study area.

The study of habitats and ecological relationships at a selected area in Tangalle revealed that each species occupies a distinctive microhabitat. *P. homarus* is an under-boulder or crevice-living species mainly associated with sand stone reefs in moderately calm and turbid waters. *P. longipes* lives in open coral reefs in both calm and rough water localities. *P. penicillatus* prefers rocky bottom areas with turbid, moderate to rough and turbulent water localities. *P. ornatus* occurs on the seaward side of sand stone or coral reef areas at comparatively greater depths. *P. versicolor* prefers live coral areas in clear and calm waters. *P. polyphagus* is a species living mainly in muddy bottom areas associated with organic matter.

All species are nocturnal in behaviour and make local movements in search of food. Several species may occur in a given habitat but the micro habitats could overlap.

Apart from *P. homarus* the other five species contributed around 10 - 20% to the total production and are regarded as living under sub-optimal conditions.

Although the fishing area ranged from 0 - 30m depth, high concentrations of lobsters were recorded between 0 - 10m depth range.

The statistical analysis revealed that there is a significant interaction between six spiny lobster species and their habitat types. The reason for the dominance of *P. homarus* in the study area is mainly correlated to the presence of extensive sand stone reefs in shallow waters. The abundance of berried females of *P. homarus* was significantly high in shallow depths (0 - 10m) than the deeper areas (11 - 30m) and this could be attributed to the high availability of hiding places in sand stone reefs.

The trammel net could be considered as the highly efficient gear for catching spiny lobsters. The major draw back of the trammel net is the entanglement of considerable quantities of under sized lobsters and difficulty in clearing them from the net. 7.75cm stretched mesh bottom set gill net and the lobster ring are other better alternatives for the lobster fishery, of which the lobster ring could be recommended.

CHAPTER 7

7. Overall Summary and Recommendations.

The south-east Asian countries have already reached near saturation levels in the exploitation of the available coastal fishery resources (Chua, 1986). Development of suitable management strategies of many of the heavily exploited fisheries is therefore of vital importance. In many parts of the world, lobster fisheries have been subjected to heavy exploitation.

Species	**E**	**Reference**
P. cygnus	0.64	Bowen and Chittleborough (1966)
H. gammarus	0.70-0.82	Hepper (1978)
J. edwardsii	0.92	Annala (1978)
H. gammarus	0.94-0.99	Briggs and Mushacke (1984)
P. homarus	0.61	Sanders and Bouhlel (1984)
P. homarus	0.50	Present study

(**E** = exploitation rate)

Hence, the present study has been undertaken to understand the status of the spiny lobster fishery along the south coast of Sri Lanka and to find solutions to the annual decline of the production.

The study of the fishery, reproductive biology and population dynamics of spiny lobster *Panulirus homarus* along the south coast of Sri Lanka revealed the following.

An extended spawning season was established with ripe ovaries been sampled from August to March in high percentages. The related species of Palinuridae have shown spawning seasons extending from two to three months to all year round. As in the case of many other spiny lobsters, male *P. homarus* were found to reach sexual maturity at a smaller size and a younger age than the females. In such situations the common tendency is that the females outnumber the males in larger size groups. Males of most species grow, mature and die faster than females. The present study also revealed that the female *P. homarus* outnumbered the males in the large size groups.

The fecundity of *P. homarus* ranged from 116×10^3 to 601×10^3 ova per year per female. Most of the larger female lobsters that were examined for fecundity studies showed two groups of ova suggesting that larger females appear to spawn twice a year or twice a spawning season. Larger females appear to spawn during the early part of the spawning season (August/ September) while the first time spawners lay their eggs in the latter part of the season (March/ April). The findings of Berry(1971b), where some of the larger females were reported to produce up to four broods per year was supported by the observed repetitive breeding among larger females in this study. The presence of a protracted breeding period and the observed length frequency distribution, especially in small size groups, confirm the presence of more than one spawning peak. This was reconfirmed by the recruitment pattern having two recruitment pulses of which one contributed more heavily to the fishery.

Although all females beyond 40-44mm carapace length group are capable of producing eggs, the highest reproductive potential was contributed by the 60-79mm carapace length group, which was estimated as 62.05% . The present study recorded a considerable egg loss during the process of incubation. Incubation has been estimated as 4-6 weeks (Berry, 1971b). A higher egg loss was observed in smaller females (19.8%) than that of larger females (6.26%).

The fishery is mainly a multi-species one, where six species of the genus *Panulirus* are caught, of which *P. homarus* contributed 75 - 85% to the total catch. Analysis of catch and effort showed a decline in the relative abundance of the stock indicating an annual drop in catch per unit effort values. The highest lobster production season (August - March) coincides with their spawning season.

The lunar cycle, which usually influences night time fisheries, showed a very high influence on the *P. homarus* fishery where catch per unit effort was very low during the full moon period and very high during the new moon. Twice monthly measurements of environmental parameters during the period of two years, indicated that the availability of *P. homarus* was unaffected by other environmental parameters such as water temperature, salinity and turbidity.

Age composition of the landings showed that the fishery is mainly based on 1.5 - 3 year old lobsters. Recruitment to the fishery occurs at 35mm total length and onwards at which time they are 1 years old. Lobsters of 6 years and older are scarce in the catches and the life span of the species is probably 7 - 8 years.

The calculated total mortality coefficient for *P. homarus* was high and ranged from 1.538 - 1.966. The natural and fishing mortality components of the total mortality, revealed very high values (M = 0.92 - 0.98 and F = 0.62-0.99). The exploitation rate for the whole population was estimated as 0.5, indicating a reasonable level of exploitation. The results of virtual population analysis (VPA) indicated the total spiny lobster population size as 4067 x 10^3 individuals. VPA also showed that a high percentage of the population consists of smaller animals below 80mm carapace length. Yield per recruit analysis indicated that the present exploitation level is 25% higher than the value it should be to result in a maximum sustainable yield. This suggests the need for a reduction of the present fishing mortality level from 0.88 to 0.77. A similar suggestions were also arrived at from maximum sustainable yield (MSY) estimates made from Schaefer and Fox models. These estimates suggest a reduction of the present fishing fleet from 315 to 300 to maintain the MSY level. The results of the ecological survey indicated the reason for the localised dominance of *P. homarus* as the availability of ample hiding places among shallow (1 - 10m) sandstone reef areas, which are extensive in the study area. The presence of five other species of spiny lobsters was considered as an intrusive element living under sub-optimal conditions.

The existing spiny lobster regulations in Sri Lanka were introduced in 1971 and still remain unchanged. These regulations (Appendix. 3.3) emphasize three main restrictions on the spiny lobster fishery. They are,

a) prohibition of catching under sized lobsters (lobsters < 8.00cm in carapace length),
b) prohibition of catching female lobsters with eggs and,
c) prohibition of catching lobsters in soft shell stage.

During the past 20 years considerable changes have been taken place in the spiny lobster fishery, of which the major changes are as follows,

a) several fold increase in the fishing effort,
b) gradual decline of the CPUE and,

c) introduction of the trammel net to the spiny lobster fishery.

An important aspect of lobster stock management is clearly illustrated by the concept - "over fishing" (the so-called "growth over fishing") which occurs when the effort is so high that the total yield decreases with increasing effort. This has been observed for some years during 1986 - 1991 period (see chapter 4.5).

In any spiny lobster fishery, it is evident that management strategy must include a consideration of two important elements,

a) legal minimum size and,

b) total amount of fishing effort.

The existing spiny lobster regulations has a consideration with respect to minimum legal size which is set as 80.0mm in carapace length. As the Sri Lankan spiny lobster fishery is a free access public fishery, no restrictions exist on fishing effort. The idea behind the minimum legal size is to allow lobsters to spawn at least once before they are caught by the gear. As far as the south coast fishery is concerned the following estimated parameters have to be seriously considered when fixing a suitable minimum legal size.

a) The smallest size caught by the fishing gear = 35mm carapace length.

b) The size at first sexual maturity = 40 - 48mm carapace length.

c) The size at spawning = 59.9mm carapace length.

d) The size range which provides the highest reproductive potential = 60 - 79mm carapace length.

e) The minimum legal size according to existing lobster regulations = 80.0mm carapace length.

The above factors show that the minimum legal size which was introduced in 1971 is still appropriate. However, undersized lobsters are clearly being caught, thus emphasis should be placed on the second element of the management strategy, the total amount of fishing effort.

Before suggesting suitable management measures on the fishing effort it is important to consider the factors which influenced the rapid development of the fishery to make it into a highly profitable venture. These factors are,

a) the development of an attractive export market,

b) low capital cost of entering the fishery,

c) incentives provided by the government such as 90% subsidy schemes and low interest bank loans to the small scale fishermen,

d) the shallow water nature of the fishery and,

e) the development of the infrastructure facilities such as ice plants, net manufacturing factories etc.

Out of these factors a) seems to be the most important as it is the desire of the fishermen as well as the company owners to make more money through the business.

The fishing pattern is highly controlled by the market prices as this fishery is mainly aimed for the export market. The commercial spiny lobster categories and typical prices paid to fishermen are as follows.

Market category (gm)	**Estimated length range (mm in CL.)**	**Price *Rs/Kg**
50 - 110	33.90 - 46.00	350.00
110 - 250	46.00 - 60.10	550.00
250 - 450	60.10 - 82.00	750.00
450 - 550	82.00 - 88.60	560.00
550 - 650	88.60 - 94.50	475.00
650 - 1000	94.50 - 110.90	425.00

CL - Carapace length. * £= 70 Sri Lanka Rupees

The above table clearly shows that the fishery is highly orientated towards the 46.00 - 82.00mm size range which fetches the highest prices. It is important to note that this market category includes a very high percentage of sexually mature and spawning lobsters. This clearly indicates that the part of the female population which contributes heavily to the total reproductive potential (60 - 79mm CL group) is completely within the high priced market category. The VPA results also support this, according to which 78% of the lobster catch is composed of illegal sized lobsters.

Another important factor, where fishing is considered, is the shallow water nature of the resource. When compared with the distributional pattern of commercial species of *Panulirus*, which extends from the shore to a depth of 90m in some other countries, (George, 1962; Sheard, 1962), the resource of *P. homarus* in Sri Lankan waters is unlikely to support a larger catch as it is confined to shallow areas.

The problem of increasing fishing pressure on spiny lobsters in the south coast has been aggravated as a result of the unsettled political situation of north and east coasts of the country. As the lobster fishery is a free access public fishery, fishermen have migrated from the north and east coasts to join this fishery due to its coastal nature and the attractive prices.

However, the available data indicate that there has been a serious decline in the CPUE in the recent years. Divers found that the areas which previously had rich lobster resources are now being depleted. Commercial fishermen who operated 20 - 30 lobster rings during 1985/86 are now using 70 - 80 rings attempting to obtain the same harvest. The intensified fishing pressure for the last five years in the south coast for the spiny lobsters has created an exploitation rate which is high enough to catch legal size and under legal size lobsters.

Possible measures for controlling fishing effort can be grouped into the following three categories,

(A) restrictions on inputs - such as limits to the number of fishermen, craft, gear, number of fishing days, close seasons, close areas etc.,

(B) an imposition of a tax on the catch, or

(C) restrictions on the output by allocating quantitative rights or quotas among fishermen.

Imposition of taxes on lobster fishermen (B) may have practical problems as they neither do not register as small scale entepreneurs, nor maintain proper records, and also due to the scattered and uncertain nature of the landing sites. When social factors of the fishing community are considered (C) is virtually impossible to implement as it may lead to conflicts among the fishing community.

When category (A) is considered the most practical and important ways to be considered are the following, A1) fishing gear - prohibition of the operation of trammel nets in the lobster grounds.

A2) fishing craft - prohibition of the use of mechanized craft in the lobster grounds.

A3) seasons - prohibition of fishing activities during the south-west monsoonal period in the lobster grounds.

A4) number of fishermen - introducing a licensing system to control the fishermen who are entering into the lobster fishery.

It is recommended that these four regulations be introduced as soon as possible. As regards A3), it is common practice to enforce regulations to reduce fishing activities during the spawning season of a particular species. This can not be implemented in the south coast lobster fishery as the fishing season and the peak spawning season (September to March) overlap each other. Hence, a complete prohibition of the spiny lobster fishery should be imposed during April to August in order to protect the spawning activities even though it is less than that of during September to March.

It is also recommended that the existing spiny lobster resources survey of the south coast should be continued to obtain precise catch, effort and length frequency data on a regular basis to maintain updated records of the fishing effort on the spiny lobster population.

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Appendix: 2.1 Pattern of variation of monthly rainfall (mm) of the study area from 1988 - 1990.

Month	1988	1989	1990
January	20.0	135.7	59.9
February	21.9	48.0	21.5
March	27.3	40.8	97.0
April	176.9	28.9	27.9
May	106.6	63.4	152.7
June	54.2	26.4	105.3
July	13.7	146.8	11.5
August	66.8	96.5	0.4
September	86.9	25.0	12.8
October	10.6	69.3	190.3
November	52.9	123.1	270.8
December	5.1	24.4	242.8

Source: Department of Meteriorology, Sri Lanka.

Appendix. 2.2 Pattern of variation in temperature (^{o}C) of the study area during the period of 1988 to 1990.

	1988	1989	1990
January	34.3	35.1	35.6
February	36.1	36.4	36.3
March	36.3	36.6	36.4
April	38.5	38.1	38.4
May	37.1	37.3	37.4
June	37.3	37.4	37.7
July	37.8	38.1	38.0
August	38.4	39.1	39.2
September	38.3	38.4	38.6
October	37.1	37.6	37.3
November	35.1	36.1	35.3
December	35.6	36.1	36.1

Source: Department of Meteriorology, Sri Lanka.

Appendix 3.1 Relationship between maturity stages of the ovaries and carapace length of female *Panulirus homarus* (combined data for the study period).

Month	Ovary Stage	Carapace length (mm) 37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1					1	1	1	2	1					6	6.0
	2						2	1	1	1					5	5.0
Aug.	3				1	1	1	4	2	1					10	9.0
	4				1	1	7	3	9	3	2	2			28	28.0
	5					1	9	8	9	4	2	1	1		35	35.0
	6						1	2	7	3	2	1	1		17	17.0
					2	4	21	19	30	13	6	4	2		100	

Month	Ovary Stage	Carapace length (mm) 37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1				2	1	2	1	1	2					9	9.0
	2					2	4	1	1	3	1				12	12.0
Sep.	3						1	2	3	3	1				10	10.0
	4						1	4	1	7	5	3			21	21.0
	5				2	1	6	4	6	6	1	3			29	29.0
	6						5	1	6	1	4	2			19	19.0
					4	4	19	13	18	22	12	8			100	

Month	Ovary Stage	Carapace length (mm) 37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1				1	2		1	1		3				8	8.0
	2				1	3	7	1	4	1					17	17.0
Oct.	3				1	2	4	2	4						13	13.0
	4					3	6	3	7	1					20	20.0
	5					3	7	4	6	7	3	1			31	31.0
	6					1	3	1	1	4	1				11	11.0
					3	14	27	12	23	13	7	1			100	

Appendix 3.1 Contd.

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
						Carapace length (mm)										
	1				1	2		3	1						7	7.0
	2			1		3	7	1	1	4					17	17.0
Nov.	3					2	1	4	1	4					12	12.0
	4				1	3	1	4	1	3	7	1			21	21.0
	5			2	2	1	1	3	3	11	2				25	25.0
	6				1	7	1	4	1	3	1				18	18.0
Total				3	5	18	11	19	8	25	10	1			100	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
						Carapace length (mm)										
	1		1	1	1	1									4	4.0
	2			1		1	2	1	2	1	1				9	9.0
Dec.	3			2	1		1	2	2		1				9	9.0
	4			1	4	8	7	4	1	3	1				29	29.0
	5			1	8	7	4	7	1		1				29	29.0
	6			2	2	2	4	7	2	1					20	20.0
Total			1	8	16	19	18	21	8	5	4				100	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
						Carapace length (mm)										
	1	1	1	3	1	1			1		1				9	9.0
	2			2	1	1	1	2	1	1					9	9.0
Jan.	3		1	3	1	1		1		1		1			9	9.0
	4			1	8	4	2	1			1				17	17.0
	5			4	12	14	7	4	1	1					43	43.0
	6		1	2	4	2	1	1	1	1					13	13.0
Total		1	3	15	27	23	11	9	4	4	2	1			100	

Appendix 3.1 Contd.

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1	1	3	2	2	1	1								8	8.0
	2	1	3	7	1	11		1							24	24.0
Feb.	3		1	1	3	1				1	1				8	8.0
	4			3	7	2	1	4							17	17.0
	5		1	4	4	9	4	2	2						26	26.0
	6			1	3	7	1	1	1		1				15	15.0
		2	8	18	20	31	7	8	3	1	2				100	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1		7	1	1	3									12	12.0
	2		3	4	14	4	1								26	26.0
Mar.	3			1	10	1		1							13	13.0
	4		2	4	1	4	2								11	11.0
	5		2	4	4	4	2	1		1					18	18.0
	6			1	2	10	4	2		1					20	20.0
			14	13	32	26	9	4		2					100	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1		1	1			1					1			4	14.8
	2			1		3		1							5	18.5
Apr.	3		1			1	2	1	1						6	22.2
	4				1	2	1	1							5	18.5
	5		1		2		1		1						5	18.5
	6				1						1				2	7.4
			3	2	4	6	5	3	2		1	1			27	

Appendix 3.1 Contd.

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1		1				1								2	13.3
	2				1			1		2					4	26.7
May.	3			1	1										2	13.3
	4				1		1								2	13.3
	5			1											1	6.7
	6				1	2				1					4	26.7
			1	2	4	2	2	1		3					15	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1				1		1								2	13.3
	2															0.0
June	3			1	2	1	1								5	33.3
	4					1		2	1						4	26.7
	5			1	1			1							3	20.0
	6					1									1	6.7
				2	4	3	2	3	1						15	

Month	Ovary Stage	37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
		Carapace length (mm)														
	1			1			1	2	2	4					10	26.3
	2					1		1	1						3	7.9
July	3						1	1	1						3	7.9
	4								3	3	1				7	18.4
	5						1	4	2	1	1			1	10	26.3
	6							3	1	1					5	13.2
				1		1	3	11	10	9	2			1	38	

Appendix 3.2 Relationship between maturity stages of the gonads and carapace length in male *Panulirus homarus*.

Month	Gonad Stage	Carapace Length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1					1	1	1	2	1				6	6.0
	2					1	2	4	1					8	8.0
Aug.	3				2	4	1	2	1					10	10.0
	4				3	4	2	11	3	12	1			36	36.0
	5				1	3	1	3	4	7	9	8	4	40	40.0
					6	13	7	21	11	20	10	8	4	100	

Month	Gonad Stage	Carapace Length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1			1	1									2	2.0
	2			1	2	1	1	4	1					10	10.0
Sep.	3		1	1	1	2	1	1	1					8	8.0
	4		1		1	3	11	4	7	1				28	28.0
	5				1	4	12	15	12	2	2	3	1	52	52.0
			2	3	6	10	25	24	21	3	2	3	1	100	

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1	1	1			1	1							5	5.0
	2			1	2	6	13	2	1						25	25.0
Oct.	3		1	2	1	4	1								9	9.0
	4		1	2	7	6	2	12	3	6	1				40	40.0
	5			1	5	1	1	4	1	4	1	1	1	1	21	21.0
		1	3	7	15	17	18	19	4	10	2	1	1	1	100	

Appendix 3.2 Contd.

Month	Gonad Stage	Carapace Length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1	1	2	1	1								6	6.0
	2	1	3	2	1	2	1							10	10.0
Nov.	3		2	4	4	6	1	1						18	18.0
	4	2	4	4	11	7	1							29	29.0
	5		1	8	7	14	4	2	1					37	37.0
		4	11	20	24	30	7	3	1					100	

Month	Gonad Stage	Carapace Length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1	10	4	1	2	1							10	10.0
	2	1	4	3	7	1	1	1						18	18.0
Dec.	3	1	1	7	1		1	1	1					13	13.0
	4	3	2	6	4	6	4	1	1					27	27.0
	5	2	4	1	2	6	4	4						23	23.0
		8	21	21	15	15	11	7	7					100	

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1	3	1	4	1			1						11	11.0
	2		1	2	4	7	1	2	1	1					19	19.0
Jan.	3			3	4	7	1	2	1	1	1				20	20.0
	4			1	6	6	7	4	1						25	25.0
	5		1	4	3	6	5	2	2	1	1				25	25.0
		1	5	11	21	27	14	10	6	3	2				100	

Appendix 3.2 Contd.

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1		8	1		1								11	11.0
	2	1	4	3	9	3	1	1							22	22.0
Feb.	3		6	3	1	4	1	1							16	16.0
	4		4	4	4	6	7	4	1						0	30.0
	5		4	2	4	3	4	1	1	1	1				21	21.0
		2	18	20	19	16	14	7	2	1	1				100	

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		4	1	3	4	1								13	13.0
	2	1	1	1	1	1	1		1						7	7.0
Mar.	3		1		3	1	4	1							10	10.0
	4		1	4	6	14	4	1	1	1					32	32.0
	5	1	1	6	5	12	8	4	1						38	38.0
		2	8	12	18	32	18	6	3	1					100	

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1	1		1				1							3	12.5
	2		1			1				1					3	12.5
April	3			3	2	1									6	25.0
	4	1				1			1						3	12.5
	5		1	4	3		1								9	37.5
		2	2	8	5	3	1	1	1	1					24	

Appendix 3.2 Contd.

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1					1	1	4	1	1			9	39.13
	2			1	1										2	8.70
May	3															0.00
	4	1		3	1										5	21.74
	5		1			2	2	1	1						7	30.43
		1	2	4	2	2	2	2	2	4	1	1			23	

Month	Gonad Stage	Capace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1			1	1	1	4	1	1				10	28.57
	2	1		2		1	3	1	1	1					10	28.57
Jun.	3		1			1		1							3	8.57
	4	1			3		1								5	14.29
	5	1	2		1	2		1							7	20.00
		3	4	2	4	5	4	4	5	2	1				35	

Month	Gonad Stage	Carapace Length (mm)														
		37	42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1			1			1		1				4	13.79
	2				1										1	3.45
Jul.	3				1		1			1					3	10.34
	4						1	4	3	1	1				10	34.48
	5				1	2	1	1	2	1	2	1			11	37.93
			1		3	3	3	5	6	3	4	1			28	

Appendix 3.3 Relationship between berried stage and carapace length of female *Panulirus homarus* (combined data for the study period).

Month	Berried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1				2	3	3	8	3	1				20	20
Aug.	2					3	3	4	2	1	1			14	14
	3				1	3	7	2	9	6	3			31	31
	4						1	3	2	11	4	1		22	22
	5					1	1	1	3	4	2	1		13	13
					3	10	15	18	19	23	10	2		100	

Month	Berried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1	1	3	4	7	5	2	1	1	1		26	15.38
	2			1	1	1	4	11	7	1	1			27	15.98
Sept.	3				1	2	1	14	9	13	9	1		50	29.59
	4					4	6	17	15	4	13	1		60	35.50
	5						1	1	1	2	1			06	03.55
			1	2	5	11	19	48	34	21	25	3		169	

Month	Berried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1	2	1	1	3	1	1					10	10.75
	2			1	1	1	2	1	1					07	07.53
Oct.	3				1	1	3	1	1	2				09	09.68
	4				3	9	11	14	5	11	3			56	60.22
	5				1		2	1	4	1	1	1		11	11.83
			1	3	7	12	21	18	12	14	4	1		93	

Appendix 3.3 Contd.

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		1	1		3	1	2	1	1				10	08.70
	2			1	3	9	4	14	1	1				33	28.70
Nov.	3				3	7	11	4	1					26	22.61
	4			1	2	8	4	9	1	2	1			28	24.35
	5				1	4	7	3	1	1	1			18	15.65
			1	3	9	31	27	32	5	5	2			115	

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1			4	1	7	1	2	3					18	14.63
	2		1	1		3	7	1	1					14	11.38
Dec.	3				3	3	17	1	1	1	1			27	21.95
	4			4	7	11	12	11	6	1				52	42.28
	5				3	1	3	3	1		1			12	09.76
			1	9	14	25	40	18	12	2	2			123	

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1			1	1	3	1	1						07	07.69
	2			4	1	1	4	3	1	1				15	17.58
Jan	3			1	7	3	4	10	4	1				30	32.97
	4			3	13	1	7	1	1	3	1			30	32.97
	5				1	1	3	1	1	1	1			09	09.89
				9	23	9	19	16	7	6	2			91	

Appendix 3.3 Contd.

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		2	7	1	4	1	1						16	17.78
	2			1	2	3		1	1	1				09	10.00
Feb.	3		3	9	7	4	1							24	26.67
	4	1	2	3	9	4	1	1						21	23.33
	5		1	3	4	3	7	1			1			20	22.22
		1	8	23	23	18	10	4	1	1	1			90	

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1		5	4	7	1		1			1			19	13.10
	2		1	2	4	1								08	05.52
March	3		1	4	7	16	9	3	1					41	28.28
	4		1	12	9	11	14	1	1		3			52	35.86
	5		1	2	2	7	4	9						25	17.24
			9	24	29	36	27	14	2		4			145	

Month	Berried stage	Carapace length (mm) 42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1			1	1		1		1				1	05	05.21
	2			1	1	1	1		3		1	1		09	09.38
April	3		4	8	7	1	1							21	21.88
	4		3	14	6	7	4	1	1	1				37	38.54
	5			3	4	4	8	4	1					24	25 00
			7	27	19	13	15	5	6	1	1	1	1	96	

Appendix 3.3 Contd.

Month	Berried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1													00	00.00
	2					1			1	1				03	75.00
May	3													00	00.00
	4							1						01	25.00
	5													00	00.00
						1		1	1	1				04	

Month	Beried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1				1		2		1					04	57.14
	2							1						01	14.29
June	3						1							01	14.29
	4							1						01	14.29
	5													00	00.00
					1		3	2	1					07	

Month	Berried stage	Carapace length (mm)													
		42	47	52	57	62	67	72	77	82	87	92	97	Total	%
	1							4	1	3	1			09	56.25
	2							1	1					02	12.50
July	3			1							1			02	12.50
	4						1							01	06.25
	5								1	1				02	12.50
				1			1	5	3	4	2			16	

Appendix 3.4 Spiny lobster regulations of Sri Lanka.

Colombo, 1973. Minister of Fisheries.

REGULATIONS

1. These regulations may be cited as the SPINY LOBSTER AND PRAWN (SHRIMP) Regulations, 1973.

2. No person shall fish for, take, or land from any vessel any spiny lobster the carapace length of which is less than eight centimetres (3.15 inches) or the tail length of which is less than eleven and one half centimetres (4.50 inches).

3. No person shall sell, purchase or have in his possession any spiny lobster the carapace length of which is less than eight centimetres (3.15 inches) or the tail length of which is less than eleven and one half centimetres (4.50 inches)

4.(1) No person shall fish for, or take any spiny lobster that is in the soft-shell stage.

(2) No person shall sell, purchase or have in his possession any spiny lobster which is in the soft-shell stage.

5. No person shall land from any vessel or sell or have in his possession any spiny lobster tail which -

(a) is in such a condition that it cannot be measured or

(b) has the calcified bar of the tergum of the first abdominal segment fractured.

6.(1) Every person who takes any spiny lobster that is carrying external eggs shall immediately return in alive with as little injury as possible into the water from which it was taken.

(2) No person shall remove the external eggs from any female lobster or from any spiny lobster tail.

(3) No person shall buy, sell or expose for sale, or have in his possession any female spiny lobster or any spiny lobster tail from which any of the external eggs have been removed.

(4) No person shall buy, sell, expose for sale or have in his possession any female spiny lobster or spiny lobster tail which is carrying external eggs.

(5) No person shall buy, sell, expose for sale or have in his possession any spiny lobster or spiny lobster tail from which any of the pleopods or swimmerets or any part thereof have been removed.

7. The Director may by notification published in the Gazette specify the size and type of lobster pot or other fishing gear that may be used for the purpose of fishing or taking of spiny lobster.

8. No person shall have in his possession, or expose for sale or sell any spiny lobster meat except on the authority of a permit issued to him in that behalf by the Director.

9. (1) A permit issued by the Director in terms of regulation 8 shall be substantially in Form A set out in the First Schedule hereto and shall be subject to the conditions specified therein.

(2) Every application for a permit under paragraph (1) shall be accompanied by an application fee of fifty rupees.

10. No person shall except on the authority of a permit issued to him by the Director in that behalf -

(a) fish for, take, or land from any vessel any spiny lobster;

(b) sell, purchase or have in his possession any spiny lobster;

the carapace length of which is in excess of eight centimetres (3.15 inches) or the tail length of which is in excess of eleven and one half centimetres (4.50 inches).

11. Every permit issued by the Director under regulation 10 shall be substantially in Form B set out in the First Schedule hereto and shall be subject to the conditions specified therein.

12. Every application for a permit under regulation 10 shall be accompanied by an application fee of two rupees.

13. (1) No person shall export or pack for export or ship for export any spiny lobster or spiny lobster meat or spiny lobster tails except on the authority of a permit issued by the Director in that behalf.

(2) Every permit issued by the Director under paragraph (1) shall be substantially in Form C set out in the First Schedule hereto and shall be subject to the conditions specified therein.

(3) Every application for a permit under paragraph (1) shall be accompanied by a fee of twenty - five rupees.

14. Every person carrying on business as an exporter of spiny lobster spiny lobster meat or spiny lobster tails shall ensure that every container in which such spiny lobster, spiny lobster meat or spiny lobster tails, is packed for export bears the date of packing.

15. The provisions of regulations 2,3 and 4 of these regulations shall apply to any spiny lobster -

(a) Which is exported or packed or shipped for export;

(b) out of which lobster meat is extracted or processed for export; and

(c) the tail of which is processed or packed for export.

16. Where there is any doubt as to the carapace length of any spiny lobster that may be exported under these regulations the tail length of such lobster shall be used as the standard of measurement.

17. For the purpose of ascertaining the tail length of any spiny lobster, the tail of such lobster shall be pressed flat on a board with the ventral surface downwards.

18. The minimum tail length of any spiny lobster that may be exported shall be eleven and one half centimetres (4.50 inches)

19. The tail length of any spiny lobster shall be the measurement of the tail from the anterior surface of the calcified bar of the tergum of the first abdominal segment along the median line to the posterior surface of the telson, as specified in the sketch shown in the Second Schedule hereto.

20. The Director may by notification published in the Gazette demarcate Ceylon Waters into such specified areas as he may deem necessary for the purpose of breeding and for the protection of the spiny lobster.

21. The Director may prohibit or restrict the taking or fishing of spiny lobster in any area specified in the notification under regulation 20 during such period as he may specify in such notification.

22. No person shall, notwithstanding that he may be the holder of a permit under these regulations, fish for, or take any spiny lobster in that part of the sea lying between a straight line running due West from the Southern most extremity of the Mount Lavinia Hotel and a straight line running due West of the Northern most extremity of the Galle Buck light house.

23. No person shall, without reasonable excuse notwithstanding that he may be the holder of a permit under these regulations, have in his possession whether in any fishing boat or otherwise any spiny lobster, spiny lobster meat, spiny lobster tails, or any lobster pot in that part of the sea to which regulation 22 applies.

24. (1) Every person carrying on the business of processing spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails for export from Sri Lanka shall -

(a) maintain records in such form as may be required by the Director of -

(i) the number and weight of spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails received each day at the premises where he carried on such business.

(ii) the person or persons from whom the spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails were received, and

(iii) the number of containers and the weight of spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails packed in such containers for export in the premises where he carries on such business; and

(b) Send a copy of every bill of landing issued to him by the exporter to the Director.

(2) Every person carrying on business as aforesaid shall at any time during his ordinary hours of business, on being reuqested to do so by the Director or his authorized representative produce for inspection all or any of the records reuqired to be maintained under paragraph (1).

(3) The Director or his authorized representative is hereby empowered to open any container in which any spiny lobsters, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails have been packed for export during the course of any inspection carried out under the provisions of paragraph (2) for the purpose of checking or verifying the accuracy of the records.

(4) Every entry in the records required to be maintained under these regulations shall be labelled or marked -

(a) With the serial number of each container in which spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails have been packed; and

(b) with the date of packing which may be a code known to the Director or his authorized representative.

(5) Every person carrying on the business of processing spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails shall ensure that every container packed for export bears a label or marking clearly showing the number of spiny lobster, spiny lobster tails, prawn (shrimp) or prawn (shrimp) tails packed in such container and the batch number of such container. Any such batch number may be a code known to the Director or his authorized representative.

25. In these regulations -

"carapace" means the outer cover of the cephalothorax or fused portion of the head and thorax of the spiny lobster;

"Carapace" length" means the length of the carapace measured from the mid-point of the anterier border of the carapace between the base of the two rostral horns along the mid-line to the posterier border of the carapace;

"Director" shall have the same meaning as in the Ordinance;

"lobster pot" includes lobster basket or any other device used for catching spiny lobsters;

"soft-shell" means the quality of the shell of the spiny lobster after moulting before it has hardened;

"spiny lobster" means any of the following species of rock lobster:

Panulirus homarus Panulirus longipes,
Panulirus versicolor, Panulirus ornatus,
Panulirus penicillatus and Panulirus polyphagus;

"Ceylon waters" shall have the same meaning as in the Ordinance;

"take" shall have the same meaning as in the Ordinance;
"Telson" means the terminal abdominal joint of the spiny lobster;
"Tergum" means the dorsal shell of the abdomen of the spiny lobster.

FIRST SCHEDULE

FORM A

PERMIT FOR THE SALE OF SPINY LOBSTER MEAT

(REGULATIONS 8 AND 9)

.... of ....

having paid a fee of Rupees ....(Rs. ....)
is hereby authorized under the Spiny Lobster and Prawn(Shrimp) Regulations 1973, to posess, expose for sale or sell any spiny lobster meat.

2. This permit shall, unless earlier cancelled be valid until.

3. This permit is subject to the following conditions -

(1) This permit is personal to the holder named herein and shall not be transferable.

(2) This permit is subject to the provisions of the aforementioned regulations.

Director of Fisheries.

Date:

Appendix 4.1 Data sheet used for the spiny lobster fishiery of south coast.

SPINY LOBSTERS OF SOUTH COAST

Date	Departure time	Arrival time	Area of fishing	Depth(m)	No. Nets/rings	Catch (Kg)	Value (Rs)

Appendix 4..2 Monthly spiny lobster production (kg) for the period 1986-1991.

	1986	1987	1988	1989	1990	1991
J.	38161	38151	36541	38366	20596	14261
F.	48511	44121	29451	33930	25662	16174
M.	24241	17660	18180	22464	12979	10500
A.	10741	7467	11221	7166	10546	7426
M.	00176	1420	1186	2156	4154	-
J.	00000	1300	1174	3128	5321	-
J.	00000	1247	2854	5500	6080	-
A.	07451	14145	23660	11466	12861	-
S.	28147	21256	18683	17687	16521	-
O.	41141	43846	26425	24819	24261	-
N.	37166	47566	29904	21948	26551	-
D.	36500	24261	17950	12651	19126	-
	272235	262330	217229	201281	184659	145083*

* Estimated based on four months data.

Appendix 4.3 Monthly fishing effort values (in craft nights) of the south coast spiny lobster fishery for the period 1986-1991.

	'86	'87	'88	'89	'90	'91
J.	10520	13541	12420	12600	13212	11520
F.	14320	11460	11380	12120	14145	11140
M.	7650	11246	10144	10461	11286	8140
A.	4120	8420	7286	8216	10214	6400
M.	560	2200	1056	2110	2680	-
J.	0	2157	1114	2020	426	-
J.	0	1396	456	2360	312	-
A.	5240	5500	4214	5654	596	-
S.	7386	8650	7426	7210	9150	-
O.	8750	13550	12850	12806	14256	-
N.	12200	15317	14210	12920	14460	-
D.	11650	16230	15738	12668	15395	-
	82396	109669	98294	101145	106126	116602

*** Estimates made on four months data**
Source: NARA spiny lobster fishery survey and present study.

Appendix 4.4.

Average catch per unit effort (CPUE) for the year 1990 considering full moon day as day one of each month.

Day	Average CPUE (Kg/craft night)
1*	-
2	1.11
3	0.81
4	0.95
5	1.31
6	1.33
7	2.31
8	1.42
9	1.93
10	1.34
11	2.13
12	3.11
13	2.37
14	2.41
15	3.51
16	3.31
17	2.24
18	2.44
19	1.77
20	2.13
21	1.86
22	1.64
23	1.74
24	1.16
25	0.56
26	0.86
27	0.91
28	1.10
29	0.64
30	0.63

Source: Sri Mic lobster processing company (1990).
*** Full moon day.**

Appendix. 5.1 Monthly relative condition factor, standard deviation for male and female *Panulirus homarus*.

	Male		Female	
Month	$\bar{K}$	**SD**	$\bar{K}$	**SD**
1989				
May	0.92	0.021	0.93	0.031
June	0.91	0.037	1.26	0.033
July	1.26	0.037	1.01	0.041
August	1.21	0.061	1.11	0.066
September	1.22	0.031	0.91	0.031
October	1.10	0.012	1.16	0.041
November	1.11	0.022	1.12	0.022
December	1.02	0.031	1.21	0.041
1990				
January	0.93	0.054	0.94	0.051
February	0.86	0.066	0.91	0.021
March	0.90	0.011	0.91	0.011
April	0.91	0.021	0.93	0.031
May	0.92	0.022	0.92	0.046
June	0.96	0.052	0.96	0.056
July	1.21	0.013	1.23	0.054
August	1.29	0.010	1.31	0.018
September	1.16	0.027	1.19	0.033
October	1.11	0.032	1.20	0.051
November	1.01	0.024	1.10	0.029
December	1.12	0.045	1.06	0.042
1991				
January	0.98	0.044	0.89	0.013
February	0.92	0.043	0.90	0.022
March	0.98	0.031	0.96	0.033
April	0.92	0.013	0.90	0.042

Appendix. 5.2a Length frequency data for male *Panulirus homarus* during the study period (in total length mm).

	1988/89 Lobster season								
Total length	Jan.	Feb.	Mar.	Apr.	Aug.	Sep.	Oct.	Nov.	Dec.
35							02		
45							02		
55							01	03	
65							02	03	
75						01	02	04	04
85		01				04	07	06	01
95	05	03		01		03	06	15	02
105	14	00		04		00	07	21	04
115	45	04	04	12	04	06	11	26	03
125	39	14	10	10	14	03	20	54	30
135	85	17	24	34	28	18	39	74	52
145	60	28	27	34	20	19	61	91	51
155	71	30	40	28	57	40	60	65	41
165	68	28	23	18	74	35	51	43	32
175	54	16	20	23	80	44	65	39	28
185	47	17	18	20	94	68	93	40	15
195	42	11	17	20	61	56	104	59	11
205	38	07	12	18	44	53	107	103	14
215	39	12	07	08	30	42	85	107	23
225	23	07	06	10	19	17	60	93	11
235	19	08	04	11	14	08	31	61	30
245	07	05	06	09	07	03	12	21	21
255	09	01	00	05	05	01	06	08	06
265	08	01	02	02		01	04	09	01
275	05		01	01			00	04	
285	01			00			05	03	
295	01			02			02	01	
305								01	
	660	215	221	270	551	442	845	954	380

Appendix. 5.2b. Length frequency data for male *Panulirus homarus* during the study period.

Total Length (mm)	Jan.	Feb.	Mar.	Apr.	Aug.	Sep.	Oct.	Nov.	Dec.
	1989/90 Lobster season								
35									
45							04		
55							03	05	
65							01	02	
75							01	03	02
85		01				05	04	07	03
95	03	05		02		04	05	13	03
105	16	01		06	01	03	09	22	06
115	50	05	07	08	06	05	12	31	04
125	36	10	13	09	17	04	17	50	31
135	52	19	27	27	27	13	43	84	61
145	51	22	21	33	24	22	56	86	60
155	54	38	25	20	61	37	55	68	44
165	47	25	23	21	82	45	71	66	42
175	52	18	23	23	97	33	68	41	22
185	44	18	17	24	82	62	84	44	23
195	28	10	13	29	74	71	125	69	29
205	33	05	16	16	31	37	89	86	24
215	30	09	06	09	37	31	94	109	15
225	21	09	03	09	26	17	52	88	14
235	15	07	04	09	12	09	30	42	35
245	05	03	04	13	04	01	11	25	22
255	04	02	01	02	04	01	07	10	04
265	06	01	01	01		03	03	09	01
275	02		01	00		01	01	01	
285	02			00			03	00	
295				01			01	02	
305							01		
	551	208	205	262	585	404	849	964	385

Appendix. 5.2c. Length frequency data for female *Panulirus homarus* during the study period.

	1988/89 Lobster season								
Total Length (mm)	Jan.	Feb.	Mar.	Apr.	Aug.	Sep.	Oct.	Nov.	Dec.
35							01	01	
45							03	01	
55							03	00	
65							04	04	
75		02					05	02	
85	03	00					04	09	
95	06	02				04	10	10	
105	14	04	03			07	06	11	01
115	19	10	05	03		04	09	19	05
125	34	24	04	07	04	09	19	40	10
135	60	40	13	13	11	10	03	40	22
145	63	68	30	12	03	09	50	50	23
155	60	44	28	08	19	07	44	26	21
165	56	31	19	14	28	19	50	40	38
175	41	26	11	30	67	31	24	20	55
185	23	34	24	16	70	28	49	30	61
195	27	19	14	15	63	44	101	40	54
205	19	18	15	18	40	43	144	74	30
215	20	17	09	20	43	24	100	60	28
225	12	11	09	30	52	30	91	57	19
235	10	09	10	31	21	20	47	28	12
245	03	10	09	25	12	19	39	20	08
255	07	09	04	12	09	13	18	15	07
265	02	07	05	09		05	08	07	09
275	04	06	04	08		02	06	06	04
285				03		06	07	04	04
295								02	
305								01	
	483	391	216	274	442	334	845	617	411

Appendix. 5.2d Length frequency data for female *Panulirus homarus* during the study period (total length)

	1989/90 Lobster season								
Total length (mm)	Jan.	Feb.	Mar.	Apr.	Aug.	Sep.	Oct.	Nov.	Dec.
35									
45							04	02	
55							03	01	
65							03	04	
75		01					03	03	
85	04	00					05	07	
95	07	01				06	11	08	
105	21	08	03			04	08	12	
115	22	14	03	02		02	11	19	08
125	38	27	02	05	02	08	20	25	11
135	64	48	15	09	04	03	06	53	20
145	75	66	41	14	03	06	38	58	27
155	77	48	31	17	17	03	60	31	25
165	57	40	32	15	32	19	31	38	42
175	48	31	11	08	37	40	37	29	52
185	32	41	28	14	65	44	56	37	79
195	26	32	13	15	74	57	76	46	62
205	23	20	18	12	50	51	86	59	32
215	18	17	21	21	61	28	97	73	37
225	21	21	13	35	28	36	64	37	23
235	14	13	13	36	24	16	64	34	16
245	07	11	09	29	23	08	51	29	08
255	04	13	04	13	12	12	20	18	19
265	02	08	03	07		04	10	07	11
275	05	06	02	07		05	08	03	04
285	01					06	07	06	01
295								01	
305									
	569	466	262	259	432	357	779	640	468

Appendix 5.3 ***Panulirus*** **spp. - Growth parameters and mortality estimates from different regions of the world (CL - Carapace Length mm).**

Source	Location	Species	Sex	L_{00} (CL)	K (yr^{-1}	Z	M	ø
Bowen & Chittlebo rough (1966)	Western Australia	*P.cygnus*	Both	-	-	0.8 - 2.4	0.59 - 2.1	-
Morgan (1977)	Australian waters	*P.cygnus*	Both	-	-	0.87 - 1.01	0.23	-
Munro (1974)	Caribbean waters	*P. argus*	Both	-	-	0.5 -1.52	-	-
Sanders & Bouhlel (1984)	Yemen waters	*P. homarus*	Male Female	136.4 117.7	0.46 0.44	2.41 2.30	0.85 0.85	3.93 3.78
Chittlebo rough (1976)	Australian waters	*P. longipes*	Both	113.0	0.46	-	-	3.77
Mohamed & George (1968)	Indian waters	*P. homarus*	Male Female	312.0 * 303.0 *	0.72 0.62	-	-	-

Appendix 5.3 contd.......

Smale (1978)	South African waters	*P. homarus*	Male Female	120.0 94.2	0.18 0.34	-	-	3.40 3,48
Ebert & Ford (1986)	Marshall Islands	*P. penicillatus*	Male Female	146.0 96.5	0.21 0.58	-	-	3.65 3.73
Arellano (1989)	Philippine waters	*P. penicillatus*	Male Female	161.0 153.0	0.13 0.17	-	-	3.35 3.68
Vranckx (1972)	New Amsterdam Is.	*J. paulensis*	Both	-	-	0.30 - 1.19	-	-
Jayawickrama (1991)	Sri Lanka	*P. homarus*	Both	287.0*	0.43	1.08	1.04	-
Present study	Sri Lankan waters	*P. homarus*	Male Female	126.8 121.3	0.214 ** 0.269 **	2.10 1.62	0.98 0.92	3.56 3.62

* L_{oo} given in total length. ** K - values computed given average O & L_{oo} through Wetherall plot.

Appendix. 6.1 Abundance of *Panulirus* lobsters recorded in five different habitats in twenty five diving operations.

	A	B	C	D	E	F
SR	26	00	01	00	00	00
SR	24	00	02	00	02	00
SR	24	00	01	00	00	00
SR	36	00	01	01	00	01
SR	36	00	02	00	00	00
LR	13	02	00	00	01	00
LR	11	01	01	00	01	01
LR	19	04	00	01	00	00
LR	12	02	00	01	00	00
LR	19	02	00	00	00	00
CR	01	03	00	00	04	00
CR	01	06	00	00	02	00
CR	02	02	00	01	03	00
CR	00	03	01	01	01	00
CR	00	03	00	01	03	00
MB	00	00	00	00	00	00
MB	01	00	00	02	00	01
MB	00	00	00	01	00	01
MB	00	00	00	03	00	01
MB	00	00	00	00	00	00
RB	02	02	07	00	01	00
RB	03	01	08	00	00	00
RB	03	01	08	01	00	00
RB	01	01	11	00	00	00
RB	02	01	10	00	00	00

A - *P. homarus* B - *P. longipes* C - *P. penicillatus*
D - *P. ornatus* E - *P. versicolor* F - *P. polyphagus*
SR - Sand stone reef LR - Lime stone reef CR - Coral reef
MB - Muddy bottom RB - Rocky bottom

Papers published from the study:

1. Jayakody, D. S. (1989). Size at onset of sexual maturity and onset of spawning in female *Panulirus homarus* (Crustacea: Decapoda: Palinuridae) in Sri Lanka. Mar. Ecol. Prog. Ser., **57**: 83-87.

2. Jayakody, D.S. (1992). On the growth, mortality and recruitment of the spiny lobster *Panulirus homarus* (Linn.) in Sri Lankan waters. Fishbyte, **10** (in press).

Vol. 57: 83–87, 1989 | MARINE ECOLOGY PROGRESS SERIES Mar. Ecol. Prog. Ser. | Published September 15

Size at onset of sexual maturity and onset of spawning in female *Panulirus homarus* (Crustacea: Decapoda: Palinuridae) in Sri Lanka

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ABSTRACT: The average length at which female spiny lobsters *Panulirus homarus* attain sexual maturity was determined in Sri Lanka from 1986 to 1988 by observing changes in length of the tail, which later provides the substratum for attachment of fertilized eggs. Results were confirmed by observing the presence of spermatophores on the females' sternum. The size at onset of oviposition (spawning) was estimated by considering the '50% ovigerous' level. Results indicate that female *P. homarus* attain sexual (gonad) maturity after a rostral carapace length (RCL) of between 38 and 47 mm is reached. The size at onset of oviposition (spawning) was estimated as 59.5 mm RCL.

INTRODUCTION

The onset of sexual maturity in female spiny lobsters can be determined by the presence of several externally visible features, viz. well-developed pleopod endopodal setae (Street 1969, Pollock & Augustyn 1982), presence of spermathecae (Munro 1974, Morizur 1983), and presence of externally attached eggs (Kensler 1967). Both Fielder (1964) and Morizur (1983) noted the state of ovary development as a feature and Templeman (1935, 1944) demonstrated that abdomen width in female homarid lobsters increased relative to body total length at sexual maturity. George & Morgan (1979) noted external elongation of the anterior pairs of walking legs of *Panulirus versicolor* corresponding with onset of maturity.

Many authors have used the '50% maturity level' (i.e. the smallest carapace length at which 50% of a population bears eggs) as an index of maturity and breeding, although studies by Chittleborough (1976) on *Panulirus longipes* and by Booth (1984) on *Jasus verreauxi* demonstrated a delay between the appearance of pleopod setae and spawning. At least 2 interconnected physiological changes appear to govern the changes associated with sexual maturity and the onset of oviposition (spawning). By itself the 50% maturity criterion can be misleading unless size at spawning is also considered. In this study the relationship is examined between carapace and abdomen (tail) lengths and the presence of eggs of the spiny lobsters *Panulirus homarus* (L.), to determine sizes at which changes occur associated with sexual maturity and onset of oviposition (spawning).

MATERIALS AND METHODS

Lobster landing sites along the south coast of Sri Lanka were visited fortnightly from 1986 to 1988 and all the lobsters *Panulirus homarus* landed by randomly selected boats on a particular day were measured at the landing site. Lobsters were handled in fresh condition and length measurements were made to the nearest mm using a measuring board. The sex of each specimen was recorded and other information for female lobsters, such as the presence of spermatophores and eggs, was recorded.

Carapace length (standard length) was measured in the mid dorsal line from the anterior end of the rostral horns to the posterior margin of the carapace. Lobsters with regenerating horns were not included in this analysis. Rostral carapace length (RCL) values were plotted against tail length values for males and females separately. The steps used in this analysis were the

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0171-8630/89/0057/0083/$ 03.00

same as those used by George & Morgan (1979) and Grey (1979) in their intersect analysis. The resulting plots were examined visually for discontinuities in the slopes of the regressions. Least squares regressions were fitted separately to immature males and females, mature males and mature females. Student's *t*-test was used to determine the validity of the slopes of regression lines. The value of the intersect of the 2 regression lines (mature males and mature females) was calculated for carapace and tail length data for which a significant difference in slope of the 2 regression lines was observed. As there was no statistically significant difference in the slopes of the regression lines of immature males and females, the data were combined to construct a single regression line.

RESULTS

Carapace length/total length and tail length relations

The fitted regression lines for the relations between RCL and total length values for male and female *Panulirus homarus* are shown in Fig. 1.

Carapace length and tail length values were also plotted (Fig. 2), and 3 regression lines were considered: (1) for immature lobsters of both sexes (below 35 mm RCL); (2) for mature males (over 50 mm RCL); (3) for mature females (over 50 mm RCL).

In fitting regressions, lengths were taken in cm. Regression equations and other relevant data are summarised in Table 1.

The carapace length vs total length plot (Fig. 1) shows a similarity in growth patterns in males and females in the early stages, but later in life, females become longer than males. When the carapace length vs tail length plot is considered (Fig. 2), the female abdomen is seen to grow faster in length than that of the male in later life. This phenomenon is considered to be an adaptation to bear eggs once they are fertilised, and the inflection point is used here as a measure of size at first sexual maturity. According to Fig. 2, the female has a longer tail than the male above a size of about 38 mm RCL. (As in Templeman [1935] and George & Morgan [1979], the inflection point [Fig. 2] has been estimated by eye.)

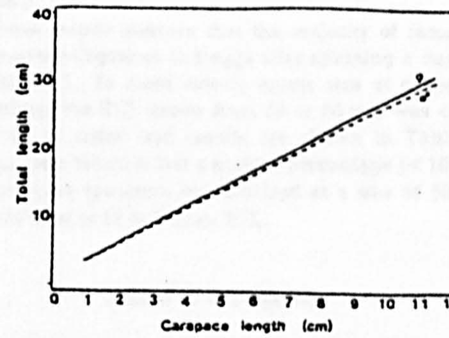

Fig. 1. *Panulirus homarus*. Fitted regression lines for total length and carapace length relationship for males and females collected from the south coast of Sri Lanka

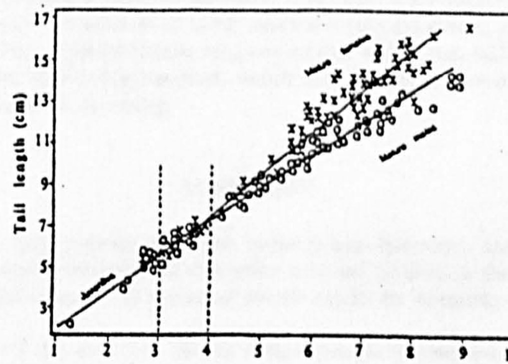

Fig. 2. *Panulirus homarus*. Fitted regression lines for carapace length and tail length of males (O) and females (X). Dotted lines show intersect area and 'point of upturn'

Spermatophore formation

Females with spermatophores were observed throughout the year but the smallest individual females bearing spermatophores were observed in October

Table 1. *Panulirus homarus*. Summary of regressions describing relationships between rostral carapace length (RCL)/total length (Lto) and RCL/tail length (Ltl) for males and females

Sex	X	Y	Regression equation	N	r	Prob > F
Male	RCL	Lto	Y = 1.3146 + 2.5158 X	320	0.9904	0.0001
Female	RCL	Lto	Y = 1.3582 + 2.5982 X	376	0.9736	0.0001
Immature male/female	RCL	Ltl	Y = 0.2353 + 1.7657 X	22	0.8657	0.0001
Mature male	RCL	Ltl	Y = 1.0231 + 1.5646 X	47	0.9664	0.0001
Mature female	RCL	Ltl	Y = −0.0938 + 1.9528 X	53	0.9539	0.0001

Table 2. *Panulirus homarus*. Summary of linear measurements, spermatophore and egg condition of the 2 smallest females observed during the study. Lto: total length; Ltl: tail length; RCL: rostral carapace length

Female no.	Lto (mm)	Ltl (mm)	RCL (mm)	Spermatophore	Eggs
1	136	89	47	White	Bright orange
2	133	85	47	White	Bright orange

1986 and November 1987. Detailed observations on these 2 females are summarised in Table 2.

The external appearance of the spermatophores indicated that the females had scraped the outer hard cover of the spermatophores to release sperms for fertilization. The presence of orange eggs further supported this observation and indicated recent fertilization. The presence of ovigerous females with spermatophores at a rostral carapace length of 47 mm indicates that they had attained sexual maturity at a much smaller size (possibly 10 mm or more smaller RCL), in agreement with the present value of 38 mm RCL estimated from the RCL/tail length studies for the onset of maturity in the female.

Size at onset of spawning

Females encountered during the study period could be broadly categorised into 2 carapace length groups, and for each the presence or absence of spermatophores and eggs was noted. Results are shown in Table 3.

These results indicate that the majority of females bear spermatophores and eggs after attaining a size of 50 mm RCL. To more closely assess size at onset of breeding, the RCL group from 50 to 60 mm was considered in detail and results are shown in Table 4. These data indicate that a smaller percentage (< 10 %) of first-time spawners are fertilized at a size of 50 to 55 mm than at 56 to 60 mm RCL.

Size at 50 % ovigerous

Numbers of females bearing extrenally visible eggs in different length groups are given in Table 5.

Percentage maturity values were plotted against the mid length values of the each RCL group on probability paper (Wenner et al. 1974), and the results are shown in Fig. 3. This technique suggests a value of 59.5 mm RCL for 50 % ovigerous level, which corresponds to size at onset of spawning.

DISCUSSION

Size at onset of sexual maturity and spawning are important biological characters that can be used in the management of exploited lobster stocks for determin-

Table 3. *Panulirus homarus*. Summary of 2 broad categories (0 to 50 mm and 51 to 100 mm RCL) of females bearing spermatophores and eggs

RCL (mm)	% without spermatophores and eggs	% with spermatophores but no eggs	% with spermatophores and eggs	N
0– 50	98.4	0.00	1.60	91
51–100	26.12	17.83	56.05	285

Table 4. *Panulirus homarus*. Summary of 2 narrow categories (50 to 55 mm and 56 to 60 mm RCL) of females bearing spermatophores and eggs

RCL (mm)	% without spermatophores and eggs	% with spermatophores but no eggs	% with spermatophores and eggs	N
50–55	85.72	5.71	8.57	33
56–60	71.43	7.14	21.43	44

Table 5. *Panulirus homarus*. Summary of percentage maturity values of females in each 5 mm RCL size class

	Length group (RCL, mm)								
	40–45	46–50	51–55	56–60	61–65	66–70	71–75	76–80	81–85
Percentage maturity	0.0	1.61	11.0	44.1	58.5	80.0	100.0	94.7	100.0

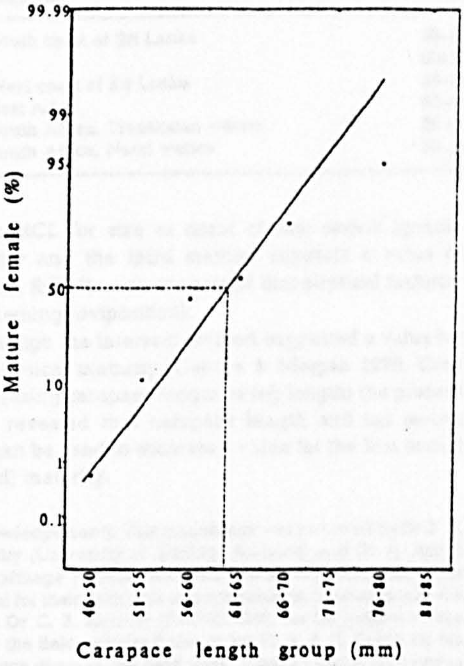

Fig. 3. *Panulirus homarus.* **Percentage of female spiny lobsters in each 5 mm rostral carapace length size class which were mature. This illustrates the probability paper technique for estimating size at onset of breeding**

ing a suitable minimum legal size (Annala et al. 1980, Booth 1984).

External secondary sexual features, such as the presence of ovigerous setae, a spermatophoric mass or external eggs, are those commonly in use for the determination of the size at first physical maturity of female lobsters. Of these features, the smallest carapace length at which 50 % have mated (generally known as 50 % maturity) is the most usually used. Information on the size at first maturity of male lobsters is generally lacking. Heydorn (1965, 1969) concluded from his work on rock lobsters that testis examination does not provide accurate results and therefore gives no reliable indications of stages in the reproductive cycle. Berry (1970) and George & Morgan (1979) observed the extreme elongation of frontal walking legs (especially 2nd and 3rd) during the period of physical maturity and suggested that this can be used to estimate the size at first physical maturity of males. Heydorn (1969) showed that the smallest sexually mature female *Panulirus homarus* observed had a carapace length of 43 mm in South African waters. Heydorn further suggested that it is possible to assume that the female population as a whole can be regarded as being sexually mature in the research area at a carapace length of 50 mm and more. Berry (1970), working in South African waters, concluded that the majority of females were mature at 54 to 60 mm carapace length. Where Sri Lankan waters are concerned, De Bruin (1962) suggested that *Panulirus dasypus* (later named *Panulirus homarus*) reach a length of 55 to 59 mm carapace length with the onset of maturity.

Booth's (1984) data on *Jasus verreauxi* indicated that there is a delay between the first development of ovigerous setae and the bearing of eggs, and further concluded that most females develop eggs at a carapace length 10 mm or more greater than that at which they first develop setae. It is seen from the present study that the graphs for males and females (Fig. 2) overlap up to 38 mm RCL, after which there is a distinct separation of regression lines. It should be noted that the smallest ovigerous females were found with RCL 47 mm. The overlapping of the graphs at RCL 38 mm might be attributed to the minimum size of the starting of gonad maturity. The separation of the graphs after 38 mm on the other hand might be due to a differential relative growth pattern between the 2 sexes. The total length vs RCL plot for both sexes (Fig. 1) also indicates a slow and gradual trend of higher growth of females relative to males with size, but from the tail length vs RCL plot (Fig. 2), the elongation of the tail of females seems to be very marked after 38 mm RCL. This is throught to be an adaptation of female *Panulirus homarus* to provide a suitable surface area under the tail for incubation of eggs after fertilization has taken place. The results obtained in this study indicate that, similar to the intersect method, linear regression analysis of carapace and tail length data can be used to differentiate juvenile from adult *P. homarus*. The estimate made, based on the '50 % ovigerous' level using the probability paper method, provides clues about size at onset of breeding and corresponds to a RCL value of 59.5 mm, a slightly higher estimate than that of De Bruin (1962). De Bruin's estimate of size at first maturity of *P. homarus* was based on data from the west coast of Sri Lanka, whereas estimates in the present study are based on data collected from the south coast. Differences in size at first maturity between localities are known to exist in several spiny lobster species (Matthews 1962, Heydorn 1965, Street 1969, Annala et al. 1980). Size at first maturity values estimated for *P. homarus* in different regions are shown in Table 6.

In the present study, 'size at first maturity' was estimated by using 3 different methods: (1) the tail length vs RCL plot; (2) observations on smallest females with spermatophoric mass and eggs; and (3) '50 % ovigerous' level using the probability paper technique. When the *Panulirus homarus* population is considered as a whole, the first 2 methods suggest values of 38 to

Table 6. *Panulirus homarus*. Size at first maturity of females from different regions of the world. CL: carapace length

Location	Size at first sexual maturity	Source
South coast of Sri Lanka	38–47 mm CL (59.5 mm for oviposition [spawning])	This study
West coast of Sri Lanka	55–59 mm CL	De Bruin (1962)
East Aden	60–70 mm CL	George (1963)
South Africa, Transkeian waters	50 mm CL	Heydorn (1969)
South Africa, Natal waters	54 mm and greater CL	Berry (1971)

47 mm RCL for size at onset of first sexual (gonad) maturity and the third method suggests a value of 59.5 mm RCL for size at onset of first physical maturity or spawning (oviposition).

Although the intersect method suggested a value for first physical maturity (George & Morgan 1979, Grey 1979) (using carapace length vs leg length) the present study revealed that carapace length and tail length data can be used to estimate a value for the first sexual (gonad) maturity.

Acknowledgements. This manuscript was reviewed by Dr D. S. McLusky (University of Stirling, Scotland) and Dr A. Ansell (Dunstaffnage Marine Research Laboratory, Scotland). I am grateful for their criticisms and suggestions. Special thanks are due to Dr C. B. Kensler (FAO/UNDP), for his helpful advice during the field visits and also to Mr H. A. R. E. Perera for his assistance given in the field work. Finally I thank anonymous referees who provided substantive comments to improve the quality of this paper. This research was supported by the National Aquatic Resources Agency, Sri Lanka.

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This article was presented by Dr D. S. McLusky, Stirling, Scotland

Manuscript first received: January 20, 1989
Revised version accepted: May 11, 1989