BIONOMICS OF THE MUD CRAB FISHERY

Scylla serrata

by

Sepalika Chandrani Jayamanne

1991

FR 847T

BIONOMICS OF THE MUD CRAB FISHERY *Scylla serrata*

BY

SEPALIKA CHANDRANI JAYAMANNE

B.Sc.(Hons)

(University of Sri Jayewardenepura)

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Philosophy of the Faculty of Applied Science, University of Sri Jayewardenepura, Nugegoda, Sri Lanka.

January 1991

The work described in this thesis was carried out by me at the National Aquatic Resources Agency under the supervision of Dr. J. Jinadasa and a report on this has not been submitted to any university for another degree.

Signed Jayamanne

Date: 11/02/91

(Sepalika Chandrani Jayamanne)

TABLE OF CONTENTS

LIST OF TABLES

L I S T O F F I G U R E S

ACKNOWLEDGEMENTS

First and foremost I wish to record my sincere gratitude to Dr. J.Jinadasa, Head, Department of Zoology, University of Sri Jayawardenepura, Sri Lanka for supervising this research project and for the guidance and constant encouragement extended to me throughout the study. I am also indebted to him for various advice and support given to me in preparation of this thesis. It is been a great pleasure to work with Dr.J. Jinadasa.

This research was a collaborative project of National Aquatic Resources Agency and Natural Resources, Energy and Science Authority (RG/85/B/5). I am indebted to both these institutions for accepting this research proposal and providing funds and the other assistance to implement the project.

I appreciate the encouragement and advice extended to me at all stages of the study by my colleagues: Mr.J.M.P.K.Jayasinghe, Mr.U.S.Amarasinghe Mr. D.S. Jayakody and Mrs.M.M.Kuruppu.

My sincere thanks are also due to the technical staff of the Inland Aquatic Resources Division for their fullest cooperation extended to me in carrying out the study. In this respect the services of the messrs Mr. N.N.E. Cooray, Mr. W.A. Sumanadasa, Mr. R.P.K. Tissa, Research Assistants and P.G. Gunasinghe and A.M.J. Costa Lab attendants are gratefully acknowledged.

I am also grateful to Miss L. Adipola for skillful preparation of the graphs and other drawings.

Lastly, I wish to express my deepest gratitude to Mr. Everard Jayamanne, my husband, for sharing the enthusiasm in my work and helping me in innumerable ways to complete my project successfully.

ABSTRACT: BIONOMICS OF MUD CRAB FISHERY IN THE NEGOMBO LAGOON

A B S T R A C T

Mud crab Scylla serrata is a commercially important species in the Negombo Lagoon. In the recent past the demand for crabs increased rapidly due to export as well as high acceptance in the local market. This resulted in rapid but hap-hazard exploitation of the resource endangering its existence in the lagoon. Thus, a necessity arose to introduce management practices to utilize the resource efficiently without overexploiting the species. In the light of this need a study was carried out to understand the biology and fishery of the Scylla serrata in the Negombo Lagoon.

The study was commenced in February, 1985 and was continued till December 1987.

The hydrobiological parameters were studied in five stations of the lagoon by collecting monthly water samples. The taxonomic features, food and feeding habits and the reproductive biology was studied by analyzing samples representing crabs of all sizes.

Carapace length was measured from market stocks at weekly intervals. The length data were analysed performing the ELEFAN II as implemented in Compleat ELEFAN in order to estimate growth parameters.

Attempts were also made to study the larval and juvenile populations by sampling with plankton and dip nets respectively.

The aspects related to the fishery was studied collecting information from fishermen and their spouses who live around the lagoon.

The salinity of the lagoon varied between 0-35 ppt. High saline waters were found near the mouth. The salinity variation was dependant on the rainfall. The water temperature ranged between 22°C - 34°C.

Turbidity in the lagoon was low during the latter years of the study. The pH in the lagoon water averaged within a short range (5 - 9). Rainfall was high in the catchment area with two rainy seasons a year.

The taxonomic status of Scylla serrata was confirmed by the characteristics: smooth granular carapace, 22 spines, and the well adapted chela. The colour of crabs was found to be environment dependant.

Large crabs mainly fed on mollusc whilst the small ones preferred crustaceans. No seasonal variation was observed in food items. The crabs feed continuously during the night and at the high tide in the daytime.

The asymptotic length was estimated to be 22.4 cm for both males and females. The ϕ' value obtained for the species was 5.7.

The estimated mortalities and exploitation rate indicates an over exploitation of the species. The

length at first capture and the size at first maturity further indicate an over exploitation of the immature population.

Length weight relationship show a good fit to the allometric growth equations with males and females showing no significant difference from a common formula.

The stage at first maturity was 12 cm in female crabs. The pre-spawning fecundity was estimated to be around 2 - 4 million. The post-spawning fecundity was around 1.5 million. The ova matures at the size of about 300 µm. The ova are found in three batches indicating partial spawning behaviour. Spawning takes place in two seasons April and August. The sex ratio was even in most size group, in most months of the year.

The attempts made to study the larval population was not successful. Juvenile crabs ranged between 2.7 - 7.0 cm. Their habitat was shallow areas in the lagoon. Juveniles occur in bulk during February/March and August/December.

Baited trap was the main gear used to catch crabs. Crabs also get caught as by-catches in drag net, dip net. Brush park also land crabs of small sizes.

Around 100 fishermen engaged in the fishery of which approximately 25% totally dependant on crab fishery alone for their living. Around 8 - 24 people daily engage in crabbing.

The catch varies with the season showing peaks in November and December. The crab landings comprise crabs of even 5 cm. Approximately 80% of the exploited stocks are less than 15 cm in carapace length.

The price of a big crab (>15 cm in carapace length) is around Rs. 17.00. A Kg of meaty crabs is worth about 3 us$.

Catch per unit effort was showing a declining tendency over the three years of study.

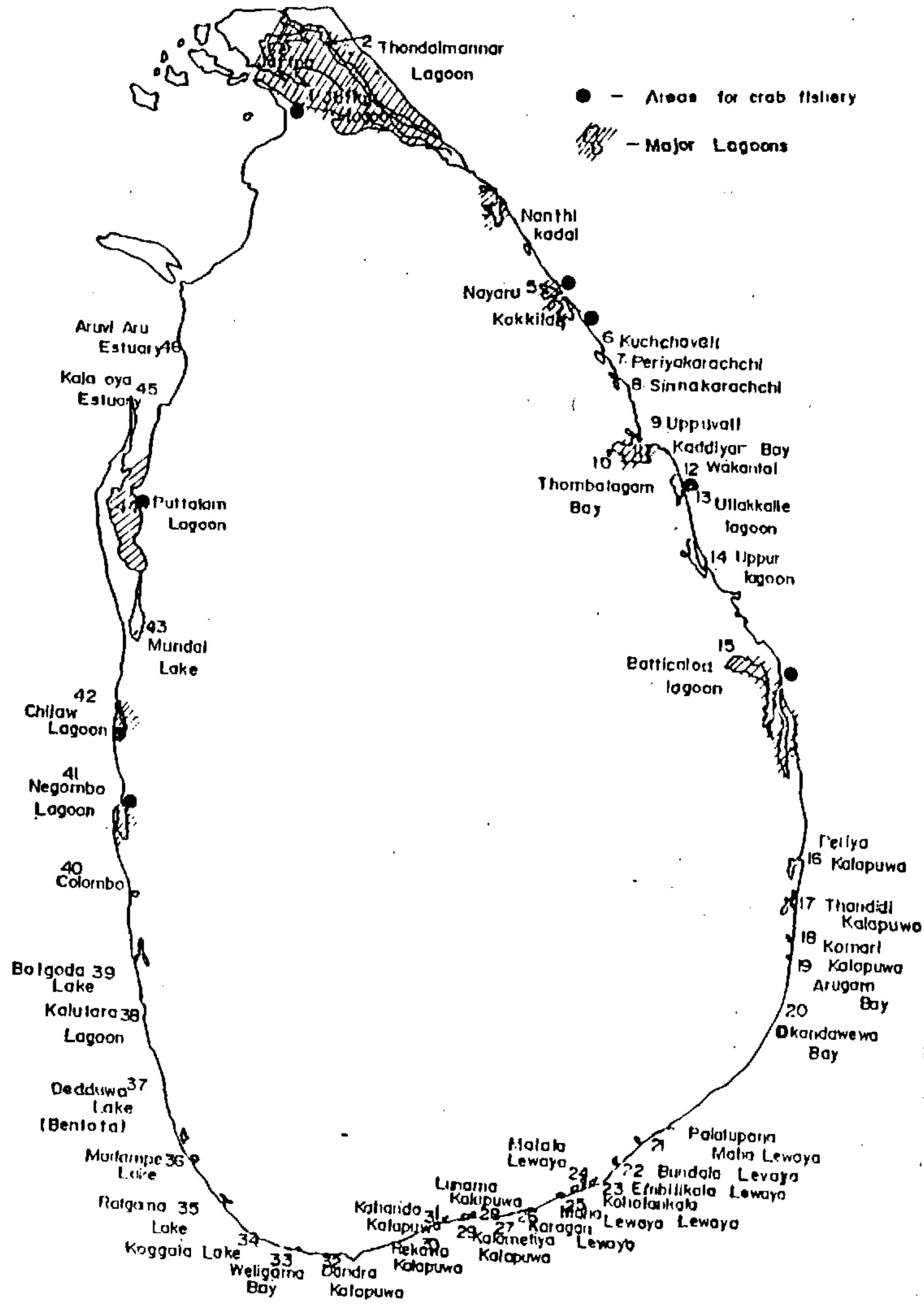
I N T R O D U C T I O N

Sri Lanka, an island in the Indian Ocean, has an estimated brackish water area of around 120,000 ha. About 65% of the brackish water area consists of estuaries and large deep lagoons. The rest comprise shallow lagoons, tidal flats and mangrove swamps (Pillay, 1967., Samaranayake, 1986).

There are about 40 lagoons and estuaries in Sri Lanka. They are mostly found in northern, north western and eastern coasts of the island (Pinto and Kotagama, 1987). Locations of major lagoons and estuaries of Sri Lanka are demarked in Figure 1 (reprinted from Samarakoon and Pinto, 1986).

Lagoonal and estuarine fauna in Sri Lanka has been a popular subject of some authors in the past. The fauna comprise fin fishes such as Chanos chanos and species of genera, Liza, Siganus, Lates, Lutjanus, Epinephalus, Etroplus, etc. (Samarakoon, 1983 and 1985 ; Wijeyaratne and Costa, 1986.), crustaceans; Penaeus indicus, P. monodon, P. semisulcatus, Metapenaeus dobsoni, M. elegans,

Fig.01 Major Lagoons and estuaries in Sri Lanka highlighting the main crab fishing areas in the country.


Areas for crab fishery
Major Lagoons
2 Thondalmannar Lagoon
Nanthi kadal
Nayaru 5
Kokkilai
6 Kuchchavali
7 Periyakarachchi
8 Sinnakarachchi
9 Uppuvali
Kaddiyar Bay
10 Thombalagam Bay
12 Wakantai
13 Ullakkalie lagoon
14 Uppur lagoon
15 Batticaloa lagoon
Periya 16 Kalapuwa
17 Thandidi Kalapuwa
18 Komari
19 Kalapuwa
Arugam Bay
20 Okandawewa Bay
21 Palatupana Maha Lewaya
22 Bundala Lewaya
23 Embilikala Lewaya
Koholankala Lewaya
Malala Lewaya 24
25 Maha Lewaya
26
27 Kalametiya Kalapuwa
Karagan Lewaya
28 Lunama Kalapuwa
29
30 Rekawa Kalapuwa
31 Kahanda Kalapuwa
32 Dondra Kalapuwa
33 Weligama Bay
34 Koggala Lake
Ratgama 35 Lake
Madampe 36 Lake
Dedduwa 37 Lake (Bentota)
Kalutara 38 Lagoon
Bolgoda 39 Lake
40 Colombo
41 Negombo Lagoon
42 Chilaw Lagoon
43 Mundal Lake
Puttalam Lagoon
Kala oya 45 Estuary
Aruvi Aru Estuary 46

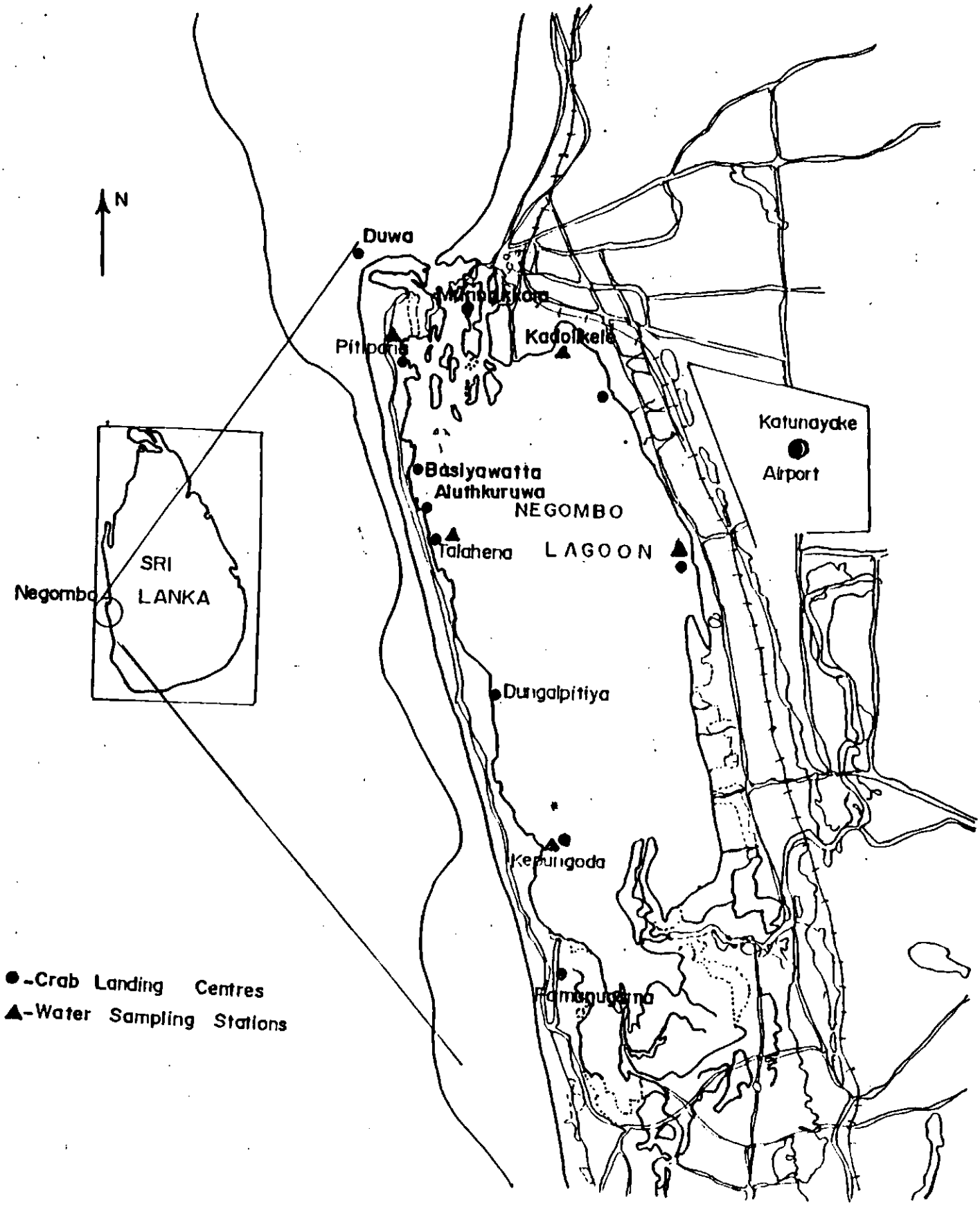
M. monoceros, and Macrobrachium species, and crabs; Scylla serrata, Neptunus pelagicus and N. sinensis (Pinto, 1986).

Molluscs and Oysters such as Crassostrea species and cockles, Anadora granosa are reported to be abundant in east and west coasts of Sri Lanka (Pinto and Wignarajah, 1980).

Negombo Lagoon (7° 10 ' N and 79° 50' E) is located in the west coast of Sri Lanka about 30 km north of Colombo (Figure 2.). It is a highly productive basin estuary with an extent of 3227 ha (unpublished data, 1989 NARA). The lagoon is connected to Ja-ela and Dandugam Oya from its southern boundary. It is open to the sea throughout the year from its northern boundary.

The main fishing attraction in the Negombo Lagoon is prawns which have a very high demand in the local and export market. Prawns are commonly fished by cast nets, stake seine nets, drag nets, drift nets, and brush parks. Crabs are also a major fishery in the Negombo Lagoon and are usually

Fig.02 Main crab landing centres and the sampling stations selected for monitoring of environmental parameters in the Negombo Lagoon.


N
Duwa
Kadolkele
Katunayake
Airport
Basiyawatta
Aluthkuruwa
NEGOMBO
Talahena
LAGOON
SRI
LANKA
Negombo
Dungalpitiya
Kepungoda
●-Crab Landing Centres
▲-Water Sampling Stations

caught by baited traps. They also get caught as by-catch in drift nets, drag nets and brush parks geared to catch prawns. Fin fish fishery too is important in the Negombo Lagoon although they are caught as by-catch of gear set for prawns. The average fin fish production in the Negombo Lagoon was estimated to be around 13 - 17/Kg/ha/yr in 1986 (Samaranayake, 1986).

1.1 The mud crab, Scylla serrata (Forskal)

The mud crab Scylla serrata is a portunid crab, a member of a group of swimming crabs having the last pair of legs flattened for swimming. Scylla serrata is the largest of the portunid crabs. It has a wide distribution, occurring around the northern half of Australia, eastward into the Pacific as far as Figi and Samoa, northwards to the Philippines, westward across the Indian ocean to the east coast of Africa (Cowan,1982). It is also known as the mangrove crab (Australia), Samoan crab (Hawaii), alimango (Philippines), tsai jim (Taiwan) and nokogiri gazami (Japan) (Cowan,1982). It is best known in

Sri Lanka as ` kalapu kakuluwa ' or ` ala man kakuluwa'. Scylla serrata is usually found in sheltered waters mostly in mangrove areas.

Disagreement still exists over the number of species in the genus Scylla. Estampador (1949) used differences in colour, morphology and habitat to classify the genus into three species (serrata, oceanica and tranquebarica. This was criticized by Stephenson and Campbell (1960) as not backed by adequate quantitative evidence. Therefore, mud crabs are often described in literature as a single species Scylla serrata. Crab farmers in Taiwan have also recognized three varieties of Scylla: the `sand crab', `red legged crab' and `white crab' (Chen, 1976), all of which were assumed to be the same species.

The life cycle of Scylla serrata consists of four stages; egg zoea, megalopa and crab. Adult crabs (130 mm carapace width upwards) are said to occupy deeper subtidal areas. But they migrate to intertidal areas for feeding (Hill et al., 1982). Although crabs mate in the estuary spawning occurs

in the sea. They return to estuarine waters after spawning (Heasman, 1980). The eggs take 12 - 30 days to hatch into a larva called zoea. The zoea is a free swimming stage about 2 mm long. Zoea lives in the sea where it feeds and passes four instar stages before moulting into a stage known as megalopa. This stage is about 3 mm long and lives in inshore waters. The megalopa stage moults into a small crab. The total larval life lasts about 30-44 days (FAO Report, 1981).

Scylla serrata is an excellent candidate for fishing and farming because of its good eating qualities, wide market acceptance and insufficient supply to meet the world demand. It is also advantageous in that it does not require freezing equipment for storage as it can survive several days outside water. Scylla serrata is easily accessible to small canoes (orus) due to its shallow estuarine habitat. It is also attracted to baited pots which do not require constant tending.

1.2 The status of the mud crab fishery in Sri Lanka

Mud crabs are found in almost all the lagoons and estuaries in Sri Lanka at varying densities. They are abundant in lagoons and estuaries of west, north, & east coasts (Jayasuriya, 1985., De Silva and De Silva, 1986). Although not in macro scale, the presence of Scylla serrata in the lagoons and estuaries of the south coast has also been reported (Maitipe and De Silva, 1986). Crabs are mostly fished in Jaffna, Kokkilai, Nayaru, Batticaloa Trincomalee, Puttalam, Chilaw, and Negombo lagoons.

The mud crab fishery is one of the most important fishing industries in Sri Lanka. It has a high demand in local and export markets. The current (1989) price of a kilo gram of meaty crabs is around Rs.120.00 (3 US$). Crabs are now becoming a popular export commodity as well. The National Aquatic Resources Agency is presently planning a research project to develop methodology for fattening crabs as a response to the growing interest of local businessmen for exporting 'fattened crabs' to Singapore and Japan.

Scylla serrata is considered as one amongst 6 species of crabs which are most important in the world market. The strong market demand for crabs in the high income areas of the world (Alverson, 1971) emphasizes the importance of crabs for a developing country like Sri Lanka. Therefore, a precise management strategy for the crab fishery based on scientifically collected information is a prime need of the country. However, the country, at present, is lacking such information with respect to Scylla serrata despite two research studies carried out in the past: Raphael (1970) and Arudpragasam (1967). These were preliminary investigations, on the aquaculture potential of the mud crab and host-parasite relationship of Scylla serrata and Octolasmis cor respectively.

1.3 Mud crab research - International experience

Although references to research studies on Scylla serrata were scant in Sri Lanka, the experience of other countries in the Asia Pacific Region was fairly wide. The annotated bibliography of Scylla serrata prepared by Matilda and Hill (1980) quotes

over 100 references on various aspects of the mud crab. The bibliography on "Mud crab fishery" prepared by SEAFDEC (1985) Aquaculture Department quotes over 200 references on Scylla serrata.

In addition to the vast literature available on the physiology of the species (Dall, 1967., Taira, 1967., Sandeman, 1973., Silvey, 1974., Hill, 1976., Leggett, 1976., Hanumante, et al., 1979) there were also references to the Biology and Fishery of the mud crab comprising studies on food and feeding (Hill, 1976 and 1979b), reproduction (Ong, 1965., Brick, 1974), abundance (Heasman, 1980), population dynamics (Hill, 1975 and 1979 a), growth (Heasman, 1980) and aquaculture (Escritor, 1972).

There were references to the distribution of mud crabs in almost all the countries of the Indo-Pacific region. These countries include Australia (Heasman, 1980), Figi (Cowan, 1982), Formosa (Nakamo, 1931 -1933), Hawaii (Atkinson, 1971), India (Jones and Sujansingani, 1952), Indonesia (Cowan, 1982), Japan (Tamura, 1970), Madagascar (Le Reste et al, 1976), Malaysia (Ong, 1966), New

Zealand (Dell, 1964., Manikiam, 1967), Pakistan (Hashmi and Zaidi, 1964), Papua New guinea (Glucksman, 1976), Philippines (Estampador, 1949), Sri Lanka (Raphael, 1970), Taiwan (Chen, 1976), Thailand (Varikul et al), and Vietnam (Serene, 1952).

The earliest reports on the mud crab studies go as far back as early 1920's and these were basically about their occurrence in certain habitats (Das Gupta Hem ch, 1924), ecology (Pearse, 1932), oogenesis (Bhattacharya, 1931), fishery (Hora, 1935) and parasites (Pearse, 1933). Majority of these studies were carried out in India.

There were a few studies on mud crab in the subsequent decades, 1940 - 1960. Amongst the few studies documented during the period, studies on taxonomy (Estampador, 1949., Barnard, 1950., Serene, 1951), morphology (Bundukul, 1957., Macnae and Kalk, 1958), breeding, rearing and life history (Arriola, 1940., Estampador, 1949., Bundukul, 1957)

and fishery (Jones and Sujansingani, 1952) were noteworthy. These studies were mostly from India and Philippines.

Studies on mud crabs became increasingly widespread in the Indo-Pacific region in 1960's with the onset of research activities in countries like Hawaii, Australia, South Africa, New Zealand, Pakistan, Malaysia and Japan. During this decade a vast amount of literature was added to the subject of mud crab. India and Pakistan documented a considerable amount of research data on physiological aspects of Scylla serrata (Ranganeker, 1954., Deshmukh and Ranganeker, 1965., Krishnamoorthy et al, 1965., Deshmukh and Ranganeker, 1966., Nagabhushanum and Rao, 1966., Menon and Sivadas, 1967 and 1968., Ranganeker and Deshmukh, 1968., Ranganeker and Madyastha, 1969). Life cycle of the mud crab (Raja Bai Naido, 1955), breeding (Ong, 1965) and rearing of crabs (Villaluz, 1953., Taira, 1965., Ong, 1966., Taira, 1967., Pillai and Nair, 1968) were also some important studies carried out during this period.

Taxonomic studies on mud crabs were also noteworthy during this period (Stephenson and Campbell, 1960., Hashmi, 1965., Sakai, 1968 and Day, 1969). George and Rao (1967) made an invaluable contribution to the literature on Scylla serrata in 1967 by preparing an annotated bibliography of the Biology and Fishery of the edible crabs in India. There were also publications on distribution of Scylla serrata in some estuaries (Manikiam, 1967 and Macnae, 1968).

During the last two decades studies on mud crabs became more and more comprehensive in the Indo-Pacific region. Research on ecology, breeding, culture and other biological aspects have progressed extensively in most countries. Studies carried out during this period made useful contributions to the knowledge of physiology of crabs. Most prominent of these were the neurophysiological studies (Sandeman and Mendum, 1971., Sandeman, 1975., Leggett, 1976., Silvey and Sandeman, 1976a, 1976b and 1976c., Mirolli, 1977, 1979 a, 1979 b etc). In addition studies on

photoreception and light sensitivity of Scylla serrata were also noteworthy (Leggett, 1976., Leggett and Stavenga, 1977).

Apart from the physiological studies there were also studies on biochemistry of the crab. Hackman (1974) studied the soluble cuticular proteins of Scylla serrata. Other biochemical studies include blood and muscle proteins of Scylla serrata (Kannupandi and Paulpandian, 1975), electrophoretic patterns of the hemolymph proteins in Scylla serrata (Maguire and Fielder, 1975), blood suger estimation (Nammalwar, 1978) and heavy metal induction of metallothionine synthesis (Olfason et al., 1979) in Scylla serrata. Studies on histochemical localization and distribution of different enzymes, lipids, acid and alkaline phosphatases and carbohydrates in hepatopancreas and cheliped muscle of Scylla serrata has also been published (Momin and Rangneker, 1974., 1975a., 1975b., 1975c., Rangneker and Momin, 1974., 1975., Momin, 1976., Momin and Momin, 1977).

Habitat of the Scylla serrata has been described by Hill (1979 a) and Hill et al. (1982). They have reported that Scylla serrata mainly occupies intertidal and subtidal sheltered areas such as mangrove roots, under stones, in reed beds and sea grass beds. The migratory habits of Scylla serrata according to size has also been described (Hill et al., 1982). Hill (1975) also found that Scylla serrata was relatively less migratory. Perrine (1978) found in the island of Ponape that there is no indication of large - scale movement by Scylla serrata. However, it has been observed that Scylla serrata move freely between the three regimes which make up their habitat; the mangrove swamp, the brackishwater channels lacing it and the shallow reefs. Le Reste et al (1976) suggested on the basis of size frequency analysis of samples of crabs that Scylla serrata migrated between mangrove and sub tidal areas in Madagascar. It has been reported from the east coast of Australia that Scylla serrata in addition to living in estuaries, also lives in projected areas behind

islands and reefs where mangrove swamps and tidal flats cover long stretches of the shore (Hyland et al., 1984). He also provide evidence to the relationship of mangrove distribution and the movement of Scylla serrata.

Dana (1972) and Maguire and Fielder (1975) contributed largely to the knowledge of taxonomy of Scylla serrata whilst Gupta and Chatterjee (1976) and Barker and Gibson (1978) concentrated mainly on the anatomy of the species.

There were also studies on food, feeding and nutritional biology of Scylla serrata. All the stages of crabs were described as predators of sessile and slow moving benthic invertebrates (Hill, 1976., 1979). Research studies carried out by Hill (1976) and Lijauco et al.,(1980) proved that only 5% of the natural diet of Scylla serrata contain fish and that it cannot entirely live on live fish. Duplessis (1971) found that female mud crabs who fed exclusively on fish suffered from nutritional deficiency.

Heasman (1980) determined the food uptake of mud crabs of various sizes at different temperatures and found that the food consumption of mud crab from post larva to 150 mm size is 3.3kg.

Two species of fungi have been isolated from eggs and larval stages of Scylla serrata (Bian et al., 1979; Bian and Egusa, 1980). Larval stages of Scylla serrata were reported to be susceptible to attacks from certain bacteria, fungi and protozoa (Ting et al ., 1981). Control methods have been developed for fungal infections by Lio - Po et al(1980).

The effect of different kinds of food on the growth of Scylla serrata has also been tested. The growth of the Scylla serrata fed with artificial food (Atkinson, 1971), Artemia nauplii (Brick, 1974) and natural food (Pagcatipunan, 1972) has been investigated and it has been found that the growth with the artificial food is better than the natural food tested. Wildman (1974)., Dickenson (1977).,

Williams (1978) and Lavina (1979) has also made significant contributions to the knowledge on the feeding biology of Scylla serrata.

The knowledge on the reproductive biology of Scylla serrata has also been broadened during the period from 1970 - 1987. Female crabs have been found to reach maturity at a size of 131 - 141 mm carapace width and they extruded upto 3 batches of eggs without mating between ovulations (Duplessis, 1971). Anatomical observations of the male reproductive organs of Scylla serrata have been reported by Gupta and Chatterjee (1976). Lavina (1977a) observed courtship and mating behavior of Scylla serrata and reported that it lasted 2 - 7 days. Effect of eye ablation on gonadal maturation of Scylla serrata has also been tested and the results were reported to be positive (Rangneker et al, 1971 and John and Sivadas, 1978).

Fecundity of Scylla serrata is estimated to be 2-6 million (Hill,1982). Mass breeding experiments on Scylla serrata has also been carried out by several authors (Escritor, 1972 ., Heasman and

Fielder, 1983 and Heasman, 1980). Sex ratio of the mud crab in estuarine conditions was found to be 50:50 (Hill, 1975., Heasman, 1980 and Williams and Hill, 1982).

Several studies have been undertaken to culture crabs. These studies have mainly dealt with growing mud crabs in ponds, cages or tanks (Escritor, 1972., Wildman, 1974 and Varikul et al.). Polyculture of crabs with other species such as Chanos chanos , Gracilaria spp etc has also been tried (Pagcatipunan, 1972 and Chen, 1976). Most of these culture practices have depended on the wild seeds (Raphael, 1970., Pagcatipunan, 1972., Chen, 1976., Lavina and Buling, 1977 and Grino, 1977). Tamura (1970) and Milne, (1976) have also made some notes on the culture of Scylla serrata. Although most of the above studies were somewhat encouraging still there are many more aspects remaining for further experimenting and development.

Several species of large teleosts are known to predate upon the mud crab (Bass et al.,1975). Heron

was also observed as a predator of Scylla serrata (Mukherjee, 1971).

Some studies related to management of mud crab fishery has also been carried out during the recent past (Glucksman, 1976., Heasman, 1980). Alverson (1971) described Scylla serrata as one amongst six species of crabs which in most important in the world market. Heasman and Fielder (1977) found that crab populations are being fished beyond their regenerative capacities and hence reviewed management strategy of Scylla serrata in Australia.

Matilda and Hill (1980) who prepared an annotated bibliography on Scylla serrata covered literature upto 1980. Another bibliography has been prepared by the Brackishwater Aquaculture Information System of SEAFDEC covering 211 research papers on Scylla serrata.

1.4 Objectives of the present study

The available literature from other countries, although they may be very useful, cannot be directly applied to local conditions for a living resource like Scylla serrata. The variables that affect to the fishery can differ from country to country, lagoon to lagoon, and time to time etc. Hence, repetition of certain studies under local situations along with innovative work is essential for the development and management of crab resource in the country. Therefore, a three-year study in the Negombo Lagoon was planned with following objectives:

1. To study the hydrobiological parameters of the Negombo Lagoon.
2. To observe the taxonomic features of the Scylla serrata in the Negombo Lagoon.
3. To study food and feeding habits of Scylla serrata in the Negombo Lagoon.
4. To study the growth parameters of Scylla serrata in the Negombo Lagoon.

5. To study the reproductive biology of Scylla serrata.
6. To study the larval and juvenile population of the Scylla serrata in the Negombo Lagoon.
7. To study the fishery and economic aspects of the mud crab fishery in the Negombo Lagoon.

M A T E R I A L A N D M E T H O D S

2.1. Measurement of hydrobiological parameters in the Negombo Lagoon.

Five sampling stations were selected to measure the hydrobiological parameters in the Negombo Lagoon. The stations were selected in order to represent the entire lagoon as much as possible in spite of the difficulties in finding access to all parts of the lagoon. The stations are highlighted in Figure 2.

Samples were collected at monthly intervals from 1985 - 1987 and the following parameters were measured.

1. Temperature: Surface water temperature was measured using a mercury bulb thermometer (Range 0°C - 100°C).

2. Salinity : Salinity was measured at the site using a Salinity Refractometer (0.- 100 ppt.).

3. **pH** : pH was measured at the laboratory using a pH meter (CHEMITRIX).

4. **Turbidity** : Turbidity was measured at the laboratory using a turbidity meter.

5. **Rainfall** : Monthly rainfall data in the Negombo Lagoon were obtained for the same period from the Department of Meteorology.

2.2 Taxonomic features of the mud crab.

The mud crab inhabiting the Negombo Lagoon was observed in order to clarify its taxonomic status. The characteristics observed were those identified and documented by Tirmizi (1986) as a guide to characterization of Scylla serrata.

2.3 Food and feeding habits

Attempts were made to identify the types of food ingested by crabs of different size groups. Crabs

obtained for this study were those caught by various gear other than baited traps because of the possibility of inclusion of the bait in the stomach contents. For this study stomachs of 392 crabs of different size groups ranging from 2 to 11 cm in carapace width were analyzed. Prior to analysis, excised stomachs were preserved in 5% formalin. Stomach contents were analyzed to the nearest taxon. The number of empty stomachs were recorded.

Qualitative as well as quantitative analyses were made on stomach contents. Percentage Occurrence Method was employed to determine relative abundance of organisms constituting the diet. The crabs examined were grouped into 1 cm size intervals and the percentage occurrence of the various food items in different size groups were calculated.

Further, an attempt was made to observe the feeding time and feeding intensity of mud crabs. Three diurnal studies were carried out using dip nets to

sample crabs at every four - hour intervals. The crabs sampled were dissected and the stomach volumes were measured in each crab.

2.4 Growth parameters of the mud crab, Scylla serrata in the Negombo Lagoon.

Carapace length (maximum width between the last antero - lateral spine on either side of the carapace) was measured in a random sample collected every week. The procedure for sampling was based on findings of an investigation made on the fishery of the crabs in the Negombo Lagoon prior to commencement of the study.

It became evident from the preliminary study that almost all crabs caught in the Negombo Lagoon come to either Katunayake, Pitipana or Negombo markets for disposal. Further it was observed that the majority of crabs landed in the Negombo Lagoon comes from the baited traps and that a marginal proportion comes from drift nets, drag nets and brush parks.

The major catch (baited trap) comes to the Pitipana market for auction in the morning whilst a small proportion goes to the Negombo market. Drift net, Drag net and brush park catches go to the Katunayake market.

Since the major catch comes from the baited traps it was decided to measure crabs at weekly intervals in the Pitipana market and to take bi-weekly measurements from Katunayake and Negombo markets.

When the catch in a sac is low and is in the range of about 50 individuals or less, all the crabs were measured. When the catch was high a random sample of about 50 were measured. Random sample were selected at "eye sight" because it is not possible to convince fishermen to permit us to sort out individual sacs in the market for a research purpose which they feel is of no interest or immediate benefit to the fishermen.

2.4.1 Analysis of length data

The length data collected during the period from 1985 -1987 were analyzed using the "Compleat ELEFAN" software package (Gayanilo et al.,1989).

Initially attempts were made to analyze data separately for each gear, but it became evident that such analysis was not possible with drift nets, drag nets, and brush parks as the data did not show adequate representation of the population. Further, the catch of these gear is also negligible. Efforts made to standardize the gear for pooling the data obtained from all four types of gear were found to be ineffective since some of the gears are fixed gear and the others are not. fixed. Hence, only the data obtained from baited traps were used for the length frequency analysis. Previous workers also have demonstrated that all gear used for this fishery are selective (Williams and Hill, 1982.).

The data were analyzed seperately for males and females and for each year. The initial analysis

proved that the growth period and recruitment period were identified in all the three years. Thus, the length frequency data of corresponding months were pooled to obtain a single length frequency sample for a 'pseudo year'.

Finally the data were analyzed to obtain growth parameters for males and females separately by using pooled data obtained from samples caught in any particular month irrespective of the year. Besides growth parameters, mortality, exploitation rate and yield per recruit analysis were also obtained by performing the ELEFAN II as implemented in Compleat ELEFAN. The data analysis procedure is as follows:

ELEFAN I is a computer programme which estimates the parameters K, L_{∞}, C and Wp of the Von Bertalanffy equation, modified to express seasonal growth in length of fish or aquatic invertebrates (Pauly and David,1981), using the length frequency data. This programme assumes that:

a. The samples used are representative of the population.

b. Length differences can largely be attributed to differences in age Samples.

c. Growth is similar from one year to the next.

d. The seasonally oscillating Von Bertalanffy growth equation provides an appropriate approximation to the growth of fish and aquatic invertebrates.

The seasonally oscillating version of the Von Bertalanffy growth function proposed by Pauly and Gaschutz (1979), has the form

$$L_t = L_\infty \left(1 - e^{-[k(t-t_o) + \frac{ck}{2} \sin(2(t-t_s))]}\right)$$

where t_o = Wp + 0.05 and all parameters are as defined in Pauly (1984) was incorporated to the ELEFAN programme.

When c=0 the equation has the form

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

which was used in the present analysis.

The procedure followed to estimate growth parameters using ELEFAN programme is as follows:

1. Length-frequency data were entered into files using ELEFAN 0.

2. Initial estimate of L_∞ (asymptotic length) was obtained using the method of Wetherall (1986), as modified by Pauly (1986) in ELEFAN II.

3. ELEFAN I was used to obtain preliminary estimates of L_∞ and K for males and females separately depending on the initial estimate of L_∞ estimated by Wetherall (1986). Using the preliminary estimates of L_∞ and K, probabilities of capture in the size classes below the fully selected length were obtained

through detailed analysis of the left ascending part of a catch curve which were subsequently used for correcting original length frequency data files. The final estimate of L_∞ and K were obtained from length frequency data files corrected for gear selection.

2.4.2 Total mortality (Z)

After growth parameters for each year had been obtained , ELEFAN II was run using the catch curve routine and total mortality (Z) for each year was estimated. ELEFAN II estimates a preliminary value for Z using the linear regression :

$$\ln (\%N/-t) = a + bt, \text{ where } t = \text{relative age}$$

Then an iteration procedure corrects the Z = -b of the regression line for the non-linearity of the growth model and for the fact that some mortality occurs within each length class. The iteration equation is :

$$\log (N_i/(1-\exp(-Z_i * -t_i)) = a-Z_i * t_i$$

2.4.3 Natural Mortality (M)

According to the Pauly (1980c) formula, the relationship is :

$$\text{Ln } M = -0.0152 - 0.279 \text{ Ln } L_{\infty} + 0.6543 \text{ Ln } K + 0.463 \text{ Ln } T \quad \ldots 1)$$

where L_{∞} is the asymptotic total length; K is the growth constant per year; and T is the annual mean temperature (°C) of the water in which the stock lives, about 28.5°C. L_{∞} (total length) was derived from the relationship between total length (X) and carapace length (Y) in the equation :

$$Y = 1.2 X - 1.3 \quad (r=1 \ , n = 465) \qquad \ldots 2)$$

and was used to compute natural mortality. Substituting these values in equation (1) natural mortality of Scylla serrata was obtained separately for males and females.

2.4.4 Fishing Mortality (F)

Fishing mortality was estimated using the relationship, $Z = F + M$.

2.4.5 Exploitation Rate (E)

Exploitation rate for males and females were estimated using ELEFAN II using the equation $E = F/F+M$.

2.4.6 Recruitment pattern

Recruitment pattern was obtained by projecting length-frequency backward onto a one-year time axis. The option of original data was used in here since the data represents catch per unit effort.

2.4.7 Yield per Recruit (Y'/R)

Relative yield per recruit estimates as a function of E were obtained using the M/K values derived from the above procedure (Beverton and Holt, 1984; Pauly and Soriano, 1986). Probability of capture

were also incorporated in estimating Y'/R values since assumption of knife-edge recruitment is not used for short lived tropical species (Pauly and Soriano, 1986). Y'/R values were obtained for five levels of sizes of first capture (Lc) without changing the slope of selection curve.

2.4.8 Length weight relationship

In order to establish the length weight relationship, weight of individual crabs were measured using a Sartorius Balance with a precision up to two decimal points. It was decided to weigh at least 25 crabs per each length group of 1 cm, in the total range of length, 2 cm to 18 cm. Totally, 459 crabs were used for this estimate.The sexes were also noted along with the weight.

2.5 Reproductive biology

In order to study various aspects of the reproductive biology of female Scylla serrata caught in the Negombo Lagoon were analyzed for a period of one year from January - December 1989.

During the year samples of female Scylla serrata were collected bi-weekly from the Pitipana landing station. The samples were selected to represent all the sizes in the catch available in the market. The samples, purchased each day, were brought live to the laboratory for analysis. The length and weights of each crab were recorded before they were dissected (live) to obtain ovaries. The different maturity stages were determined following the scale used for Cancer irroratus, by Bigford (1979). The stages of the gonadal development were;

Virgin (immature) I - Ovary very small and thread like. Eggs not visible. Located dorsally to the digestive gland.

Developing II - Ovary slightly thick. White to pale yellow in colour. Ovary occupies 1/4 - 1/2 of the digestive gland.

Mature III - Ovary bright yellow to orange in colour, occupies 1/2 to 1 of the digestive gland.

Gravid IV - Ovary bright orange. Thoracic region full of ovary. Eggs clearly distinguishable.

Spawning V - Eggs between the abdominal flap. Orange - ash in colour. Eggs clearly distinguishable to naked eye.

Spent VI - Ovary small and shrivelled. Pale yellow or white in colour. Few mature eggs might remain.

After the stages of maturity were recorded the ovaries were excised and fixed in Guilson fluid and 5% formalin. The fixed ovaries were used for two studies, viz. fecundity and ova diameter frequency. The studies were carried out by using 4

ovaries of mature crabs and spawned egg masses of 10 crabs.

2.5.1 Fecundity

In order to prepare the specimen for ova counting, first the ovaries were mopped by a blotting paper to remove all moisture. Then 5 pieces, each weighing approximately 0.5 g were cut from the middle region of the ovary and were weighed and the exact weights were recorded to the nearest mg. Thereafter each piece containing separated eggs were diluted in 100 ml water and 5 ml (1 ml at a time) was taken out for counting the ova using a magnifying glass. These counts were used to estimate the fecundity. i.e. the number of ova in the ovary.

2.5.2 The ova diameter analysis

Ovaries of crabs belonging to 6 different stages of maturity (immature, developing, mature, spawning, post - spawning and spent) were investigated by screening all parts of the ovary. Portions weighing

about 5 grams comprising anterior, middle and posterior parts of the ovary were well mixed with water and the ova were observed under a microscope. The ova diameters were measured by using a ocular micrometer scale at a magnification of 0.5 mm to each micrometer division. Ova diameters were pooled for ova of different maturity stages.

2.6 Larval and Juvenile population

2.6.1 Observation on the Larval population

Initial attempts to study the larval populations was confined to the mouth of the lagoon. Later it became evident that crab larvae were absent near the mouth of the lagoon. Therefore, in the last two years sampling was carried out at the sea near the mouth of the lagoon.

Larval population was studied by taking plankton samples, monthly, using a plankton net of 70 μ. Sampling was carried out during early hours of the day (between 6.00 a.m. to 9.00 a.m.) and the net

was dragged against the current at an approximate speed of two knots. Samples were immediately preserved in 5% formalin prior to analysis.

Three diurnal surveys were also carried out during the course of the study, collecting samples at every four-hour intervals.

2.6.2 Observation on the Juvenile population

During the early part of the study an attempt was made to study the juvenile population by sampling with a drag net of size 1 m x 1 m . This attempt was unsuccessful and it was decided to use a dip net. The net was operated by one person and crabs caught in a 30-minute operation in shallow waters taken as a sample. Sampling was carried out bi-weekly for a period of 16 months. Further three diurnal surveys were also carried out at the Kadolkelle station (Figure 2.) by collecting juveniles at four hour intervals using a hand operated dip net. In each instance the net was operated by a single person in 30-minute sessions.

Salinity and water levels were also measured simultaneously. The tidal amplitude at the highest high tide and lowest low tide were recorded for each cycle as given in the tide tables of the Department of Meteorology.

2.7 Fishery and economic aspects of the mud crab

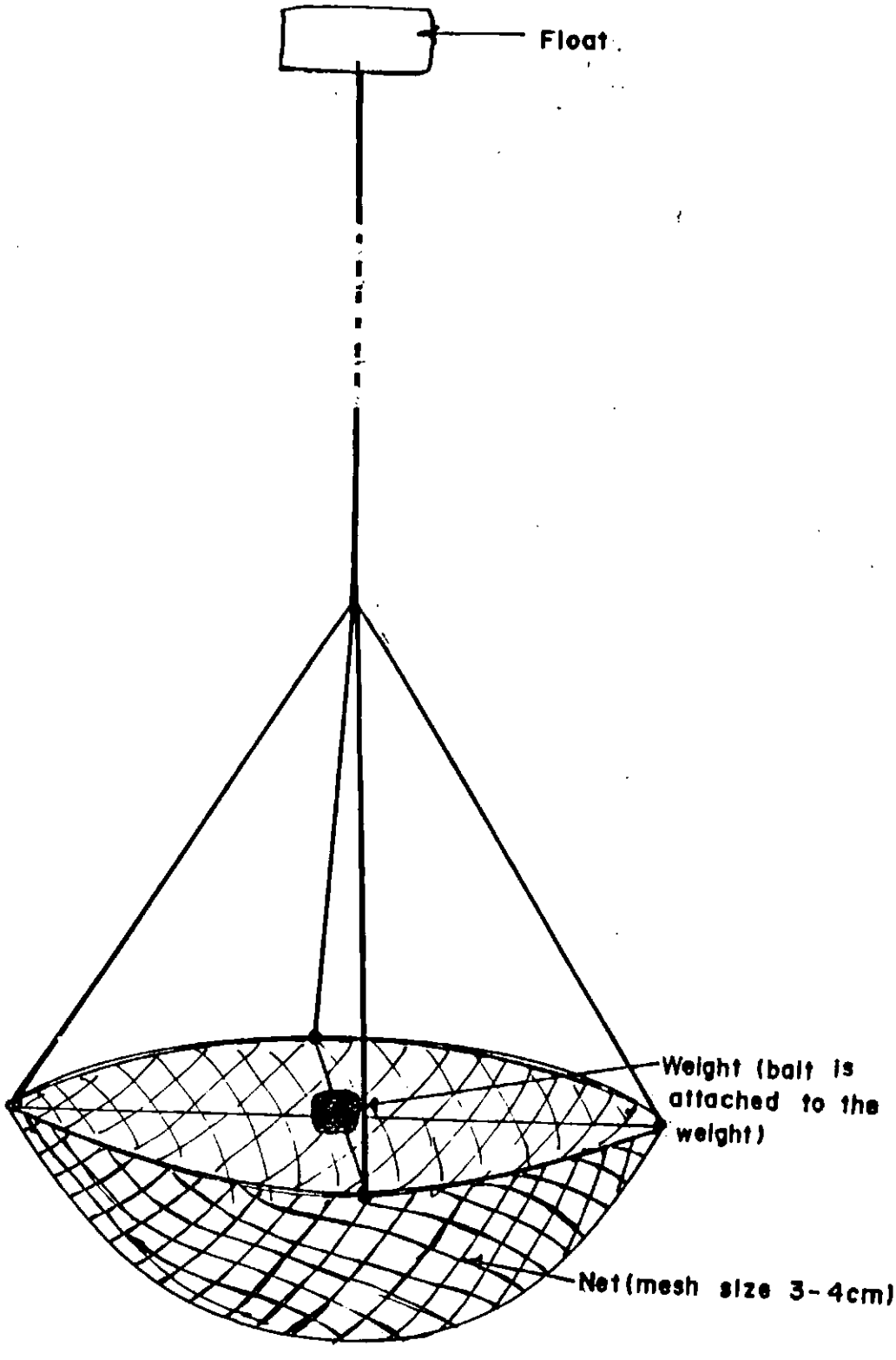
Crab fishing is carried out in almost all parts of the Negombo Lagoon. Traditional methods are still used for catching crabs. Among the gears used baited trap is the most common. Crabs also get caught in drift nets, drag nets and brush parks as a by-catch of prawns.

Prior to beginning of the sampling a preliminary survey was carried out to find the number of fishermen engaged in the crab fishery. This was carried out by visiting all the fishing villages around the Negombo Lagoon and collecting information from fishermen. The information collected were number of fishermen in each area and the method used for catching crabs etc.

2.7.1. Description of fishing gear

Baited trap: Baited trap is a device specially designed for fishing crabs. It is an inexpensive simple device which can be handled with ease. The trap is made by tying a net to a circular frame made of a mangrove root or a wire. Mesh size of the net varies from 3.75 cm - 5.00 cm (Stretched mesh). The diameter of the circular frame is about 1 - 1.5 meters. The frame is held by three ropes and a float from the upper side. Two nylon strings run across the diameter of the frame at an angle of 90°. A weight (generally a stone) is tied to the strings at the point where the two strings cross each other. Bait is tied to the weight with a string (See Diagram 1).

The gear is operated by a single person with the aid of a canoe (small boat). One fisherman usually takes about 50 - 100 traps and lays the traps in a suitable area as he paddles along. Traps are laid one by one keeping a 3-4 meters gap from one to another. After laying the traps the fishermen waits for about 30 - 60 minutes and starts to lift the



The baited trap

traps one by one. The trapped crabs are collected and the traps laid again. The fisherman changes the site if the operation is not successful. The activity goes on for 3 - 5 times. The fishing operation is carried out either at night or day at the ease of the fisherman. The fishermen who go out for fishing both day and night are very few.

The daytime catches are landed at about 1.00 - 3.00 p.m. and the night catches are landed at about 2.00 - 5.00 a.m.. Both catches whether landed in the afternoon or following morning comes to the market at the same time brought by spouses of the fishermen, usually in the morning. Most of the catches from baited traps come to the Pitipana market except for a few who operate near Kurana area who sell their catch at the Negombo market.

The catch is brought to the market in sacs made of nylon. Each sac contains about 20 - 50 crabs depending on the size. The crabs are not sold individually by the spouses of the fishermen. The common buyers of the sacs are intermediate vendors and the nearby hotelliers.

In the beginning of the research study there were no buyers for exporting crabs. However, in the latter part of the study a sudden increase was observed in buyers of crabs for exporting to Singapore.

Drift net: Drift nets are made by sewing 5 -7 pieces of netting (mesh size 1.25 cm, and height of 2 - 3 meters) together. Teppam (form of a raft) are used to drift these nets. The net is stretched vertically across the lagoon during late nights or early morning. This unfolded net is anchored at each end by means of two weights and is lifted early in the morning. The catch is brought to the market either Pitipana or Katunayake, by the fisherman himself. Drift net is operated only once a day. Fish, prawns and crabs get caught in these nets. These fishermen consider crabs as a nuisance because of the damage they cause to nets. Thus, they often kill the crab by chopping the chela. These crabs are auctioned at the market along with fish and prawns.

Drag net: The drag net consist of two wings and a 'sac like part' in the middle of the wings. It is about 5 - 6 meters in length and the mesh size of the nets is around 1.06 - 1.26 cm (stretched mesh).

Weights are fixed to the bottom line of the net. Drag net is manipulated by two men at each end of the net. The net is drawn along the grass patches in the lagoon keeping the lower edge closer to the bottom. The net is drawn along the current. This gear is usually operated late in the night and early morning. The catch is disposed as in the case of drift nets.

Brush parks: Brush parks are made of mangrove branches fixed in shallow areas of the lagoon. These branches are pegged down by mangrove sticks in such a way so as not to scatter by the movement of water. A brush park is round in shape and about 5 - 6 meters in diameter. This is kept in the water until the mangrove branches exhibit a copious growth of algae which attract fish and prawns. It takes about six months for a brush park to come into this stage.

The catch is collected by encircling the brush park with a net with the aid of vertically fixed sticks around the brush park and by cautiously removing the mangrove branches to allow collecting the trapped fish by a scoop net. Collection of fish usually takes place early in the morning and the operation lasts about 3 hours. Usually, fish and prawns get trapped in the brush parks. Crabs do not get trapped in bulk in brush parks. Operation of a brush park requires only a single person. The catch is sold as similar to drag net and drift net.

2.7.2 Crab Landing centers in the Negombo Lagoon

Crabs caught by baited traps are landed at eleven landing stations in the Negombo Lagoon. They are; Katunayake, Kurana, Taladuwa, Munnakkaraya, Pitipana, Basiyawatta, Talahena, Aluthkuruwa, Dungalpitiya, Kepungoda and Pamunugama (Figure 2). Landing of crabs often takes place between 4.00 a.m. - 6.00 a.m. and 1.00 p.m. - 3.00 p.m. in all the landing centers. However, all these catches ultimately come to either Katunayake, Pitipana or Negombo market for disposal. Both night and

morning catches come to the market at the same time between 4.30 - 9.00 a.m. in the morning. This routine of crab fishermen was considered for developing the sampling procedure in the present study.

2.7.3 Catch Statistics on the adult population

Sources of Data Collection: As mentioned above the 'baited trap fishermen' in all parts of the lagoon bring their catch to the Pitipana market except those who operate near the Kurana area. They take their catch to the Negombo market. Almost all fishermen send their catch to the market through their spouses. Therefore, these women were selected as the main source of data collection.

Drift net catches are mainly brought to the Katunayake market. A minor proportion goes to the Pitipana market. Fishermen them selves bring the catch to the market and thus the data collection was easy when the fishermen arrive at the market or when the catch was auctioned.

Collection of data from drag nets and brush parks too were similar to the collection of data from drift nets.

Period and Frequency of Data Collection : The data collection was commenced in January 1985. At the beginning attempts were made to obtain weekly data collections from all the eleven landing stations in the lagoon. However, later it was learnt that the entire stock comes to either Pitipana, Negombo or Katunayake markets for selling and thus it was decided to take weekly data from only those three markets. The weekly data collections were continued only for baited trap catches because baited trap was the only gear which was specifically laid for crab capture in the Negombo Lagoon. However, bi-weekly data collections were made with respect to other gear though the catches were negligible. Data collections were carried out uninterruptedly for three years ending in December 1987.

Types of Data Collected : The following data were collected by observing and interviewing each and

every crab fisherman, or the spouse with respect to the particular day of data collection.

a. Area of operation (Landing site).

b. Gear used.

c. Number of traps operated (if the gear is a baited trap) .

d. Total number of crabs caught.

e. The time spent for the entire operation i.e. from the time of departure to the lagoon to the arrival to the landing centre with the catch.

f. Price: Price of all the sacs in which crabs are brought to the market an the number of individuals in each sac.

g. Sex : Sex of each crab was recorded. Sex could be easily identified by the shape of the abdomen.

In males the abdominal flap is narrow and pointed whereas in females it is wide and wedge shaped.

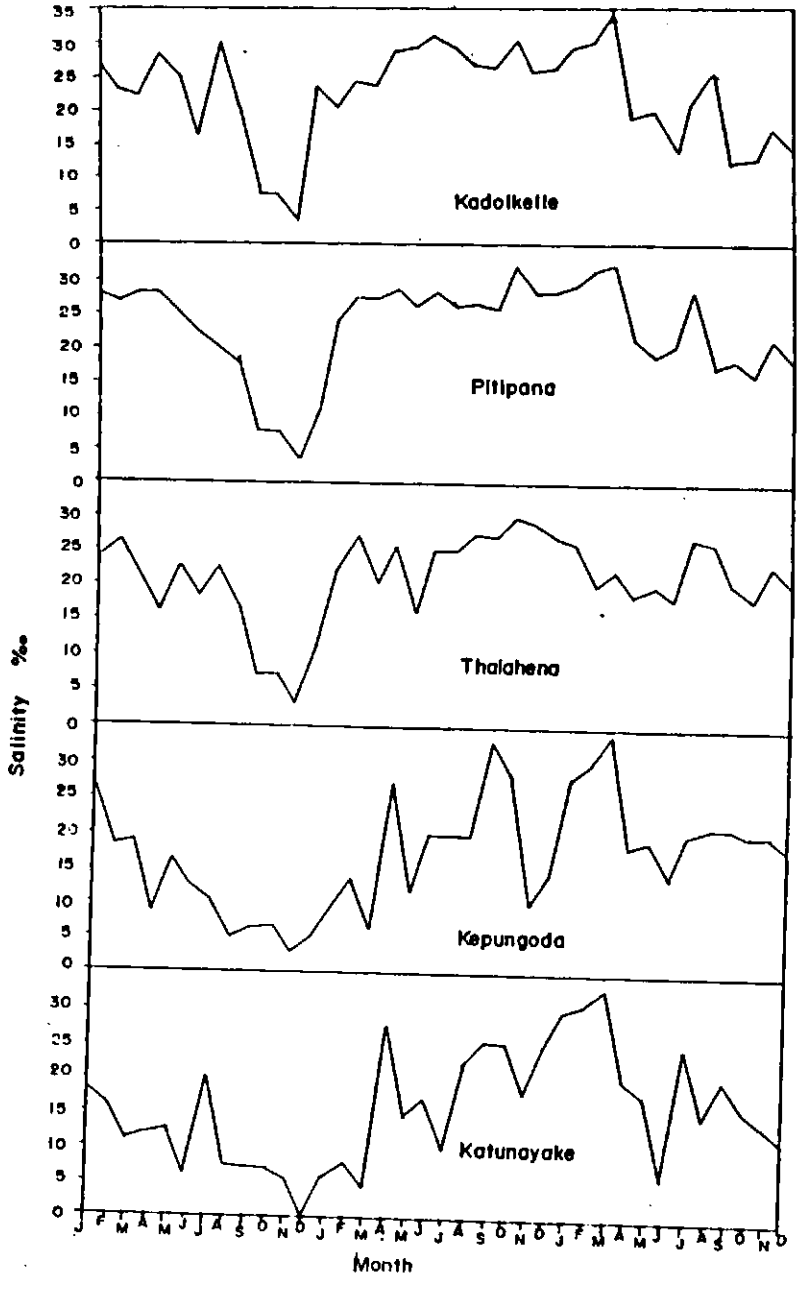
R E S U L T S

3.1 Hydrobiological parameters in the Negombo Lagoon

Salinity

Seasonal variations in salinity at five sampling stations in the Negombo Lagoon are shown in Figure 3. A similar pattern of salinity variation was observed in three stations close to the mouth of the lagoon (Kadolkelle, Pitipana and Thalahena). In the two stations of the upper reaches, salinity fluctuations were more pronounced. Salinity fluctuated between 0 ‰ - 35 ‰ in the upper reaches and between 5 ‰ - 35 ‰ in the lower reaches. Low salinity periods were observed from August to December in 1985 and in 1987 in the lower reaches. In 1986, salinity was always higher than 15%. in the lower reaches.

Fig.03 Seasonal variations in the salinity‰ at five sampling stations in the Negombo Lagoon during the period from January - December 1987.


Kadolkelle
Pitipana
Thalahena
Kepungoda
Katunayake
Salinity ‰
Month
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Water temperature

Figure 4 indicates the seasonal fluctuations in Air temperature (°C) during the period of study. Air temperature fluctuated between 24 °C - 32 °C in Kadolkelle, 22 °C - 34 °C in Pitipana, 23 °C - 32 °C in Talahena, 22 °C - 33 °C in Kepungoda and 24 °C - 33 °C in Katunayake.

Turbidity

Turbidity in 5 sampling stations are given in Figure 5. Turbidity fluctuated widely during 1985. In the KadolKelle station high turbidity values were observed in March , June and August 1986. During the other period turbidity lied between 2-8 NTU. In Pitipana turbidity was high only in June and July 1985 and May 1986, while it fluctuated between 2 - 10 NTU during the other period. Talahena station also showed a similar pattern. But the turbidity was higher during June - September 1985, and August 1986. In the upper reaches turbidity fluctuated widely during the years 1985 and 1986. Here, the peak seasons were observed

Fig.04 Seasonal variations in the water temperature (°C) at five sampling stations in the Negombo Lagoon during the period from January - December 1987.

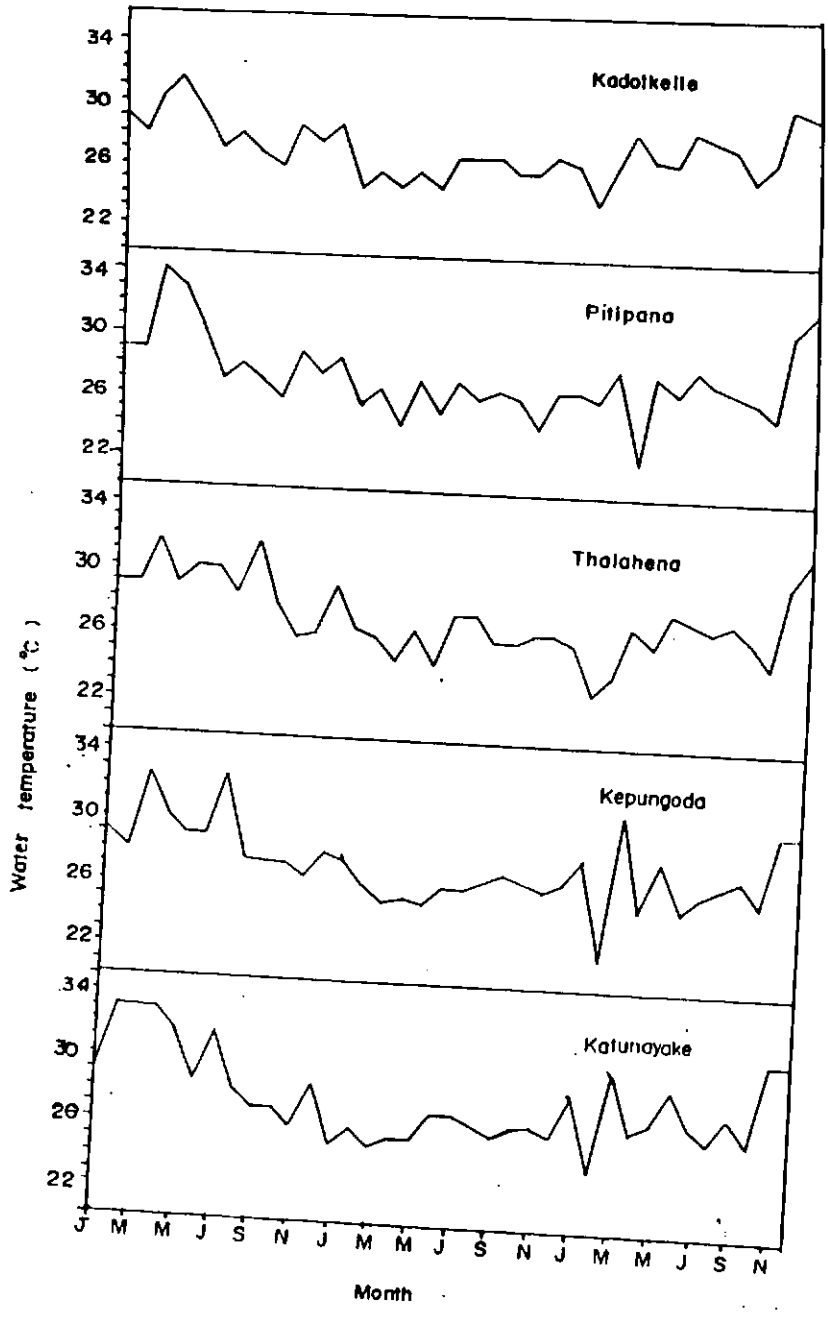
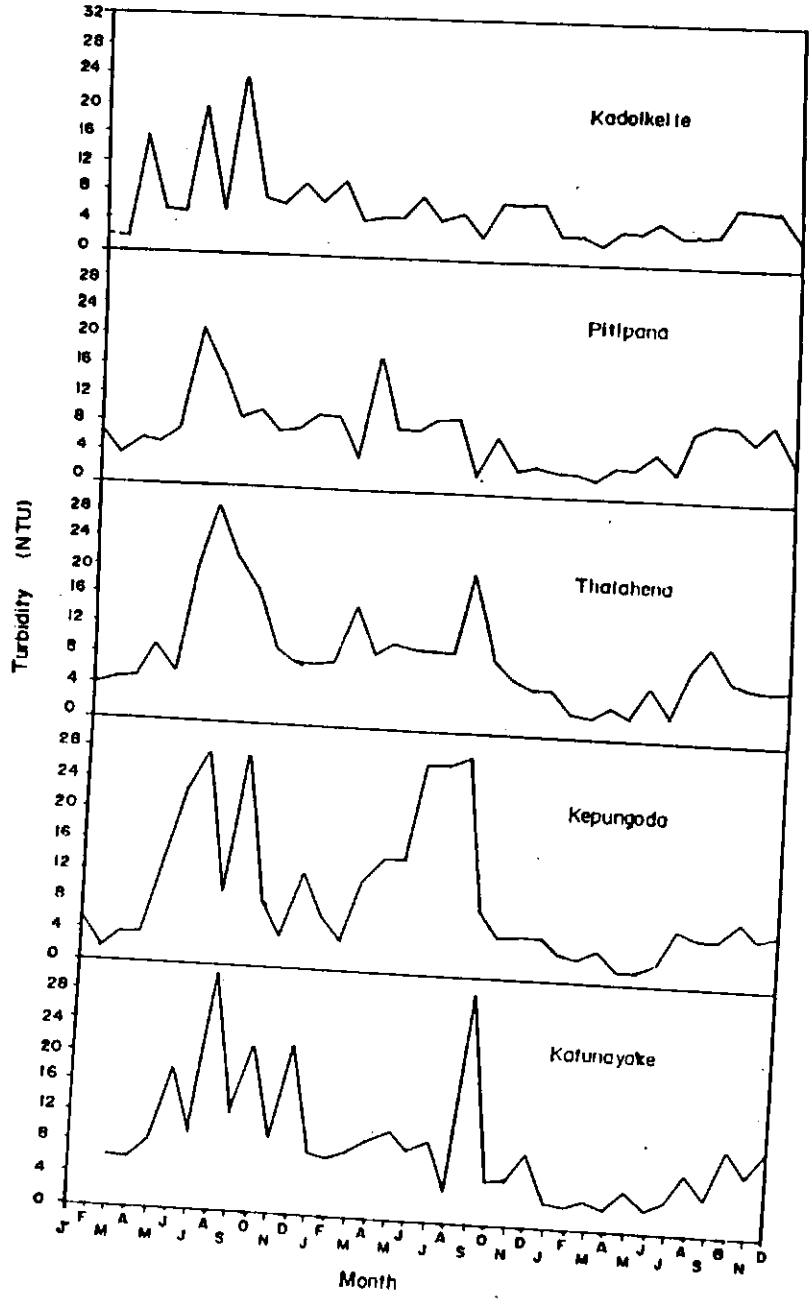

Kadolkelle
Pitipana
Thalahena
Kepungoda
Katunayake
34
30
26
22
Water temperature (°C)
J M M J S N J M M J S N J M M J S N
Month

Fig.05 Seasonal variations in the turbidity (NTU) at five sampling stations in the Negombo Lagoon during the period from January - December 1987.


Kadolkelle
Pitipana
Thalahena
Kepungoda
Katunayake
Turbidity (NTU)
Month

during June - September and June - August in 1985 and 1986 respectively in Kepungoda and September 1985 and 1986 in Katunayake.

pH

The seasonal variations in pH in the five stations in the Negombo Lagoon are illustrated in Figure 6. pH varied between 5 - 9 in all the stations during the study period with a mean around 8.0.

Rainfall

Rainfall data was collected from meteorological rainfall station situated in the catchment area of the Negombo Lagoon. The monthly rainfall totals for the years 1985, 1986 & 1987 were collected and analysed.

The catchment area of Negombo Lagoon falls within the wet zone of Sri Lanka. The annual rainfall for the years 1985, 1986 and 1987 were 1678 mm, 2075 mm and 2053 mm respectively, for the catchment area of the Negombo Lagoon.

Fig.06 Seasonal variations in the pH at five sampling stations in the Negombo Lagoon during the period from January - December 1987.

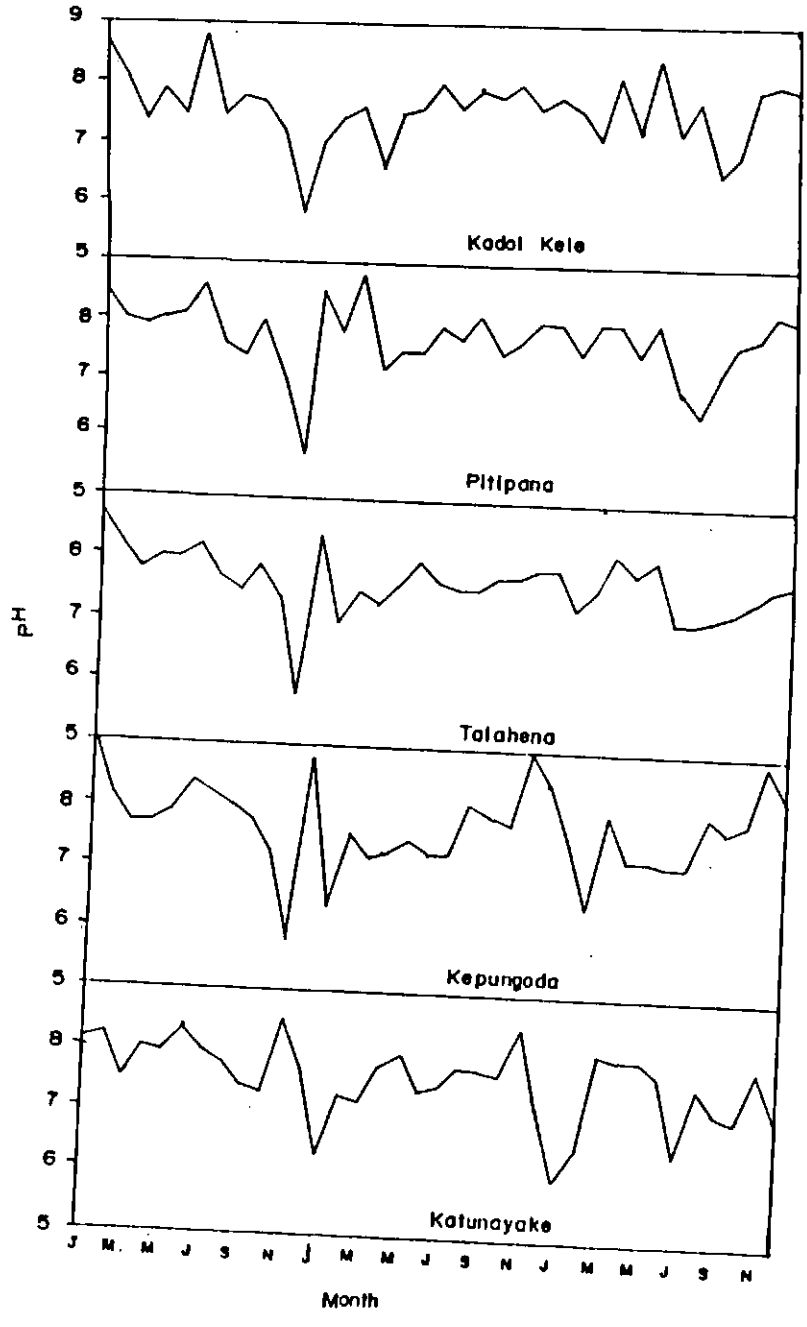
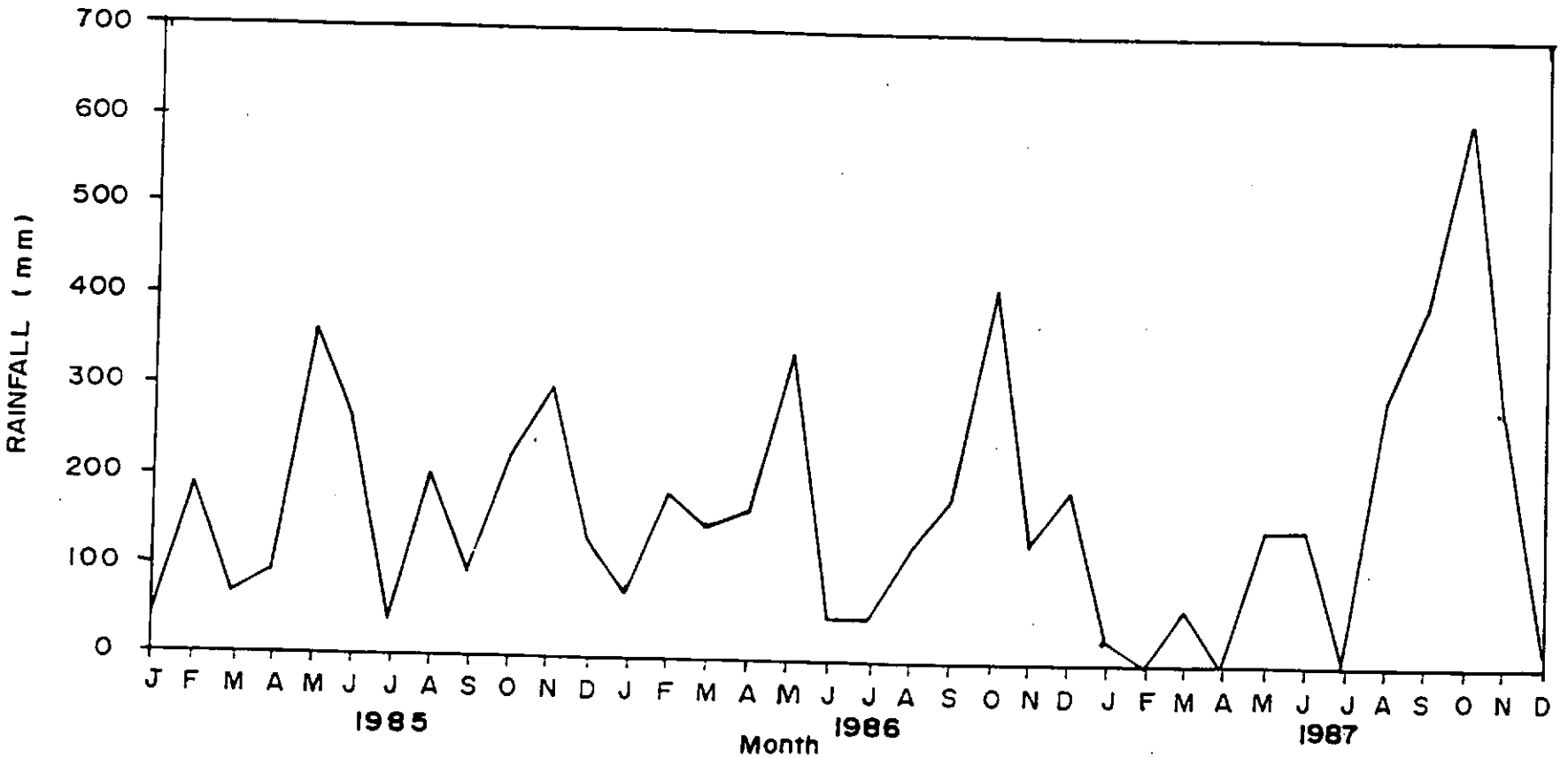

Kadol Kele
Pitipana
Talahena
Kepungoda
Katunayake
pH
Month
J M M J S N J M M J S N J M M J S N

Fig.07 Monthly variations in rainfall in the catchment area of Negombo during the period from January 1985 - December 1987.


700
600
500
400
300
200
100
0
RAINFALL (mm)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1985
1986
1987
Month

The rainfall in the catchment area showed a certain seasonal regularity. There was a change between a relatively wet and dry period twice in a year (Figure 7). The monthly rainfall varied between 35 mm in January and 362 mm in October in 1986. In 1987 rainfall varied from 0 mm to 617 mm Some rain was received every month in the years 1985 and 1986. In 1987 there was no rain during the months of February and April. Relatively higher rainfalls were observed in May, June and November 1985, in May and October 1986 and in July August and september 1987.

3.2 Taxonomic features of the mud crab

Using the characteristics identified by Tirmizi (1986) as a guide, the morphological characteristics of the mud crab in the Negombo Lagoon were carefully examined. The following observations were made as major characteristics of Scylla serrata.

1. Carapace

The carapace is smooth and bordered by 22 spines, four between the eyes and nine each on the antero-lateral borders. The colour of the carapace varies from greenish blue to greenish brown. The expression of colour is found to vary with the environment. The brownish colour was more prominent in crabs found in mangrove areas (Figure 8 a).

2. Cheliped

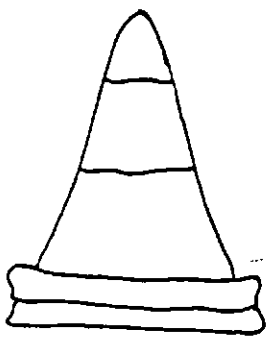
The first pair of legs has been adapted to form an exceptionally strong and large pair of chelipeds. This pair ends with strong claw-like structure, chela. The fingers of the chela bears toothed cutting edges while its palm bears two subequal teeth at distal and proximal ends. The merus which holds the chela is armed with sharp teeth on its anterior margin. The posterior margin bears two small spines (Figure 8 b).

3. Walking legs

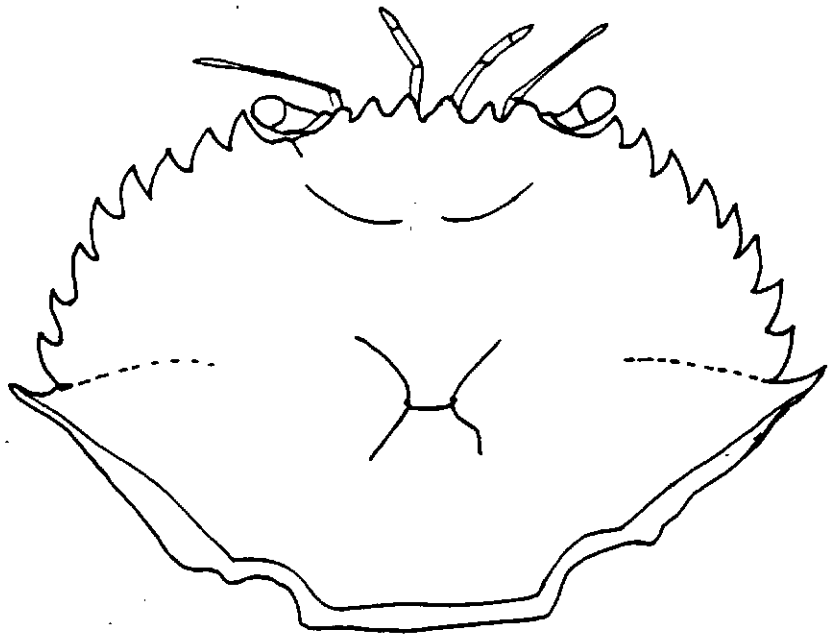
The four walking legs are unarmed and slender. The last pair exhibits a paddle-like modification for swimming and burrowing (Figure 8 e).

Fig. 08 Characteristic features of the mud crab Scylla serrata a. carapace, b. female abdomen, c. male abdomen, d. cheliped, e. last walking leg.

(b.)

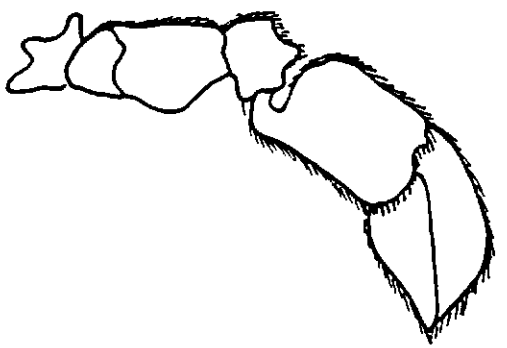


(c.)



(a)

(d.)



(e.)

4. Abdomen

The abdomen is made of five segments, where 3, 4 and 5 are fused. This too exhibits sexual dimorphism where males show a relatively thin abdomen (figure 8 b and c).

3.3 Food and Feeding habits of the mud crab Scylla serrata in the Negombo Lagoon.

3.3.1 Percentage occurrence of different food items

The stomach contents of Scylla serrata comprised crustaceans, bivalves, small crabs, gastropods, small fish, plankton and plant debris. Besides these, the stomachs also contained a fair amount of sand particles. This suggests that Scylla serrata is predominantly a carnivore feeding in the benthic zone of the lagoon (Table 1).

The percentage occurrence of the food items of Scylla serrata showed a marked variation in different size groups (Table 1). The crabs of smaller length groups (less than 7 cm) were found to feed predominantly on small crustaceans while it

Table 1 : Percentage occurrence of food items in different size groups of Scylla serrata.

Size Range	Number dissected	Small crustaceans	Bi-valves	Gastropods	Fish	Sand	Plant matter	small crabs
2.0 - 2.9	50	80.00	-	20.00	-	100.00	-	-
3.0 - 3.9	64	56.25	-	12.50	-	100.00	37.50	-
4.0 - 4.9	76	78.95	5.26	5.26	5.26	100.00	5.26	-
5.0 - 5.9	48	45.00	10.00	10.00	5.00	78.00	-	-
6.0 - 5.9	52	75.00	25.00	-	8.33	76.66	-	5.00
7.0 - 7.9	46	-	62.50	-	12.50	70.28	-	8.33
8.0 - 8.9	28	60.00	-	40.00	40.00	85.00	-	12.50
9.0 - 9.9	16	-	33.33	33.33	33.33	78.00	-	20.00
10.0 -10.9	12	-	66.66	33.33	33.33	75.21	-	-

was found that those in higher length groups (7-11 cm) feed heavily on bivalves (Table 1). The crabs of all the size groups had higher percentages of sand particles in their stomachs (75% - 100%). Plant matter was observed in about 37.5% of crabs of the size group 3.0 - 3.9 cm. The other food items such as gastropods and fish were found in 5% - 40% of crabs in the length range 4.0 - 11.0 cm and 5% - 20% of crabs of 5.0 - 9.0 cm length range. The percentage occurrence of food items increases with the size of crabs.

3.3.2 Seasonal variation of the food items

The stomach contents of Scylla serrata were analyzed monthly from January 1988 to December 1988 (Table 2). The sample comprised crabs of all size groups within the range 2.0 - 11.0 cm. The results show that the crustaceans dominate the food of mud crab throughout. Bi-valves, gastropods and sand particles were also found in significant quantities throughout the period of study. The results

Table 2 : Relative abundance of food items in different months of Scylla serrata in the Negombo during May 1988 to December 1988.

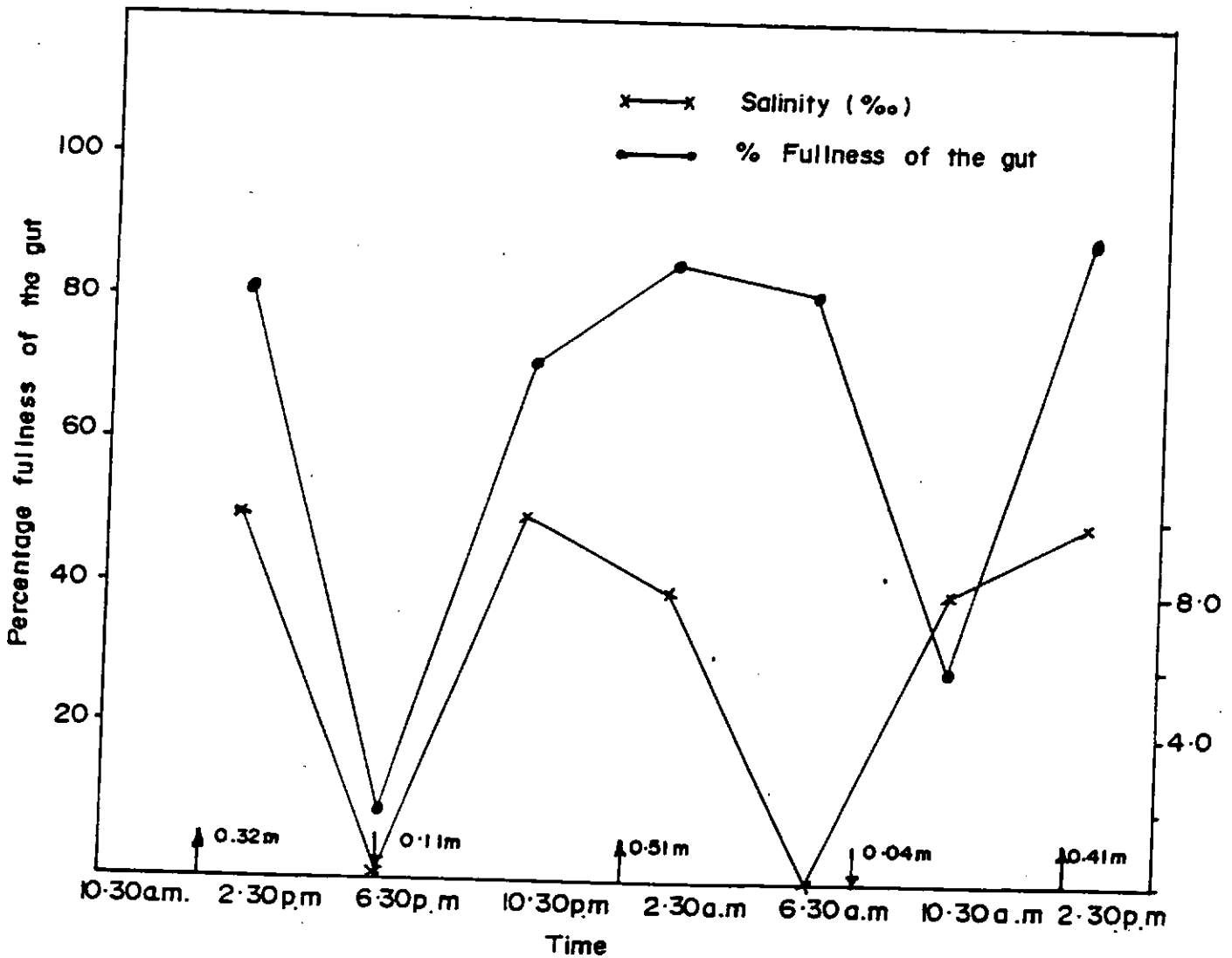
Items of food	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Small crustaceans	51.34	61.28	57.25	50.18	40.68	51.34	45.37	48.12
Bi-valves	37.80	20.42	30.18	28.23	37.34	46.20	38.02	25.28
Gastropods	5.12	-	4.28	11.45	8.45	-	4.12	9.28
Fish	-	2.42	3.82	4.36	1.64	-	-	-
Sand	3.74	16.98	4.47	15.28	8.89	2.46	10.49	17.32

indicate that there is no significant variation in food constituents in different seasons of Scylla serrata in the Negombo Lagoon.

3.3.3 Feeding time

Juvenile crabs caught by hand nets were used for determining the feeding time. Juvenile crabs caught at every 4-hr intervals within a 24 -hour duration were examined to determine the degree of fullness of the stomach. The stomachs were graded into 6 categories: empty, 1/4 full, 1/2 full, 3/4 full, full and gorged. Percentage fullness of the stomach at 4 hr observations, the tide level and salinity at the time of sampling are given in Figure 9. The results indicate that the juveniles begin to feed with the influx of sea water at high tide, during the daytime. The night feeding shows no connection with the tide and that they feed throughout the night irrespective of the tide.

Fig.09 Variations in the percentage fullness of the gut of juvenile Scylla serrata, salinity%. and tide level at four hour intervals during a day in the Negombo Lagoon.


Salinity (‰)
% Fullness of the gut
Percentage fullness of the gut
100
80
60
40
20
8·0
4·0
0.32m
0·11m
0·51m
0·04m
0.41m
10·30a.m.
2·30p.m
6·30p.m
10·30p.m
2·30a.m
6·30a.m
10·30a.m
2·30p.m
Time

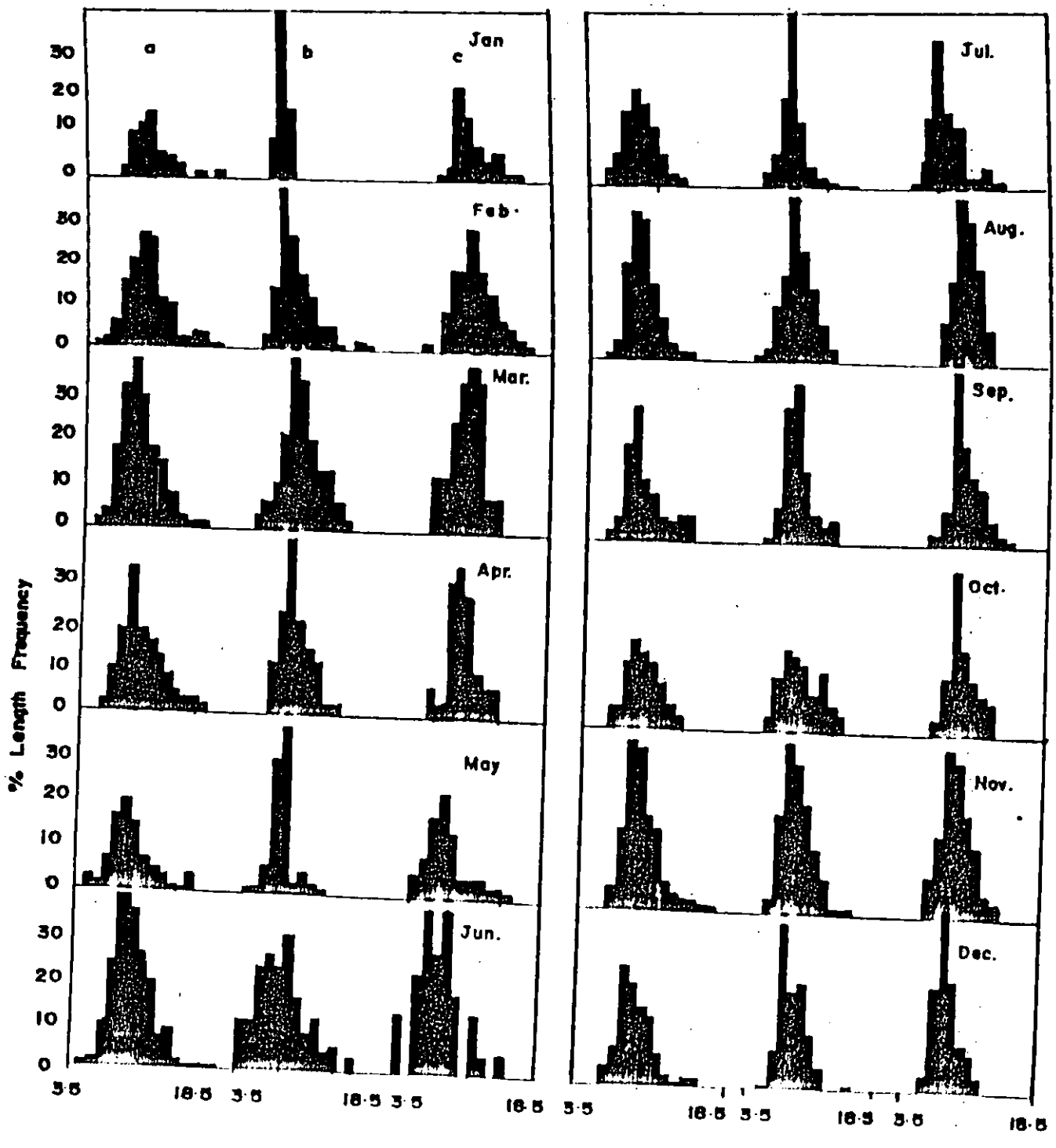
3.4 Growth parameters of the mud crab Scylla serrata in the Negombo lagoon.

The length frequency distribution at different places of the lagoon for the year 1985 is given in Figure 10. This data includes the measurements obtained from crab samples caught by baited traps. The frequency distributions were drawn separately for 3 areas; lower (Pitipana), middle (Talahena) and upper (Pamunugama) areas. The data reveals that the population structure with respect to size of crabs was similar in all three areas throughout the year. The populations were distributed around the same mean (8 - 9 cm) in all the three areas with a similar seasonal variation.

Therefore, the data of all the stations were pooled for further analysis. The method of data pooling was described in the previous chapter, under 2.4.1 (page 20 para. 2).

The first estimates of Loo and Z/K obtained using the method of Wetherall (1986), as modified by

Fig.10 Length frequency distribution of Scylla serrata in three different areas of the Negombo Lagoon : a) Pitipana b) Talahena and c) Pamunugama during the period, January 1985 - December 1987.


a
b
c
Jan
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
% Length Frequency
0
10
20
30
5·5
18·5

Pauly (1986) for males and females are given in table 3.

The length frequency distribution for the 3 years 1985, 1986 and 1987 for the four gears, baited traps, drift net, drag net and brush parks are given in Figure 11. The results indicate that the number of crabs caught by gear other than traps were minimal. The size distributions of the crabs caught by the four types of gear are as follows:

Gear	Length range
Crab trap	4 cm - 19 cm
Drift net	3 cm - 16 cm
Drag net	4 cm - 12 cm
Brush pile	3 cm - 18 cm

3.4.1 Growth parameter estimates

Final length frequency data of male and female Scylla serrata which were used to estimate growth parameters are given in Tables 4 and 5. First estimates of the asymptotic length (L_{∞}) and the ratio between the coefficients of mortality and

Table 3: The first estimates of the asymptotic length (L_{∞}) and mortality coefficient/ growth co -efficient (Z/K) in the male and female Scylla serrata of the Negombo lagoon during the three years, 1985, 1986 and 1987 as derived by the Wethereall method.

Year	Sex	L_{∞}	Z/K	r
1985	Male	20.55	4.71	- .94
	Female	18.39	3.30	- .93
1986	Male	19.25	4.13	- .93
	Female	18.73	3.23	- .96
1987	Male	26.49	7.78	- .97
	Female	20.82	4.31	- .97

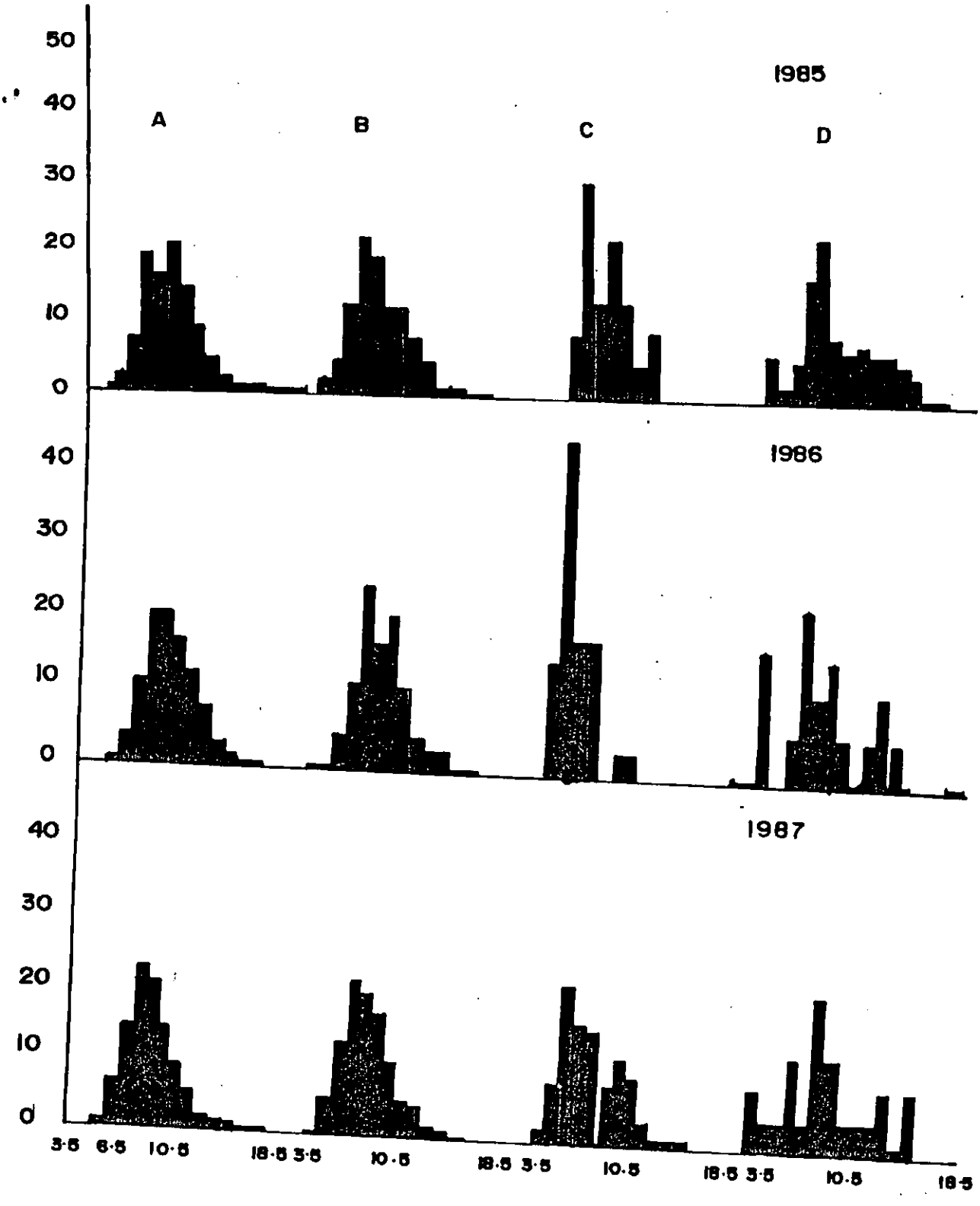
Table : 4 Pooled length frequency data of male Scylla serrata in the Negombo lagoon

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.5												
4.5	1	4	5	1	3	2						
5.5	16	14	5	6	4	14	10	6	2	2	1	2
6.5	74	75	46	42	17	23	42	41	29	13	26	47
7.5	160	148	164	115	60	127	98	122	121	62	97	173
8.5	357	335	269	161	137	164	184	221	291	123	289	427
9.5	443	306	209	123	145	203	207	287	338	294	596	353
10.5	324	236	148	85	127	199	184	216	310	243	424	319
11.5	220	167	60	45	78	97	169	145	207	200	241	218
12.5	106	76	36	26	53	50	102	77	107	148	159	122
13.5	48	32	20	19	36	42	56	41	75	88	62	51
14.5	25	14	4	8	13	18	17	20	31	48	27	21
15.5	11	5	4	4	10	10	7	10	27	12	13	13
16.5	6	6		0	6	10	6	2	6	14	10	8
17.5	2	1		1	3	7	1	3	4	2	5	1
18.5	1				2	2				5	4	1
						1				1	3	1
Total	1784	1419	1133	636	691	970	1085	1191	1548	1255	1957	1757

Table : 5 Pooled length frequency data of female Scylla serrata in the Negombo lagoon

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.5												
4.5		4	4	3	8	8	3	1				1
5.5	6	20	10	13	13	11	9	7	4	2	4	30
6.5	30	67	50	52	85	25	29	29	23	3	29	107
7.5	105	182	132	162	191	90	91	95	128	53	182	240
8.5	193	338	246	193	227	174	195	266	236	265	282	397
9.5	251	309	252	151	136	197	255	339	309	269	562	392
10.5	331	278	201	142	77	209	233	354	363	216	450	262
11.5	272	159	181	104	56	147	198	276	234	188	221	288
12.5	359	116	91	48	28	84	150	150	138	148	129	153
13.5	76	36	48	26	13	58	85	106	114	63	75	30
14.5	39	28	17	16	13	25	32	38	55	25	33	14
15.5	15	19	10	12	82	23	25	26	40	18	13	9
16.5	14	15	4	7	5	19	12	7	19	14	2	7
17.5	7	4	4	3	1	8	0	6	12	0	1	2
18.5			3			2	3	4		1		2
						5		1				
Total	1698	1575	1253	932	935	1085	1320	1705	1675	1440	1983	1934

Fig.11 Length frequency distribution of Scylla serrata in the Negombo Lagoon according to different gears ; a) Traps b) Drift net c) drag net d) brush piles during the period, January 1985 - December 1987.


1985
A
B
C
D
50
40
30
20
10
0
1986
40
30
20
10
0
1987
40
30
20
10
0
3·5
6·5
10·5
18·5
3·5
10·5
18·5
3·5
10·5
18·5
3·5
10·5
18·5

growth (Z/K) were obtained for male and female Scylla serrata based on the annual length frequency distributions with the Wetherall plot :

	Males	Females
L	23.252	19.790
Z/K	6.359	3.344
r	- 0.983	- 0.987

Running the same length frequency data through the search routines provided in the ELEFAN I programme gave best estimates of L_{∞} = 22.0 cm and K = 0.68 per year for males and L_{∞} = 21.8 cm and K = 0.60 per year for females. In order to give more emphasis on the smaller size groups the length frequency data used for ELEFAN I programme was corrected for gear selection. Figures 12 and 13 show the fitting of the growth curve at the estimated values of L_{∞} = 22.34 cm and K = 0.721 per year for males and L_{∞} = 22.20 cm and K = 0.560 per year for females as derived from the corrected data. The values of L_{∞} estimated were found to be close to the largest size of crabs in the samples.

Fig.12 Restructured length frequency data (ELEFAN I) and superimposed growth curve for male Scylla serrata in the Negombo Lagoon as derived from corrected data. The estimated values are Loo = 22.3 cm and K = 0.72 per year.

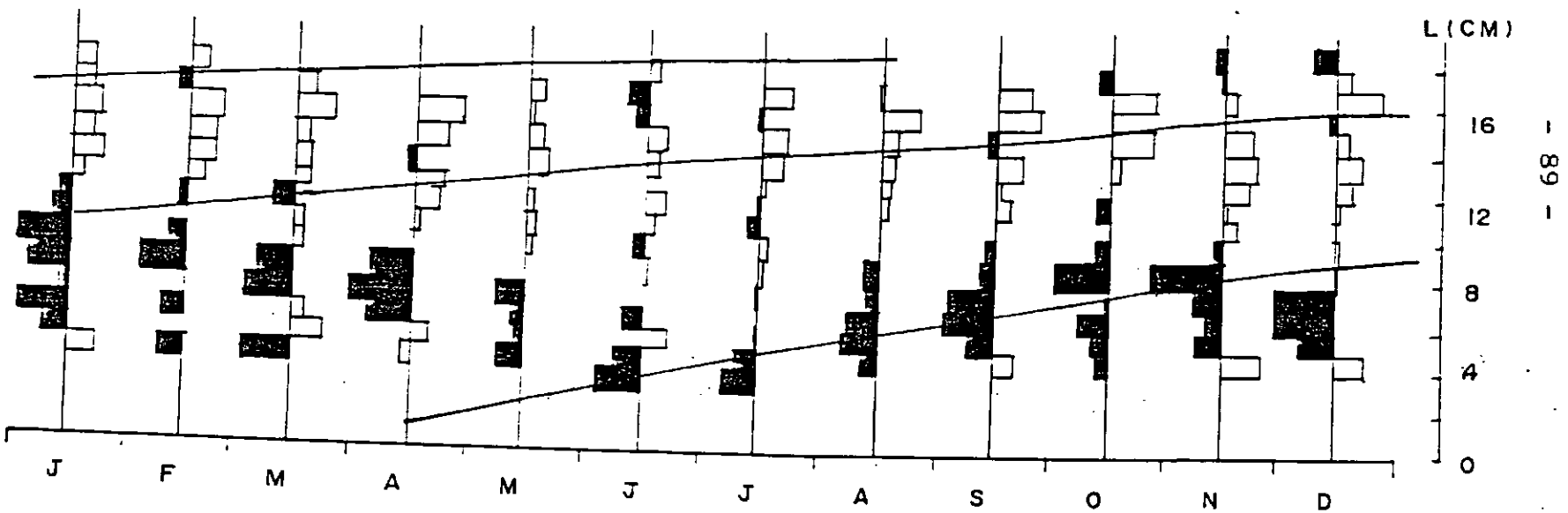
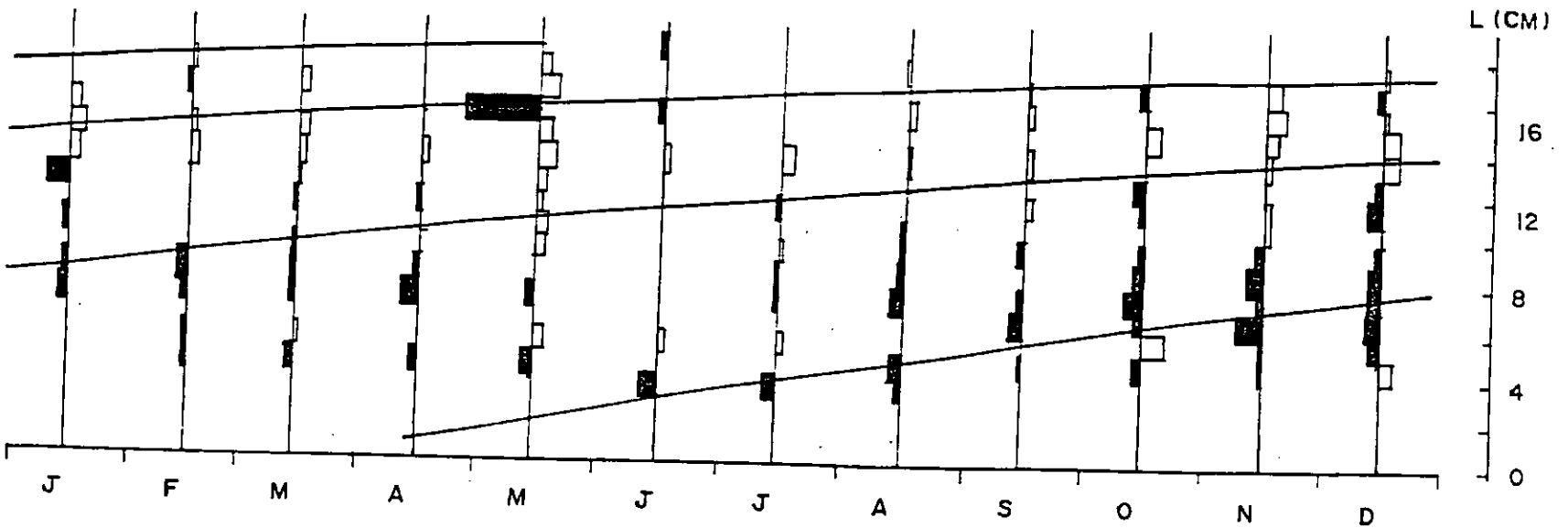

L (CM)
16
12
8
4
0
J
F
M
A
M
J
J
A
S
O
N
D

Fig.13 Restructured length frequency data (ELEFAN I) and superimposed growth curve for female Scylla serrata in the Negombo Lagoon as derived from corrected data. The estimated values are Loo = 22.2 cm and K = 0.56 per year.


L (CM)
16
12
8
4
0
J
F
M
A
M
J
J
A
S
O
N
D

3.4.2 Mortality, Exploitation rate and length at first capture

Figure 14 and 15 show the length converted catch curves and selection curves obtained for males and females, using the final values of L_{∞} and K. The values of total mortality coefficient (Z), natural mortality coefficient (M), fishing mortality (F) and the exploitation rate (E) for male and female Scylla serrata are given in Table 6. The estimated mean size at first capture is 7.597 for males and 8.070 for females (Table 6.).

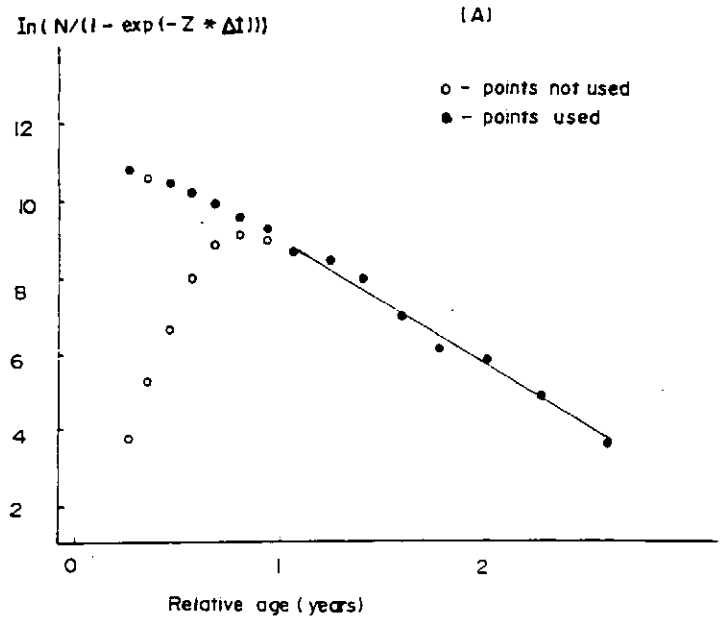
3.4.3 Recruitment pattern

Figure 16 shows the recruitment patterns of male and female Scylla serrata using the L_{∞} values 22.34, 22.20 and K values 0.721, 0.560 respectively for males and females. The figure 16 suggest that there are two recruitment pulses per year for both males and females.

Table 6 : Estimates of mortality parameters, exploitation rate and size at first capture for Scylla serrata in the Negombo lagoon (L_{∞} and K values derived from corrected length frequency data were used for obtaining Z).

Sex	Z	M	F	E	L_{50} (cm)
males	4.676	1.576	3.100	0.663	7.597
females	1.293	1.338	1.955	0.594	8.070

Fig.14 Length-converted catch curve (A) and resultant curve (B) for male Scylla serrata in the Negombo Lagoon based on uncorrected length-frequency data, (Loo = 22.3 cm, K = 0.72 per year and M = 1.57).


In (N/(1 - exp(-Z * Δt)))
(A)
o - points not used
● - points used
12
10
8
6
4
2
0
1
2
Relative age (years)

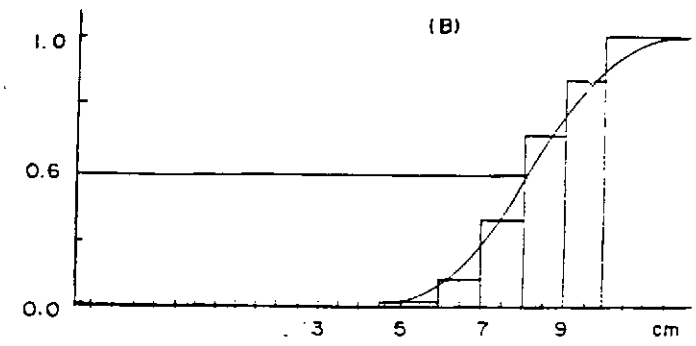
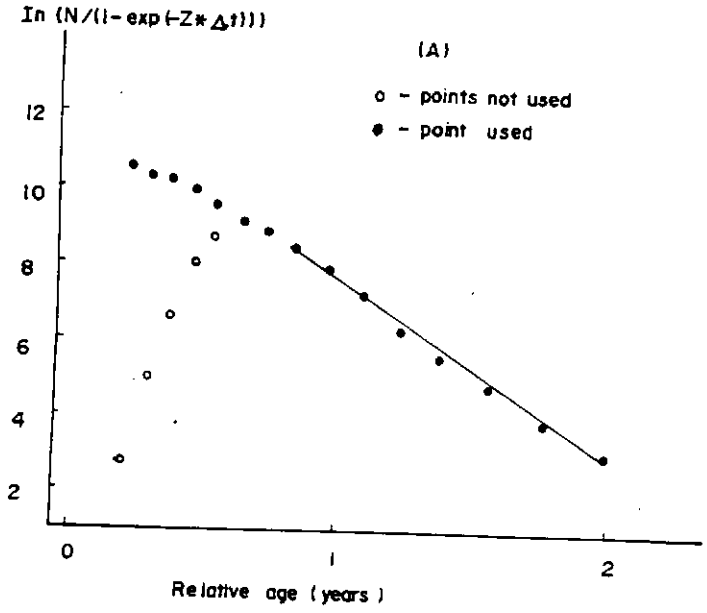

(B)
1.0
0.6
0.0
3
5
7
9
cm

Fig.15 Length-converted catch curve (A) and resultant curve (B) for female Scylla serrata in the Negombo Lagoon based on uncorrected length-frequency data. (L_{oo} = 22.2 cm, K = 0.56 per year and M = 1.34).


In (N/(1-exp(-Z*Δt)))
(A)
o - points not used
● - point used
12
10
8
6
4
2
0
1
2
Relative age (years)

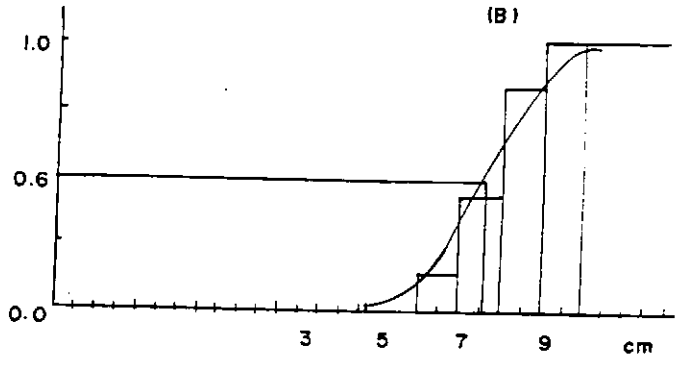
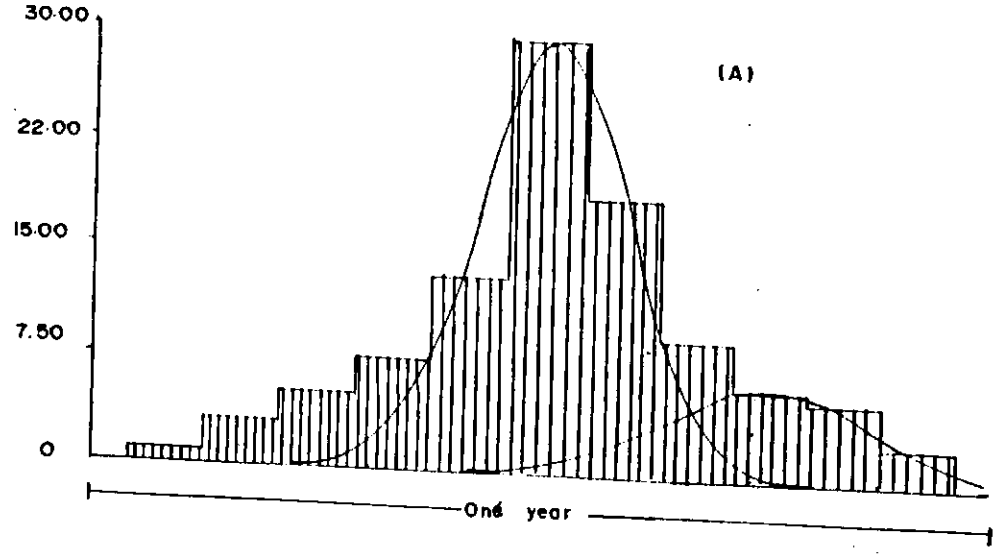
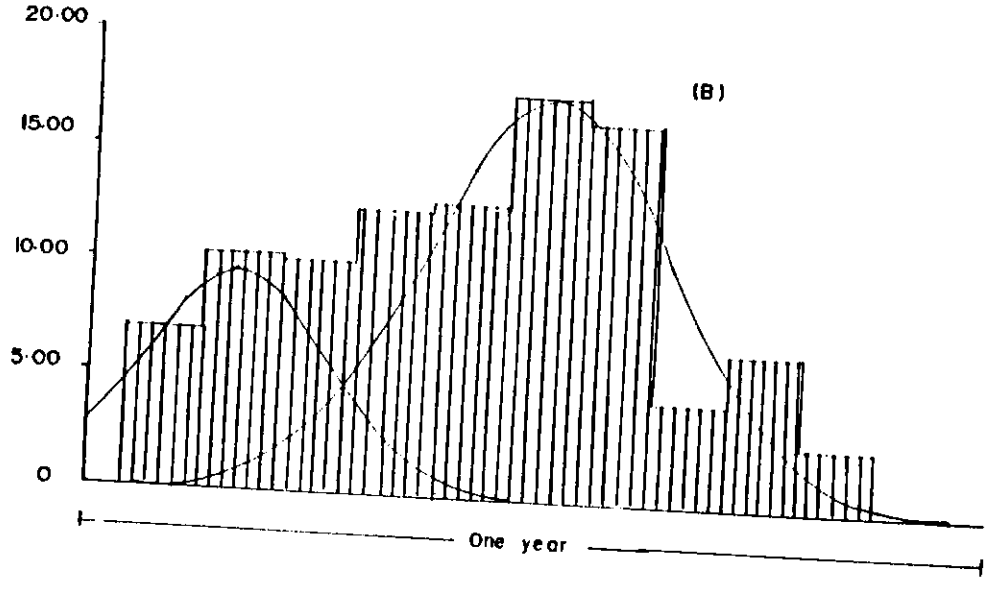

(B)
1.0
0.6
0.0
3
5
7
9
cm

Fig.16 Recruitment pattern for male (A) and (B) female Scylla serrata, in the Negombo Lagoon.


30·00
22·00
15·00
7·50
0
(A)
One year


20·00
15·00
10·00
5·00
0
(B)
One year

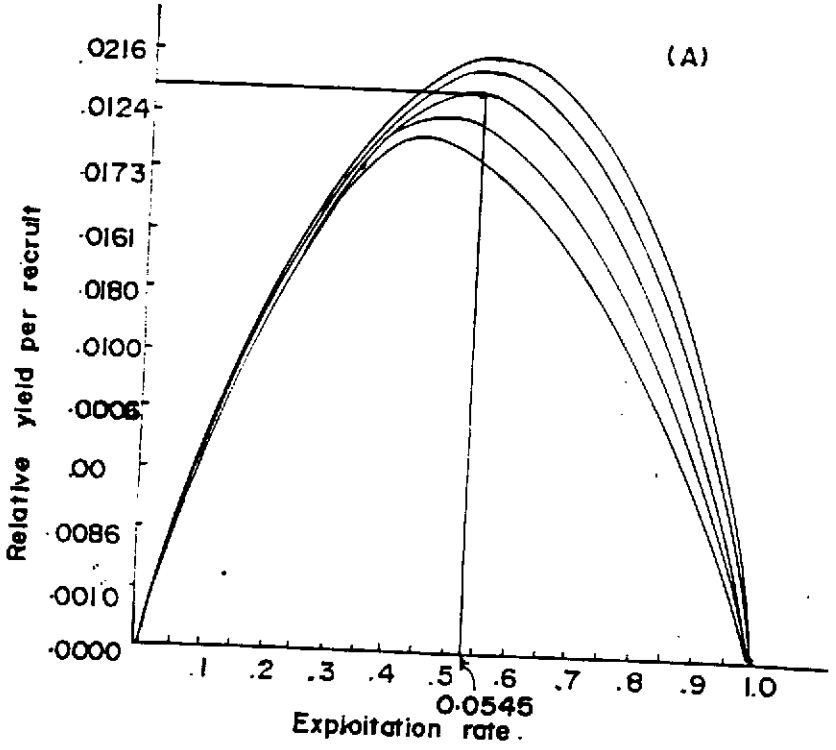
3.4.4 Yield/Recruit (Y/R) and Biomass/Recruitment (B/R)

Using the final values of L_{∞} and K together with the probabilities of capture obtained from the selection curve, yield per recruit and biomass per recruit were computed as shown in Figure 17 and 18 respectively. The yield per recruit reaches a maximum at the exploitation rate of 0.66 for males and 0.59 for females. As the E increases beyond this value, Y/R decreases. Y/R and B/R obtained by changing L_c are also included in figures 17 and 18. It shows that the increasing L_c could increase the yield while the decreasing L_c decreases the yield.

3.4.5 Length - Weight Relationship

The relationship between the length and weight of the mud crab appears to follow the allometric growth formula, $W = a L^b$ where W = Weight in grams, L is the carapace length in centi meter and a and b are constants. The regression equations

Fig.17 Relative yield per recruit and biomass per recruit as a function of exploitation rate (E = F/Z) in Scylla serrata males in the Negombo Lagoon.


(A)
.0216
.0124
·0173
·0161
·0180
·0100
·0006
.00
·0086
·0010
·0000
Relative yield per recruit
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
0·0545
Exploitation rate.

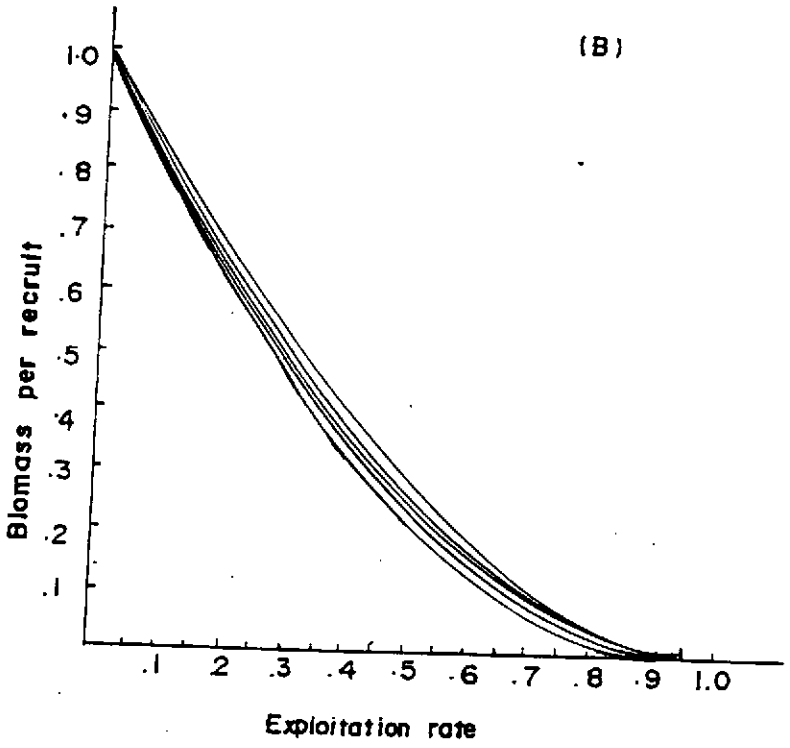
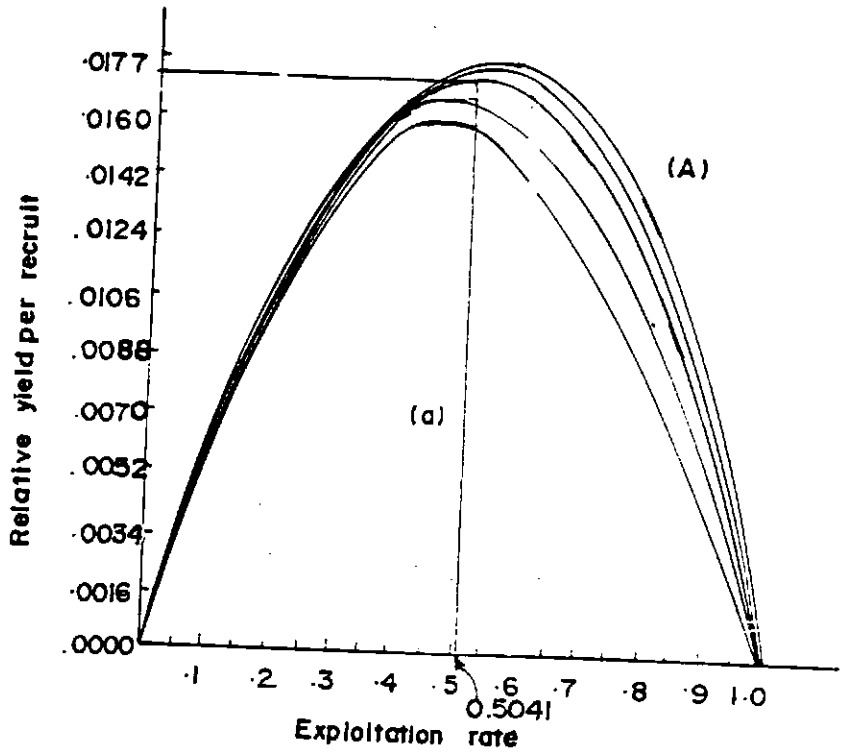
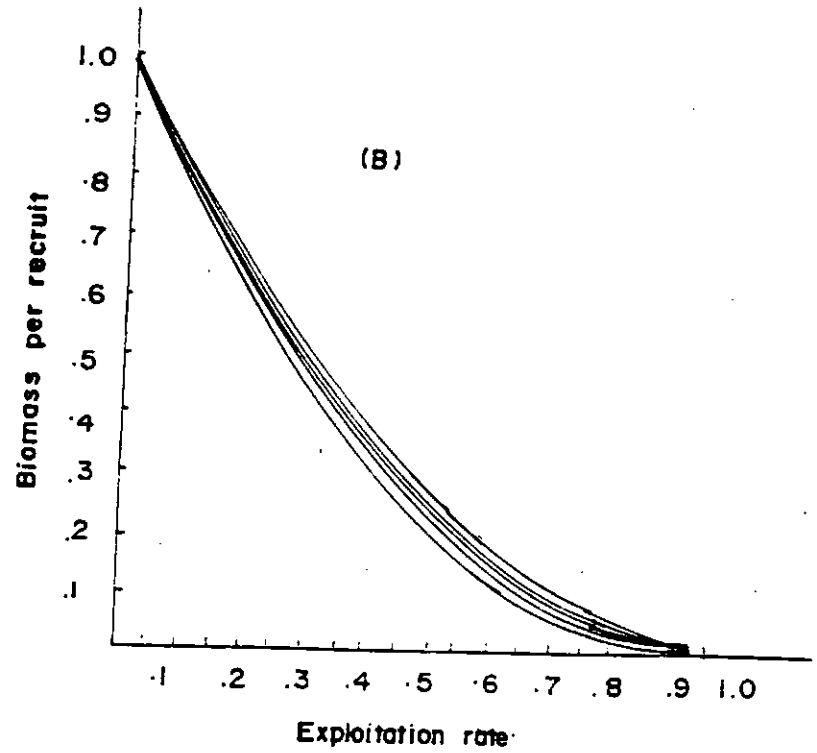

(B)
1·0
·9
·8
.7
.6
.5
.4
.3
.2
.1
Biomass per recruit
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
Exploitation rate

Fig.18 Relative yield per recruit and biomass per recruit as a function of exploitation rate (E = F/Z) in Scylla serrata females in the Negombo Lagoon.


Relative yield per recruit
·0177
·0160
·0142
.0124
.0106
.0088
.0070
.0052
.0034
.0016
.0000
(A)
(a)
·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0
0.5041
Exploitation rate


Biomass per recruit
1.0
.9
·8
.7
.6
·5
·4
.3
.2
.1
(B)
·1 .2 .3 .4 ·5 ·6 .7 .8 .9 1.0
Exploitation rate

were computed separately for males and females and respective correlation coefficients were calculated.

The two equations were as follows:

Regression equation

Females:

$$\text{Log } W = -0.6525 + 2.8461 \text{ Log } L \quad (r = 0.99)$$

$$(n = 260)$$

$$W = 0.2226 \; L^{2.8461}$$

Males :

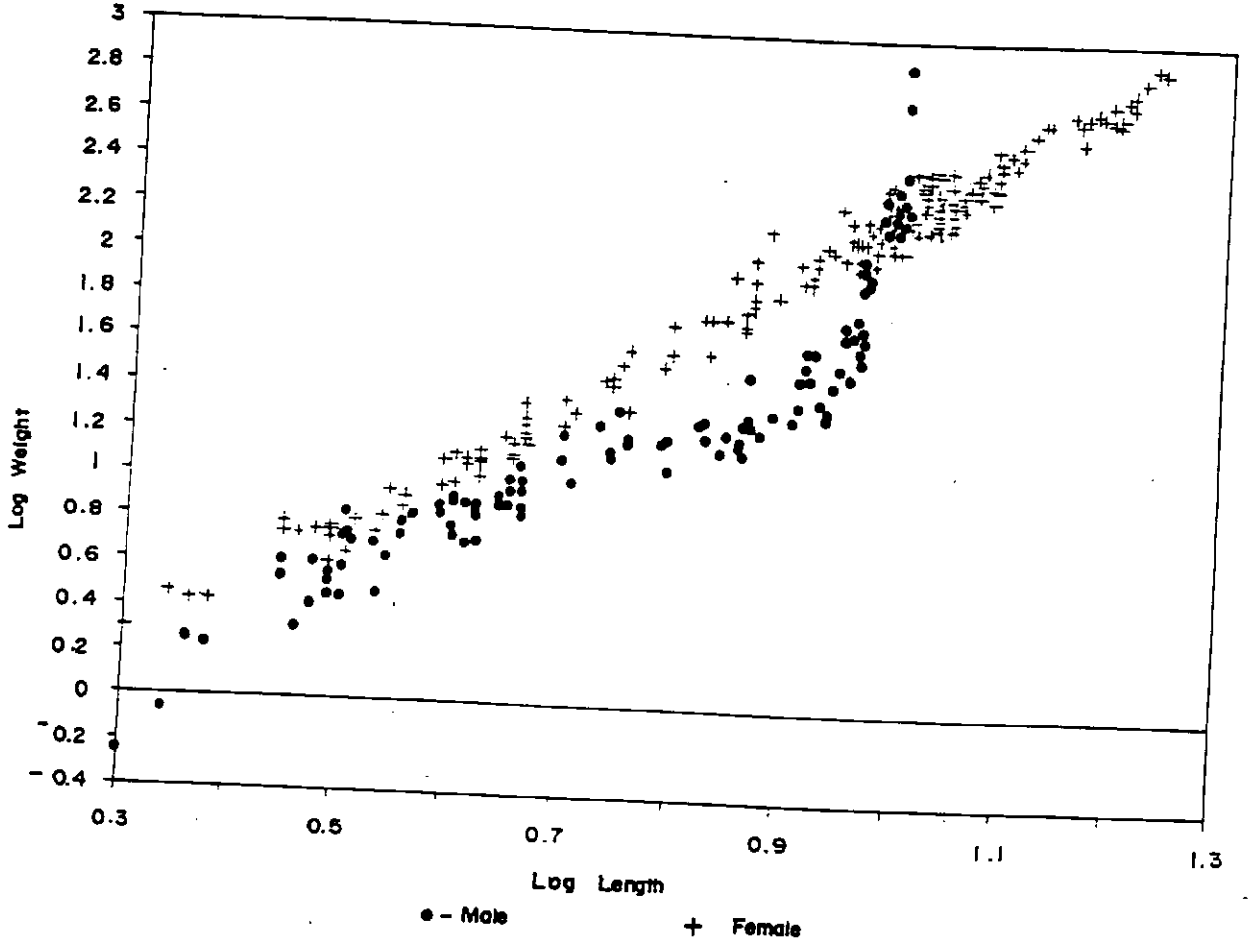
$$\text{Log } W = -0.7446 + 3.0054 \text{ log } L \quad (r = 0.98)$$

$$(n = 159)$$

$$W = 0.1801 \; L^{3.0054}$$

The values of the correlation coefficients clearly indicate that both the above regression equations fit well with the observed data. The two regressions are illustrated in Figure 19.

Fig.19 Logarithmic relationship between length and weight of male and female Scylla serrata in the Negombo Lagoon.


3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Log Weight
0.3
0.5
0.7
0.9
1.1
1.3
Log Length
● - Male
+ Female

Further, a statistical test was made to study the significance of the two equations obtained for males and females. The test revealed that there was no difference between

i. The variance of the two sets of data
ii. The slope of the two regression equations
iii. The intercept of the two regression equations

Hence, a single equation was computed for both females and males using pooled data (Figure 20). The final equation reads as follows :

$$\text{Log } W = -0.6821 + 2.8934 \text{ Log } L \quad (r = 0.98)$$

$$(n = 419)$$

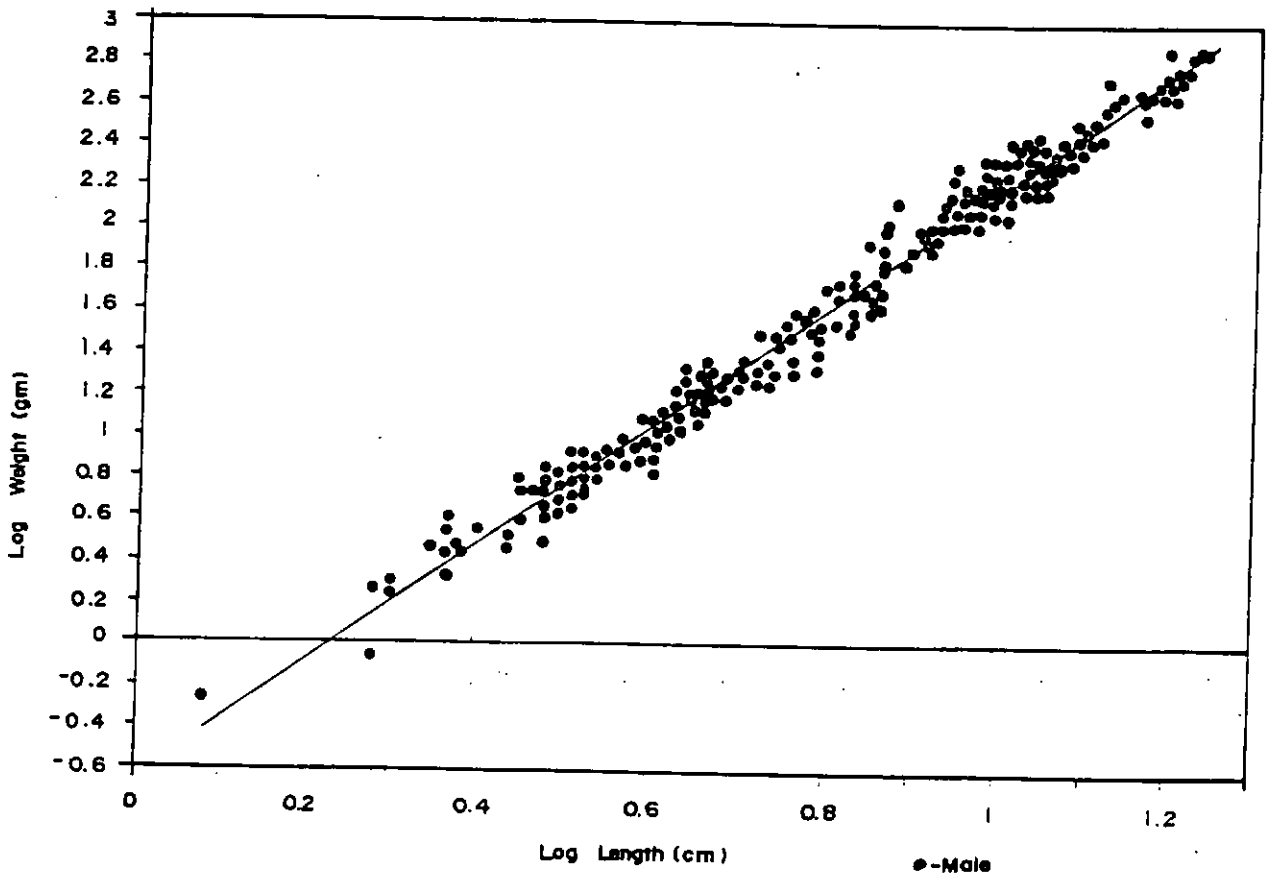
$$W = 0.2079 \; L^{2.8934}$$

3.5 Reproductive biology of Scylla serrata in the Negombo Lagoon.

3.5.1 Size at first maturity

In order to determine the size at first maturity the female crabs of maturity stages I and II were

Fig.20 Logarithmic relationship between length and weight of Scylla serrata in the Negombo Lagoon.


Log Weight (gm)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.2
0.4
0.6
0.8
1
1.2
Log Length (cm)
●-Male

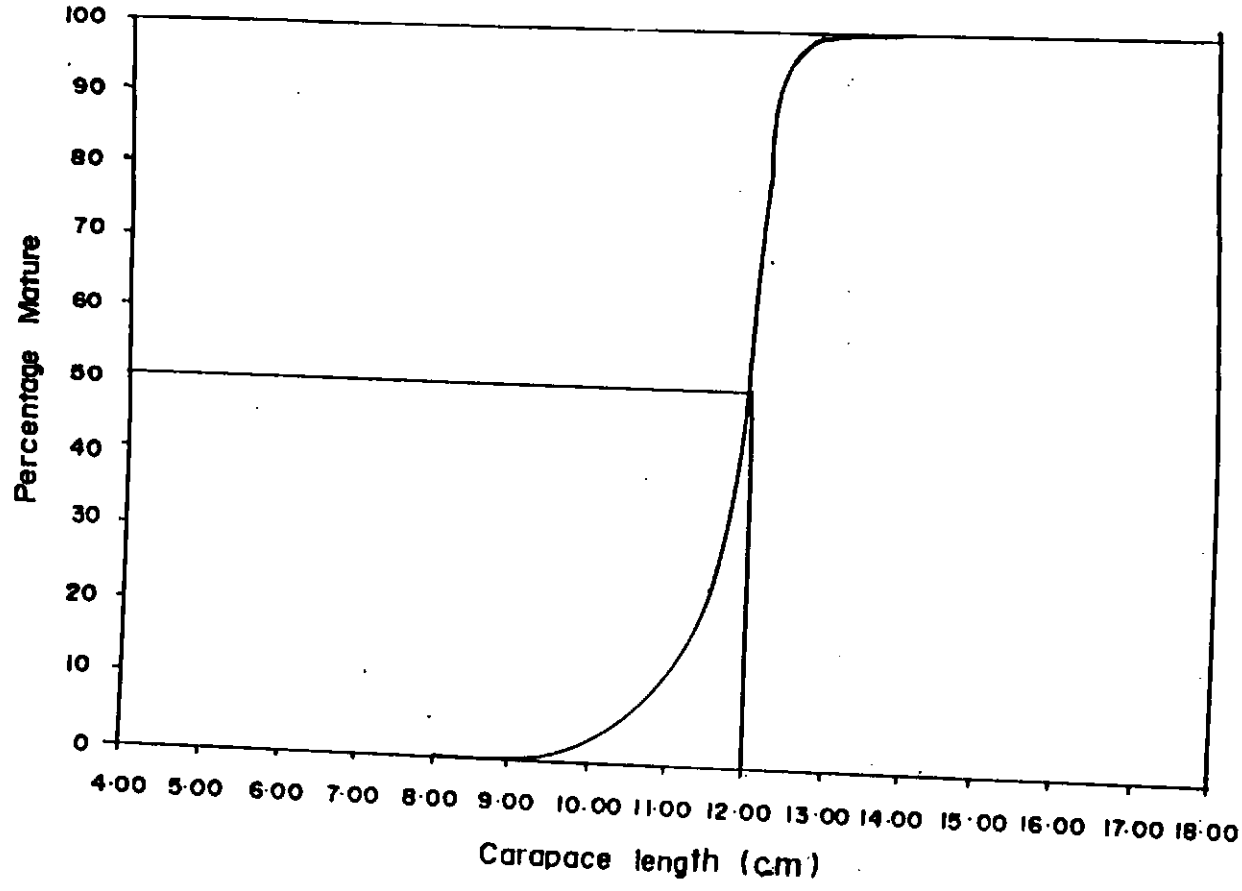
considered as immature and stage III and above as mature. Only females were chosen for this study because of the difficulties in identifying the maturity stages in males.

The size at first maturity was determined by observing the gonads of female crabs of different sizes ranging from 4.0 cm - 18.00 cm. in carapace width. The crabs were grouped into 1 cm classes and the percentage of mature crabs in each class was calculated. The percentage of mature females was plotted against the length class and the curve was smoothened (Figure 21). Figure 21 shows that all the crabs below the length 10 cm were immature while those above 13 cm were mature. 50% maturity was obtained at the 12 cm length. Therefore, the estimated size at first maturity is around 12 cm.

3.5.2 Fecundity

Two types of ova were counted to estimate the fecundity of Scylla serrata. The first was the ova of the matured ovary and the second was the spawned or shed ova found attached to the abdominal

Fig.21 The relationship between the carapace length and percentage maturity of Scylla serrata in the Negombo Lagoon.


100
90
80
70
60
50
40
30
20
10
0
Percentage Mature
4·00 5·00 6·00 7·00 8·00 9·00 10·00 11·00 12·00 13·00 14·00 15·00 16·00 17·00 18·00
Carapace length (cm)

appendages (ova of ovigerous females). The two fecundities were termed as pre-spawning fecundity and post-spawning fecundity. The pre-spawning fecundity ranged from 1.76×10^6 to 3.5×10^6. The post-spawning fecundity varied from 1.28×10^6 to 1.84×10^6. Figure 22 shows the relationship between post spawning fecundity and the carapace length. The results show that the post spawning fecundity is linearly correlated ($r = 0.89$) to the carapace length and the estimated regression equation is

$$F = -185449 + 146795\ CL \qquad (r = 0.89)$$

3.5.3 Seasonal variations in the maturity stages in female crabs

The percentage occurrence of different maturity stages by months is given in Figure 23-a,b,c,d,e). More immature females are recorded during June - July and November -December (Figure 23-a). Higher percentages of developing crabs are observed in January, March and August. Two peaks are demonstrated in the percentage occurrence of

Fig.22 The relationship between the carapace length and the post-spawning fecundity of Scylla serrata in the Negombo Lagoon.

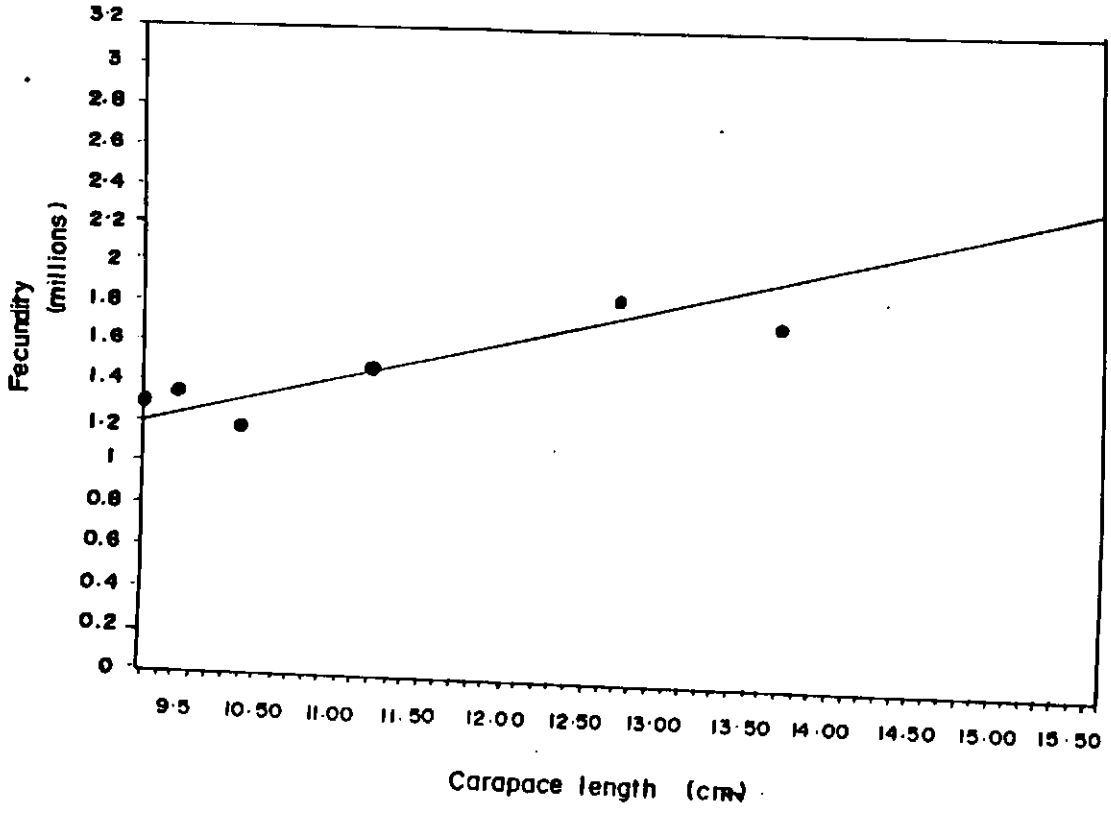
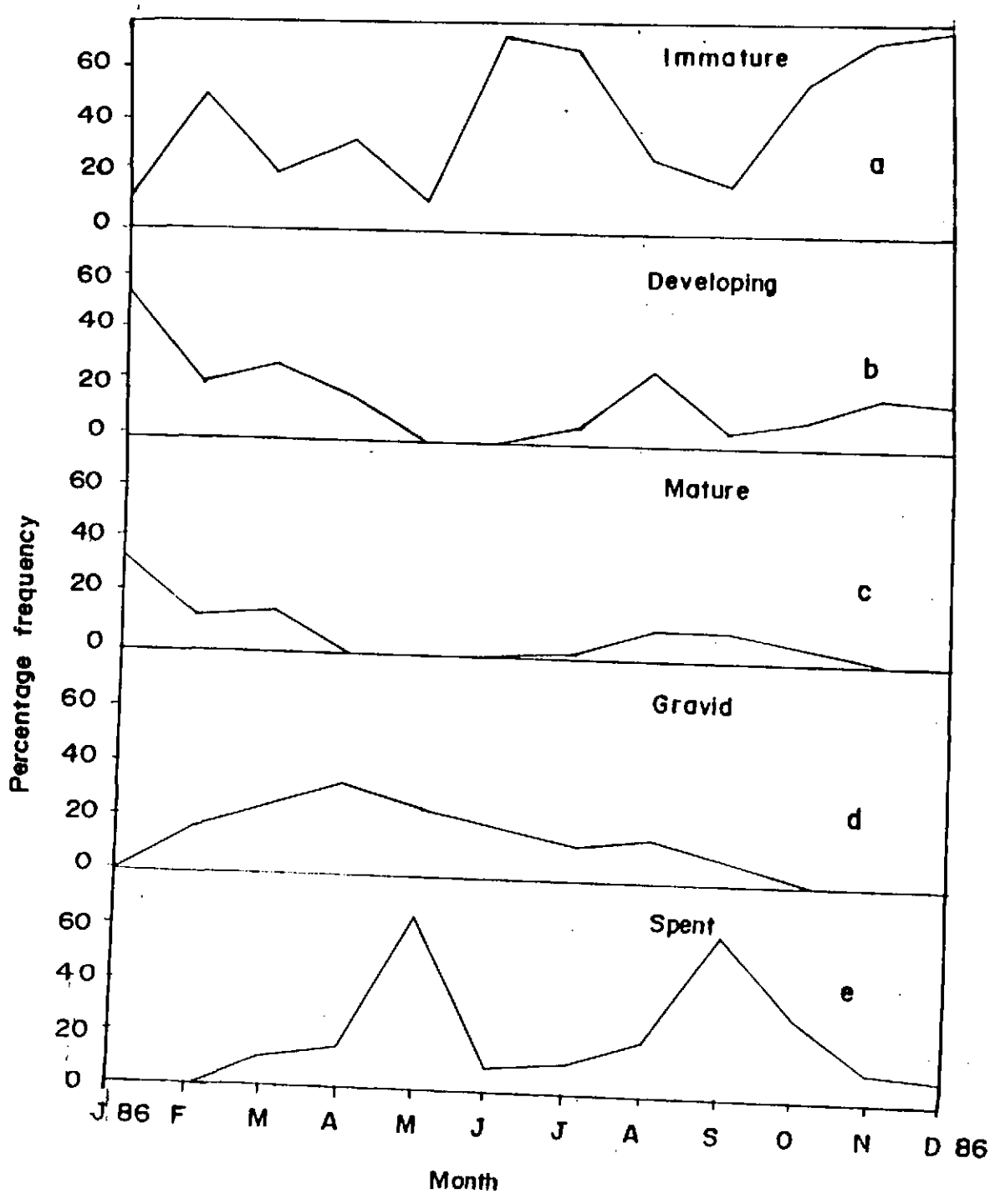

Fecundity (millions)
3·2
3
2·8
2·6
2·4
2·2
2
1·8
1·6
1·4
1·2
1
0·8
0·6
0·4
0·2
0
9·5
10·50
11·00
11·50
12·00
12·50
13·00
13·50
14·00
14·50
15·00
15·50
Carapace length (cm)

Fig.23 Seasonal variations in the percentage frequency occurrence of different maturity stages of Scylla serrata in the Negombo Lagoon.


Immature
a
Developing
b
Mature
c
Gravid
d
Spent
e
60
40
20
0
Percentage frequency
J 86
F
M
A
M
J
J
A
S
O
N
D 86
Month

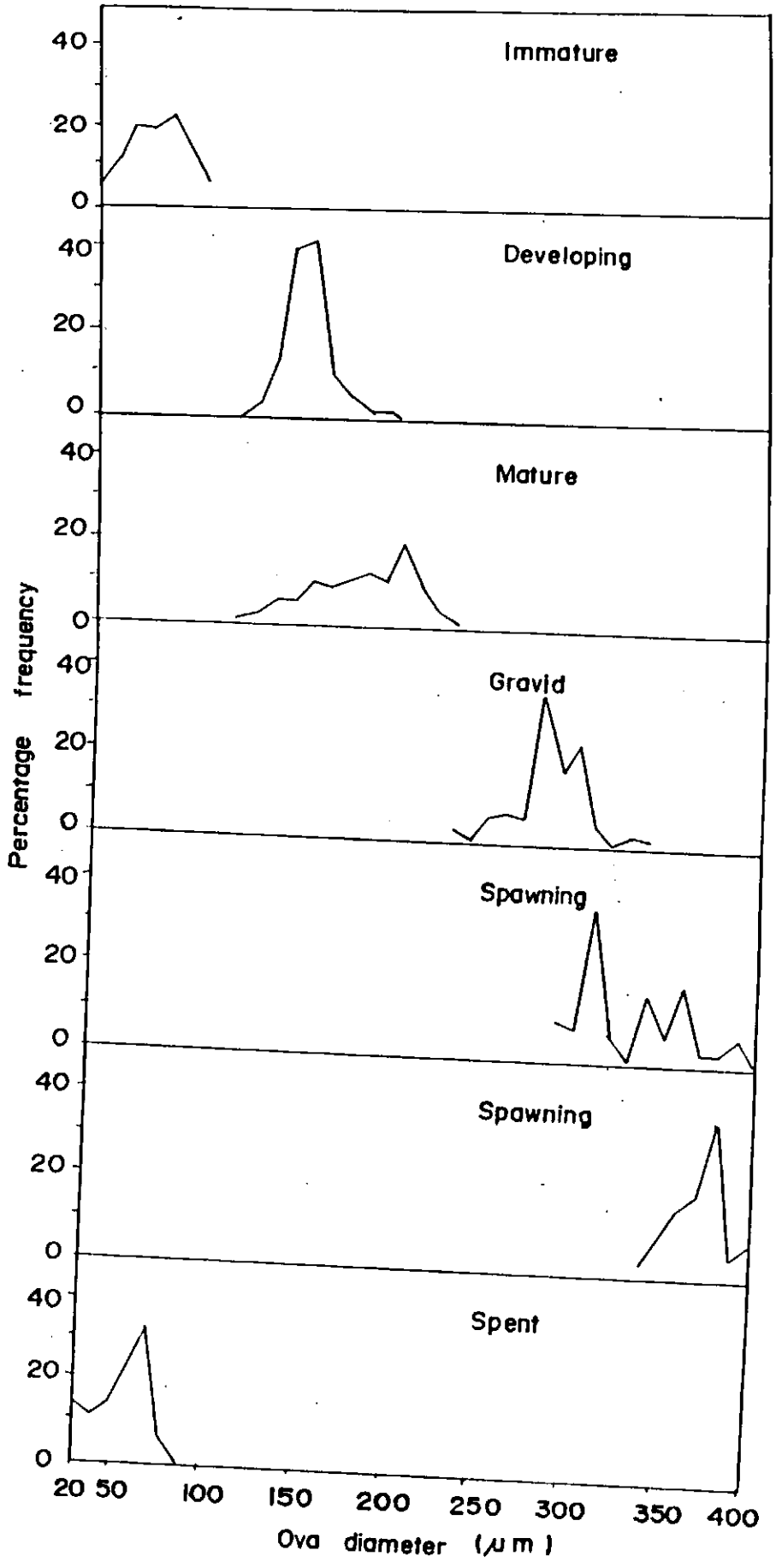
mature female crabs during the periods January-March and August - September. The maturity stages IV and VI (Gravid and Spent) exhibit two clear peaks (Figure 23 - d and e), first peak in April and the second in August. In spent females the peaks were observed in May and September.

3.5.4 Ova diameter frequency

Ova diameter frequencies were studied in six different stages of maturity. In each instance ova were taken from the anterior, middle and posterior regions of the ovary and were measured in a mixed sample. Figure 24 presents the data obtained with respect to each maturity stage.

Maturity stages I and II (immature and developing) show single peaks with modes lying between the range of 50 - 70 μm and 140 - 150 μm respectively (See figure 24 a & b). The mature stage (III) (Figure 24 - c) shows three peaks of which the third is the most conspicuous. The first peak appears between 110 - 150 μm and the second peak between 150 - 180. These two indicate two batches

Fig.24 Ova diameter frequencies of Scylla serrata at different maturity stages in the Negombo Lagoon.


Immature
Developing
Mature
Gravid
Spawning
Spawning
Spent
40
20
0
Percentage frequency
20 50 100 150 200 250 300 350 400
Ova diameter (μm)

of developing ova. The third peak which appears between 180 - 230 μm is the most developed batch of all and represents the mature ova. The fourth maturity stage (gravid) too shows three batches of ova (Figure 24 - d). The first group between 240-270 um, second group 270 - 290 μm and the third between 290 - 320 μm. The third batch might be the ripe ova which is about to be shed. At this stage the thoracic region of the crab is full of ova.

The fifth stage consists of two types of ova viz., the ova in the ovary and the shed ova still attached to the abdominal appendages. The ova in the ovary shows an irregular pattern within the size range of 290 - 400 μm (Figure 24 e). The shed ova show a single peak at 380 .um and this lies between 340 - 400 μm (Figure 24 e). The sixth stage is the spent stage which comprises a single batch of immature ova between the size range 50 - 100 μm (Figure 24 f).

3.5.5 Sex ratio

The distribution of crabs according to sex in commercial catches during the period from Jan. 1985 - Dec. 1987 was tabulated along with the chi-square values calculated for each length group (1 cm size groups) assuming a sex ratio of 1:1 (see Table 7.).

The sex ratio shows an uneven variation in the three years of study. In the first year the males and females were evenly distributed in smaller and larger length groups. However, the chi-square value was significant in favour of males in the length range 7.5 - 9.5 cm. In the second year males and females were even in much larger groups extending upto 9.5 cm and also in the two largest groups 17.5 and 18.5 cm. The chi-square values were significant in favour of females in the length range 13.5-16.5 cm. However, in the length groups 6.5 and 7.5 cm the chi-square significance was in favour of males. In the third year female significance was (6.5 - 15.5 cm) demonstrated in a much broader range.

Table 7: Sex ratio in different size groups in commercial catches in the Negombo lagoon during the three years, January 1985 - December 1987.

Year	1985			1986			1987		
Mid length (cm)	No. of males	No. of females	X^2 value	No. of males	No. of females	X^2 value	No. of males	No. of females	X^2 value
4.5	20	21	0.02	4	9	1.92	2	3	0.20
5.5	51	50	0.01	44	23	6.58	34	69	11.89
6.5	266	210	6.58	287	214	10.63	226	359	30.24
7.5	734	597	14.10	751	692	2.41	531	760	40.62
8.5	1286	924	59.29	1301	1236	1.67	904	1194	69.18
9.5	938	766	127.36	1292	1280	0.06	785	1207	89.28
10.5	566	592	0.58	1004	1176	13.57	501	837	84.19
11.5	413	395	0.40	686	851	17.71	326	570	66.44
12.5	193	210	0.72	342	631	85.84	181	368	63.68
13.5	78	84	0.22	147	245	24.50	93	146	11.75
14.5	32	47	2.85	73	129	15.52	54	94	10.80
15.5	37	30	0.72	24	63	17.48	25	47	6.72
16.5	17	17	0	17	44	11.95	19	32	2.37
17.5	7	8	0.26	6	10	1.00	6	8	0.28
18.5	3	4	0.57	2	2	0	3	6	0

The seasonal variation in the occurrence of males and females in commercial catches is illustrated in Table 8. The male : female ratio is found to be significant in favour of females in most months. However, in the month of June, in all the three years, the males and females were even in the catch.

3.6 Larval and juvenile population

3.6.1 Larval population

All the attempts made for collecting larval stages of crabs were unsuccessful. During the period of the study, zoea stage of crabs was found in two instances in April but the numbers found were not encouraging. One megalopa larva was found near the mouth of the lagoon during September 1987. Larval stages of crabs were not found even in the diurnal samples of plankton.

3.6.2 Juvenile population

Seasonal distribution of the juvenile crabs in 5 sampling stations of the Negombo Lagoon from

Table 8 : Sex ratio of crabs in commercial catches in the Negombo lagoon during the three years , 1985, 1986, and 1987.

Year / Month	1985 No. of males	1985 No. of females	1985 X^2 value	1986 No. of males	1986 No. of females	1986 X^2 value	1987 No. of males	1987 No. of females	1987 X^2 value
January	48	74	5.54	1071	557	162.00	425	764	300.40
February	189	326	37.37	865	727	11.96	172	287	92.16
March	235	323	13.88	623	544	5.35	234	349	75.79
April	195	406	74.08	284	336	4.36	103	179	64.54
May	200	300	20.00	175	224	6.02	242	338	14.40
June	187	213	1.90	296	345	3.75	389	424	1.51
July	262	336	9.16	446	527	24.89	258	335	10.00
August	330	413	9.27	439	661	44.80	264	483	64.20
September	341	200	36.74	630	799	19.99	423	542	14.67
October	562	354	47.23	596	708	9.61	267	488	64.69
November	1125	541	204.71	179	391	78.85	527	921	107.21
December	954	564	100.20	374	723	111.03	386	596	147.99

February 1987 - May 1988 is illustrated in Figure 25.

The data shows that the juvenile occurrence was high in February to March and August to December. The size of juveniles varied from 2 - 7 cm in carapace length with a mean of 3.5 cm. Among five stations the juvenile occurrence was low in Seeduwa and Kepungoda as compared to Kadol Kelle, Pitipana and Talahena which were relatively closer to the mouth of the sea. The juveniles were almost non existent in March - August in Seeduwa and Kepungoda.

Diurnal variations of the abundance of juvenile crabs as studied by three diurnal cycles carried out in the Kadol kelle station during the period from Nov,87 - Dec,88 (Figure 26.) revealed the following :

A similar pattern was demonstrated in the abundance of juvenile crabs in all the three cycles. There was a clear relationship with the tidal fluctuations and the occurrence of juveniles.

Fig.25 Seasonal fluctuations in the abundance of juveniles of Scylla serrata in five areas of the Negombo Lagoon during the period, January 1985 - December 1987. a) Katunayake b) Kadol kelle c) Pitipana d) Talahena e) Kepungoda.

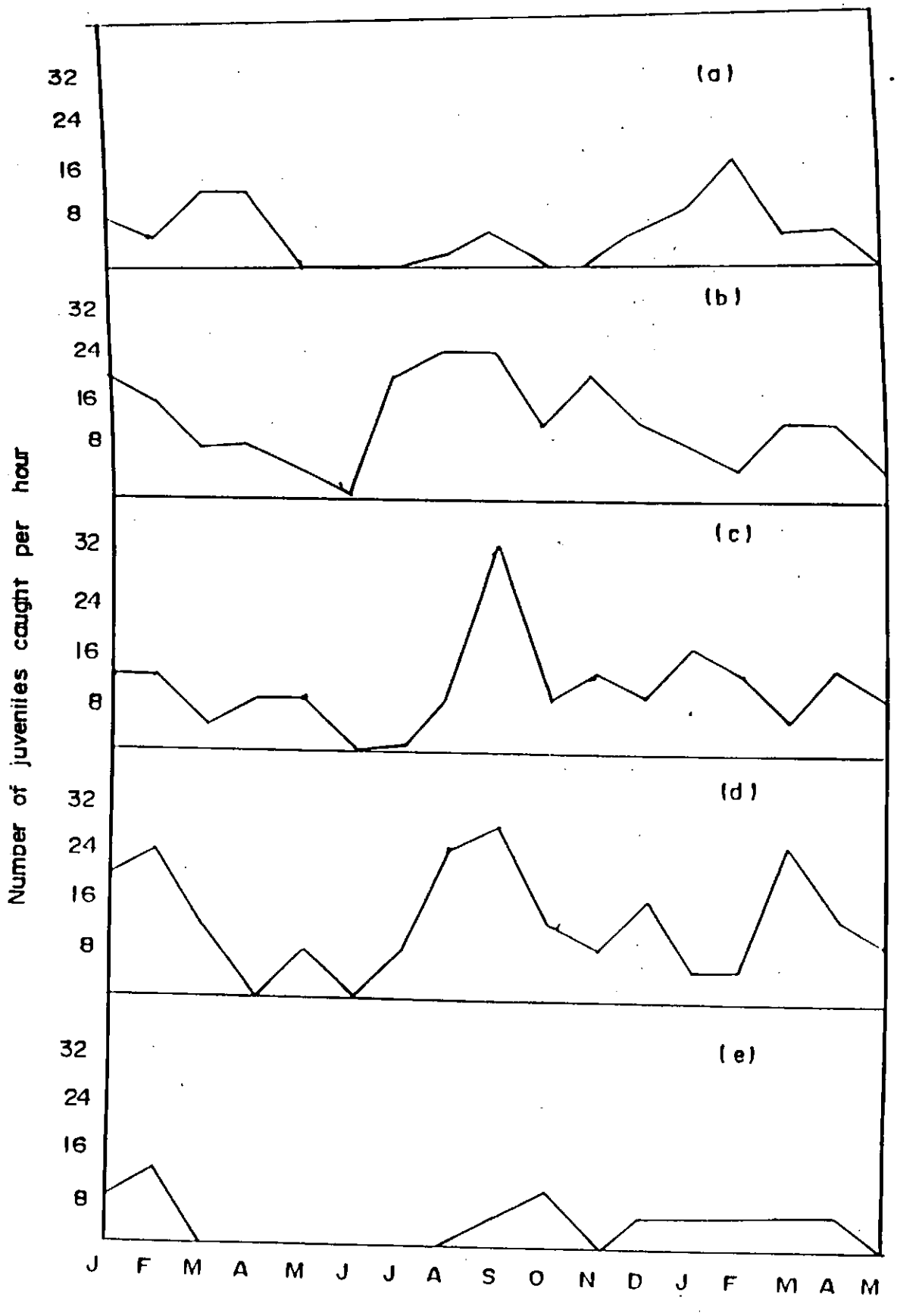
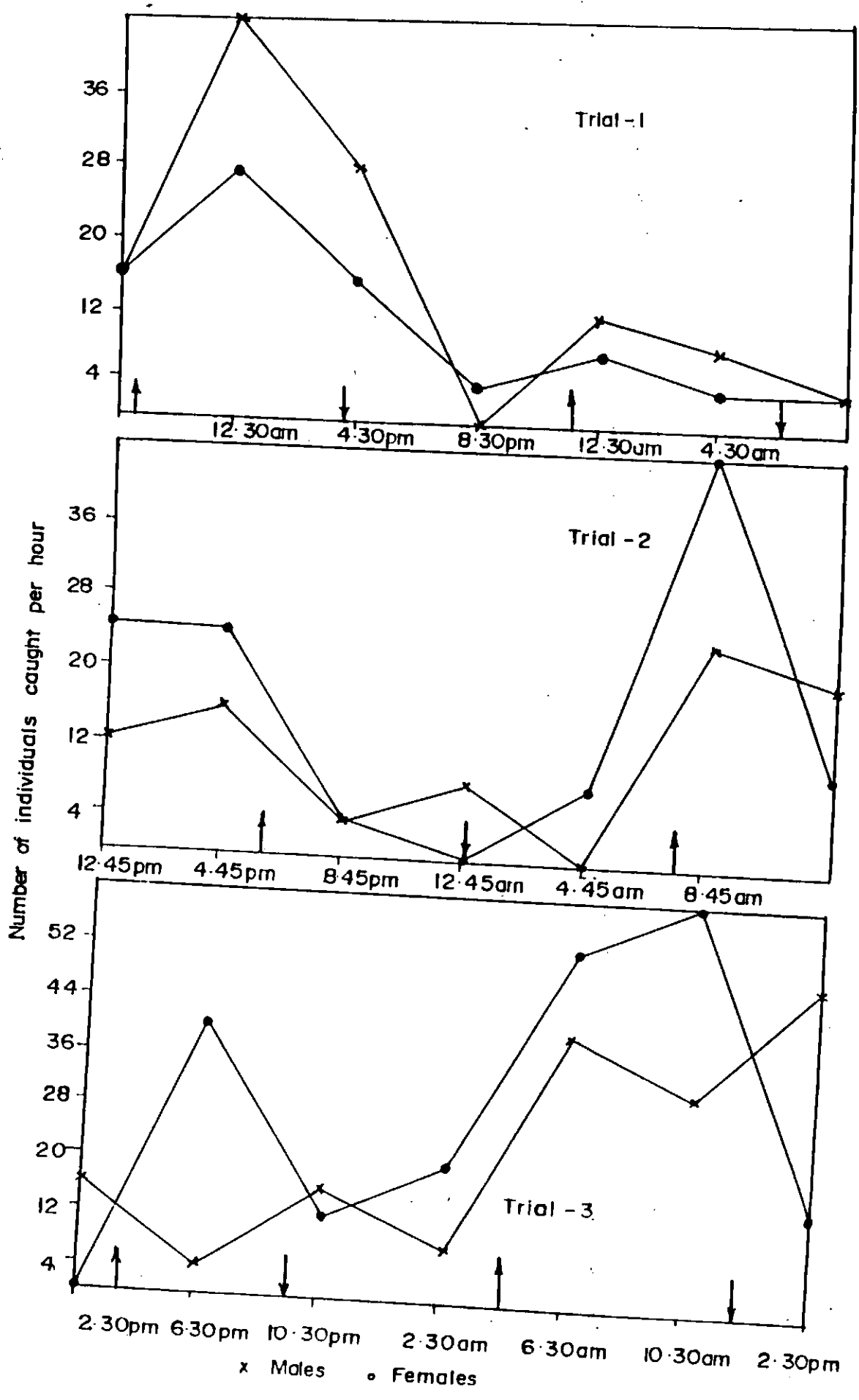

(a)
(b)
(c)
(d)
(e)
32
24
16
8
Number of juveniles caught per hour
J F M A M J J A S O N D J F M A M

Fig.26 Diurnal fluctuations in the abundance of juveniles of Scylla serrata in the Negombo Lagoon.


Trial - 1
36
28
20
12
4
12·30am
4·30pm
8·30pm
12·30am
4·30am
Trial - 2
36
28
20
12
4
12·45pm
4·45pm
8·45pm
12·45am
4·45am
8·45am
Number of individuals caught per hour
52
44
36
28
20
12
4
Trial - 3
2·30pm
6·30pm
10·30pm
2·30am
6·30am
10·30am
2·30pm
x Males
o Females

Highest occurrence of juvenile crabs were observed during the high tide.

3.7 Fishery and economic aspects of Scylla serrata

The number of crab fishermen according to each landing center of the Negombo Lagoon is given in table 9. A considerable number of fishermen are from Munnakkaraya and Talahena. From the total of 103 only 25 fishermen entirely live on the crab fishery. The other fishermen mainly depend on fin fishes and prawns, although they fish crabs occasionally.

The average number of

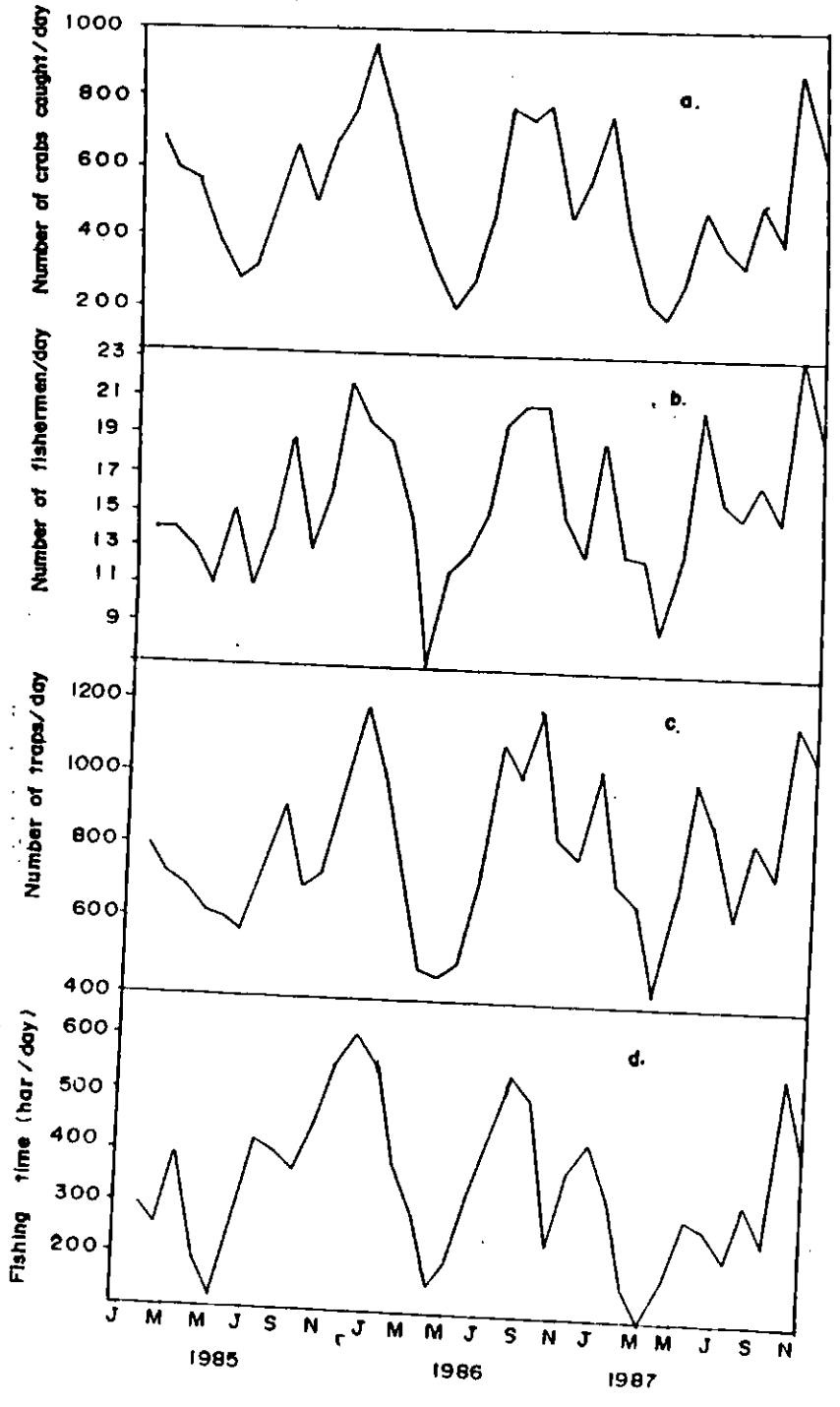
a. crabs caught in a day
b. fishermen engaged in crab fishing in a day
c. traps operated in a day
d. hours spent by a fisherman a day

were plotted for the three years of the study (Figure 27). The weekly data were pooled and the average was taken for each month.

Table 9. Number of fishermen engaged in the crab fishery in the Negombo lagoon and their distribution according to landing centers around the lagoon.

Landing center	No. of fishermen fully engaged in crab fishery	No. of fishermen partly engaged in crab fishery	Total No.of fish-ermen
Pamunugama	1	6	7
Kepungoda	2	2	4
Dungalpitiya	1	3	4
Talahena	11	17	28
Basiyawatta	1	2	3
Aluthkuruwa	3	2	5
Munnakkaraya	2	28	30
Taladuwa	1	9	10
Kurana	0	5	5
Pitipana	1	4	5
Maha weediya	1	1	2

Fig.27 Seasonal fluctuations in:a) Number of crabs caught per day,b) Number of fishermen per day, c) Number of traps operated per day, d) Fishing time in the Negombo Lagoon during the period January 1985 - December 1987.


Number of crabs caught / day
1000
800
600
400
200
a.
Number of fishermen/day
23
21
19
17
15
13
11
9
b.
Number of traps/day
1200
1000
800
600
400
c.
Fishing time (hor / day)
600
500
400
300
200
d.
J M M J S N J M M J S N J M M J S N
1985
1986
1987

The average number of fishermen engaged in crab fishing in a day fluctuates between 8 and 24. In general, more fishermen are found to be engaged in crab fishing during the last four months of the year. Further the fishing activity was found to be continuous throughout the year. The number of traps operated per day paralleled the number of fishermen engaged in a day during the 3 years 1985.1986 and 1987.

The variation in number of crabs caught per day parallels the fishing time. The number of crabs caught per day varies between 200 - 900 crabs a day with peaks observed in November and December.

The variation of the price of the crabs of different sizes during the period from July 1985-December 1987 are given in Table 10. These were the prices in the market in days of data collection. The prices were recorded according to size of the crabs, small (5 - 9 cm carapace length), medium (9 - 13 cm carapace length) and large (>13 cm carapace length) .

Table 10. Seasonal variation in the price of the crabs during the period from July 1985-December 1987 in the Negombo lagoon.

Month	Price (in rupees)		
	5 - 9 cm	9 - 13 cm	13 - 17
JUL'85	1.33	3.52	12.60
AUG	1.20	3.00	12.00
SEP	1.25	3.31	17.32
OCT	0.78	4.40	11.24
NOV	0.60	2.36	9.66
DEC	1.00	2.81	17.85
JAN'86	1.00	3.75	18.00
FEB	1.30	3.88	18.15
MAR	1.06	3.00	17.50
APR	1.08	4.16	18.60
MAY	2.80	7.33	21.10
JUN	1.90	3.50	17.50
JUL	1.64	2.90	9.05
AUG	0.79	2.61	14.00
SEP	1.29	3.20	9.25
OCT	1.16	2.81	11.68
NOV	1.07	4.09	9.20
DEC	1.10	3.10	10.20
JAN'87	1.00	2.65	10.80
FEB	1.05	3.64	14.00
MAR	1.00	5.00	16.00
APR	1.80	6.15	18.00
MAY	1.19	4.41	25.00
JUN	1.10	5.20	18.50
JUL	1.05	5.50	14.75
AUG	0.90	5.30	14.00
SEP	1.30	4.80	10.00
OCT	1.15	4.28	9.60
NOV	1.10	3.80	9.10
DEC	0.90	3.70	9.00

Table 11. Seasonal variation in the average price/crab and the percentage frequency of abundance in three size ranges of crabs in the Negombo lagoon during the period from July 1985 - December 1987.

Month	Average price /crab (Rs.)	percentage frequency of abundance		
		5 - 9 cm	9 - 13 cm	13 - 18 cm
JUL'85	2.43	83.0	15.2	1.8
AUG	1.84	58.7	40.2	1.1
SEP	1.80	73.3	24.8	1.9
OCT	2.13	53.5	43.6	2.9
NOV	1.90	44.6	52.1	3.3
DEC	2.39	45.3	50.2	4.5
JAN'86	2.38	31.9	65.0	3.1
FEB	2.22	46.6	50.7	2.7
MAR	2.15	54.0	43.9	2.1
APR	2.64	53.9	42.9	3.2
MAY	3.80	49.0	44.1	6.9
JUN	2.67	40.6	53.7	5.7
JUL	2.47	35.4	57.1	7.5
AUG	2.48	45.9	47.6	6.5
SEP	2.56	37.8	54.3	7.9
OCT	2.14	28.1	60.6	11.3
NOV	2.13	34.5	59.0	6.5
DEC	1.09	25.4	71.1	3.5
JAN'87	3.28	14.3	74.1	11.6
FEB	3.35	24.3	64.7	10.9
MAR	4.41	16.2	66.5	17.3
APR	3.07	34.7	59.0	6.3
MAY	2.75	45.5	48.5	6.0
JUN	2.35	54.4	40.4	5.2
JUL	3.19	35.5	61.1	3.4
AUG	2.89	40.5	55.2	4.3
SEP	2.27	46.7	50.2	3.1
OCT	2.26	51.1	47.2	1.7
NOV	1.81	67.6	31.5	0.9
DEC	2.61	63.0	36.1	0.9

Table 12. Price variation of the meaty crabs (weighing more then 300g) in the export market and the number of intermediate vendors in the Ngombo lagoon during the study period (1985 - 1988).

Year	Price/ kg (Rs.)	Number of intermediate vendors
1985	30 - 50	1
1986	50	1
1987	50	1
1988	90 - 120	3

The prices of small crabs were almost uniform throughout the period of study.. But the price of medium and large sized ones changed remarkably from time to time. The price of small crabs remained at about Rs.1.00 /crab while the price of medium size crabs changed between Rs.2.00 - 7.50/crab. The price of large crabs varied between Rs.9.00-25.00/crab. Higher prices were often observed in May and lower prices in September and December.

Further Table 11 also furnishes the percentage frequency of each size along with the price. It is alarming to note that more than 80% of crabs caught in the Negombo Lagoon are either small or medium. Table 12 shows the variation of the price of meaty crabs in the export market during the 3 year period, and the number of intermediate vendors engaged in collecting meaty crabs. The price of meaty crabs weighing more than 300 g have shown a marked increase in the price from 1985 (Rs.30-50/kg) to 1988 (Rs.90 - 120/kg).

3.7.1 Catch per unit effort (CPUE)

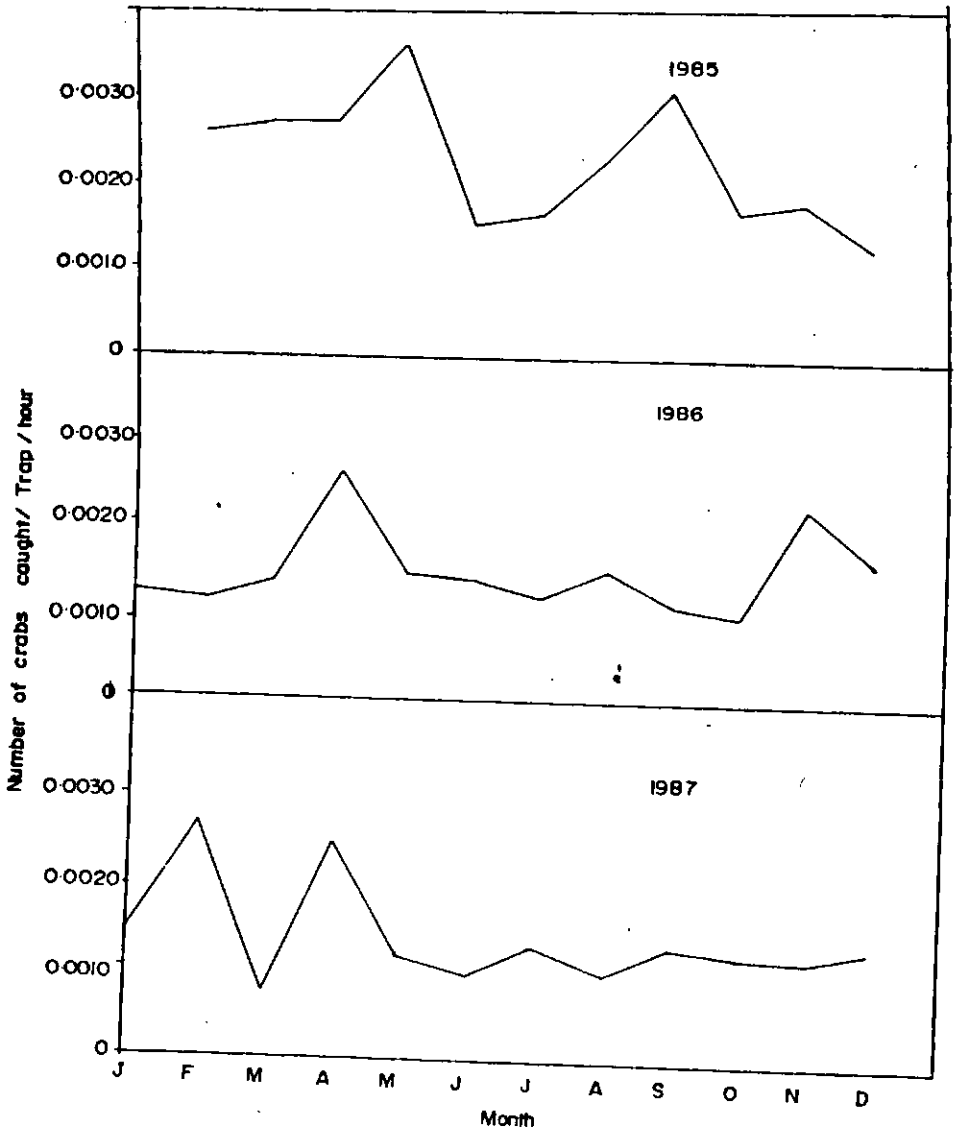
The following data were used to calculate the variation of catch per unit effort with the time:Total catch (No. of individuals), fishing time and number of traps operated in each day of sampling.

The fishing effort was considered in terms of trap hours. The number of individuals caught were taken as the total catch .

Thus the CPUE was calculated as the number of crabs caught per trap per hour (CPUE = C/ H x T). CPUE's were calculated separately for each month.

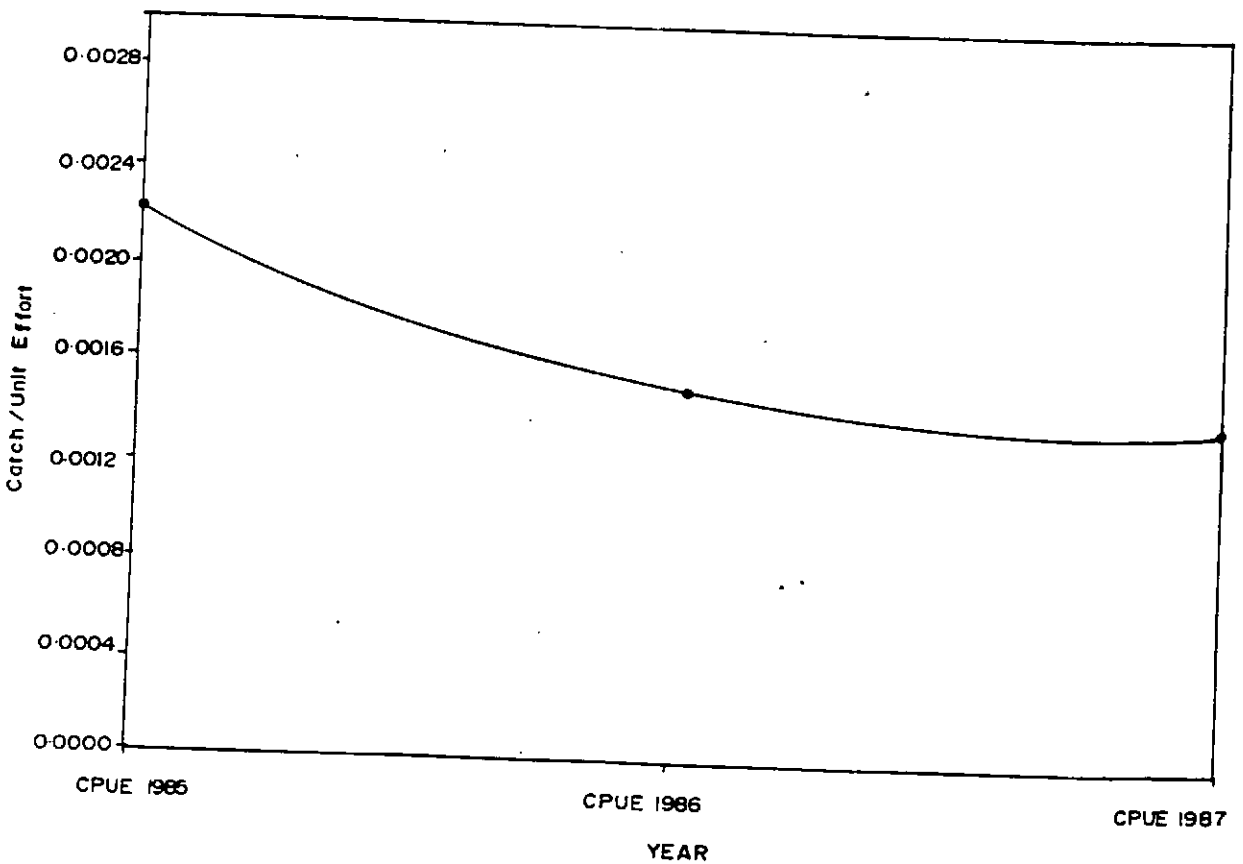
Figure 28 gives the seasonal variation of CPUE during the three years 1985, 1986 and 1987. CPUE varied between 0.0012 - 0.0036 in 1985, between 0.00010 - 0.0026 in 1986 and between 0.0008-0.0027 in 1987. The annual mean of CPUE were found to be 0.0022, 0.0015 and 0.0014 in 1985, 1986 and 1987 respectively. The CPUE was highest in May 1985 and was lowest in March 1987. The trends in CPUE

Fig.28 Seasonal variations in the catch per unit effort of Scylla serrata during the period, January 1985 - December 1987.


1985
1986
1987
0·0030
0·0020
0·0010
0
Number of crabs caught/ Trap / hour
J
F
M
A
M
J
J
A
S
O
N
D
Month

were similar during the three years except for the slow gradual decrease in the magnitude of the peaks. High CPUE's were found in May 1985, April 1986 and in February and April in 1987. The annual CPUE was calculated for the three years and were plotted in Figure 29. This shows that there is a slight decreasing trend in the CPUE with the time.

Fig.29 Annual catch per unit effort of Scylla serrata in the Negombo Lagoon during the period, 1985 - 1987.


0·0028
0·0024
0·0020
0·0016
0·0012
0·0008
0·0004
0·0000
Catch / Unit Effort
CPUE 1985
CPUE 1986
CPUE 1987
YEAR

D I S C U S S I O N

Negombo Lagoon by its location in the wet zone exhibits characteristics of a typical tropical lagoon. The hydrobiological parameters in the lagoon are either directly or indirectly related to the monsoon rains.

The salinity in the lagoon varies between 0-35 ppt with high salinity observed near the mouth of the lagoon. Lagoon as a whole becomes fresh twice a year, i.e. in May/June and in November/December which correspond to the south-west and north-east monsoons respectively. Previous limnological studies on the Negombo Lagoon too have revealed similar salinity variations with minor alterations at times (De Silva and Silva, 1979).

The water temperature in the lagoon does not appear to exhibit large fluctuations. The lowest temperature recorded during the study was 22°C and the highest was 34°C. The temperature range recorded by Silva and De Silva in 1979 was also very close to the present values (25°C - 35°C).

Turbidity in the Negombo Lagoon was extremely high in 1985 as compared to the subsequent years,1986 and 1987. Rainfall in the catchment area was vice versa in 1986 and 1987 showing high rainfall than the previous year 1985. However, a contradictory situation was observed in a neighbouring estuary (Kelani) where turbidity showed a positive correlation with rainfall (Sumitra-Vijayaraghavan and Jayamanne, 1985).

The difference in the two instances could be attributed to the fact that the Kelani estuary is fed by a large river with heavy land run off, whereas the Negombo Lagoon is a solitary water body with marginal input from the canals Dandugam Oya and Ja-ela.

The lagoon water was slightly less acidic exhibiting a marginal pH variation of 5.0 - 9.0, the average pH being 8.0. Previous limnological studies on the Negombo Lagoon too records a similar range (De Silva and Silva, 1979).

Rainfall during the 3 years of study shows a clear difference between 1985 and the subsequent years. The total which was 1678 mm in 1985 was lower than that of 1986 and 1987 which were 2075 mm and 2053 mm. The rainfall pattern exhibits the wet zone characteristics, two rainy seasons a year, May/June and November/December, the second being more prominent.

References to taxonomy of crabs in Sri Lanka were scant. There was no key for identification and probably those who have mentioned Scylla serrata in their texts have used a guide prepared for crabs elsewhere. Some early literature that cited, Scylla serrata are Boone (1934)., Sakai (1965)., Arudpragasam (1967)., Raphael (1970)., and Pinto (1986). In the present study Scylla serrata was identified according to characteristics in the taxonomic guide prepared by Tirmizi (1986). According to this guide Scylla serrata is characterized by a smooth and granular carapace which is greenish in colour. The carapace comprises 22 spines of which four lie between the eyes and rest, 9 each on antero lateral borders. Boone

(1934) and Sakai (1965) too have noted similar characters. The current observations too confirm these characteristics of Scylla serrata. But it was observed that the colour of the carapace was not always greenish. Brownish ones were also observed, particularly, in mangrove areas. This agrees with the findings of FAO report (1981) that the colour of crabs vary with the environment to a certain extent. Besides this observation in colour variation all other characteristics mentioned were in favour of the hypothesis of Stephenson and Campbell (1960) that the mud crabs comprise the single species, Scylla serrata.

Food and feeding habits of Scylla serrata have been studied by various authors in the past. According to Arriola (1940), Scylla serrata was an omnivore, a scavenger and a cannibal. Crabs possess contact chemoreceptor in the dactyls of their walking legs to locate their food (Hill, 1979b). Molluscan remains and crustacean remains have been identified as major gut contents (Hill, 1979 b). Further, their prey groups were identified as burrowing bivalves, attached bivalves and smaller crabs.

The present study reveals that Scylla serrata in the Negombo Lagoon feeds on different varieties of food and the type of food is determined by the size of crab. Small crabs (2 - 6 cm) feed mainly on crustaceans while the medium size ones (6 -10 cm) preferred bi-valves of the burrowing type. However, the food of much larger groups were not analysed in the present study owing to the difficulty in obtaining such crabs without using baited traps.

In general, the food items of Scylla serrata in the Negombo Lagoon comprised small crustaceans, bi-valves, gastropods, fish, plant matter, crabs and sand. This agrees with the earlier findings that Scylla serrata is an omnivore (Arriola, 1940). The presence of fish remains was rare and this agrees with findings of Hill (1976), in Queensland. The preference of small crabs for small crustaceans proves the predatory behavior of Scylla serrata which has also been reported earlier by Hiatt (1944), in Hawaii. It is also seen that there is no significant seasonal variation in the food constituents of Scylla serrata.

Diurnal studies revealed that Scylla serrata start feeding with the onset of the high tide in the daytime and ceases to feed with the onset of the low tide. They were found to feed continuously throughout the night irrespective of the tidal variations. Hill's (1976) findings in Queensland too shows a similar pattern. He stated that "Scylla serrata, remains buried during the day time and emerges at sunset to feed intermittently throughout the night".

Preliminary observations on samples of Scylla serrata caught from different places of the lagoon revealed that the individuals in these samples fall within a similar size range with a mean length of 8-9 cm. Thus, the length frequency analysis was confined to pooled data from all landing stations.

The method employed to analyze the length frequencies was a very recently developed procedure (Soriano et al, 1989 and thus it is very unlikely that similar growth parameter estimates would be reported elsewhere.

Thus, the estimated values of L_{∞}, which was 22.4 for females and 22.36 for males are very much closer to the largest Scylla serrata specimens observed during the present study and to the previously recorded largest specimens in the world (Jones and Sujansingani, 1952., Heasman, 1980).

The present study indicates differences in the growth parameters of male and female Scylla serrata. The males and females grow to a similar Loo value (22.4 - females, 22.36 - males), but the rate at which they grow is different. Female Scylla serrata grows at a slower rate than males. This phenomenon has also been reported by Venema (1988) in the red crab Geryon quinquedens off Mozambique. The ϕ' value of 5.70 (in terms of natural logarithms) which is a characteristic of the species has also been recorded by Venema (1988). This value is close to the ϕ' value (5.2) obtained by Venema (1988) for the red crab. Gear selectivity was found to be an important factor, particularly in the case of the traps where it was difficult to estimate growth parameters. The population was found to be distributed around 8.5 - 10.5 cm in

carapace length. Smaller crabs of the size range 3 - 4 cm were found only in the month of June in all three years. This indicates an influx of smaller crabs into the population during this part of the year. However, attempts made at pooling the length data of three years made the growth parameter estimation more reliable.

Relative high values of mortality and exploitation rates indicate that the crab population in the Negombo Lagoon is over exploited. The present exploitation rate, E = 0.663 for males and E = 0.594 for females is much higher than the optimum level of exploitation. The high value of Total mortality (Z) which is 4.676 for males and 2.293 for females is due to the high value of fishing mortality (F) which is 3.100 for females and 1.955 for males. This indicates that the crabs are vulnerable to the gear (traps) used. The fishing intensity of crabs is known to be very high in the Negombo Lagoon due to the export market demand. Year-round exploitation of immature crabs by traps, drift nets, etc, observed during the present study supports the estimated value of exploitation

rates (E = 0.663 for males, E = 0.594 for females) which are very high.

The observed difference in total mortality between males and females (male = 4.676, female = 2.293) could be a result of difference in migration. Hill (1975) and Heasman (1980) observed offshore migration of female Scylla serrata for spawning. This makes male Scylla serrata more vulnerable to the fishing gear used.

The recruitment pattern estimated here suggests two recruitment pulses per year. This is in agreement with the findings of the present study which showed two pulses in percentage frequency of mature females. Brick (1974), Heasman (1980) and Arriola (1940) have also observed two spawning seasons in Scylla serrata.

The length at first capture which is 8.0 cm in carapace length is small compared to the size at first maturity of the crab which is found to be 12.00 cm. This suggests that the growth overfishing (over exploitation of immature crabs) also takes

place in the mud crab fishery of the Negombo Lagoon.

The size of crabs caught depends on two factors, distribution pattern of crabs and spawning migration by females (Williams and Hill, 1982). In the Negombo Lagoon baited traps were only operated in sub-tidal areas of around 1 m depth. Most of the areas are shallow in the Negombo Lagoon and less than 1 m in depth. The mean water level of the lagoon varies from 15 - 52 cm (Pinto and Wignarajah, 1980). The bigger crabs (15 cm) confine to deeper canals made for boats moving towards the sea for fishing. The lagoon is open to the sea throughout the year. The female crabs above 11 -12 cm may be migrating to sea for spawning. All these factors indicate that the main crab fishing area comprises crabs of 8 - 11 cm size range. As a result, consistent modes were observed in the monthly samples of Scylla serrata population.

Difficulties encountered during the present study regarding the length frequency analysis were

mainly due to the above factors. Williams and Hill (1982) reported similar difficulties in Queensland where stake-seine catches were used to analyze the length frequencies. According to their observations Scylla serrata cannot be collected by using divers because of the high turbid conditions found in the estuarine areas. They were seldom captured in trawls, apparently because they can bury or avoid trawls. Therefore, it is important to devise a gear which could provide unbiased samples of crabs in order to get more precise growth parameters.

Y'/R (yield per recruit) analysis suggests that increasing L_c (length at first capture) is the only possibility which could be used for increasing the yield in crab fishery. Hence, the mesh size of the traps currently being used in the Negombo Lagoon should be increased in order to increase the yield. In the management point of view it should be noted that further increase of fishing effort may be harmful to the fishery.

Length and weight of Scylla serrata shows a very good correlation following allometric growth

formula; $W = aL^b$. As in many fish species, the length weight relationships in males and females do not show a significant difference. Thus both males and females appear to grow in equal proportions although the females tend to grow fast in early stages.

Reproductive biology is also another aspect of Scylla serrata that has not been studied extensively in the past in other countries of the Indo-Pacific region. The present study succeeded in estimating the stage at first maturity, fecundity and spawning seasons of Scylla serrata in the Negombo Lagoon.

Of the population, 50% of the female mud crabs in the Negombo Lagoon appear to reach maturity at the size of 10 cm in carapace length. In South Africa the stage at first maturity of the mud crab was estimated to be around 13 - 14 cm (Duplessis, 1971). In Philippines, the size range of the ovigerous females was observed by two authors.

Escritor (1970) reported this range as 8.5 - 11.1 cm and Estampador (1949 b) as 10.0 - 12.5 cm. Ong (1965) observed berried mud crabs of 12 cm in carapace length. In the present study, berried females observed were around 9.8 - 13.0 cm in carapace length.

The pre-spawning fecundity of Scylla serrata in the Negombo Lagoon was estimated to be around 1.76-3.5 million.

The post-spawning fecundity was around 1.28 - 1.84 million. The size range of females used to estimate the fecundity was of 9.8 - 13.8 cm length range. Similar estimates were reported from Philippines. Arriola (1940) reports that, in Philippines, the estimated fecundity of Scylla serrata is around 2.0 million eggs. Varikul et al.(1970) reported from Thailand that their estimate of fecundity was around the same range (1 - 3 million). It should be noted that the above estimates mentioned in other countries were all with respect to post-spawning fecundity.

The current findings with respect to Scylla serrata are that: the ova mature at the size of 240 - 320 µm in diameter. The ovary consists of 3 batches of ova indicating partial spawning behavior. Scylla serrata was also reported as a multiple spawner who is able to extrude three batches of eggs without mating between ovulations (Ong, 1965).

Based on the occurrence of spawning females of Scylla serrata in the lagoon, two seasons have been identified as spawning periods; April and August, which is confirmed by the presence of spent females in subsequent months May and September. Two spawning seasons per year have also been reported by Arriola (1940) in Philippines (May and September), Brick (1974) in Hawaii (May and October) and Le Reste (1976) in Madagascar (April/May and June/July). Pillay and Nair (1968) observed only one month of spawning (January) by Scylla serrata in India. Others have observed single seasons of longer durations; Heasman (1980) in Queensland (April-August), Estampador (1949 b) in Illoilo (August - November) and Varikul (1970) in Thailand (July - December). Pillai and Nair

(1968) have also reported that continuous breeding of Scylla serrata occurs throughout the year. The sex ratio of mud crab was 1:1 in most of the size groups in the Negombo Lagoon in 1985. However, in the two subsequent years female dominance was significant in most of the size groups except in the month of June. This may be connected with the recruitment pattern of juveniles which were most abundant in June. This uneven distribution of males and females contradicts the findings in other parts of the world where the sex was always reported to be even (Hill, 1975., Heasman, 1980., Williams and Hill, 1982).

Attempts made at studying the larval population were found to be unsuccessful. The area covered for collection of larval stages of crabs extended from the mouth of the lagoon to about 1 km offshore. Hence, the absence of larvae may be due to the fact that they were confined to much further areas of the sea or sheltered areas such as rocks. Otherwise, it may be that they had escaped through the plankton net used. Further research is needed for the study of larval stages. However, it may be

noted here that similar attempts made by Matilda and Hill (1980) at Queensland too failed in obtaining a sizable larval population for an analysis.

Juveniles of mud crabs are usually identified from their size. Heasman (1980), defined juvenile crabs as the ones smaller than 10 cm in carapace length. The habitat of juvenile crabs has been studied extensively by Hill in Queensland (1975). The juveniles move freely in shallow waters for feeding and shelter in small creeks and channels, sea grass beds, under stones and between roots of mangroves (Hill et al.,1982). The distribution of juveniles differ from that of sub adults which were between 10 cm - 15 cm and adults, >15 cm. Juveniles upto 8 cm were largely found in intertidal flats (Heasman, 1980). They were also found to live in association with the aquatic macrophytes (Hill, 1979a).

In the Negombo Lagoon the juvenile crabs in the range of 2 - 7 cm inhabit shallow areas around 50-75 cm depth. The crabs caught by hand nets during the low and high tides fall within this size range.

The absence of adult or sub-adult crabs in this area suggests that their habitat was in much deeper areas in the Negombo Lagoon.

The occurrence of juveniles in the Negombo Lagoon was at peak levels in February - March and August-December. According to a FAO report a crab takes about 35 - 43 days to become a juvenile of 1 mm size. The growth curve developed by Fielder and Heasman (1978) suggests that a crab attains the size of 2 - 8 cm within 3 - 8 months after hatching. Hence, a crab takes an average time of about 3 - 4 months to become a juvenile. By considering this, a very rough estimate can be made on the period of recruitment of Scylla serrata to the Negombo Lagoon by subtracting 4 months from the peak months. Thus, it can be suggested that the recruitment occurs in October - November and March - September within a given year.

The number of juvenile crabs caught during the high tide were much higher than those caught at low tide. The crabs may be showing a tendency to come out of their burrows during the high tide which

made them more vulnerable to the gear. The baited trap called "Kakulu Atangu" was the major gear operated for capturing crabs in the Negombo Lagoon. Besides this trap, they were also landed as by-catch in drift net, drag net and brush park operations.

There were similar gear in other countries too. In Queensland the crabs are usually caught by box shaped wire traps (60 cm x 25 cm x 25 cm). Cylindrical wire mesh pots or cane pots (diameter = 1 m, height = 25 cm), drop dilly pots and hooks are also used in crab capture (Hill,1980). In Mozambique and South Africa too similar gear are used (FAO Report, 1981). The commonly used gear in India are Noli-Jal (gill net) and Konkre Karriya (box trap) which is similar to the baited trap in Sri Lanka (Jones and Sujansingani, 1952).

About 100 fishermen claimed to have engaged in crab fishing in the Negombo Lagoon during the time of the survey and approximately 25 of them are entirely dependant on the crab fishery for their

survival. The others engaged in crab fishing only during periods when prawns were less abundant. The number of fishermen engaged in crab fishing per day varied from 8 - 24. The number was high during last four months of the year.

Although crab fishing exists throughout the year in the Negombo Lagoon, the catch varies remarkably, showing peaks in November and December. The catch appears to be extremely low in May and June. Crab fishing was also found throughout the year in other parts of the Indo-Pacific region. In Queensland peak catches were observed from January to May. The catches were low in November (Heasman and Fielder, 1977). In Chilka lake, India, high catches were observed during the period, August - October (Jones and Sujansingani, 1952).

The number of crab traps laid per day varied from 420 - 1200. Corresponding variations were observed with the number of fishermen, fishing time and the catch. However, the number of traps laid by each fisherman was around 50 and that did not vary much.

Therefore, the number of traps operated in a day is entirely dependent on the number of fishermen engaged in fishing. These traps were laid three meters apart and the fishermen had to stay alert to guard them from thieving. The fishing time varies from 2 - 24 hours a day with an average of 6 - 8 hours for a man day.Similar data were not reported from other countries.

Unlike in Queensland there are no legal barriers for local fishermen regarding the size of crab that can be exploited. According to Australian Fish Board it is illegal to catch crabs less than 15 cm carapace length (Hill,1982). The local catches contain crabs of very small sizes and the stock that comes to the market even carries crabs smaller than 5 cm. The data of the present study reveals that approximately 80% of the exploited stock comprises crabs below 15 cm width. The tragedy of this is, that the fishermen continue to exploit large quantities of immature crabs for a relatively poor return as the demand for immature crabs is low. The fishermen bring their catch to the market

in a sac made of nylon thread. The price of a sac of crabs is determined by the number of big crabs (over 13 cm) in the sac and not by the weight of the sac.Legal sizes for crab capture has not been reported from other countries except Australia.

The price of a big crab is determined by the total catch of the day or the supply in the lagoon. The average price of a big crab is around Rs.17/=. The price of a big crab even goes up to Rs.25/= per crab when the supply is low. After the export of crabs began in 1987 the price of meaty crabs increased even further.

The exporters buy them at Rs. 90 - 120 per kg. The price of crabs is a supply dependent factor. The supply can be affected by many factors such as environmental parameters, seasonal changes, biological characteristics etc.

References to population dynamics of Scylla serrata have been very scant. This may be due to lack of efficient techniques to study this aspect of crab.

The most feasible method for sampling crabs is the baited trap. But this method has certain limitations. This gear is highly selective because it is connected with the feeding response of the crab. Feeding of crabs is often affected by factors such as temperature, moulting, etc., (Chittleborough, 1975., Hill, 1980 ., Passano, 1960., Williams and Hill, 1982).

However, in Sri Lanka the crabs are exposed to harmful lower temperatures in nature. Yet factors such as type of the bait, moult condition etc. can cause biased sampling. Most of the crab fishermen use ray fish (Pastinachus sephen) as their bait. Cow offals and gills of shark too are very common baits used by the fishermen in the Negombo Lagoon. Mullet, the most common bait used in Australia (Hyland et al, 1984) is never used as a bait by the Sri Lankan fishermen although it is freely available in the area.

Catch per unit effort was found to be relatively high in April and May of all the three years. However, the catch was low in these months. Hence,

the high values observed in CPUE was mainly due to the decrease in number of fishermen. Since the catch was low the price was high during these periods.

CONCLUSION

Scylla serrata is one among 6 species of crabs which are of great importance in the world market. The strong market demand for crabs in the high income areas of the world emphasizes the importance of crabs for a developing country like Sri Lanka. Thus, it demands a prime need to develop a management strategy for optimum use of this resource.

Unlike in other countries, there are no legal barriers existing in Sri Lanka with respect to the size of the crab that can be exploited. Hence, the local catches comprise crabs of very small sizes often smaller than 5 cm carapace length. Approximately 80 % of the exploited stock comprises crabs below marketable size.

In the recent past, the exploitation of the resource was governed by the export market for crabs. High prices tempted fishermen even to catch very small crabs such as 4 cm because they too could be sold. Since there is no management the

exploitation continues destroying a large proportion of the recruitment stocks. As a result, the future of the fishery is in jeopardy.

Overexploitation is so marked that the rate of crab fishing has exceeded the maximum sustainable yield.

Hence, a need to develop regulations for crab fishermen is a prime requirement. Otherwise the present trends would definitely lead to extinction of the species in the lagoon.

The following suggestions could be made to conserve the crab resource in the country.

Stringent rules should be made to prevent fishing of immature crabs. Fishing community in the Negombo Lagoon should be enlightened with the knowledge of positive effects of protecting immature crabs because they are the people who directly benefit in the future. The mesh size of the crab traps should be specified to allow escape of immature crabs.

Crab fattening is a useful phenomenon that should be developed and introduced to crab fishermen. Since newly moulted crabs have no demand in the market, crab fattening can be tried locally using low-cost methods. Development of a method to rear newly moulted crabs for just 2 - 3 weeks in a home made pond/tank could attract crab fishermen to do fattening in the homes.

Mass breeding and culture of crabs are other important areas. But before initiating any large scale projects a fair amount of research should be carried out to develop technology for mass breeding and culture. Feasibility of carrying out such research should also be considered. Since crab has good export potential, research on these lines could be considered as an area of priority for a developing country like Sri Lanka.

REFERENCES

1. Alverson, F.G. (1971), " International trade crab.FAO / UNDP / IOPC / DEV / 71 / 66. 20pp".

2. Arriola, F.J. (1940), "A preliminary study of the life history of Scylla serrata (Forskal). Phil. J. Sci. 73 (4) : 437 - 454".

3. Arudpragasam, K.D. (1967), "Distribution and variation in form of the cirripede Octolasmis cor in relation to the respiratory current of its host Scylla serrata. Ceylon J. Sci. 27 (1-2) : 105-115".

4. Atkinson, J.M.(1971)," Factors affecting the growth rate of Samoan crab, Scylla serrata in Hawaii. (Unpub. report) Univ. Hawaii, Dep. Zool. 5p".

5. Barker, P.L. and Gibson, R.(1978)," Observations on the structure of the mouth parts, histology of the alimentary tract and digestive physiology of the mud crab Scylla serrata (Forskal) (Decapoda : Portunidae). J. Exp. Mar. Biol. Ecol., 32 : 177 - 196".

6. Barnard, K.H.(1950)," Descriptive catalogue of South African Decapod Crustacea. Ann. S. Afr. Mus. 38 : 1-836".

7. Bass, A.J., D'Aubrey, J.D. and Kristnasamy, N. (1975)," Sharks of the east coast of southern Africa. Invest. Rep. oceanogr. Res. Inst., Durban 38 : 1 -100".

8. Beverton, R.J.H. and Holt, S.J. (1966), " Manual of methods for fish stock assessment. Part 2. Tables of yield function. FAO. Fish. Tech. Pap.38. Rev. 1:38."

9. Bhattacharya, D.R. (1931)," On cytoplasmic inclusions in the oogenesis of Scylla serrata. All Univ. Studies, 8(2) : 63-103".

10. Bian, B.Z., Hatai, K., Po, G.L. and Egusa, S. (1979)," Studies on fungal diseases in crustaceans 1. Trans. Mycol. Soc. Jpn. 20(2) : 115 - 124".

11. Bian, B.Z. and Egusa, S. (1980)," Atkinsiella hamanaensis sp.nov. isolated from cultivated ova of the mangrove crab, Scylla serrata (Forskal). J. Fish. Dis., 3(5) : 373-385".

12. Bigford, T.E. (1979)," Synopsis of biological data on the rock crab, Cancer irroratus Say. FAO synopsis No.123. NOAA Technical Report NMFS Circular 426. Rockville".

13. Boone, L. (1934), " Scientific results of the world cruise of the yacht "alva", 1931, William K. Vanderbilt, Commanding. Bull. of the Vanderbilt Mar. Museum. 5. pg.68 - 73"

14. Brick, R.W. (1974)," Effects of water quality, antibiotics, phytoplankton and food on survival of larvae of Scylla serrata (Crustacea : Portunidae). Aquaculture 3 (3) : 231 - 244".

15. Bundukul, S. (1957)," Experiment on rearing Scylla serrata. Thai. Fish. Gaz. 1 : 61 - 82".

16. Chen, T.P. (1976)," Aquaculture practices in Taiwan. Page Bros. (Norwich) U.K. 163 pp".

17. Chittleborough, R.C. (1975)," Environmental factors affecting growth and survival of juvenile western rock lobsters Panilurus longiceps (Milne Edw.). Aust. J. Mar. Freshwat. Res. 26 : 177 - 196".

18. Cowan, L. (1982), " Crab farming in Japan, Taiwan and the Philippines. Qld. Dept. of Primary industries. Brisbane. QI 84009".

19. Dall, W. (1967)," Hypo-osmoregulation in Crustacea. Comp. Biochem. Physiol.(A) 21 : 653 - 678".

20. Dana, J.D. (1972)," United States exploring expedition XIII, Crustacea (1), p.270".

21. Das Gupta Hem ch. (1924)," On the occurrence of Scylla serrata (Forskal) in the upper tertiary bed of Hathab Bhavanagar (Kathiawar). J. Asiat. Soc., Bengal, 10 : 239-241".

22. Day, J.H. (1969)," A guide to marine life on South African shores. A.A.Balkema, Cape town. pp. 73 and 112".

23. Dell, R.K. (1964)," The large Indo-Pacific swimming crab, Scylla serrata (Forskal) in northern New Zealand. Rec. N.Z. Dom. Mus. (Welington) 5(8) : 59-62".

24. Deshmukh, R. and Ranganeker, P.V. (1965), " Some observations on the neurosecretary system of the marine crab, Scylla serrata (Forskal). J. Biol. Sci., 8(1) : ".

25. Deshmukh, R. and Ranganeker, P.V. (1966)," Some observations on the hormonal control of chromatophores in the crab Scylla serrata (Forskal). J. Biol. Sci., Bombay 9 : 25-29".

26. De Silva S.S. and Silva, E.I.L. (1979),"Fish fauna of a coastal lagoon in Sri Lanka:Distribution and seasonal variation. Bull. Fish. Res. Stn., Sri Lanka. 29 : 1-9".

27. De Silva, K.H.A.M. and De Silva, P.K. (1986),"An ecological study of the mangrove fauna in the west coast of Sri Lanka. Cey. Jour. of Sci.(Bio. Sci.) 19 & 30: 35 - 63 .

28. Dickenson, R.E. (1977), The occurrence and natural habitat of the mangrove crab Scylla serrata on Ponape and Guam. (Unpub.Thesis) U. Guam. Mar. Lab. 79 pp.

29. Duplessis, A. (1971), "A preliminary investigation into the morphological characteristics, feeding, growth, reproduction and larval rearing of Scylla serrata Forskal (Decapoda : Portunidae), held in captivity.(Unpub.) Fish. Dev. Corp. S.Africa. 24p."

30. Escritor, G.L. (1970), "A report on experiments in the culture of the mud crab, Scylla serrata. IPFC / C70 / Sym. 46, 14th. Sess., Bangkok or Coastal Aquaculture in the Indo-Pacific Region, T.V.R.Pillay, Fishing News (Books), 1972".

31. Estampador, E.P. (1949), "Scylla (Crustacea : Portunidae) II. Comparative studies on spermatogenesis and oogenesis. Philip. J. Sci. 78 (3) : 301-353".

32. FAO report 1981 - "Report on the mangrove crab Scylla serrata and its utilisation with particular reference to Mosambique. FAO/GCP/MOZ/06 (SWE)".

33. Fielder, D.F. and Heasman, M.P. (1978)," The mud crab.BOOKLET Queensl.Mus.11".

34. Gayanilo F.C., Jr., Soriano, M. and Pauly, D.(1989),"A draft guide to the Compleat ELEFAN. ICLARM Software 2,67. International Center for Living Aquatic Resources Management, Manila, Philippines".

35. George, P.C. and Rao, P.V. (1967)," Annotated bibliography of the biology and fishery of the edible crabs of India".

36. Glucksman, J. (1976), Investigation of some common assumptions concerning mud crab (Scylla serrata) marketing in Port Moresby. Papua New Guinea. Agric. J. 27(3) : 49".

37. Grino, E. (1977),"Notes on the local practices of culturing Scylla serrata in Aklan, Capiz and Illoilo provinces. (unpub.) S.E. Asian Fish Dev Center, Illoilo City, Philippines".

38. Gupta R.S. and N.B. Chatterjee (1976),"Anatomical observations of the internal male reproductive organs of Scylla serrata. Ind. J. Physiol. Allied Sci. 30(1)".

39. Hackman, R.H. (1974),"The soluble cuticular proteins from 3 arthropod species Scylla serrata, Decapoda, Portunidae, Boophilus microplus (Acarina: Ixodidae) and Agrianome spinicollis (Coleoptera:Cerambycidae). Comp. Biochem. Physiol. B., 49(3), 457-464".

40. Hanumante, M.M., Farooqui, U.M. and Nagabhushanam, R.(1979),"Effect of pharmacological and endocrinological stimulations on respiration of the marine crab Scylla serrata. Indian J. Exp. Biol. 17(9): 964 - 965".

41. Hashmi, S.S. (1965),"Crabs of west Pakistan. Symposium on Crustacea. J. Mar. Biol. Ass. India" pp 67.

42. Hashmi, S.S. and Zaidi, S.S. (1964), "Incidence of Lepas infestation on the gills of Scylla serrata in Karachi waters" 16(1) :

43. Heasman, M.P. (1980),"Aspects of the general biology and fishery of the mud crab Scylla serrata (Forskal) in Moreton Bay, Qld. Unpubl. Ph. D.Thesis, Zool. Dept., Univ. Qld.".

44. Heasman, M.P. and Fielder,D.R. (1977), "The management and exploitation of the Queensland mud crab fishery. Aust.Fish. 36(8) : 4 - 8".

45. Heasman, M.P. and Fielder, D.R. (1983)," Laboratory spawning and mass rearing of the mangrove crab, Scylla serrata (Forskal), from first zoea to first crab stage. Aquaculture, 34 : 303-316".

46. Hiatt, R.W. (1944), "Food chains and the food cycle in Hawaiian fish ponds. Part II.Biotic Interaction. Trans. Am. Fish. Soc. 74 : 262 - 280".

47. Hill, B.J. (1975),"Abundance, breeding and growth of the crab Scylla serrata (Forskal) in two South African estuaries. Mar. Biol. 32 : 119 - 126".

48. Hill, B.J. (1976),"Natural food, Fore-gut clearence rate and activity of the crab Scylla serrata. Mar. Biol. 34 : 109-116".

49. Hill, B.J. (1979a),"Biology of the crab Scylla serrata (Forskal) in the St. Lucia system. Trans. Roy. Soc. S.Afr. 44".

50. Hill, B.J. (1979b),"Aspects of the feeding strategy of the predatory crab Scylla serrata. Mar. Biol. 55 : 209-214".

51. Hill, B.J.(1980),"Effects of temperature on feeding and activity in the crab Scylla serrata. Mar. Biol. (in press)".

52. Hill, B.J. (1982), "The Queensland mud crab fishery. Qld. Fish. Info. Series FI 8201, 54 pp".

53. Hill, B.J., Williams, M.J. and Dutton, P. (1982),"Distribution of juvenile, sub adult and adult Scylla serrata (Crustacea : Portunidae) on tidal flats in Australia. Mar. Biol. 69 : 117 - 120".

54. Hora, S.L. (1935),"Crab fishing at Uttarbhag, Lower Bengal. Curr. Sci., May : 543 - 546".

55. Hyland, S.J., Hill, B.J. and Lee, C.P. (1984), "Movement within and between different habitats by the Portunid crab Scylla serrata. Mar. Biol. 80 : 57-61".

56. Jayasuriya, P.M.A. (1985),"The present status of fin fish and crustacean fishery of Puttalam Lagoon. J. Nat. Aq. Res. Agency 32(1 and 2) : 94-103".

57. John, S. and Sivadas, P. (1978), "Morphological changes in the development of the ovary in the eyestalk ablated estuarine crab, Scylla serrata (Forskal). Mahasagar, Bull. of the Nat. Inst. of Ocean. 11(1 and 2) : 57 - 62".

58. Jones, S. and Sujansingani, K.H. (1952), "Notes on the crab fishery of the Chilka Lake. J. Bombay Nat. Hist. Soc. 51 (1) : 128 - 134".

59. Kannupandi, T. and Paulpandian, A.L. (1975),"Studies on the blood and muscle proteins of crabs of Porto Novo. Bull. Dep. Mar. Sci. Univ. Cochin 7(3) : 609-622".

60. Krishnamurthy, K., Ramprasad, T.N.C. and Venkateswarulu (1965),"Free amino acids in the blood of Ocypoda platytarsis and Scylla serrata. Proc. Symposium on Crustacea, Ernakulam, Mar. Biol. Assoc. India Symp. Ser. 2 : 1026-1028".

61. Lavina, Alice Fe (1977a),"Courtship and mating behaviour of Scylla serrata in captivity. 4pp.".

62. Lavina Alice Fe.(1979),"Some laboratory indications for crab fattening. Asian Aquaculture 2(2)".

63. Lavina Alice Fe and Buling, A.S. (1977), "The propagation of the mud crab Scylla serrata (F.) de Haan. SEAFDEC Q. Res. Rep.2 : 9-11".

64. Leggett, L.M.W. (1976),"Polarised light sensitive internurones in a swimming crab. Nature, 262 : 709 - 711".

65. Leggett, L.M.W. and Stavenga, D.G. (1977), "Dual clock and feedback control of crab photoreceptor sensitivity. Proc. Aust. Physiol. Pharmacol. Soc. 8(1), 97pp".

66. Le Reste, L., Feno, L. Ramelson, A. (1976), "Etat de nos connaissances sur le crabe de vase Scylla serrata Forskal a Madagaskar. Paris, Office de la pecherche Scientifique et Technique Outre Mer. 32p".

67. Lijauco, M.M., Prospero, O.Q. and Rodriguez, E.M. (1980), "Polyculture of milkfish (Chanos chanos) and mud crab (Scylla serrata) at two stocking densities. Q. Res. Rep. SEAFDEC Aq. Dept., 4(4) : 19-23".

68. Lio - Po, G., Sanvictores, M.E.G., Baticados, M.C.L. and Lavilla, C.R. (1982),"In vitro effect of fungicides on hyphal growth and sporogenesis of Lagenidium spp. isolated from Penaeus monodon larvae and Scylla serrata eggs. J. Fish. Dis., 5(2) : 97-113".

69. Macnae, W. (1968),"A general account of the fauna and flora of mangrove swamps and forests in the Indo west Pacific. Adv. Mar. Biol. 6 : 73-270".

70. Macnae, W. and Kalk, M.(1958),"A natural history of Inhaca Island, Mozambique. Witwatersrand U. Press, Johannesburg, S.Africa. 163pp.".

71. Maguire, G.B. and Fielder, D.R. (1975), "Disc electrophoresis of the hemolymph proteins of some portunid crabs, Decapoda, Portunidae. Part I Effects of storage. Comp. Biochem. Physiol. A. 52(1) : 39-42".

72. Maitipe, P. and S.S. De Silva (1986),"The structure and function of kraal, a fishing gear, in a Sri Lankan lagoon. J.Fish. 33, 1: 137 -143".

73. Manikiam, J.S. (1967),"The occurrence of the mud crab, Scylla serrata in New Zealand. N.Z. Mar. Dep. Fish.Tech. Rep.,24".

74. Matilda, C. and B.J.Hill (1980), "Annotated bibliography of the Portunid crab Scylla serrata (Forskal). Qld. Fish. Serv. Tech. Rep. 3 : 1 - 17".

75. Menon, K.R. and Sivadas, P. (1967),"Blood suger regulation in the crab Scylla serrata : effect of injecting eyestalk extract. Ind. J. Exp. Biol. 5 : 176-178".

76. Menon, K.R. and Sivadas, P. (1968), "Hormonal control of blood calcium and suger levels in the estuarine crab Scylla serrata (Forskal). Proc. Ind. Acad. Sci. (B).: 132- 140".

77. Milne, P.H.(1976),"Fish potential in the Philippines. Notes Doc. Peches Piscic 13 : 10-19".

78. Mirolli, M. (1977),"Spatial decay of the responses to stretch and to injected current in the coxal receptors of the crab Scylla. Biophys. J. 17(2) : 195A".

79. Mirolli, M. (1979a),"The electrical properties of a crustacean sensory dendrite. J. Exp. Biol. 78 : 1-28".

80. Mirolli, M. (1979b),"Electrogenic sodium ion transport in a crustacean coxal receptor. J. Exp. Biol. 78 : 29-46".

81. Momin, M.A. (1976),"Influence of eyestalk removal on the histochemical distribution of oxidative enzymes in the cheliped muscle of Scylla serrata. J. Exp. Mar. Biol. Ecol. 24(1) : 83-92".

82. Momin, M. A. and Momin, V.M. (1977), "Histochemical localization of glycogen and somerepresentative enzymes of glycolytic cycle in the cheliped muscle of Scylla serrata (Brachyura, Decapoda). Zool. J. Linn. Soc. 60(4) : 367-380".

83. Momin, M.A. and Rangneker, P.V. (1974), "Histochemical localization of acid and alkaline phosphatases and glucose-6-phosphatase of the hepatopancreas of the crab Scylla serrata (Forskal). J. Exp. Mar. Biol. Ecol. 14 : 1-16".

84. Momin, M.A. and Rangneker, P.V. (1975a), "Variants in the histochemical patterns of lipids in the hepatopancreas of Scylla serrata (Forskal) (Brachyura, Decapoda). Z. Mikroskanat. Forsch. 89(1) : 170-182".

85. Momin, M.A. and Rangneker, P.V. (1975b), "Histochemical patterns of lipolytic enzymes of the hepatopancreas of Scylla serrata and their possible relation to eyestalk factors. Zool. J. Linn. Soc. 57 : 75-84".

86. Momin, M.A. and Rangneker, P.V. (1975c), "Histochemical localization of oxidative enzymes in the hepatopancreas of Scylla serrata (Forskal) (Brachyura : Decapoda). J.Exp. Mar. Biol. Ecol. 20 : 249-264".

87. Mukherjee, A.K. (1971),"Food habits of water birds of the Sundarban, West Bengal. II Herons and bitterns. J. Nat. Hist. Soc. Bombay, 68 : 37-64".

88. Nagabhushanum, R. and Rao, K.R. (1966), "Neurosecretory system of portunid crab Scylla serrata, morphology, histochemistry. J. Anat. Soc. India. 15(3) : 138-144".

89. Nakamo, S. (1931 -1933), "On culture of Chanos chanos (Forskal) at Tainan. Formosa. Suisan-kai, p. 588-602".

90. Nammalwar, P. (1978),"Blood suger estimation in the estuarine crab Scylla serrata (Forskal). ICAR, Reg. Cent. for Cent. Mar. Fish. Res. Inst., Tamilnadu, India".

91. Olfason, R.W., Kearns, A. and Sim, R.G. (1979),"Heavy metal induction of metallothionein synthesis in the hepatopancreas of the crab Scylla serrata. Comp. Biochem. Physiol. B., 62(4) : 417-424".

92. Ong, Kah Sin (1965),"The early development stages of Scylla serrata (Forskal) (Crustacea : Portunidae) reared in the laboratory. IPFC Proc. II,135-146".

93. Ong, Kah Sin (1966),"Observations on the post-larval life history of Scylla serrata (Forskal), reared in the laboratory. Malay. Agric. J. 45 : 429 -".

94. Pagcatipunan, R. (1972),"Observations on the culture of alimango, Scylla serrata at Camarines Norte (Philippines). Coastal Aquaculture in the Indo- Pacific region, T.V.R. Pillay, Fishing News (Books) : 362-365".

95. Passano, L.M. (1960),"Molting and its control IN : The physiology of Crustacea Vol 1. Ed. by T.H. Waterman. New York : Academic Press".

96. Pauly, D. (1980c),"On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons, Cons. Int. Explor. Mer. 39(3) : 179-192".

97. Pauly, D. (1984),"Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM studies and reviews. 8, 325 p. International Center for Living Resources Management., Manila, Philippines".

98. Pauly, D. (1986),"On improving operation and use of the ELEFAN programs. Part II. Improving the estimation of Loo. Fishbyte 4(1) : 18-20".

99. Pauly, D. and David, N. (1981),"A BASIC program for the objective extraction of estimation of growth parameters from length frequency data. Meeresforsch 28(4) : 205-211".

100. Pauly, D. and Gaschutz, G. (1979),"A simple method for fitting oscillating length growth data, with a program for pocket calculators. I.C.E.S.C.M. 1979/G : 24. Demersal fish Cttee. 26p.".

101. Pauly, D. and Soriano, M.L. (1986),"Some practical extensions to Beverton and Holt's relative yield-per-recruit model. P.491-495. In: J.L.Maclean, L.B. Dizon and L.V. Hosillos (eds.). The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines".

102. Pearse, A. (1932),"Observations on the ecology of certain fishes and crustaceans along the bank of the Malta river at Port Canning. Rec. Indian. Mus.,34 : 289-298".

103. Pearse, A. (1933),"Parasites of Siamase fishes and crustaceans. J. Siam. Soc. Nat. Hist. Suppl., 9(2) : 179-191".

104. Perrine, D. (1979),"The mangrove crab (Scylla serrata) on Ponape. Pub. by Mar. Res. Divn, Ponape, E.Carolin Islands".

105. Pillai, T.G. (1967),"Brackishwater fishery resources. Bull. Fish. Res. Stn. Ceylon 18 : 75-85".

106. Pillai, K.K. and Nair, N.B. (1968), "Observations on the reproductive cycles of some crabs from the South - West coast of India. J. Mar. Biol. Ass. India. 10 : 1 - 2".

107. Pinto, L. (1986),"The mangrove eco-system."Vidurava", Bulletin of NARESA, Vol.9, No.1".

108. Pinto, L. and Wignarajah, S. (1980),"Some ecological aspects of the edible oyster Crassostrea cucullata (Born.) occurring in association with mangroves in Negombo Lagoon, Sri Lanka. Hydrobiologia, 69 : 1-2".

109. Raja Bai Naido, K.G. (1955),"The early developmaent of Scylla serrata (Forskal) De Haan and Neptunus sanguinolentus (Herbst). Ind. J. Fish. 2 : 67-76".

110. Rangneker, P.V. (1954),"A comparative study of the blood volume in the crustaceans Scylla serrata, Panilurus polyphagus and Partelphusa querini. J. Anim. Morph. Physiol., Baroda, 1 : 62-64".

111. Rangneker, P.V. and Deshmukh, R.D. (1968), "Effect of eyestalk removal on the ovarian growth of the marine crab Scylla serrata (Forskal). J. Anim. Morph. Physiol., Baroda, 15 : 116-126".

113. Rangneker, P.V. and Madyastha, M.N. (1969),"Effect of eyestalk removal on the rate of oxygen consumption in the crab Scylla serrata (Forskal). J. Anim. Morph. Physiol., Baroda, 16(1) : 84-88".

114. Rangneker, P.V. Madhyastha, M.N. and Latey, A.N. (1971), "Hormonal control of reproduction in the male crab Scylla serrata. J. Anim. Morph. Physiol. 18(1) : 17-29".

115. Rangneker, P.V. and Momin, M.A. (1974), "Histochemical studies on the distribution and hormanal regulation of carbohydrates in the hepatopancreas of the crab Scylla serrata (Forskal). Z. Mikrosk. - Anat. Forsch. 88 : 871-883".

116. Rangneker, P.V. and Momin, M.A. (1975), "Histochemical observations on the occurrence of glycolytic and pentose phosphate cycle enzymes in the hepatopancreas and their possible relation to eyestalk factors in the crab Scylla serrata (Forskal). Z. Mikrosk.-Anat. Forsch. 89(1) : 128-142".

117. Raphael, Y. I. (1970),"A preliminary report on the brackish water pond culture of Scylla serrata (Forskal) in Ceylon. IPFC / C70 / SYM 21, 14TH Sess.,Bangkok., also Coastal aquaculture in the Indo-Pacific Region, T.V.R.Pillay, Fishing News (Books), 1972".

118. Samarakoon, J.I. (1983),"Breeding patterns of the indigenous cichlids Etroplus suratensis and Etroplus maculatus in an estuary in Sri Lanka. Mahasagar,16(3): 357 - 362".

119. Samarakoon, J.I. (1985),"Experimental seed production in Etroplus suratensis by induced pair formation and breeding through environmental manipulation. Aquaculture, 46(4): 323 - 332".

120. Sakai, T. (1965),"The crabs of Sagami Bay. Collected by His Majesty the Emperor of Japan. ed. Biological Laboratory, Imperial Household, Tokyo".

121. Samarakoon J.I. and Pinto, L. (1986), "Synthesis report for information in critical habitats in coastal zone. Technical report. CCD/USAID/URI.pg 41".

122. Samaranayake, R.A.D.B. (1986),"Status and prospectus for brackishwater aquaculture in Sri Lanka. J.Inland Fish. 3:88-90".

123. Sandeman, D.C. (1973),"Dynamic recepters in the statocysts of crabs. Schoene, Hermann (ed.), Fortschritte der Zoologie 23 (1)".

124. Sandeman, D.C. (1975),"The excitation and electrical coupling of four identified motoneurones in the brain of the Australian mud crab, Scylla serrata. Z. Vergl. Physiol. 72(2) : 111-130".

125. Sandeman, D.C. and Mendum, C.M. (1971), "The fine structure of the central synaptic contacts on an identified crustacean motoneuron. Z. Zellforsch. 119 : 515-525".

126. SEAFDEC (1985),"Mud crab bibliography. Compiled by the Library and Documentation services. Br. Aq. In. Sys. SEAFDEC Aq. Dept. Tigbauen, Iloillo, Philippines".

127. Serene, R. (1951),"Les especes du genre Scylla a Nhatrang (Vietnam). IPFC Proc. II : 133-137".

128. Serene, R. (1952),"Les especes du genre Scylla a Nhatrang (Vietnam). Proc. IPFC., 3(2) : 133-137".

129. Silvey, G.E. (1974),"Integration at a sensory motor synapse in the oculomotor system of the crab Scylla serrata. Am. Zool. 14(4)".

130. Silvey, G.E. and Sandeman, D.C. (1976a), "Integration between statocyst sensory neurons and oculomotor neurons in the crab Scylla serrata. I. Horizontal compensatory eye movements. J. Comp. Physiol. 108 : 35-43".

131. Silvey, G.E. and Sandeman, D.C. (1976b), "Integration between statocyst sensory neurons and oculomotor neurons in the crab Scylla serrata. II. The sensory to motor synapse. J. Comp. Physiol. 108 : 53-65".

132. Silvey, G.E. and Sandeman, D.C. (1976c), "Integration between statocyst sensory neurons and oculomotor neurons in the crab Scylla serrata. IV. Intergration phase lags and conjugate eye movements. J. Comp. Physiol. 108 : 67- 73".

133. Stephenson, W. and Campbell, B. (1960), "Australian portunids (Crustacea : Portunidae) IV. Remaining genera. Aust. J. Mar. Freshw. Res. 11(1) : 111-115".

134. Sumitra-Vijayaraghavan and Jayamanne, S.C. (1985),"Seasonal variations in quality, composition and energy values of detritus in the Kelaniya estuary. J. Nat. Ag. Res. Ag. Sri Lanka. 32 : 138-146".

135. Taira, M. (1965),"Experiment on rearing of Scylla serrata. Ann. Rep. Shizuoka Prefectural Fisheries Exp. Stn, p.171".

136. Taira, M. (1967),"Rearing of Scylla serrata in individual Ann.Rep. Shizuoka Prefecture Fisheries Exp Station".

137. Tamura, T. (1970),"Propagation of Scylla serrata. Mar. Aquaculture. 15(12) : 1-3. National Science Foundation, Washinton, D.C.".

138. Ting, Y.Y., Lin, M.N., Luo, W.S. and Tserng, B.S. (1981), "Studies on the spawner rearing and reproduction of mud crab Scylla serrata. China Fish. Aquaculture".

139. Tirmizi, N.M. (1986),"Mangrove crabs of Karachi. Directorate of publications. Pakistan Agricultural Research Council, P.O.Box.1031. Islamabad. 50 pgs."

140. Varikul, V.S., Phumiphol, S. and Hongpromyart, M. (1970), "Preliminary experiment on pond rearing and some biological studies of Scylla serrata (Forskal). IPFC/C70/SYM 49, 14TH Sess.,Bangkok., also Coastal Aquaculture in the Indo - Pacific Region, T.V.R.Pillay, Fishing News (Books), 1972".

141. Venema, S.C., Christensen, J.M. and Pauly, D. (eds.) (1988), "Contributions to the tropical fisheries biology. Papers prepared by the participants of the FAO/DANIDA follow-up training cources on fish stock assessment in the tropics. Hirtshals, Denmark, 5 - 30 May 1986, and Manila, Philippines, 12 January - 6 February 1987. FAO Fish. Rep.,(389) : 519 p.".

142. Villaluz, D.K. (1953),"Cultivation of crabs. 1. Alimango cultivation. IN: Fish farming in the philippines. Manila, Bookman. p.149-151".

143. Wetherall, J.A. (1986),"On improving operation and use of the ELEFAN program. Part II. Improving the estimation of Loo. Fishbyte 4(1) : 18-20".

144. Wijeyaratne, M.J.S. and Costa, H.H. (1986), "Application of 'Yield per recruit' and ~Surplus yield' models to the grey mullet fishery of Negombo Lagoon, Sri Lanka. J. Inland Fish. 3 : 3-14".

145. Wildman, R.D. (1974),"Aquaculture in the national sea grant program. NOAA. Tech. Rep. Nat. Mar. Fish. Serv. Circ. 388".

146. Williams, M.J. (1978),"Opening of bivalve shells by the mud crab Scylla serrata (Forskal). Aust. J. Mar. Freshwat. Res., 29(5) : 699-702".

147. Williams, M.J. and Hill, B.J. (1982), "Factors influencing pot catches and population estimates of the Portunid crab Scylla serrata. Mar. Biol. 71 : 187 - 192".