STUDIES ON THE FISHERY AND CULTURE PROSPECTS OF MUD CRABS (GENUS *SCYLLA* de HAAN) ALONG THE KERALA COAST

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BY

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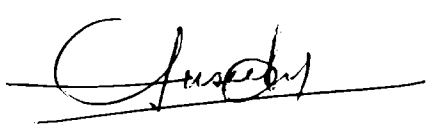
MARCH 1997

-dedicated to my mother

CERTIFICATE

This is to certify that the thesis entitled '**Studies on the fishery and culture prospects of mud crabs (Genus *Scylla* de Haan) along the Kerala coast**' is a bonafide original research work conducted by Shri Anil, M.K., under my guidance and supervision. I further certify that no part of this thesis has previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles of recognition.



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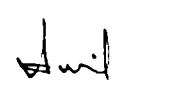
DECLARATION

I hereby declare that this thesis entitled '**Studies on the fishery and culture prospects of mud crabs (Genus *Scylla* de Haan) along the Kerala coast**' is a record of original and bonafide research carried out by me under the supervision and guidance of Dr. C. Suseelan, Senior Scientist, Central Marine Fisheries Research Institute, Kochi and that no part thereof has been presented for the award of any other degree, diploma, associateship, fellowship or other similar recognition.



M.K. ANIL

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PREFACE

The mud crabs of genus *Scylla* have come into prominence in India since early eighties with the commencement of live crab export to South East Asian countries. Prior to this new development, the mud crabs formed only a fishery of sustenance level in isolated brackishwater regions and inshore areas for domestic marketing. The recent collapse of shrimp aquaculture industry in the country created a feeling of uncertainty about the future of coastal aquaculture in India and in this context the success of mud crab culture in countries like Taiwan, Malaysia, Philippines and Thailand kindled hope for diversification of the aquaculture industry in this direction. Realizing the vast potential for development of mud crab fishery in the Bay of Bengal region, Thailand hosted an international seminar at Surat Thani to review the status of exploitation, culture and trade of mud crabs in the member countries of the Bay of Bengal Programme in 1991 and the proceedings of the seminar brought out in 1992 (Anon., 1992b). This seminar revealed that India lags far behind many of the South East Asian countries in culture and propagation of mud crabs, although the country has vast brackishwater areas ideally suited for this purpose. The sudden impetus for exploitation of mud crabs in the brackishwater areas of the country to support the lucrative live crab exportrade is causing great concern for the sustainability of the wild stocks. This necessitates appropriate steps for scientific management and conservation of the resource. Mud crab culture has also not taken root in the country to flourish as an organised industry in the absence of viable seed production and farming technologies.

Kerala has been one of the leading maritime states in India for the exploitation and export of mud crabs (Raj, 1992). Many brackishwater systems like the Ashtamudi lake, Vembanad lake, Cochin backwaters and Korapuzha estuary are well known for their rich population of mud crabs. Realizing the imperative need to build up a strong scientific base for proper management and conservation

of the resource and also to develop proper technologies for seed production and farming of mud crabs, a detailed study was undertaken on the mud crabs of Kerala coast and the results are described in the thesis.

The thesis is presented in four chapters. Chapter I deals with a general introduction which outlines the objectives of the study providing an exhaustive review of works on crabs with particular reference to mud crabs. Chapter II describes the material and methods used for the study.

Chapter III include the results and discussion which are presented in four sections. In the first section, Taxonomy and distribution of mud crabs are dealt with. Two species of mud crabs encountered during the study are described and their identity is established on the basis of morphological and electrophoretic studies. The second section comprises the bionomics and life history in which various aspects such as reproduction, larval development, growth and behavioral features are described. The reproductive biology of both the species is described and compared in varying details encompassing the gross structure and histology of reproductive systems, spermatogenesis, oogenesis, ovarian maturation, minimum size of mature female, fecundity and breeding. Various changes that take place during the incubation period as well as during larval development of both the species have been elucidated. The growth of the two species has been studied by rearing crabs in the laboratory and ponds, and also by statistical analysis of size frequency data of crabs from the capture fishery.

Section three deals with the capture fishery in which fishing methods, seasons, landings and population characteristics such as size distribution, sex ratios and breeding population in respect of both the species have been dealt with in detail and discussed.

In the fourth section, briefly describing the mud crab culture techniques, regional status of mud crab farming in the Indo-Pacific is reviewed, and the re-

sults of fattening and grow out experiments conducted during the study are described. Details such as biochemical changes during fattening are also elucidated. In addition to this, the section deals with the results of larval feeding and experimental seed production of *S. oceanica* .

Chapter IV gives a summary of the important findings of the study, which is followed by a detailed list of references on the subject matter.

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CHAPTER 1
INTRODUCTION

INTRODUCTION

Fish and fisheries make an important contribution to the world's food supply, and are a source of income for over 100 million people who depend directly or indirectly on fisheries for their livelihood (Anon., 1996a). The global fish production has risen to about 100 million metric tons (Anon., 1995) and this is regarded as being at or close to the maximum biological limit. Projected population growth over the next 10-15 years implies an increase in global demand of about 20 million metric tons if per capita consumption remains steady. Asia is believed to face the greatest gap between supply and demand. To satisfy the demand will require improving the management of fisheries, making better use of the catch and increasing production through aquaculture.

India is one of the leading fish producing countries in the world and an important supplier of fishery products in the international market. The country's prominence in the world market is mainly through the export of crustacean products which remained the back bone of the fishery industry for nearly half a century. Among the seafood items exported from the country, crustaceans comprising of prawns, lobsters and crabs accounted for about 45% in terms of weight and 70% in terms of value of the total export earnings of Rs. 35,000 million from the marine products during the year 1995-96 (Anon.,1996b, 1997).

Among crustaceans, crabs occupy the third rank, the first and second positions being given to prawns and lobsters on account of their demand in the overseas market. According to Suseelan (1996 b) an average of about 25000 t of crabs are exploited annually from the marine sector, of which over 50% is landed along

the Gujarat and Tamil Nadu coasts. Being a commodity of lesser export value in the processed form, no commercial operation is directed towards this resource in a big way in the country. However, with the mordernisation of fishing methods, crabs are increasingly landed as bycatches of shrimp trawlers and other fishing units throughout the country.

Out of 8 species of commercially important portunid crabs of India (Rao *et al.*, 1973), the mud crabs of genus *Scylla* are exceptionally important due to their large size and better nutritive value and hence in great demand in the domestic market. The mud crab emerged as a commodity for export in live condition in 1982 (Raj, 1992) which marked the beginning of a flourishing export industry for the crab which remained unimportant for ages. Mud crabs support fisheries of considerable magnitude in the South East Asian countries like Philippines, Indonesia, Thailand, Malaysia and in countries bordering the Bay of Bengal (Anon., 1992b). According to available information, nearly 30,000 metric tons of mud crabs are exploited annually in the Indo-Pacific region of which about 40% is contributed by Philippines and the rest mainly by Indonesia and Thailand (Anon., 1995). India is estimated to have a potential resource of about 8400 t of mud crabs (Prasad, 1990). The export of live mud crabs from India to countries like Singapore, Malaysia and Hongkong stimulated increased exploitation of mud crabs from their natural habitats such as brackishwater lakes, estuaries, mangrove areas and inshore waters during the past 10-15 years and the fishing pressure on this limited resource is ever on the increase. The attractive prices offered for live crabs in the export trade prompted efforts to culture mud crabs in some parts of India as practised in a more organised manner in the South East Asian countries (Kathirvel, 1995; Babu,1995; Suseelan *et al* ., 1995; Suseelan, 1996 a). As a result of this renewed interest in mud crab production and export, India has been able to make a steady progress in live crab export, the quantity exported increasing from 36 t in

1987-88 to 728 t valued at Rs.52 million in 1993-94 (Anon., 1996b).

As in the case of any other valuable aquatic resource, development of mud crab fishery will be possible only through careful management of the wild stock at sustainable yield level and additional production through aquaculture. In India the capture fishery for mud crab is in a disorganised manner (Srinivasagam & Kathirvel, 1992) and the culture fishery is only in the infant stage, that too based on natural seed resources. There has not been any systematic investigation on mud crabs of India so far. The taxonomic status of mud crabs is still a controversial subject and little is known of their biology/larval history in the country. The techno-economic viability of mud crab culture also is not established in a convincing manner to lure entrepreneurs to take up large scale mud crab farming with confidence. This is because of the lack of scientific basis to plan culture programs for successful results. Considering the gaps in our knowledge on this group a study on the fishery and culture prospects of mud crabs was taken up with particular reference to Kerala coast and the results are presented in the thesis.

Review of Literature

A perusal of the available literature on the brachyuran crabs would reveal that most of the earlier works on this group relate to taxonomic aspects as could be evident from the classical works of Linnaeus (1758), Fabricius (1798), de Haan (1833), Dana (1852), Wood-Mason (1871), Henderson (1893) and Alcock (1895, 1896, 1898, 1899 a, 1899 b, 1899 c, 1900) from different parts of the world including the Indian subcontinent. Later, many authors have contributed greatly to the systematics of Indian Brachyura particularly from the mainland, the notable contributions being those of de Man (1908), Kemp (1915, 1923), Gravely (1927), Chopra (1931, 1933, 1935), Chopra and Das (1937), Panikkar and Aiyar (1937), Pillai (1951),Chhapgar (1957) and Sankarankutty (1966). Faunistic accounts of brachyuran crabs of Andaman-Nicobar Islands have been dealt with by Alcock (1899a), Chopra

(1935), Sankarankutty (1961 b), Premkumar and Daniel (1971) and Kathirvel (1983). Borradaile (1902), Sankarankutty (1961a), Meiyappan and Kathirvel (1978) and Suresh (1991) reported on crabs of Lakshadweep Islands.

Information on the fishery of crabs of Indian waters is available from the works of Rai (1933) who dealt with the magnitude of production together with information on some aspects of the biology of crabs of Bombay coast. Later, Chopra (1936, 1939) furnished details of crab fishery of Indian coast in general. Chidambaram and Raman (1944), Prasad and Tampi (1952) and Chacko and Palani (1955) dealt with the crab fishery of east coast, whereas Menon (1952), George and Nayak (1961) and Chhapgar (1962) reported on the crab fishery of the west coast. An annotated bibliography of the fishery and biology of edible crabs of India was published by George and Rao (1967). The crab fishery of India was reviewed in greater detail by Rao *et al.* (1973). Since then many authors have reported on regional crab fisheries, which included accounts of Jones and Sujansinghani (1952), Prasad and Tampi (1952), Chacko *et al.* (1953), Chacko and Palani (1955), Chacko (1957), Chacko and Rajagopal (1964), Balasubramanian (1966), Thomas (1971), Mohanty (1973 a, b), Datta (1973), Ansari and Harkantra (1975), Mohanty (1975), Srinivasagam (1975), Ameer Hamsa (1978), Radhakrishnan (1979), Lalitha Devi (1985), Sreenivasagam and Raman (1985) and Joel and Raj (1987).

Various aspects of the biology of portunid crabs have been documented from about the middle of this century, the notable contributions from India being those of Krishnaswamy (1967), Rahman (1967), Chandran (1968), Pillai and Nair (1968, 1971 a & b, 1973a, 1975), Nagabhushanam and Kulkarni (1977), Ajmalkhan and Natarajan (1979), Joel and Sanjeevaraj (1982), Sethuramalingam *et al.* (1982), Pillai and Subramoniam (1984), Bawab and El.Sherif (1988) and Jacob *et al.* (1990).

The contributions of Fasten (1926), Nath (1932), Iyer (1933), Cronin (1947), Ryan (1967a,b), Adiyodi (1968), Langreth (1969), Chiba and Honma (1971, 1972),

Vasisht and Relan (1971), Diwan and Nagabhushanam (1974), Joshi and Khanna (1982a,b) and Adiyodi and Subramoniam (1983) on the reproductive biology of portunid crabs are considered as classical works which have been profusely referred to in the subsequent studies world over.

Morphology of the ovary and oogenesis in crabs have been studied by several workers like Harvey (1929), Hard (1942), Ryan (1965), Adiyodi (1968), Diwan and Nagabhushanam (1974), Chiba and Honma (1971), Vasisht and Relan (1971), Joshi and Khanna (1982) and Bawab and El-Sherief (1989). Cheung (1966), Hinsch and Cove (1969), Hinsch (1970), Komm and Hinsch (1985, 1987) studied the ultrastructure of ovary and oogenesis and Hinsch (1971) and Goudeav (1982) the ultrastructure of fertilization in marine crabs. The ultrastructure of male reproductive system was documented by Brown (1966), Hinsch (1969, 1988), Reger *et al.* (1984), Jamieson (1989), Hinsch (1980, 1988) and Tudge (1991, 1992) in varying details. Spalding (1942), Mathew (1953, 1956) and Subramoniam (1984) dealt with the spermatophore formation in crabs.

Larval development of brachyuran crabs of India has been studied by many workers like Menon (1933, 1937, 1940), Prasad (1954) and George (1958) based on plankton collections. Later many workers have traced out the larval history of brachyuran crabs by rearing berried females in the laboratory and then constructing the larval history by separating further stages from the plankton samples. Naidu (1950, 1954, 1955, 1959, 1960a, b, 1962, 1972, 1974) studied the early development of many species and postlarval development of few species of crabs. Prasad and Tampi (1953, 1957) could hatch out the first zoea of *Neptunus pelagicus* and *Thalamita crenata* in the laboratory. Sankolli (1961) described the early larval stages of the leucosid crabs *Philyra corallicola* and *Arcania septemspinosa*.

Later, the larval history of several species including the commercially important portunids was traced out fully or partly through laboratory rearing by

Sastry (1973), Krishnakumari and Rao (1974), Kakati and Sankolli (1975a, b, c), Srinivasagam and Natarajan (1976), Kakati (1977) Kakati and Nayak (1977), Kannupandi *et al.* (1980) and Mercy Thomas (1984). Raman *et al.* (1987) traced out larval history of *P. pelagicus* by hatchery rearing from berry to 2nd instar stage.

Investigations on mud crabs began with the first record of *Cancer serratus* in the middle of 18th century by Forskal (1755). This was followed by the studies of several workers like Herbst (1796), Fabricius (1798), de Haan (1833), Milne Edwards (1834), Dane (1852) and Stimpson (1907) from differed parts of the Indo- Pacific region. Detailed taxonomic revision of the genus *Scylla* de Haan was made by Estampador (1949 a, b) which was subsequently reviewed by Stephenson and Campbell (1960) who suggested the need for more work on the group. Quite recently Fuseya and Watanabe (1996) from Japan proposed three species for genus *Scylla* on the basis of variation noticed through electrophoretic analysis.

From Indian waters references to the occurrence of species of mud crabs have been made from about the close of 18th century with the report of Fabricius (1798) who described *Portunus tranquebaricus* based on specimens obtained from Tanquebar (Tharagampady of Tamil Nadu coast). Subsequently authors like Alcock (1899), de Man (1908), Kemp (1915), Gravely (1927), Pears (1932), Chopra and Das (1937), Panikkar and Aiyar (1937), Pillai (1951), Naidu (1953), Chhapgar (1957, 1962), Balasubramanian (1966), Rekha (1968), and Premkumar and Daniel (1971) made mention of species of *Scylla* while dealing with the fishery and faunistic accounts of portunid crabs. Detailed taxonomic investigations on the group from India were undertaken by Joel and Raj (1980, 1983) from Pulicat lake along the Tamil Nadu coast, Kathirvel (1981) and Radhakrishnan and Samuel (1982) from Cochin backwaters along the Kerala coast. Quite recently Kathirvel and Srinivasagam (1992 b) made a critical review of the taxonomic studies on mud crabs and suggested the existence of two distinct species along the Indian coast.

Information on the fishery and biological aspects of mud crabs from differ-

ent parts of the Indo-Pacific are available from the works of Heasman and Fielder (1977), Williams and Hill (1982), Hill(1984b) and from the reports and papers presented at the seminar on the mud crab culture and trade, held at Surat Thani province of Thailand in 1991 (Cholik and Hanafi, 1992; Khan & Alam, 1992; Jayamanne, 1992; Lee, 1992; Tookwinas *et al.*, 1992; Larda and Mondragon, 1992; Ahmed, 1992).

From India, notable accounts on regional fishery of *S. serrata* include those of Chacko (1956) from Ennore estuary, Prasad and Neelakantan (1969) and Prasad *et al.* (1990) from Karwar, Parida (1970) and Patnaik (1991) from Chilka lake, Shanmugam and Bensam (1970) and Jameson *et al.* (1982) from Tuticorin coast, Krishna and Kannupandi (1984) from Porto Novo, Chandrasekharan and Natarajan (1987) from Pitchavuram mangrove and Devasia and Balakrishnan (1985) and Sheeba Tharian (1988) from Cochin backwaters.

General accounts on the biology of *S. serrata*, including physiology of moulting, have been provided by many workers like Arriola (1940), Chacko (1956), Anon. (1968) Rekha (1968), Atkinson (1971), Varikul *et al.* (1972), Hill (1975a, & b, 1978, 1979 b), Haesman (1980), Williams and Lee (1980), Jameson *et al.* (1984) and Robertson (1987). Barker and Gibson (1978) dealt with the structure of mouth parts and histology of alimentary tract and digestive physiology, while Hill (1976, 1979 a, 1980), Anon. (1975), Williams (1978) and Prasad *et al.* (1988) reported on the natural food, foregut clearance rate, feeding strategy and effect of temperature on feeding of *Scylla serrata* in great detail. Joel and Raj (1986) studied the food and feeding habits of two species, namely, *S. serrata* and *S. tranquebarica* from Pulicat lake. Growth of *S. serrata* has been reported by Ong (1966), Escritor (1970), Raphael (1970), Duplessis (1971), Wildman (1974) and Marichamy and Rajapackiam (1992). Information available about the growth in natural habitat is very meagre (Mercy Thomas *et al.*,1987; Lalitha Devi, 1985).

Various aspects of the reproductive physiology of *S. serrata* have been documented, of which the studies of Ezhilarasi and Subramoniam (1980) on spermathecal activity and ovarian development and those of Ezhilarasi (1982) and Nagabhushanam and Farooqui (1982) on biochemical changes during ovarian maturation are noteworthy. Nagabhushanam and Farooqui (1981, 1982 b) worked on the photoperiodic stimulation of ovary, while Rangnekar and Deshmukh (1968) and John and Sivadas (1978, 1979) studied the effect of eye stalk ablation on ovarian maturation of *S. serrata*. The effect of hormones on ovarian development was dealt with by Sarojini *et al.* (1985, 1990). Anatomy of male reproductive system of mud crab was dealt with by Gupta and Chatterjee (1976). Uma and Subramoniam (1979, 1982) worked on the histochemical characteristics of spermatophore layers and biochemical aspects of seminal plasma and spermatophore of *S. serrata*. Jayalectumi and Subramoniam (1989) reported on the cryopreservation of spermatophore and seminal plasma of this species. Heasman *et al.* (1985) reported on the mating and spawning behaviour of *S. serrata*.

The biochemical aspects and nutritive value of mud crabs have been dealt with by many workers like Gangal and Magar (1964), Chinnamma George and James (1971), Deshmukh and Rangnekar (1973), Hackman (1974), Senthikumar and Desai (1978), Kannan and Ravindranath (1980), Radhakrishnan and Samuel (1985) and Chinnamma George *et al.* (1986).

Naidu (1955) was the first to describe the early development of *S. serrata*. Credit goes to Ong (1964, 1966) for rearing the zoea of this genus through all the larval stages and tracing out the postlarval history. Brick (1974) investigated on the effect of water quality, antibiotics, phytoplankton and food on the survival and development of larvae. Hill (1974) worked out the salinity and temperature tolerance of zoea of *Scylla*. Simon (1974), Lavina and Buling (1977), Chen and Jeng (1980), Anon. (1981), Fukui (1981), Ting *et al.* (1981), Haesman and Fielder (1983),

Dominisac and Dejarme (1984), Haesman *et al.* (1985), Jamari (1992) and Marichamy and Rajapackiam (1984, 1992) added further information on the larval development and survival of *S. serrata* through laboratory studies.

The crab farming methods around the world have been described by Bardach *et al.* (1974) and Pillay (1990). Cowan *et al.* (1984) dealt with in detail the crab farming methods practised in Japan, Taiwan and Philippines.

Mud crab farming methods in Philippines include Polyculture, monoculture and fattening as described by Escritor (1970, 1973), Pagcatipunan (1972), Catanaoan (1972), Robles (1978), Lapie and Librero (1979), Lavina (1979, 1980), Lijavco *et al.* (1980), Baliao *et al.* (1981), Larde (1992) and Samonte and Agbayani (1992). Sivasubramaniam and Angell (1992) reported an average production of 111 kg of crabs, 500 kg of milkfish and 52 kg of shrimp from polyculture ponds and 339 kg of mud crab from 1 ha monoculture pond in Philippines. The state of art of mud crab culture in Malaysia has been described by Ferdouse (1990) and Chong (1992). According to Chong (1992), mud crab farming in Malaysia involves both grow-out culture and fattening. Pond culture is subsistence in nature producing less than 50 t per year whereas fattening, which is mostly practised in floating net cages, produces more than 600 t. Chen (1990) dealt with in detail the crab farming methods practised in Taiwan. Unlike in other countries, mud crab farming here is a well organised industry with nursery, grow-out and fattening operations and the yield varies from 5000-9000 crabs/ha. Taiwan is reported to have achieved success in hatchery production of mud crabs with survival rate upto 60% and a production rate of 6000 seed/t of rearing water (Sivasubramaniam & Angell, 1992). Inspite of several attempts to culture mud crabs in Srilanka (Rhaphel, 1970, 1972; How-Cheong & Amendakoon, 1992; How-cheong *et al.*, 1992; De Silva, 1992) the mud crab farming in the country is still in its infancy. Recently Samarasinghe *et al.* (1992) successfully cultured mud crabs in an old semi-inten-

sive shrimp culture pond and achieved a production of 394 kg/3900 m^2/115 days and reported a survival of 43.7%. Several workers have attempted experimental culture of mud crabs in Thailand, and some of the notable trials were those of Bindakul (1975), Varikul *et al.* (1972), Hanvivatanki (1990), Prinpanapong and Youngwanichsaed (1992) and Rattanachote and Dangwatankul (1992). Harvey (1990) and Suresh (1991) dealt with in detail the status of mud crab farming in Thailand, while Hanvivatanki (1990) discussed about the economics of mud crab fattening in Surat Thani province of Thailand. According to Suresh (1991) mud crab farming in Thailand is either fattening (to produce gravid females) or a short term culture involving stocking crabs of 200-300 g weight and raising them to 400-500 g weight in about a month's time. From Indonesia, Gunarto *et al.* (1987) described about the mud crab culture at different salinity levels and Gunarto and Cholik (1990) about the effect of stocking density. Cholik and Hanafi (1992) reviewed the fishery and culture of mud crabs in Indonesia in great detail.

Mud crab culture is in its infant stage in Bangladesh (Ahmed, 1992), while it is an age old practice in China where farming is done in about 1400 ha with a total annual production of 2000 t(Yalin & Qingsheng, 1994). There is virtually no mud crab farming in Australia, but many have pointed out its potential there (Hill, 1984a; Cowan, 1984; Gillespie & Burke, 1991). Japan is unique in having very large scale programme for replenishing depleted marine fishery resources including crabs by hatchery bred seedling in the natural water beds and mud crab seedlings were stocked in lake Hamans as part of such programmes, (Cowan, 1984; Sivasubramanian & Angell, 1992). Japan is also reported to have achieved species- wise seed production of mud crabs (Fuseya & Watanabe, 1996).

In India, the prospects of mud crab culture was pointed out as early as the middle of this century (Naidu, 1955). Subsequently, Radhakrishnan and Samuel (1980), Nagabhushanam *et al.* (1982), Chandrasekaran and Perumal (1993),

Vishwakumar (1994) and Kathirvel (1994, 1995) also discussed the possibility of enhancing production of mud crabs through farming. Availability of crab seeds in nature was studied by Sreenivasagam *et al.* (1988) from Madras, Kathirvel (1980) from Cochin and Chandrasekaran and Natarajan (1987) from Pitchavaram mangroves. Information about culture of mud crabs in cages is available from the works of Marichamy *et al.* (1980), Raman *et al.* (1980), Natarajan and Thangaraj (1983), Bensam (1986) and Marichamy *et al.* (1986) and in the open brackishwater systems from those of Babu and Manjulatha (1995), Suseelan *et al.* (1995), Suseelan and Anil (1995) and Suseelan (1996a). Srinivasagam and Kathirvel (1992) reviewed the experimental culture of mud crabs in India in great detail.

CHAPTER II
MATERIAL AND METHODS

MATERIAL AND METHODS

The material for this study was mainly obtained from three brackishwater systems of Kerala, namely, Ashtamudi lake, Cochin backwaters and Korapuzha estuary (Fig.1) between August 1992 and June 1995. In addition to this, some specimens of mud crabs were also collected from the Pulicat lake and estuarine areas of Tharankampady along the Tamil Nadu coast for taxonomic purpose. The mud crabs caught from the inshore waters and landed at the Munambam harbour (Kochi) were also occasionally observed for biological studies. Brief description of Ashtamudi lake, Cochin backwaters and Korapuzha estuary are given below.

Ashtamudi lake: The Ashtamudi lake is a palm-shaped brackishwater system having eight branches as the name implies, situated in Quilon District between Lat. 8°48' N and 9°28'N and Long.76°28'E and 77°17'E. With a total extent of about 32 km^2 water area, this lake also forms an estuary of river Kallada and remains connected with the sea through out the year. The salinity of the lake ranges between 8 ppt and 33 ppt in most part of the year except during the monsoon period when the water gets considerably diluted due to freshwater inflow from River Kallada (Thresiamma Mathew & Nair, 1980; Suseelan & Kathirvel, 1982).

Cochin backwaters: Cochin backwater (Fig.1) and the connected Vembanad lake extent between Alleppey in the south and Munambam in the north (Lat. 9° 30'-10° 12'N) is the largest estuarine system on the west coast of India. It has a length of about 110 km (Devasia & Balakrishnan, 1985). The width varies between a few hundred meters to about 14.5 km and covers approximately an area of 233 km.

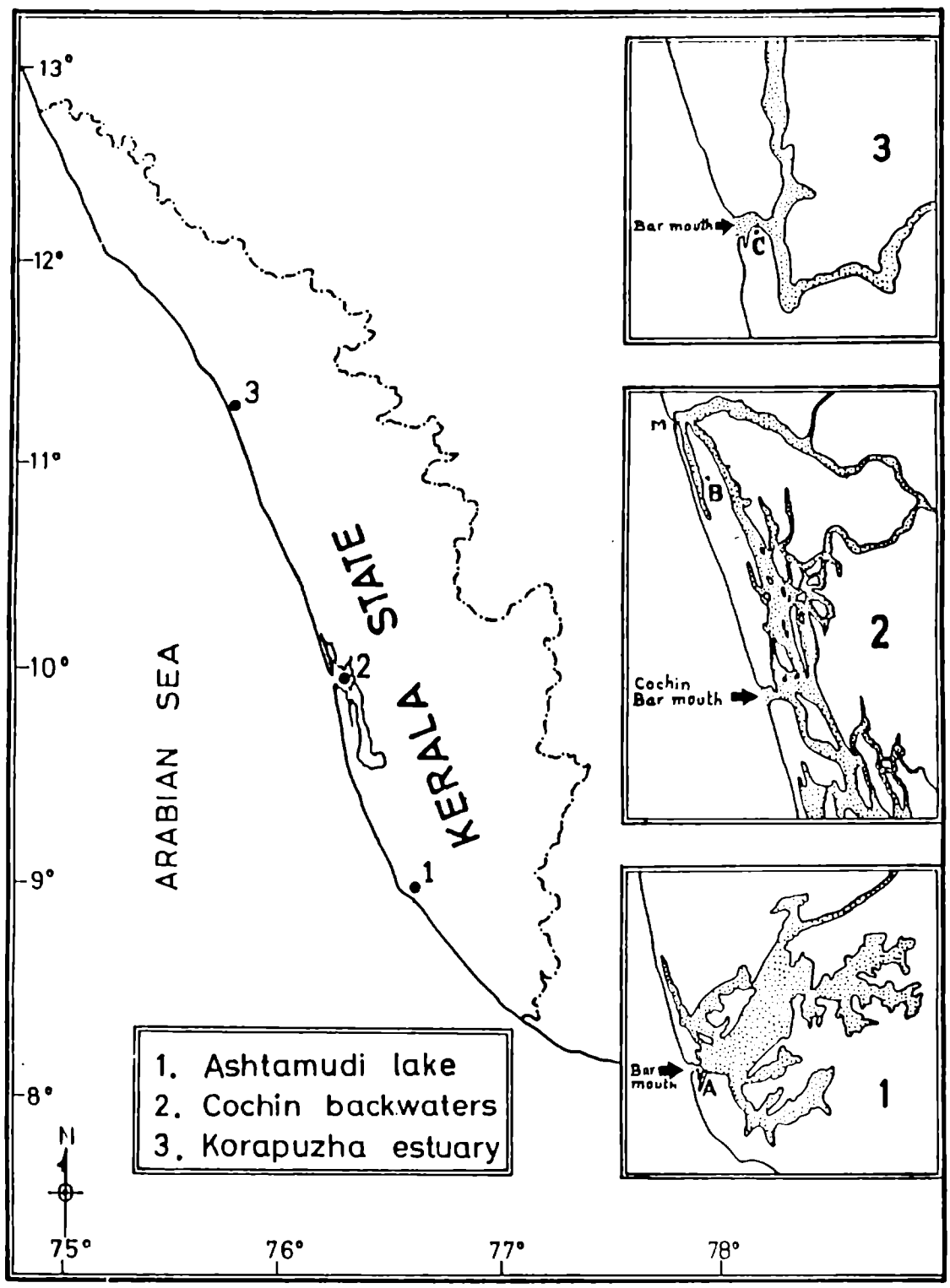


Fig. 1. Map showing study area.A-C, observation Centres:
A - Kavanadu, B - Pallipuram, C - Elathur.
M - Munambam.

Hydrographic parameters of Cochin backwater was investigated in great detail by Qasim and Gopinathan (1969). The Cochin backwater is subjected to strong tidal influence from the sea and mixing of freshwater from river systems in the south and north, thus providing estuarine condition with higher salinity gradient towards the vicinity of barmouth. During the south west monsoon season almost freshwater conditions prevail through out the backwater at the surface with saline condition at the bottom where the depth is considerable.

Korapuzha estuary: The estuary is located at Elathur, Kozhikode (Calicut) between Lat.11°21' - 11°24'N and Long.75°44' - 75°46'E. This perennial estuary receives freshwater from River Agatapuzha from the northern side and River Dannur Puzha from the southern side.

After a preliminary survey of the mud crab fishery of these brackishwater systems, 3 important landing centres, one each in Ashtamudi lake (Kavanadu), Cochin backwater (Pallipuram / Palliport) and Korapuzha estuary (Elathur) were fixed for regular sampling and monitoring of the catch. Each observation centre was visited once a month and observations were taken on fishing methods, crab landings, species composition (by commercial grades) and biological aspects. Size measurements were recorded sexwise for a random sample of 40-100 crabs of each farm (species) depending on their availability. The measurements were taken for carapace width (CW) extending between the tip of the ninth anterolateral spines to the nearest millimeter using vernier calipers and weight of the whole body using a monopan balance to represent the size of the crab.

Taxonomic studies

Various morphological characters, colour marking and behavioral pattern were observed for taxonomic purpose. For conformation of specific identity electrophoretic studies were also undertaken using material from both the coasts of India. The electrophoretic technique adopted was that of Davis (1964) with slight

modifications as described below.

Electrophoresis was carried out on horizontal PAGE system (Multiphor II) from Pharmacia. During standardisation of methodology, different percentages of acrylamide concentrations which determine the porosity of separating gel were tried. They were 7%, 8%, 8.5% and 10% and out of these, separating gel of 8.5% acrylamide concentration along with 4% stacking gel was found to give better resolution of proteins and this percentage was used in further analysis.

The following buffers and other reagents were used for electrophoresis.

1. Acrylamide N. N'- methylene bis Acrylamide mix (30%) stock.

   a. Acrylamide - 29.1 gm (29.1 %)

   b. Bisacrylamide - o.9 gm (0.9 %)

Both the monomers were dissolved in minimum volume of double distilled water made up to 100 ml and filtered through Whatman No.I, filter paper and stored in amber coloured bottles at 4°C.

2. Separating gel buffer:

   1.8 M. Tris HCl (pH:8.9)

   Tris - 21.9 gm

   TEMED - 250 µl

Dissolved in minimum volume of double distilled water and adjusted the pH with 2 N HCl to 8.9 and then made up to 100 ml and stored at 4°C.

3. Stacking gel buffer:

   0.5 M Tris-HCl (pH : 6.8)

   Tris - 6.057 gm

Dissolved in minimum volume of doubled distilled H_20 and adjusted the pH with 2N HCl and made up to 100 ml and stored at 4°C.

4. Ammonium per sulphate (APS) 10% stock 0.1 gm of APS was dissolved in 1 ml of double distilled water. This is used as a stock solution for both separating and stacking gel.

5. Electrode buffer:

0.192 M. Tris-glycine (pH: 8.3)

Weighed out 36 gm of Glycine, dissolved in 2 litres of double distilled water and adjusted the pH to 8.3 by using 2M Tris and made up to 2.5 litres.

6. Sample buffer

Stacking gel buffer - 7 ml

Glycerol (20%) - 2 ml

Bromophenol blue (0.5% stock) - 1 ml

7. Staining solution:

Coomassive Brilliant Blue R - 250 - (0.15 %)

Weighed 0.75 gm of CBB-R 250 and dissolved in 230 ml of Methanol and 230 ml of double distilled water, stirred well for half an hour 40 ml of glacial acetic acid was added and filtered through crude filter paper and stored in amber coloured bottles.

8. Destaining solution:

Methanol - 150 ml

Glacial Acetic acid - 70 ml

Mixed and made up to 1 litre with double distilled water.

The following gel mix was standardised for 8.5% of separating gel.

Separating gel mix - 50 ml

Acrylamide Bisacrylamide mix - 14.166 ml

1.8 M Tris-HCl (pH - 8.9) - 6.25 ml

D.O.H_2 0 - 4.59 ml

APS - 25 ml

400 µl of APS from the 10% stock solution was made up to 25 ml with double distilled water so that final concentration of APS in gel mix would be 0.08%.

The above solution was cast into the cassette set for slab gels 2 mm thickness. Two or three drops of Butanol was layered over the gel after pouring the gel to avoid meniscus formation.

Stacking gel: After the polymerisation of the separating gel butanol overlay it was removed and washed with distilled water. Water droplets, if any, was removed by using filter paper strips. Then the following composition of the stacking gel mix was poured over the separating gel.

Acrylamide - 3.33 ml

+

Bisacrylamide

0.5M Tris HCl - 6.25 ml

(pH - 6.8)

D.D.$H_2$0 - 15.295 ml

TEMED - 25 µl

APS (10% stock) - 100 µl

The gel cassette was kept for ten to fifteen minutes for the polymerisation of stacking gel.

The crab samples were collected and transported in live condition to the laboratory and stored at -20°C in deep freezer. At the time of processing the samples were taken out from the freezer and allowed to thaw to room temperature. About 1 g of body muscle was cut out using scissors and after washing with ice cold double distilled water, tissue was thoroughly minced keeping it in a cavity block kept over ice slab. Minced tissue was transferred into an ice cold homogenising glass tube and one 1 ml of ice cold double distilled water was added and contents homogenised using a motor driven tissue homogenizer with rotating teflon pestle. To the homogenate 1 ml of ice cold double distilled water was added and homogenised again. The homogenate was transferred into ice cold centrifuge tubes and the centrifugation was carried out for 20 minutes at 10000 rpm at 4°C in a high speed refrigerated centrifuge (Savant, USA).

The supernatant obtained after the centrifugation was used for electrophoretic analysis. 35 ml of sample supernatant was mixed with equal volume of sample buffer (1:1 ratio) in a microplate. The polymerised gel was set on the multiphorII electrophoretic system and the pre run was carried out at 75 mA for 10 minutes. The sample (70 ml) was loaded into the well and electrophoresis was carried out at a constant current of 65 mA for 3 hours. The temperature of the cooling plate was maintained at 10°C throughout the electrophoretic run.

Immediately after the electrophoresis, the gel was transferred into a plastic tray containing staining solution and kept immersed in it for about 1 1/2 hours. After staining, the staining solution was removed and destaining solution was added. After about 30 minutes destaining solution was replaced with fresh destainer. Photographs of the protein band on the gel was taken after complete removal of the background stain.

Study of reproductive biology

The crabs were sexed based on the shape of abdomen and number of pleopods. In the case of female crabs, the pleopods were examined for the presence of eggs or egg remnants or their absence on pleopods, colour of egg mass was also noted.

The anatomy of male and female reproductive systems was studied by dissecting mature crabs. After dissection, the gonads and other parts were examined under a dissection microscope for closer study of anatomical features. For studying maturation process, the ovaries were classified into five maturity stages by modifying the methods suggested by Haefner (1977). For histological studies, gonads and other parts of the reproductive systems were cut and fixed in Bouin's fluid from live crabs. The tissues fixed in Bouin's fluid were washed overnight in running tap water to remove the excess picric acid. These tissues were dehydrated using an alcohol series (30-100% alcohol) and cleared in methyl benzoate. The tissues were further cold impregnated with wax shavings in a 1:1 ratio. Subsequently the solvent was evaporated by placing the tissue in an oven at 58°C. The tissues were transferred through two changes of fresh molten wax (Paraffin wax with cersin, BDH, MP 58-60°C). Tissue blocks were prepared by using paper boats or small glass troughs after proper orientation.

Serial sections of block were cut at approximately 6-8 μ thickness using a rotary microtome (Weswox Optik model T-1090A). Sections were affixed on clean glass slides using fresh Mayer's egg albumin-glycerol (1:1 V/V) and flattened by placing on a slide warmer with a drop of distilled water. Subsequently the water was drained off and slides were then used for histological observations. Staining was done by using Harris haematoxylin stain (Preece, 1972) with 1% aqueous eosin as the counter stain. Sections to be stained were first deparaffinized in two changes of xylene and then hydrated through a down series of ethanol grades. They were

then blued using tap water or lithium carbonate. Eosin stained sections were repeatedly washed in 95% alcohol to remove the excess eosin. Slides were further dehydrated in absolute alcohol and cleared in xylene and mounted with DPX or Canada balsm of neutral pH. Mounted slides were examined under a monocular microscope.

Micrometric measurement of oocyte in different stages of maturation were taken using an occular micrometer (ERMA, Japan) calibrated with stage micrometer. As oocyte strongly deviated from a spherical shape, the average of the largest and smallest axes of oocyte found in a maturity stage was taken. Spermatogonial and sperm cell diameter were also recorded in the same manner.

Photomicrographs of histological preparations of ovary and testes were taken using a binocular compound microscope ('Microstar', American Opticals, U.S.A.) and with a camera unit. Appropriate projection eye piece was used and the photographs were taken using 24 x 36 mm ORWO NP 22 (125 ASA, Panchromatic) black and white negative film.

The fecundity was calculated by counting the number of eggs present on the pleopod in ovigerous condition. As the loss of eggs during incubation was not known, only crabs carrying eggs in the early stages of embryonic development were used for this purpose. The egg carrying pleopods were first removed from the crab and immersed them in concentrated solution of sodium hydroxide as suggested by Melville Smith (1987). The eggs became free from the pleopods after 3-6 hours. The eggs were then filtered and weighed to nearest 0.1 mg using an electronic balance (Mettler, PC 440, Switzerland). A sample of the egg mass thus separated was weighed and counted and total number of whole egg mass was determined using the formula.

$$F = P/P1 \times n$$

Where P = the weight of egg mass; P1 = the weight of the sub sample and

n = the total number of eggs in the subsample.

Growth studies

Growth in juvenile phase was studied by rearing the baby crab in laboratory. In the case of *S. oceanica,* the study was conducted using animals produced in the laboratory. Fifteen healthy instar-I were used for the study. In the case of S. serrata the seed were collected from stake nets operated in the tidal canal of Vypeen Island. The animals thus collected were acclimatized at 15 ppt salinity. From this, 25 animals of about 2 cm carapace width were sorted out and used for the experiment.

All the rearing trials were conducted at 15 ppt salinity. For this filtered sea water diluted with dechlorinated tap water was used. These animals were stocked individually in 40 litre plastic tubs containing 35 litres of diluted sea water (15 + 2 ppt). The tubs were arranged in such a way that all the tubs received uniform light condition. Animals were fed daily with clam meat. Every day before feeding, excess feed and faecal matter were siphoned out and the water was replaced to the original level. The water in the tubs was changed completely once a week. Crabs were observed every day for moulting, and at each moult the carapace width as well as weight measurements were taken as described by Ong (1966). The experiment was conducted during the period May 1994-April 1995.

For analysing growth in natural environment, monthly size frequency distribution was worked out by grouping length measurements in 10 mm size classes. From the size frequency data, modal values were estimated using Bhattacharya (1967) method and using these modes growth parameters K and L were estimated following Gulland and Holt (1959) plot method using FISAT Computer programme (FAO-ICLARM stock assessment tools (ver.1.0).

Data on growth was also collected from the grow-out culture pond at

monthly intervals. On each observation day 20-25 crabs were collected randomly using the ring nets and carapace width and weight measurements were taken and growth calculated.

Estimation of carapace width - weight relationship

Carapace width-weight relationship was estimated using the log form of allometric growth equation $w = aL^b$, where w = expected weight, L = total carapace width and 'a' and 'b' are constants calculated by the least square method. The difference in CW - weight relationship between sexes was tested by ANOVA using suitable computer programme.

Study of sex ratios

The sex ratios of commercial catches were analysed month-wise and size-wise for both the species and the same were tested using the chi-square analysis as per Panse and Sukhatme (1978).

Assessment of crab landings

On each observation day, the total crab landing at a particular centre was recorded species wise and grade wise. In addition to this, similar information for other fishing days of the month was also recorded from merchants' diary for as many days as possible. The average daily crab landing was worked out from the data thus obtained and raised to the number of fishing days to assess the monthly total crab landing of that centre.

Larval rearing studies

For studying incubation, larval development and seed production, berried specimens were collected from the wild. Berried specimens of *Scylla oceanica* were obtained from shrimp trawlers and those of *Scylla serrata* from Chinese dip nets operating near Cochin bar mouth. Spawners were immediately transferred to water of same salinity in 50 l aerated plastic jars and transported to the field labo-

ratory of CMFRI, Narakkal. At Narakkal the spawners were transferred to 2 ton fibreglass tanks filled with clean filtered and aerated sea water. Live clam was opened and given to the animals as feed. Every day half of the water was exchanged with fresh seawater after siphoning out the excess food, excreta and shed out eggs. Continuous aeration was given throughout the incubation period. Development of eggs was monitored by taking small samples from the berry using a small forceps and observing it under microscope. Photomicrographs of developing eggs were also taken.

Only active zoeae were collected from the incubation/spawning tanks for larval rearing studies. Inorder to facilitate replication of the experiments, zoea were reared in 2200 ml glass troughs of hemispherical shape filled with 2 litres of filtered and aerated sea water. Each trough was stocked with larvae at the rate of 50 numbers/litre. For every larval feed three replicates were tried. Salinity was maintained at 34-35 ppt., pH 7.8-8.2 and temperature 27-30°C. Every day larvae were counted and transferred to fresh sea water using wide bore pipette. Troughs were arranged in such a way to ensure uniform light conditions to all the containers.

During the larval rearing experiments five larval feeds such as *Chlorella marina, Brachionus plicatilis, Artemia salina* nauplii, egg custard and microencapsulated feed were given individually and in combination. The live feeds were developed in the laboratory. Inoculum for the pure culture of *Chlorella marina* was obtained from CMFRI algology laboratory in sterilized 250 ml conical flask. Filtered sea water of 35 ppt salinity was taken in clean 3 litre Haufkin culture flasks and plugged with cotton. It was sterilized by boiling it on a hot plate for 5 minutes and the water in the flask was allowed to cool over night. To this A, B and C solutions of Conway or Walne's nutrient medium was added using a sterile pipette. Composition of the medium is given below.

Conway or Walne's medium:

Solution A

Sodium nitrate/Potassium nitrate	100 g
Sodium phosphate	20 g
Ferric chloride	1.3 g
Manganese chloride	0.36 g
Boric acid	33.4 g
EDTA	45 g

Dissolved in 1 litre of distilled water.

Solution B (Trace metals)

Zinc chloride	2.1 g
Calcium chloride	2.0 g
Ammonium molibdate	2.0 g
Copper sulphate	2.0 g
Distilled water	100 ml

Dissolved in 1 litre of distilled water.

Solution C (Vitamin stock)

B 12	5 mg
B 1	100 mg

Dissolved in 100 ml of distilled water.

One ml each of solution A and B and 0.1 ml of solution C were added to 1 litre of algal culture medium. To this medium pure culture was inoculated with-

out any contamination and the plugged flasks were kept under direct sun light near the windows. The inoculated *Chlorella* developed into fully grown cultures within 4-6 days and served as stock for mass culture.

Mass culture was done in 50 litre perspex tanks filled with filtered aerated sea water enriched with Conway or Walney's medium. One litre Inoculum was used for 50 litres of sea water. Culture attained harvestable concentration within 5-7 days. Concentration of the culture was measured using haemocytometer. Every day half of the culture was harvested and replaced the same with fertilized sea water.

The rotifer *Brachionus plicatilis* used for the study was obtained from local brackishwater ponds. Pond water was filtered through a zooplankton net and the plankton collected was carefully transferred to 1 litre plastic container filled with pond water. Plankton sample so collected was brought to the laboratory and egg bearing parthenogenic females were isolated and slowly acclimatized to *Chlorella* medium taken in a beaker (1 litre) with mild aeration. Within four days the stock was ready. Mass culture of rotifers were done in 10 liter flasks filled with *Chlorella* medium. Rotifer was inoculated at the rate of 10/ml, and within 4-6 days it attained a density of 250 ml. Rotifers were harvested by filtering the culture using a zooplankton net and the same volume was replaced with fresh *Chlorella* medium. Baker's yeast was also given to the fast multiplying rotifers when *Chlorella* was insufficient to feed them.

Artemia cysts were procured from Prime Artemia Incorporated, USA and Ballarpur Industries, Gujarat. Artemia cysts were hatched in 5 litre glass beaker containing sea water of 30 ppt salinity and 8-8.2 pH. Cysts were added at the rate of 2 g/litre and vigorous aeration was provided from the bottom of the container to ensure that the cysts were in suspension. For optimizing hatching continuous illumination (40 watt fluorescent) was provided 20 cm above the water surface.

Hatching was over in 18-24 hours in the case of the US brand and 36-40 hours in the case of the Indian brand. Nauplii were harvested from the bottom of the container after light and air were turned off for 15 minutes and siphoning them to a zooplankton net without disturbing the unhatched eggs settled at the bottom. *Artemia* nauplii were rinsed in fresh seawater before feeding. *Artemia* suspension was made by grinding the nauplii in a mixer for few seconds.

Fresh chicken eggs were used for making egg custard. Egg white and yolk were taken in a bowl and blended with little fresh water. This mixture was then steamed till it hardened well. This steamed egg was passed through 200 micron sieve to produce desired particle size.

Microencapsulated feed used was obtained from SANDERS BRINE SHRIMP COMP. INC., USA, whose composition is given bellow.

Protein	46%
Lipid	18%
HUFA	2.5%
Ash	0.12%
Moisture	8.5%

Crab culture experiments

Crab fattening experiments were carried out in a brackishwater pond of 0.05 ha (Plate 40a) situated in Vypeen island. The pond was connected to Cochin backwaters by a 5 m wide canal of about 200 m length. The pond had a strong bund of 3 m width at the top. A sluice gate of 1 m width connected the pond to the tidal canal. Average depth of the pond was 1.5 m.

In order to prevent escape of crabs over the bund a perimeter fencing of 1 m height was provided using nylon netting of 20 mm mesh size (Plate 40a). The

netting was supported by split bamboo sticks fixed on the dyke at 2 m intervals. The net was fixed in such a way that the lower portion of the same was buried in soil and secured firmly with bamboo pegs. The sticks were planted in slanting manner overhanging the pond to prevent crabs from climbing over the fence. Bund near the sluice gate was reinforced with bamboo matting as the crabs showed a strong tendency to burrow near the sluice gate. A watchman was arranged to keep vigil to prevent poaching. Four fattening trials were conducted between August 1992 and April 1993. The fattening period varied from 45 to 60 days.

During the experiments physico-chemical parameters like temperature, salinity, dissolved oxygen and pH were measured at an interval of 7 days.

Grow-out culture experiment was carried out in a pond of 0.1 ha. area, which was connected to the Cochin backwaters through a 1 m wide sluice gate. A 4 m wide strong bund separated the pond from the backwater on one side and the other 3 sides were surrounded by land mass. The pond had an average water depth of 1.2 m. A perimeter fencing was also given to prevent the escape of crabs as in the case of fattening pond. Since the crabs showed tendency to burrow near the sluice gate, the bund adjoining the sluice gate was reinforced with bamboo mats. Only one culture experiment was carried out in this system, which extended for a period of six months from August 1993 to February 1994. The physico-chemical parameters were also recorded as in the case of fattening experiments.

Analysis of physico-chemical parameters

Temperature: A centigrade thermometer graduated 0-50°C was used to measure water temperature.

pH: pH was determined using a digital pH meter in the laboratory after sampling.

Salinity: Water samples collected from 5 cm below water surface was used for

salinity estimation. The salinity was determined by Mouris titration method (Strickland & Parsons, 1968).

Dissolved oxygen: Dissolved oxygen was estimated by "Winkler method" (Strickland & Parsons, 1968).

The proximate composition of crab meat before and after fattening was analysed to find out the possible biochemical change in the crab meat during fattening. Standard methods AOAC (1965) were used for determination of moisture, ash, crude protein, total lipid, crude fibre and nitrogen free extract (NFE).

CHAPTER III
RESULTS AND DISCUSSION

SECTION 1

TAXONOMY AND DISTRIBUTION

Among the brachyuran crabs those belonging to the family Portunidae are important from the commercial point of view as most of the crab fisheries of the world are contributed by the members of this family. According to the checklist of this family published by Stephenson (1972), there are about 210 valid species existing in the Indo-Pacific region. Most of the species occupy the inshore waters and some occurring in the inland brackishwater systems as well. Considerable taxonomic investigations have been carried out on this family all over the world and more particularly in the Indo-Pacific region. The works of Alcock (1899 a), Barnard (1950), Chhapgar (1958) and Stephenson (1961, 1972) provide considerable information on the taxonomy of this group which is being revised from time to time. The family has the following diagnostic features as modified from Alcock (1899 a) and Stephenson (1972).

Carapace depressed or little convex, generally broader than long and widest at the last antero-lateral teeth, front broad and cut into 2-6 lobes or teeth, antero-lateral border cut into many teeth, antennules folded transversely, antennal flagellum almost always long and slender, fifth pair of walking leg generally natatorial, atleast last two joints flattened, broad and strongly fringed with setae; male genital opening coxal.

Great majority of the species of the family Portunidae are easily recognized

by the paddle-shaped fifth pair of walking legs which is adapted for swimming.

In Indian region, most of the commercially important crabs of this family belong to the subfamily Portuninae (Rafinesque). Members of this subfamily have a typical portunid shape with very broad carapace bearing 4-9 anterolateral teeth. The basal joint of antennae is usually broad and its anterolateral angle some times lobulated. Cheliped are longer than all legs and the last pair typically paddle shaped.

In Indian coast, 5 genera viz *Charybdis, Lupocyclus, Portunus, Scylla* and *Thalamita* have been reported under the subfamily portuninae by various workers. Members of all genera except *Lupocyclus* and *Thalamita* contribute to the fishery. These five genera can be distinguished by various characters mainly on the basis of the number, size and arrangement of antero-lateral teeth on carapace and the structure of chelipeds. The five genera can be distinguished by the following key.

Key to Indian Genera of Subfamily portuninae

1. Carapace with 8-9 antero-lateral teeth - 2

   Carapace with 5-7 antero-lateral teeth - 3

2(1). Surface of carapace clearly divided into regions; last antero-lateral teeth long or moderately long - *Portunus*

   Surface of carapace with ill-defined regions; last anterolateral teeth not unusually long; hand of cheliped inflated and smooth - *Scylla*

3(1). Antero-lateral teeth alternately large

and small; carapace front protruding;

chela extremely long - *Lupocyclus*

Antero-lateral teeth not alternately

large and small; carapace front not

protruding - 4

4(3). Distance between outer orbital teeth

considerably less than greatest width

of carapace - *Charybdis*

Distance between outer orbital teeth not

much less than greatest width of carapace - *Thalamita*

GENUS *SCYLLA* DE HAAN, 1833

This genus is represented only in the Indo-Pacific region and the following are its diagnostic characters.

Carapace broad, moderately convex, nearly even, front cut into four teeth (excluding inner orbital teeth); antero-lateral border oblique, arched longer than postero-lateral, cut into 9 subequal teeth; postero-lateral angles rounded; upper orbital margin with two fissures; chelipeds massive, wrist and hand smooth, with definitely placed spines, hand inflated; propodus of fifth leg longer than broad, dactylus typically foliaceous for swimming; abdomen of male broadly triangular, 5 segmented, third to fifth terga coalesced.

Members of the genus *Scylla* are generally known as "Mud crabs", "Green crabs" or "Mangrove crabs". They occupy the inshore sea as well as brackishwater environments contributing to the commercial fishery.

The taxonomy of mud crabs of the genus *Scylla* has been a subject of con-

troversy as regards the number of valid species existing under the genus as reported from different parts of the Indo-Pacific. After the first record of *Cancer serratus* by Forskal (1755) the correct identity of any particular species under the genus could not be established for nearly a century until Estampador (1949 a & b) made a thorough taxonomic revision of the group, who recognised three species and one variety whose validity was questioned by Stephenson and Campbell (1960) who opined that more work was needed before adopting Estampador's classification. Quite recently, Fuseya and Watanabe (1996) proposed three species for genus *Scylla* on the basis of variations noticed through electrophoretic analysis of the allozymes.

From India, Joel and Raj (1980, 1983) reported the occurrence of two species of the genus *Scylla* from the Pulicat lake viz. *S. tranquebarica* and *S. serrata,* whereas Kathirvel (1981) reported the occurrence of *Scylla oceanica* and *S. serrata* in Cochin backwaters. Later Radhakrishnan and Samuel (1982) distinguished one species, *Scylla serrata,* and a variety which they named as *Scylla serrata serrata* from Cochin backwaters. Discussing the taxonomic problems of mud crabs in India, Kathirvel and Srinivasagam (1992b) recently concluded that at least two distinct species namely *S. serrata* and *S. tranquebarica* exist under the genus *Scylla* in the Cochin Backwaters. They also presumed that *S. oceanica* could be a synonym of *S. tranquebarica.* Babu (1995) reported that the mud crabs of Andhra Pradesh, Maharashtra and Gujarat are represented by *S. serrata, S. oceanica* and *S. tranquebarica* without going into the details of taxonomic aspects.

During the present investigation the identity of the species of genus *Scylla* occurring along the coasts of Kerala and Tamil Nadu has been critically examined on the basis of morphological characters, colour variations, electrophoretic pattern of muscle myogen and biological as well as behavioural observations on individual species. Two distinct types of mud crabs have been recognized during this

study, which are assigned to *Scylla serrata* (Forskal) and *Scylla oceanica* (Dana) and the same are described and discussed.

Discription of species

SCYLLA SERRATA (FORSKAL)

(Plate 1a, b; 2 a, b; 3a, b; 4a)

Synonymy

Cancer serratus Forskal, 1755, p. 90.

Lupea tranquebarica Milne-Edwards, 1834, p. 448.

Scylla serrata de Haan, 1850, p. 44.

Scylla serrata Miers, 1880, p. 238.

Scylla serrata Miers, 1886, p. 185.

Scylla serrata De Man, 1888, p. 332.

Scylla serrata Chia-Jui Shen, 1932, p. 32.

Scylla serrata Estampador, 1949, p. 99.

Scylla serrata var. *Paramamosain* Estampador, 1949, p. 104.

Scylla serrata Joel & Raj, 1980, p. 39, Fig.2.

*Scylla serrata serrata*Radhakrishnan & Samuel, 1982, p.5, Fig.1A.

Scylla serrata serrata Mercy Thomas, 1984, p. 21, Fig. 3d.

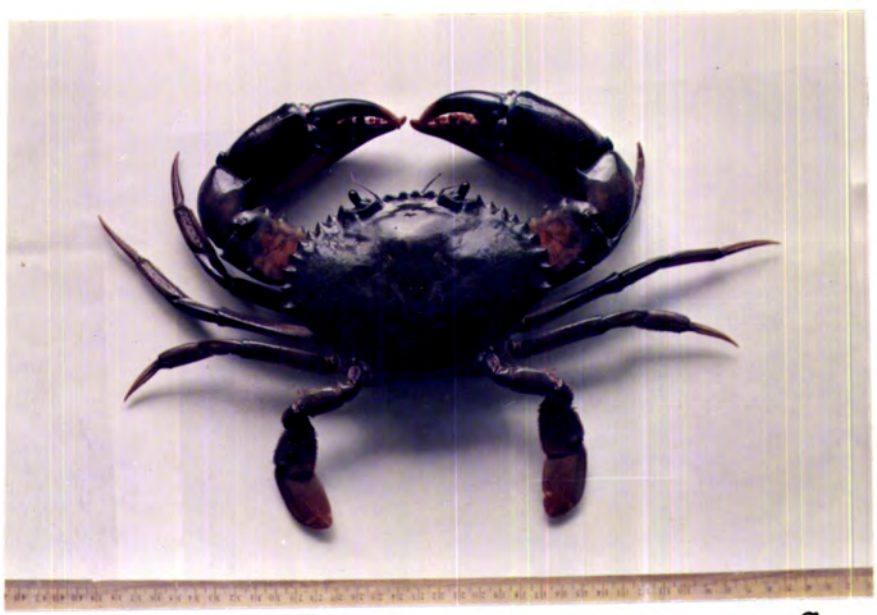
Scylla serrata serrata Sheeba Thariyan, 1988, p. 16, Pl. 1b.

Scylla serrata Kathirvel & Srinivasagam, 1992b, p. 127, Fig.1.

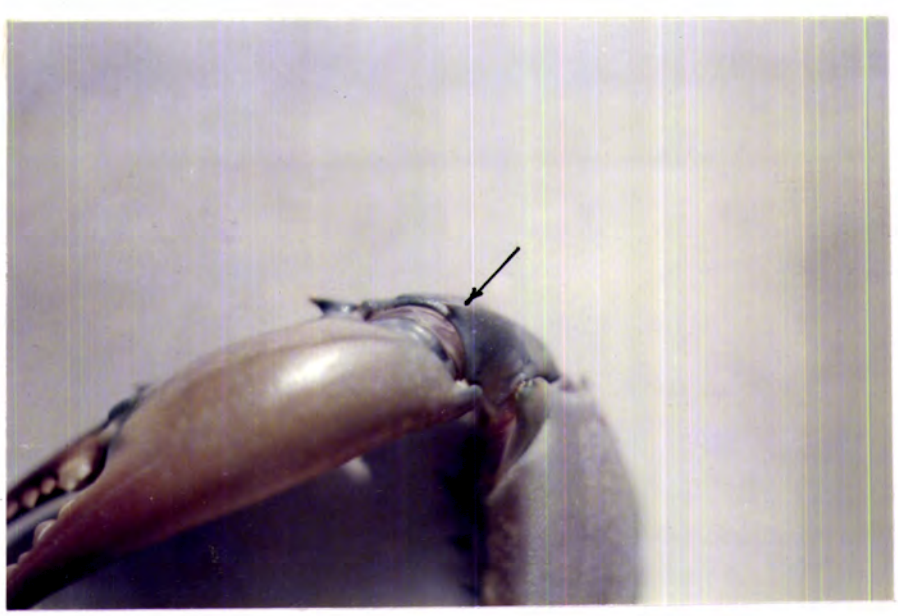
Scylla serrata Fuseya & Watanabe, 1996, p. 705.

Material examined

1721 juvenile and adult males upto 16 cm CW and 1750 juvenile and adult females upto 14 cm CW, collected from Ashtamudi lake, Cochin backwaters and Korapuzha estuary (Kerala coast) between August 1992 and July 1993. 16 juvenile



a



b

PLATE 1

a. *Scylla serrata* (Forskal) adult male dorsal view

b. *S. serrata* left cheliped showing characteristic single spine on the outer side of carpus

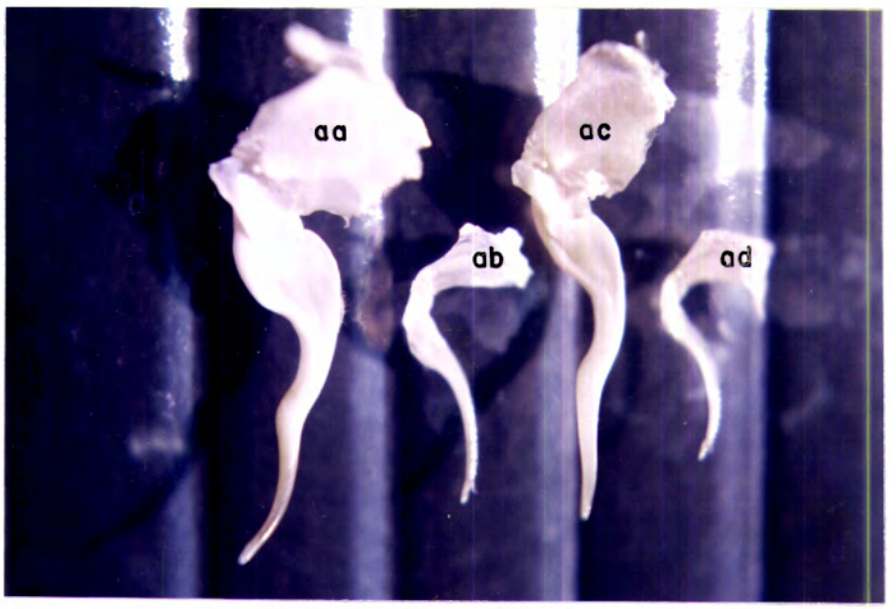
a

b

PLATE 2

a. *S. serrata* adult male ventral view

b. *S. serrata* adult female ventral view



a

b

PLATE 3

a. *S. serrata* and *S. oceanica* male pleopods

aa, *S. serrata* 1st pleopod of adult male
ab, *S. serrata* 2nd pleopod of adult male
ac, *S. oceanica* 1st pleopod of adult male
ad, *S. oceanica* 2nd pleopod of adult male

b. *S. serrata* and *S. oceanica* male pleopods

ba, distal end of adult male pleopod of *S. serrata* magnified;
C - chromatophores
bb, distal end of adult male pleopod of *S. oceanica* magnified

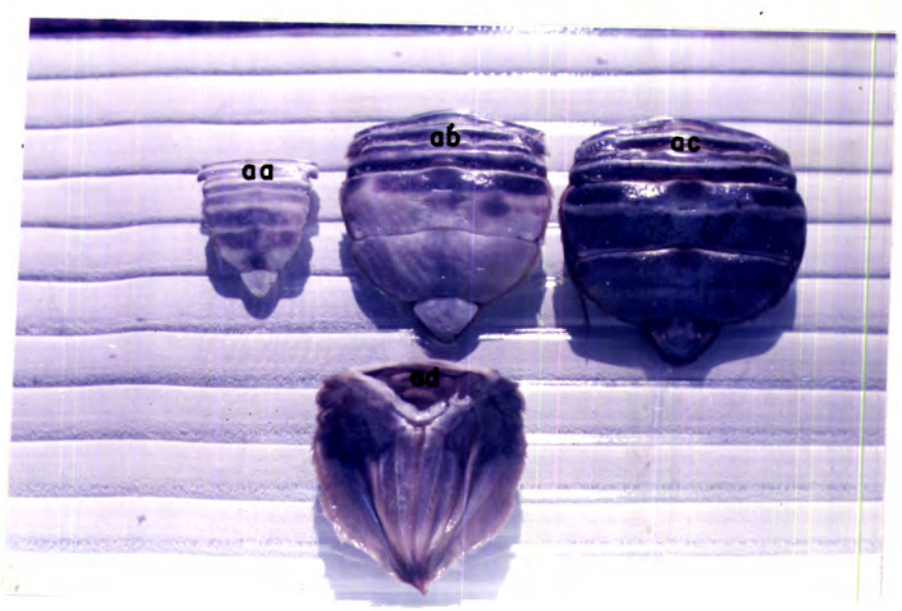


PLATE 4

a. *S. serrata* female abdomen

aa, immature; ab, maturing; ac, mature and ovigerous; ad, mature inner view

and adult males upto 14 cm CW and 14 juvenile and adult females upto 12.5 cm CW, collected from Pulicat lake and Tharankampadi (Tamil Nadu coast) during May-June 1993.

Morphological Description

Carapace 1.3-1.5 times broader than long, strongly convex (Pl.1 a) almost smooth except for a faint granular ridge running obliquely inwards across branchial region between last anterolateral teeth, cardiac region with a shallow 'H' shaped groove; front teeth blunt, almost equal in size and arranged in a straight line, antero-lateral border cut into 9 anteriorly truncated teeth of almost equal size; posterior border adjoining abdominal plate slightly convex.

Abdomen in adult female about 1.2 times longer than broad, abdomen of male triangular, evenly tapering (Pl.2 a, b).

Antennules folded transversely; chelipeds massive, armed with three spines on the anterior border and two on the posterior border-one terminal and other submedian, wrist and hand smooth without ridges, inner angle of carpus with a strong spine and outer angle rounded carrying a small spine (Pl. 1b), hand with three tubercles; legs smooth, 4th joint of 5th leg longer than broad, dactyl glabrous, ovate, the hinder half projecting apically in a minute point.

First male pleopod rather long, outer border of basal lobe more rounded (Pl.3 a), mid region with thick spinules, tip brownish in colour (Pl. 3 b) in fresh condition due to the presence of chromatophores.

Colour: In fresh condition, carapace ferrugenous brown in colour and in some cases with a dark greenish tinge. No ornamental markings are present except for a few faint polygonal markings on the last two segments of the swimming legs. Abdomen is whitish in males and juvenile females and this colour changes with maturation of the ovary. In mature females the abdomen has a bluish or dark

violet colour (Pl. 4 a) at the time of spawning and throughout the ovigerous period, and this colour gradually fades after the eggs hatch out.

SCYLLA OCEANICA (DANA)

(Plate 3a, b, 5a, b, 6 a,b, 7a)

Synonymy

Scylla tranquebarica Var. *oceanica* Dana, 1852,p. 270, Pi.XVI, Fig.6.

Scylla tranquebarica Var. *oceanica* Stimpson, 1907, p.75.

Scylla oceanica Estampador, 1949, p. 101, Pl.1, Fig.1.

Scylla tranquebarica Joel & Sanjeevaraj, 1980, p. 39, Fig.1.

Scylla serrata Radhakrishnan&Samuel,1982,p.5,Fig.1A.

Scylla serrata Mercy Thomas, 1984, p.21, Fig.3C.

Scylla serrata Sheeba Thariyan, 1988, p. 15, Pl.1a.

Scylla tranquebarica Kathirvel & Srinivasagam, 1992b, p. 127

Scylla tranquebarica Suseelan & Anil, 1995, p. 124

Scylla oceanica Fuseya & Watanabe, 1996, p. 705.

Material examined

1428 juvenile and adult males upto 20.9 cm CW and 1348 juvenile and adult females upto 19 cm CW, collected from Ashtamudi lake, Cochin backwaters and Korapuzha estuary (Kerala coast) between August 1992 and July 1993. 12 juvenile and adult males upto 18 cm CW and 15 juvenile and adult females upto 17 cm CW, collected from Pulicat lake and Tharankampady (Tamil Nadu coast) during May-June 1993.

Morphological description

Carapace 1.3-1.5 times broader than long, moderately convex, (Pl.5 a) not very smooth, provided with a faint granular ridge running obliquely inwards across branchial region between last antero-lateral teeth, cardiac region with a deep 'H'

a

b

PLATE 5

a. *Scylla oceanica* (Dana) adult male dorsal view

b. *Scylla oceanica* left cheliped showing two characteristic spines on the outer side of carpus

a

b

PLATE 6

a. *S. oceanica* adult male ventral view

b. *S. oceanica* adult female ventral view

PLATE 7

a. *S. oceanica* female abdomen

aa, immature; ab, maturing; ac, mature; ad, mature inner view

shaped groove; front teeth sharp, arranged in straight line, antero-lateral border cut into 9 anteriorly truncated teeth of almost equal size; posterior border adjoining abdominal plate straight.

Abdomen in adult female about 1.2 times longer than broad, same in male triangular, evenly tapering (Pl.6a, b).

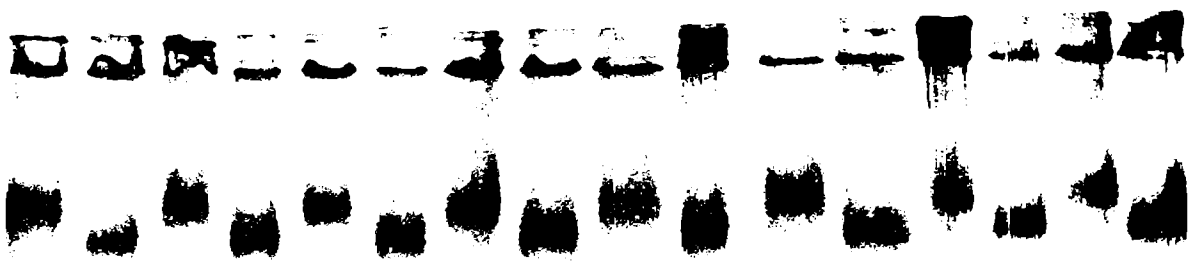
Antennules folded transversely; chelipeds massive, not more than twice the length of carapace, armed with three spines on anterior border and two on posterior border of which one terminal and other submedian, wrist and hand smooth without ridges, inner angle of carpus bearing a strong spine and outer angle rounded bearing two strong spines (Pl.5b), hand with three tubercles; legs smooth, 4th joint of 5th leg longer than broad, dactyl glabrous, ovate, the hinder half projecting apically in a minute point.

First male pleopod long, outer border of basal lobe moderately rounded (Pl.3 a), mid region with less spinules, tip whitish in colour (Pl.3 b) due to the absence of chromatophores (Pl.3b).

Colour: In fresh condition carapace is grayish or grayish green in colour with small whitish gray spots; anterolateral margin whitish on the ventral side. All legs with large polygonal pigmented areas of gray colour bordered with purplish brown lines in both sexes, abdomen of males and immature females whitish (Pl.7 a), abdomen of adult females with permanent ornamental (polygonal) markings similar to those found on legs.

Electrophoretic results

Muscle myogen electrophoretic pattern of the crab materials collected from Cochin backwaters, Ashtamudi lake, Korapuzha estuary and Pulicat lake were analysed and the electrophorograms and their related schematic patterns are shown in Plate 8, 9, 10 and 11. The electrophorograms recorded for all these stations



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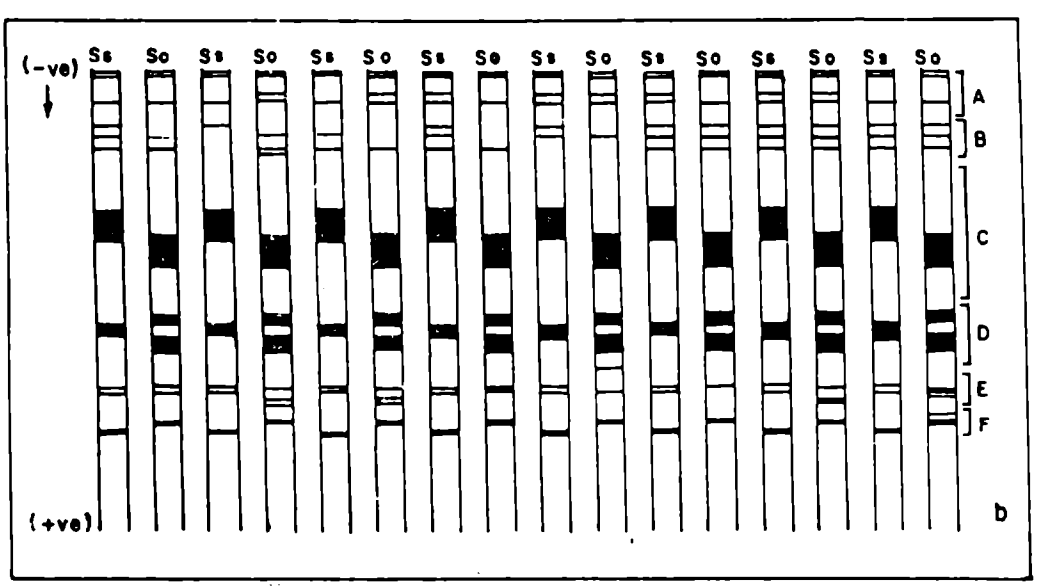
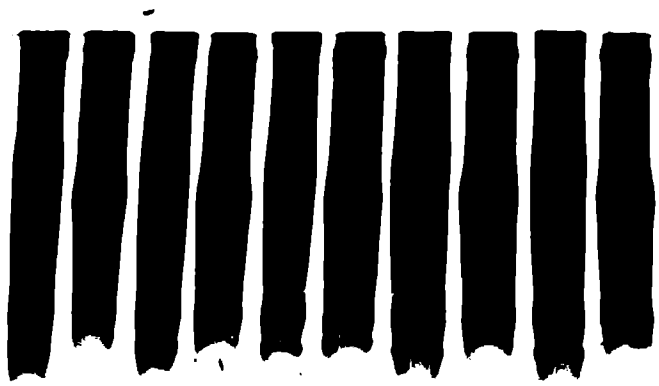


PLATE 8 ·

a. Slab electrophorogram of myogen of *Scylla* species (Cochin backwaters)

b. Schematic pattern of the slab electrophorogram shown in 'a'

Ss, *Scylla serrata* ; So, *Scylla oceanica*



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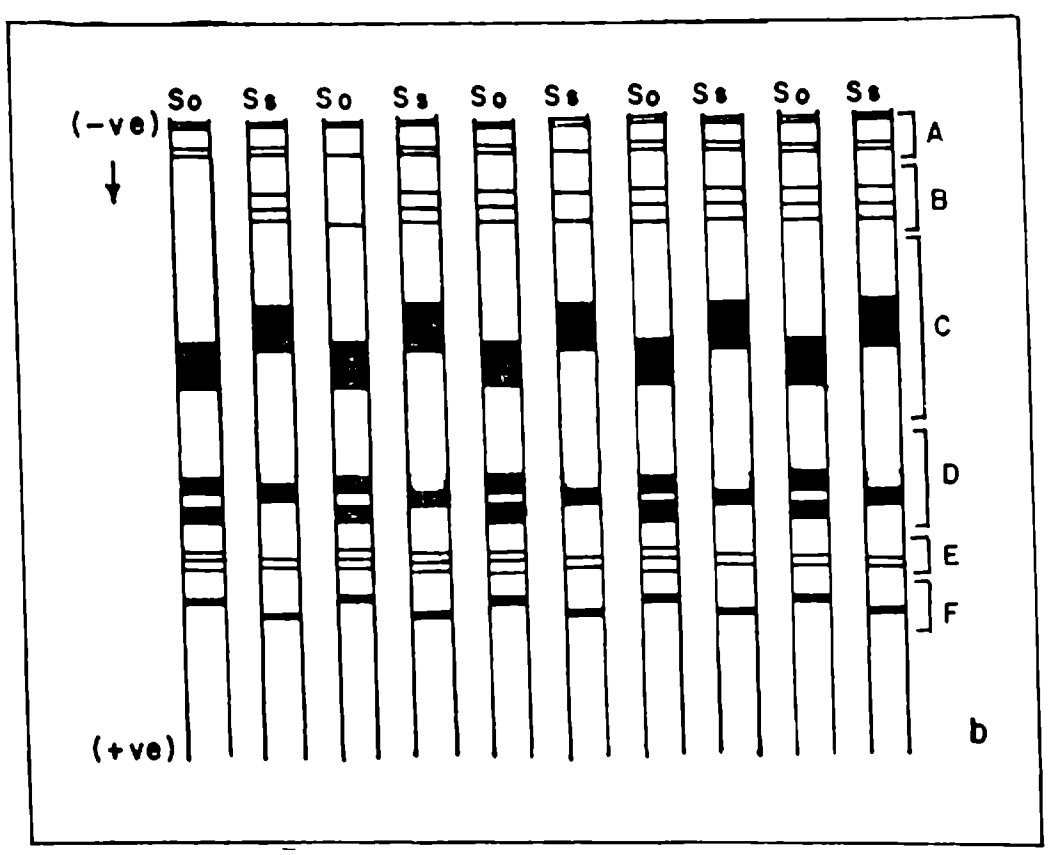


PLATE 9

a. Slab electrophorogram of myogen of *Scylla* species (Ashtamudi lake)

b. Schematic pattern of the slab electrophorogram shown in 'a'

Ss, *Scylla serrata* ; So *Scylla oceanica*

a

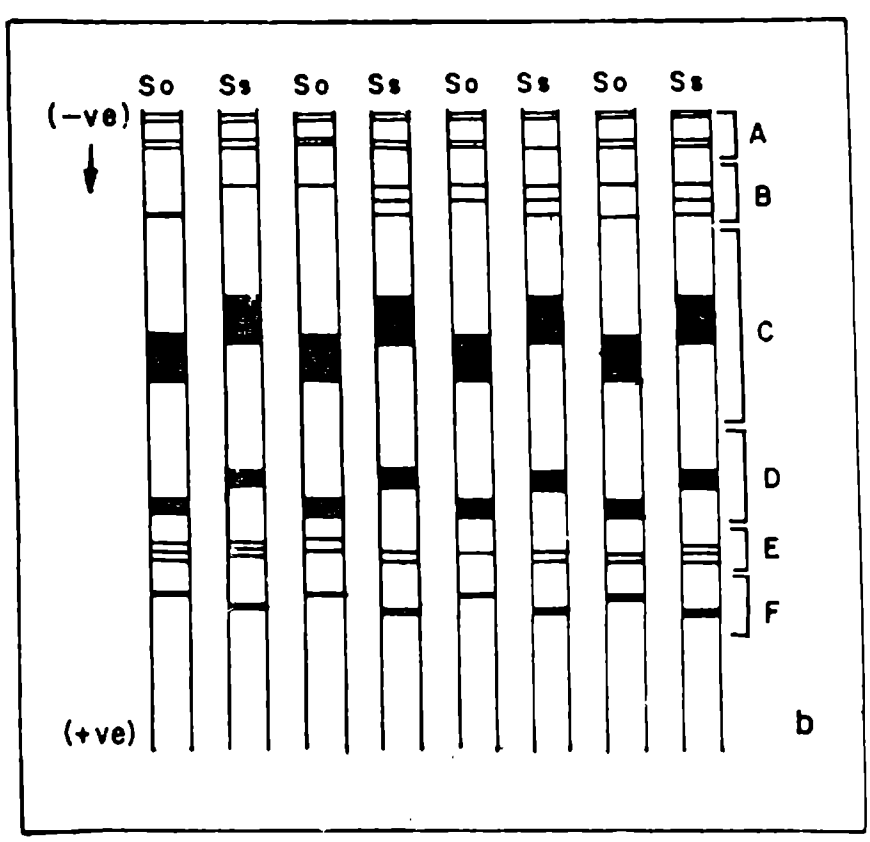
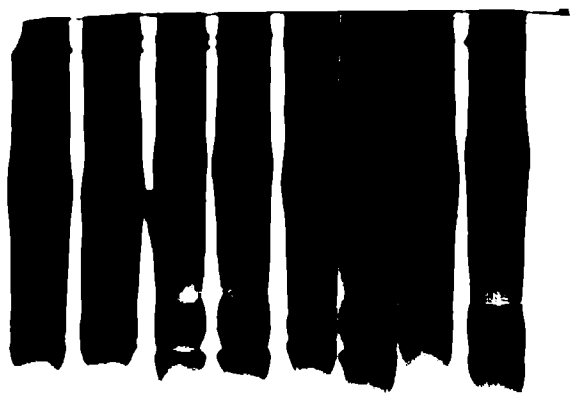


PLATE 10

a. Slab electrophorogram of myogen of *Scylla* species (Korapuzha estuary)

b. Schematic pattern of the slab electrophorogram shown in 'a'

Ss, *Scylla serrata* ; So, *Scylla oceanica*



a

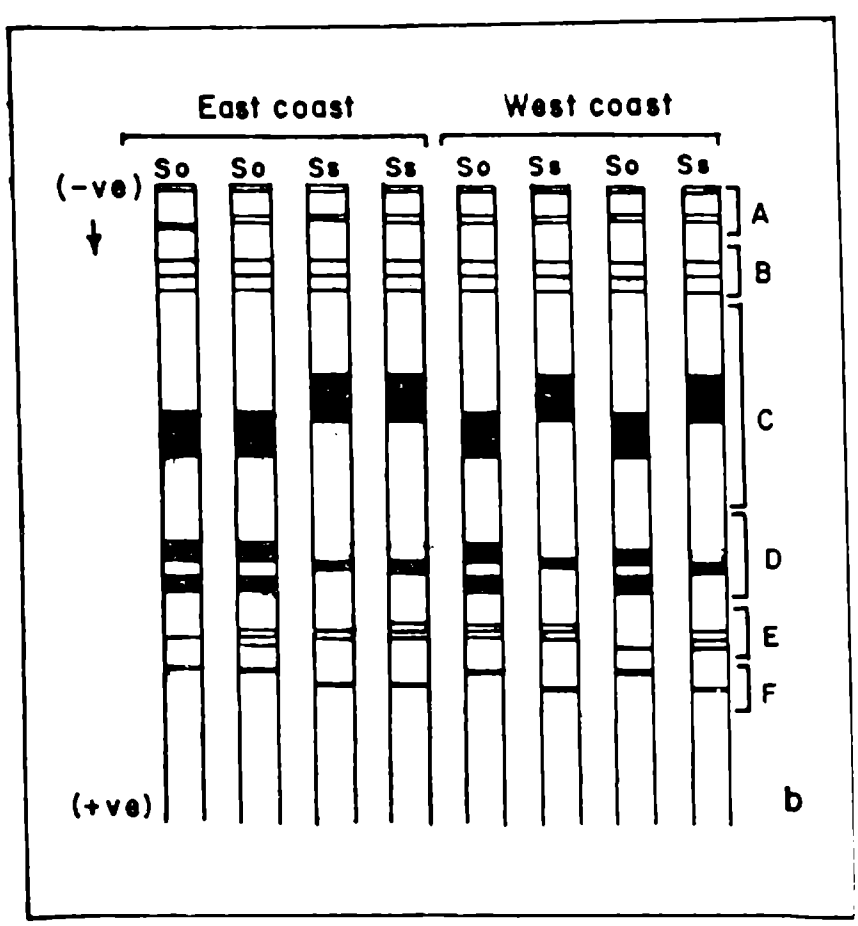


PLATE 11

a. Slab electrophorogram of myogen of *Scylla* species (East and West coast)

b. Schematic pattern of the slab electrophorogram shown in 'a'

Ss, *Scylla serrata* ;So,*Scylla oceanica*

were similar with minor differences. The banding pattern of these proteins obtained on polyacrylamide gel is divided into 6 zones for the purpose of interpretation.

In zone A and B the crabs belonging to both the species have shown single and double banded protein pattern. In zone C all the crabs of *Scylla serrata* showed an intensely stained protein band with considerable length reflecting high content of it in the animal with slow electrophoretic mobility. In the case of *S. oceanica* a comparatively low molecular weight protein which was intensely stained and with fast electrophoretic mobility was observed in this zone. In zone D all the animals belonging to *S. serrata* showed single banded pattern whereas *S. oceanica* showed a double banded pattern. Contrary to the above observation, animals of both the groups collected from Korapuzha estuary have shown a single banded pattern. Both the groups of animals tested have shown an irregular banding pattern in zone E (Single, double or triple). In the zone F, *S. serrata* showed a comparatively low molecular weight fast moving protein band, whereas *S. oceanica* showed a high molecular weight band with slow electrophoretic mobility.

Distribution

The Genus *Scylla* enjoys a wide distribution in the Indo-Pacific region, being found along the east coast of Africa, Madagascar, Red Sea, Pakistan, east and west coast of India, Andaman-Nicobar Islands to Japan, Australia, New Zealand, Hawaii and Tahiti (Stephenson & Campbell, 1960; Kathirvel, 1981; Fuseya & Watanabe, 1996).

In India according to the available literature, mud crabs under the name *S. serrata* occur in estuaries of the rivers Ganga, Mahanadi, Godavari, Krishna and Cauvery and the brackishwater lakes Chilka and Pulicat on the east coast, the estuaries of Narmada and Tapti and the brackishwaters of Kerala on the west coast

and the mangroves of Andaman and Nicobar Islands (Jones & Sujansinghani, 1952; Chacko & Rajagopal, 1964; Evangeline, 1967; Rao *et al.*, 1973; Srinivasagam, 1975; Trivedi & Patel, 1975; Ansari & Harikantra, 1975; Ram & Chandramohan, 1978; Kathirvel, 1981; Babu & Manjulatha, 1995). In addition to this, other varieties under the name *S. tranquebarica*, (Joel & Raj, 1980; Kathirvel & Srinivasagam, 1992b), *S. serrata serrata* (Radhakrishnan & Samuel, 1982) or *S. oceanica* (Babu & Manjulatha, 1995) are also reported to occur in the estuaries, backwaters and mangrove areas of Kerala, Tamil Nadu and Andhra Pradesh. These species also occur in the inshore marine environment of the respective regions (Rao *et al.*, 1973; Shanmugam & Bensam, 1980; Kathirvel, 1981; Joel & Raj, 1983; Sheeba Thariyan, 1988; Babu,1995).

The present study establishes that the mud crab population of Kerala and Tamil Nadu coasts is formed by atleast two species, *S. serrata* and *S. oceanica.*

Discussion

The taxonomy of genus *Scylla* has received considerable attention ever since Estampador (1949 a,b) made a revision of the genus recognising 4 different types whose specific status remains unsettled.

Forskal (1755) introduced a species of mud crab for the first time under the name *Cancer serratus*. Later Fabricius (1798) described *Portunus tranquebaricus*, probably from a specimen obtained from Tranquebar (Tharankampady of Tamil Nadu coast), India. Keeping the burrowing habits of the species in mind, de Haan (1833) assigned the generic name as *Scylla* and named the representing species as *S. serrata*. Milne Edwards (1834), naming the crab as *Lupa tranquebarica*, observed that it was the biggest species of Portunidae attaining 6-8 inches (15-20 cm), with grayish green colour and inhabiting the Asiatic Seas. Dana (1852) considered this crab as *Scylla tranquebarica* var. *oceanica*. Alcock (1899a,b,c), who did extensive

carcinological work on Indian materials, used the name *Scylla serrata* for the specimens collected from the brackishwater areas of India.

Until Estampador (1949 a, b) divided the mud crabs into three species and a variety, it was generally agreed by most carcinologists that there existed only a single species under this genus, which was referred to in different names. Based on the distinction made by the Philippine fishermen on the basis of colour markings Estampador (1949 a) classified the crabs of *Scylla* into two groups: 'Banhawin' and 'Mamosain'. The first group consisted of crabs with green colour and polygonal markings on all legs and chelipeds, while the second group with dark brown colour and without any markings on legs and chelipeds. 'Banhawin' crabs were free swimming, while 'Mamosain' inhabited holes. He, (Estampador, 1949 a) distinguished three distinct species namely *Scylla serrata, S. oceanica* and *S. tranquebarica* and one variety *S. serrata* var. *Paramamosain* based on the colour of carapace, polygonal markings, 'H' mark on carapace, nature of frontal teeth, length of cheliped in relation to length of carapace and the habitat of the animals. *S. oceanica* and *S. tranquebarica* belonged to 'Banhawin' group as they were free swimming. *S. serrata* was assigned to the 'Mamosain' group as they lived in burrows in mangrove areas, and the variety *S. serrata* var. *Paramamosain* was created by the same author for the variation he noted among specimens of *Scylla serrata* in the arrangement of frontal lobes, nature of spines at the base of fingers and colouration. Estampador (1949 b) supported this classification by variations noticed in the spermatogenesis and ookinesis and also based on form and physical condition of chromosomes. Though Screne (1952) also adopted the above nomenclature for mud crabs of Vietnamese waters, Stephenson and Campbell (1960), working on the systematics of Australian portunid crabs, could not agree with this classification and suggested more taxonomic work on the group.

Recent studies conducted from Indian waters (Joel & Raj, 1980, 83,; Kathirvel,

1981; Radhakrishnan & Samuel, 1982; Kathirvel & Srinivasagam, 1992b) have established the existence of more than one species of mud crabs, which are conventionally referred to as *S. serrata* in most part of the Indian coast.

Joel and Raj (1980, 83) made the first critical study on the taxonomy of mud crabs in India based on the material collected from Pulicat lake, Kovalam backwaters, Pondicherry and Tuticorin bay on the south east coast of India. Examination of several specimens of males and females of *Scylla* has enabled these authors to differentiate two distinct "forms" which they assigned to the species *S. tranquebarica* (Fabricius) and *S. serrata* (Forskal) conforming more to the description of Estampador (1949 a) for the two species respectively. Subsequently Kathirvel (1981) came across one larger and one smaller species of *Scylla* in Cochin backwaters, which showed variations in colour, frontal teeth, carpal spines, maximum sizes attained and the sizes at first maturity of females. He, however, could not establish them as two valid species for want of distinct morphological differences and hence referred commonly as *S. serrata.* Later Radhakrishnan and Samuel (1982) reported *S. serrata* from the Cochin backwater and described a subspecies *S. serrata serrata.*

Comparing the salient observations of Kathirvel (1981), Radhakrishnan and Samuel (1982) and Joel and Raj (1980,1983), Kathirvel and Srinivasagam (1992) opined that what Radhakrishnan and Samuel (1982) reported as *S serrata* could be *S. tranquebarica* and the subspecies *S. serrata serrata* could be *S. serrata.* Later, discussing the taxonomic status of mud crabs in the Indo-Pacific region, Kathirvel and Srinivasagam (1992) concluded that there were atleast two distinct species under genus *Scylla,* namely, *S. serrata* (Forskal) and *S. tranquebarica* (Fabricius) characterised by differences in size, spines on the outer border of the carpus of cheliped and habitat preferences. They also believed that *S. oceanica* could be a synonym of *S. tranquebarica* on the contention that the colour variations between

species noted by the different workers could be due to geographic variations.

Examination of several specimens from different brackishwater systems of Kerala as well as from the south east Coast of India during the course of the present investigation has made it possible to establish that the mud crabs of *Scylla* occurring in this region comprise undoubtedly of two distinct species which are referable to *S. serrata* (Forskal) and *S. oceanica* (Dana). *S. serrata* is the smaller

Table 1: Important distinguishing characters of *S. serrata* and *S. oceanica* from the Kerala and Tamil Nadu coast.

Scylla serrata (Forskal)	*Scylla oceanica* (Dana)
Carapace strongly convex, almost smooth.	Carapace moderately convex not very smooth.
'H' shaped groove on carapace shallow	'H' shaped groove deep
Front teeth blunt	Front teeth sharp
Outer angle of carpus of cheliped with a single small spine.	Outer angle of carpus of cheliped with two sharp spines
Outer border of basal lobe of of 1st male pleopod markedly rounded, tip brownish in fresh condition.	Outer border of basal lobe of 1st male pleopod less rounded, tip whitish in fresh condition.
Colour of carapace ferrugenous brown, sometimes with a dark greenish tinge.	Colour of carapace grayish green with whitish gray spots.
Ventral side of anterolateral margin of carapace bluish in colour.	Ventral side of anterolateral margin of carapace whitish in colour.
No polygonal pigmented markings on body except for few faint markings on last 2 segments of swimming legs.	Clear polygonal pigmented markings present on all walking legs in both sexes and on abdomen of mature females.
Colour of abdomen changes from whitish to bluish or violet during maturation of ovary.	No change in colour pattern of abdomen of female after attainment of maturity.

species burrowing in habit and the other the larger one *S. oceanica* which is more free moving in habit. The important distinguishing features of these two species as observed during the present study are summarised in Table 1.

The descriptions given by earlier workers for species of *Scylla* are rather confusing for fixing them on any particular species with a good measure of certainty. After the first record of *P. tranquebaricus* by Fabricius (1798) from Tranquebar (Tamil Nadu coast) Alcock (1899) made for the first time a proper taxonomic observation on mud crabs obtained from different regions of the Indian coast. He noted "one or sometimes two" spines on the outer angle of wrist (carpus), and chelipeds measuring "not quite twice the length of carapace in adult male" on the specimens at his disposal. Though he considered *Scylla tranquebarica* (Dana) as a synonym of *S. serrata* (Forskal) the above character relating to chelipeds is one of the distinguishing features of *S. oceanica* as per Estampador's (1949 a) classification. Joel and Raj (1980, 1983) concluded in their taxonomic remarks that the genus *Scylla* was represented by two species *viz S. serrata* and *S. tranquebarica* in Pulicat Lake and neighbouring areas of the south east coast of India. These authors have indicated most of the morphological distinguishing characters shared by both *S. tranquebarica* and *S. oceanica* as per the classification of Estampador (1949 a), for their species *S. tranquebarica* as diagnostic features in comparison with *S serrata*. While doing so they also remarked on the reticulation or markings on the body as present only on the abdomen of mature females but absent on carapace, walking legs and chelate legs of the specimens ` they designated as *S. tranquebarica*. A close scrutiny of their photographs (Joel & Raj, 1980, Fig. 3; Joel & Raj, 1983; Fig. 3 A) would clearly show that the reticulate markings are present on the chelate legs, which is a characteristic feature of *S. oceanica* (Estampador, 1949 a). Quite recently Fuseya and Watanabe (1996) established three distinct species for the genus *Scylla*, namely, *S. serrata, S. tranquebarica* and *S. oceanica* on the basis of electro-

phoretic studies. The gene replacement found at 3 of the 17 loci of 11 enzymes studied and the relatively large genetic distance between the species provided strong evidence that these three species are distinctly different agreeing with Estampador's classification. The genetic analysis of these authors showed that *S. serrata* and *S. tranquebarica* are genetically more closely related than *S. oceanica*. The mean heterozygosity of each species was 0.049 for *S. serrata*, 0.014 for *S. tranquebarica* and 0.004 for *S. oceanica*.

The present analysis of various taxonomic characters of the material on hand has enabled to segregate the species with high degree of confidence as *S. serrata* (Forskal) and *S. oceanica* (Dana) Table 2 summarises the important distinguishing characters between *S. oceanica* and *S. tranquebarica* as per the present observations and those characters considered to be of taxonomic value for the

Table 2: Comparison of important taxonomic features between *S. oceanica* and *S. tranquebarica*

Taxonomic features	Present observations *S. oceanica*	Observations of Estampador (1949 a)[1] and Fuseya and Watanabe (1996)[2]	
		S. oceanica	*S. tranquebarica*
Colour of carapace	Grayish green	Grayish/grayish green[1]	Olive green/ purplish brown[1]
Polygonal pigmented markings	Present on all walking legs including chelipeds in both sexes and on abdomen of adult female	Present on all walking legs including chelipeds and on abdomen in female[1] and a few markings	Distinct only on the last pair of legs on female abdomen
Length of cheliped in adult male	Not more than twice the length of carapace	Not more than twice the length of carapace[1]	More than twice the length of carapace[1]
Max. size observered	209 mm CW	220 mm[1]	Not mentioned[1]
Mean heterozygosity in electrophoretic studies		0.004 [2]	0.014 [2]
Habit	'free living'	Prefers 'nomadic' life[1]	Not mentioned

purpose by the other workers.

The technique of separation and structural studies of proteins in solving taxonomic uncertainties was used by many workers (Alston & Turner, 1963; Manwell & Ann-Baker, 1963; Herzberg & Pasteur, 1975). It is a well established fact that genetic information coded into molecules of deoxyribonucleic acid (DNA) are translated through a series of reactions into the structure of proteins (Perutz, 1962; Yanofsky *et al.*, 1963). Therefore it is considered to be the simplest and dependable method to test the true identiy of species.

Analysis of zymograms of the two types of mud crabs collected during this investigation revealed that there exist distinguishable biochemical differences between them in their muscle myogen electrophoretic profile (Pl. 8, 9, 10 & 11). Screening of large number of samples of both the types of crabs belonging to different age groups, maturity, moult stage and colour pattern has revealed that they belong to two different groups. In zone E, the variations observed could not be genetically interpreted. In zones like A, B and D there existed two to three protein loci commonly shared by both the species. This would indicate that both the types of crabs might have evolved from a common ancestor.

A clear difference between the two species was observed in the zone C. It was observed that an intensely stained protein band with considerable length reflecting high content of it in the animal myogen with different electrophoretic mobility in all the individuals studied. In the case of *S. serrata* this zone was represented by a high molecular weight slow moving band which was absent in *S. oceanica*, instead a low molecular weight fast moving band was observed. This was the most striking difference observed in the protein profile. This type of difference in the expression of protein banding suggests a difference in the genomic constitution of the two species of crabs. Another interesting assumption which can be made out from this observation is that these proteins may have significant

biological role in the body of these animals since they are present in high concentration in all the animals examined. In the zone E the muscle myogen pattern obtained in the individual samples has shown an irregular banding patterns. This zone cannot be considered as species specific or genetically defined polymorphic zone. Hence it may be a physiologically or environmentally influenced protein band.

Another species specific difference was observed in zone F of the electrophorogram. This zone was represented by a low molecular weight fast moving band in *S. serrata* and a high molecular weight slow moving band in *S. oceanica*. Therefore zone C and F shows clear difference in the protein profile of the mud crabs lying in conflict regarding their identity. In addition to the differences in the morphological and biological features, the electrophoretic pattern of muscle myogen (Pl.8, 9, 10, & 11) traced out during the present study gives added evidence suggesting that *S. serrata* and *S. oceanica* are distinctly different as also established by Fuseya and Watanabe (1996).

SECTION 2

BIONOMICS AND LIFE HISTORY

A knowledge of the behavior and biological aspects of an animal is of prime importance for its judicious exploitation, management and conservation. The biology embodies various life processes such as reproduction, food and feeding, growth, larval development and migration. Though some information on these aspects are available for the mud crabs in general no specific studies have been carried out on individual species after establishing their correct identity. During the present study an attempt has been made to elucidate the biological characters of the two species *S. oceanica* and *S. serrata* which coexist in the same environment.

REPRODUCTION

The reproductive biology of brachyuran crabs has been extensively studied from different parts of the world (Arriola, 1940; Spalding, 1942; Cronin, 1947; Estampador, 1949 b; George, 1963; Ryan, 1967 a,b; Knudsen, 1960; Hartnoll, 1968; Hinsch & Walker, 1974; Haefner, 1977; Johnson, 1980; Diesel, 1989,1990). The brachyurans possess sperm storage organs that can be categorized into two types on the basis of their morphology, position in relation to ovary and their functioning during spawning. They are (1) the thelycum of the Podotremata and (2) seminal receptacle of Eubrachyura (Diesel, 1989,1990). The thelyca are paired or unpaired sternal invaginations, without any connection to ovary, that open on the coxa of third pereiopod (Gordon, 1963). The seminal receptacles of Eubrachyurans to which the genus *Scylla* belongs, are enlargements of paired female genital ducts (Ryan, 1967 b; Hartnoll, 1968; Johnson, 1980; Hinsch, 1988 b, Adiyodi & Anilkumar, 1988; Beninger *et al.*, 1988; Diesel, 1989).

Sexuality

Brachyuran crabs are dioecious and the sexes could be distinguished by a number of external and internal characters. In *S. serrata* and *S. oceanica* males grow to a larger size and their chelate legs are massive compared to the females of

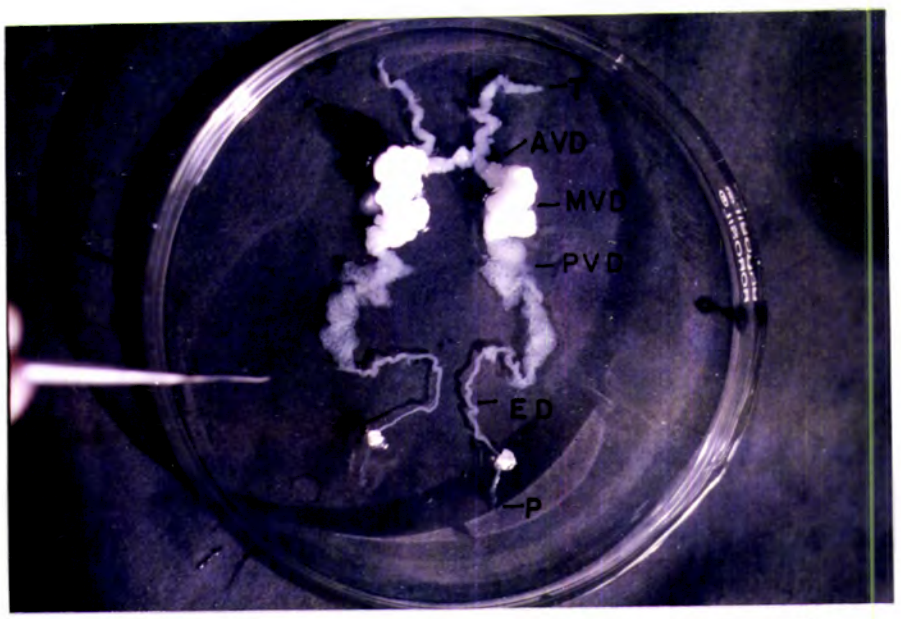
the same size. Male crabs are characterized by the inverted 'T' shaped abdomen (Pl. 2 & 6), while in female it is broadly triangular in immature crabs but turns to semicircular in adult crabs. In *S. oceanica* females, the colour of the abdomen is whitish in juvenile, but permanent polygonal pigmented markings develop as the animal matures (Pl.4) . In *S. serrata* females on the other hand, the colour of the abdomen is whitish but turns bluish or violet (sometimes with white bands) as the ovary develops. This colour may revert back after the incubation period is over (Pl.7, 2). In males the pleopods are modified as copulatory organs on the first and second abdominal somites. In the case of females, the first four abdominal somites carry pleopods which are biramous and possessing setae for attachment of eggs for brooding.

Structure of male reproductive system

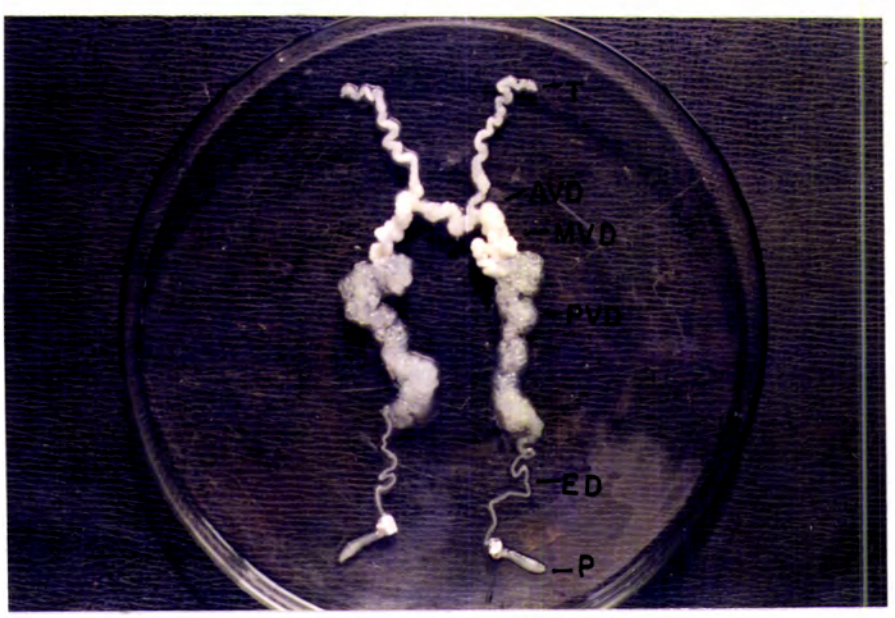
The reproductive system of male crab is bilateral and roughly in the form of English alphabet 'H' in both the species (Pl. 12 & 13). It consists of paired testes, vas deferens, ejaculatory ducts and external penes. The first and second abdominal appendages are highly modified to function as copulatory organs.

Testes: Mature testis has the appearance of a moderately thick convoluted tube. Its position is beneath the hypodermis of carapace and just above the hepatopancreas. The organ is opaque with irregular surface and a short commissure joining the testes of both the sides a little ahead of the middle of carapace. In immature males, the testes are translucent, small and difficult to make out on dissection.

Vas deferens: The vasa deferentia may occupy a large part of the central body cavity and it has three distinct regions, the anterior vas deferens (AVD) the median vas deferens (MVD) and the posterior vas deferens (PVD) (Pl.12). The AVD consists of narrow tightly coiled tubes, which are opaque and whitish in colour, situated dorsally on either side of the median line of carapace between stomach and pericardium. It rests on the massive median vas deferens. These coils are so fused that they cannot be separated or straightened by dissection. The coils in-



a



b

PLATE 12

a. Male reproductive system of *S. serrata*

b. Male reproductive system of *S. oceanica*

T - Testis AVD - Anterior vas deferens
MVD - Median vas deferens PVD - Posterior vas deferens
ED - Ejaculatory duct P - Penis

crease in thickness posteroventrally and lead into the median vas deferens. The MVD is the most massive part of the system. This consists of bigger coils which are fused to each other and hence difficult to separate into individual tubes. Both the AVD and MVD are filled with a white viscous fluid. The MVD leads to a thin walled transparent posterior vas deferens (PVD). It is a long convoluted tube of lesser diameter than MVD but with a higher diameter than that of the AVD and filled with a clear fluid. Posterior vas deferens is massive anteriorly and in the posterior region it slowly narrows to form the ejaculatory duct. Ejaculatory duct is a relatively straight, narrow, smooth and transparent tube. This tube passes through the musculature of the fifth walking leg and opens at the base of the coxal segment through the penis.

Penis: The penis arises from the ventro-median border of the coxopodite of the fifth periopod. It is a slender weak transparent tube with an opaque gonoduct at the centre. It is 1 to 2.2 mm in diameter and 10 to 15 mm in length. Penis lies between the ventral surface of thorax and the under turned abdomen and found inserted in the proximal foramen of first pleopod.

Pleopods 1 and 2 (Pl. 3): The highly specialized first pleopod of male is the functional intromittent organ. It has two joints, the basal one is broad and flattened on its inner surface, while the terminal segment is long and tapering and has a sinuous out line. The first pleopod or gonopod is a deeply grooved structure in which the edges of the grooves are fused to form a tube. On the inner surface of the base of the terminal joint is the trough like excavated area which receives the spermatophores and seminal fluid from the penis and the groove acts as a tube during the copulation to transfer these materials into the seminal receptacles through the oviduct of the female.

The second abdominal appendage is unsegmented and is also highly modified. This forked rod like appendage presumably helps by keeping the spermatophores confined in the funnel tube in forcing the seminal products into the vulva

of female (Estampador, 1949b).

Histology

The cross section of the testes of both the species of crabs indicates a very similar histological pattern (Pl. 13 a & b). Each testis consists of unequal lobes which are formed by numerous convoluted seminiferous tubules of varying sizes encompassed in a double layered testicular wall. The outer layer is a delicate membrane while the inner one is of fibrillar connective tissue. Each section contained several profiles of testicular lobules and each lobule was covered by a thin connective tissue around most of its periphery. Usually constituents of the lobules showed confluence with the constituents of the adjacent lobules at certain points. It was found that all these spermatogenic lobules were connected to seminiferous ducts either directly or through neighbouring lobules. Each of these individual lobules has two distinct zones, a germinal zone with germ cells in the early stages of spermatogenesis and the inner lumen packed with developing germ cells (Pl. 13c & d). Different tubules of same section may contain germ cells in different stages of development. However, most of the developing germ cells in the inner lumen of the specific lobule were more or less in the same stage of development.

In lobules containing germ cells in the early stages of spermatogenesis, these cells completely fill the lobules, whereas those tubules containing germ cells in advanced stages of development exhibit an accentric lumen. The serial sections of the entire testes showed more or less uniform pattern of distribution of lobules with some striking modifications at the terminal part. In this area, wall of the lobule was found modified to a cuboidal or low columnar epithelium instead of thin connective tissue layer separating the lobules in other parts (Pl. 13 c & d). This type of modification was observed in both the species.

A cross section of the proximal part of AVD is shown in the plate 13 e & f. As can be seen in the Plate, the different portions of the AVD, which have come in the plane of section, are represented by many closed circles, each enclosing a num-

PLATE 13

Photomicrographs of testis and proximal part of AVD of mud crab species

a. Transverse section of testis showing seminiferous lobules (SL) in *S. serrata* (200 x)

b. Transverse section of testis showing seminiferous lobules (SL) and seminiferous duct (SD) in *S. oceanica* (200 x)

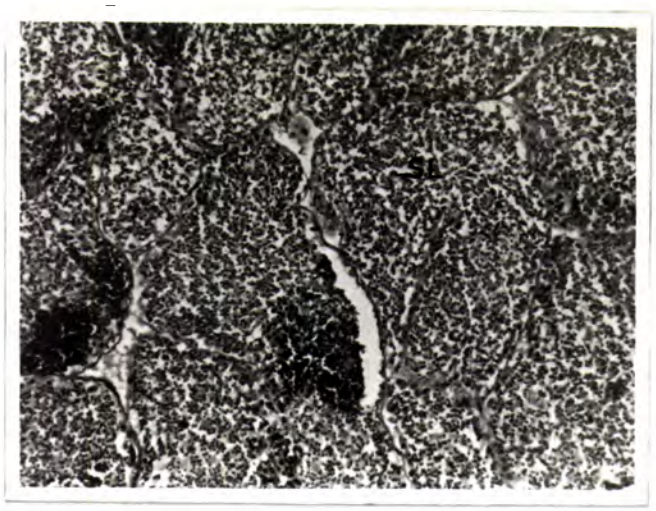
c. Proximal part of testis showing lobules surrounded with columnar epithelial cells in *S. serrata* (200 x)

d. Proximal part of testis showing lobules surrounded with columnar epithelial cells in *S. oceanica* (200 x)

GZ - germinal zone

e. Anterior vas deferens proximal region showing cuboid epithelial cells (EC) and sperm mass (SM) in *S. serrata* (50 x)

f. Anterior vas deferens proximal region showing cuboid epithelial cells (EC) and sperm mass (SM) in *S. oceanica* (50 x)



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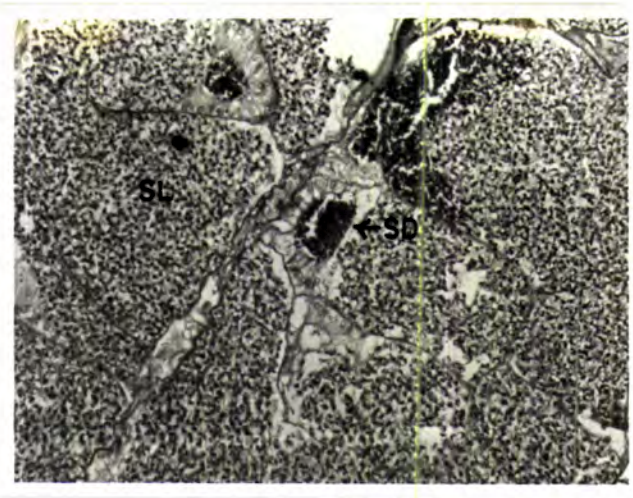

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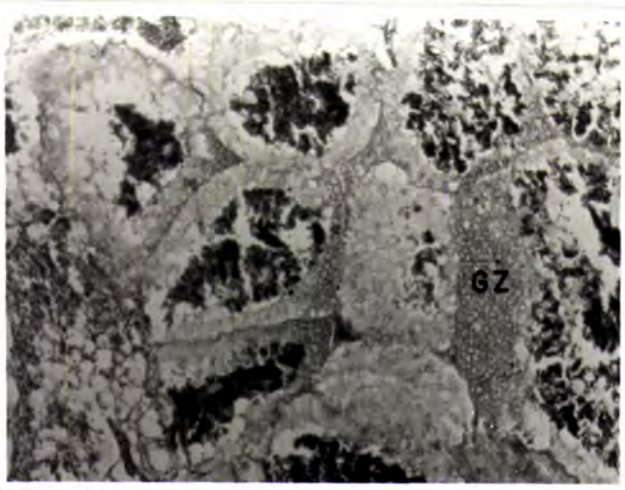

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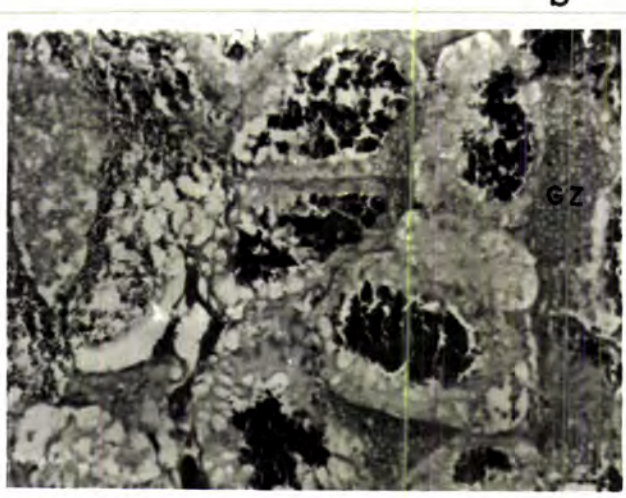

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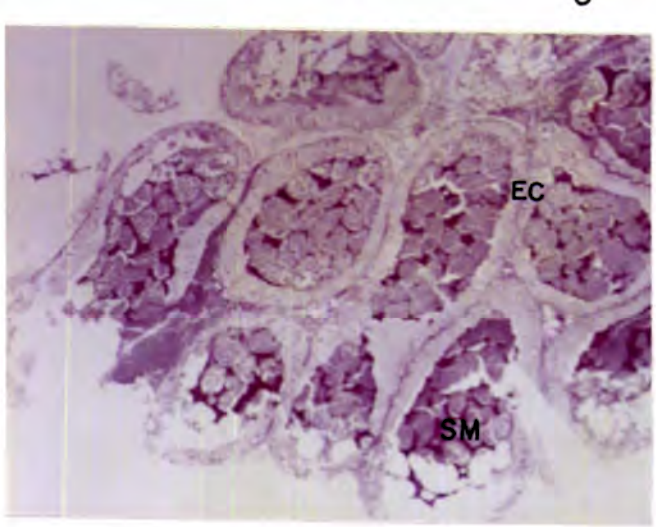

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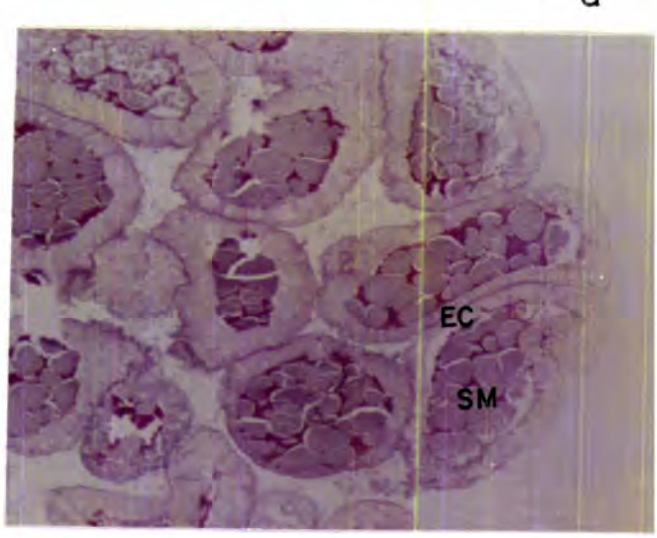


f

PLATE 13

ber of sperm packets or sperm mass. The lumen is filled with a viscous fluid. At the proximal part of AVD, the wall is lined with cuboidal epithelium surrounded by thin strata of muscle connective tissue and an outer connective tissue covering. The distal portion of the wall of AVD is lined with tall columnar epithelial cells showing foliation towards the lumen (Plate 14 a & b) which is secretory in nature. The sperm mass is more condensed in this part of AVD.

The cross section of MVD reveals that the wall is formed of thin epithelial and muscular layers surrounded by the connective tissue layer. Epithelial cells show no secretory activity. The lumen is filled with a granular substance in which the fully formed non-pedunculate spermatophores are found embedded (Pl.14 c-f). Spermatophores are spherical or elliptical in shape and their sizes ranged from 28 μ to 93μ in *S. serrata* and from 33μ to 116μ in *S.oceanica*. The double layer of spermatophore is clearly visible in plate 14 f.

The epithelial cell layer of DVD is formed of cuboidal epithelial cells (Pl.15 a & b). The lumen of the DVD is devoid of any spermatophores, but filled with an eosinophilic gelatinous substance. The terminal portion of ejaculatory duct which is circular in cross section and is made up of columnar epithelial cells surrounded by thick muscular layers.(Pl. 15 c & d).

No significant difference in the morphology and histology of male reproductive system is noticed among the two species of mud crabs except for the fact that the spermatophores are slightly larger in size in *S. oceanica* than in *S. serrata.*

After the formation of spermatozoa in the seminiferous tubule they get accumulated and transferred to the anterior vas deferens in which the sperm mass are made into spherical or ovoid bodies, the spermatophores (Pl. 13, b, c; 18 c, d). The grouping of spermatozoa into discrete clumps or sperm masses is observed in the proximal part of the AVD (Pl. 13 e, f) and they become more condensed in the distal part of the AVD. The epithelium of the latter consists of tall columnar cells (Pl. 14 a, b) which are secretory for the formation of spermatophoric

PLATE 14

Traansverse section of distal part of AVD, middle portion of MVD and spermatophores of mud crab species

a. Distal part of AVD showing columnar epithelial cells (EC) and more condensed sperm mass (SM) in *S. serrata* (100 x)

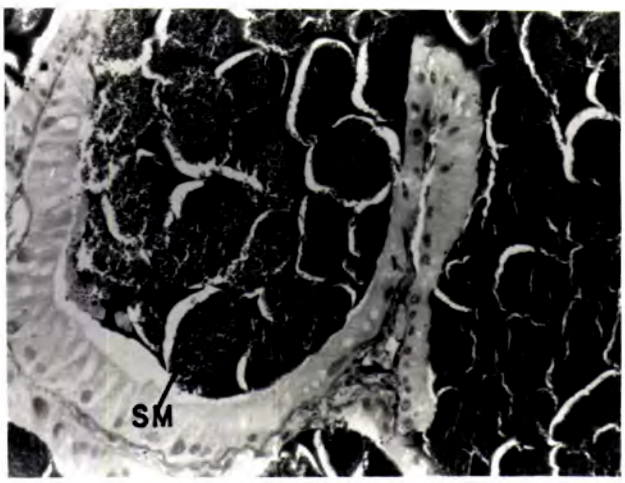
b. Distal part of AVD showing columnar epithelial cells (EC) and more condensed sperm mass (SM) in *S. oceanica* (200 x)

c. Middle vas deferens showing spermatophores (SPH) and surrounding granular substance in *S. serrata* (100 x)

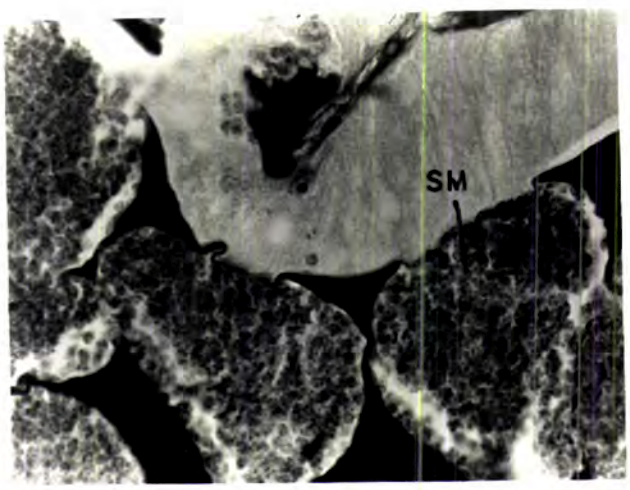
d. Middle vas deferens showing spermatophores (SPH) and surrounding granular substance in *S. oceanica* (100 x)

e. Spermatophore (SPH) of *S. serrata* (400 x)

f. Semi-thin section of spermatophore (SPH) of *S. oceanica* (400x)



a



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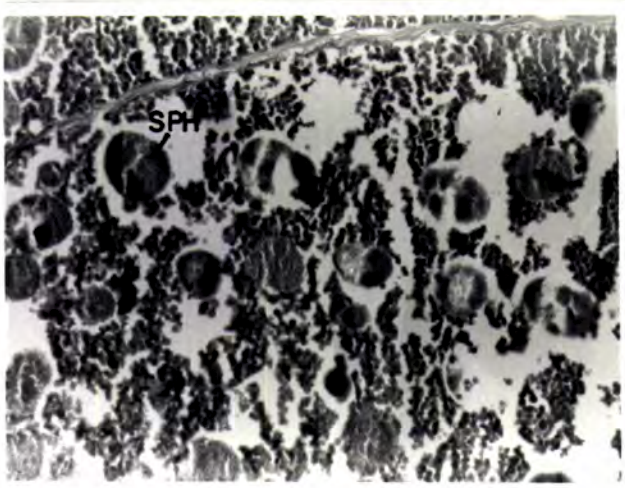

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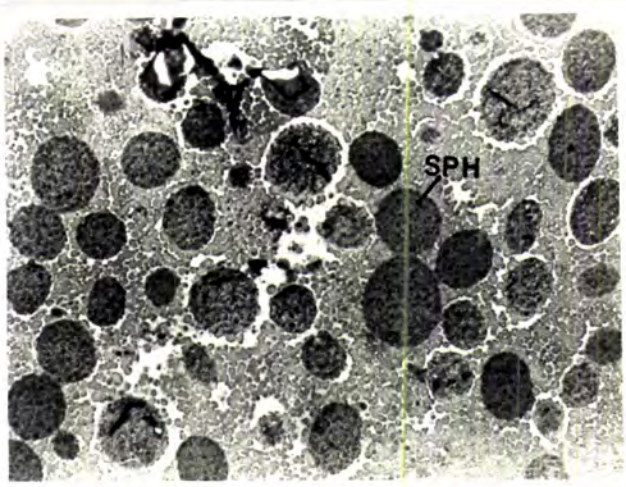

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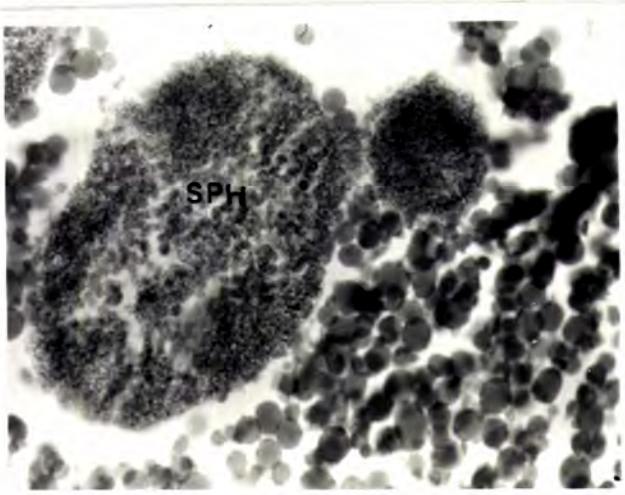

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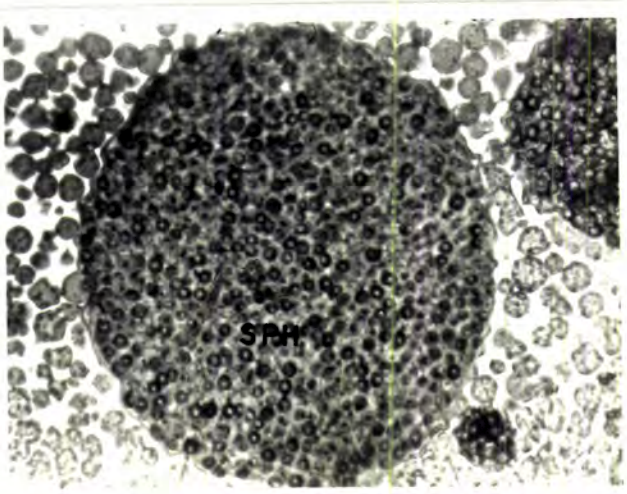

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PLATE 14

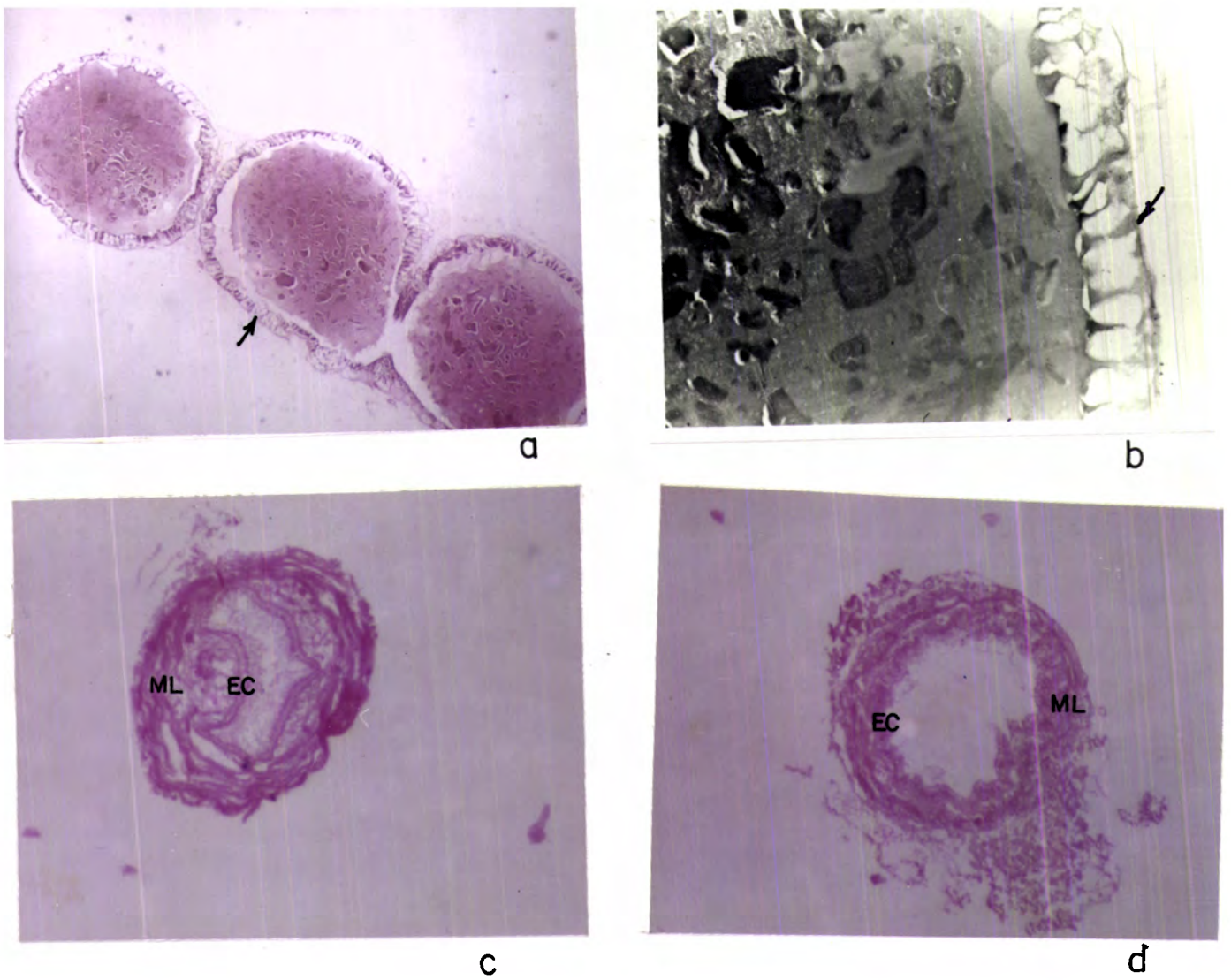


PLATE 15

Transverse section of DVD and distal part of ejaculatory duct of mud crab species.

a. Distal vas deferens with cuboidal epithelial cells and eosinophilic granular fluid filling the lumen in *S. serrata*. (50 x)

b. Distal vas deferens with cuboidal epithelial cells and eosinophilic granular fluid filling the lumen in *S. oceanica* (100 x)

c. Distal part of ejaculatory duct showing columnar epithelial cells (EC) and muscle layer (ML) in *S. serrata* (50 x)

d. Distal part of ejaculatory duct showing columnar epithelial cells (EC) and muscle layer (ML) in *S. oceanica* (50 x)

walls. Fully formed spermatophores with double wall are seen embedded in the granular matrix of the median vas deferens (Pl.14 c, d, e & f).

Spermatogenesis

Spermatogenesis and sperm differentiation have been studied in both the species of crabs and it was found to be a continuous process taking place in each of the testicular lobes. Even though the division of spermatogenesis into discrete stages is some what arbitrary, different transitional stages during this process have been critically investigated in both the species in order to check whether there is any noticeable difference in the development of male gametes.

Spermatogenesis begins with the multiplication and differentiation of sperm mother cells or primary spermatogonial cells. The primary spermatogonial cell is characterized by a thin rim of cytoplasm around a vesicular nucleus containing peripheral chromatin granules (Pl.16 a, b). This is the largest cell encountered during the process of spermatogenesis and its size diminishes in the successive divisions and transformation. Most of the primary spermatogonial cells later on divide mitotically giving rise to secondary spermatogonial cells (Pl.16 c, d). The secondary spermatogonial cells are smaller and are characterized by the homogenous distribution of chromatin granules in the nucleus. The undifferentiated cells are the resting spermatogonia, which may give rise to the subsequent generation of sperms. Further mitotic division of the secondary spermatogonial cells results in the formation of large number of primary spermatocytes which are still smaller than the preceding cells (Pl.17 a, b). It is interesting to note that, just before the division, scattered chromatin granules get arranged centrally as a thick linear strand. Various phases of mitotic division are discernible in these dividing spermatogonial cells (Pl.16 e, f).

The primary spermatocyte has a prominent dark nucleus with basophilic chromatin materials in the nucleoplasm (Pl. 17 a, b). The primary spermatocytes undergo reduction division to form secondary spermatocytes, which are nearly

PLATE 16

Transverse section of testis of mud crab species
a. Part of lobule showing primary spermatogonia (PSG) in *S. serrata* (400 x)

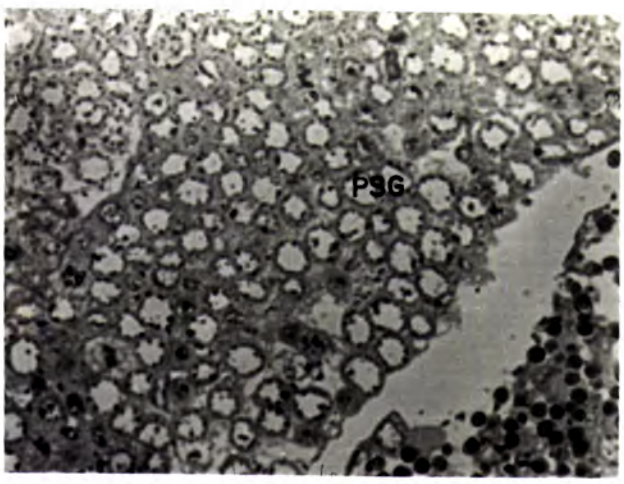
b. Part of lobule showing primary spermatogonia (PSG) in *S. oceanica* (400 x)

c. Part of lobule showing secondary spermatogonia (SSG) in *S. serrata* (400 x)

d. Part of lobule showing secondary spermatogonia (SSG) in *S. oceanica* (400 x)

e. Part of lobule showing linearly arranged centrally located chromatin material during the division of secondary spermatogonia in *S. serrata* (400 x)

f. Part of lobule showing linearly arranged centrally located chromatin material during the division of secondary spermatogonia in *S. oceanica* (400 x)



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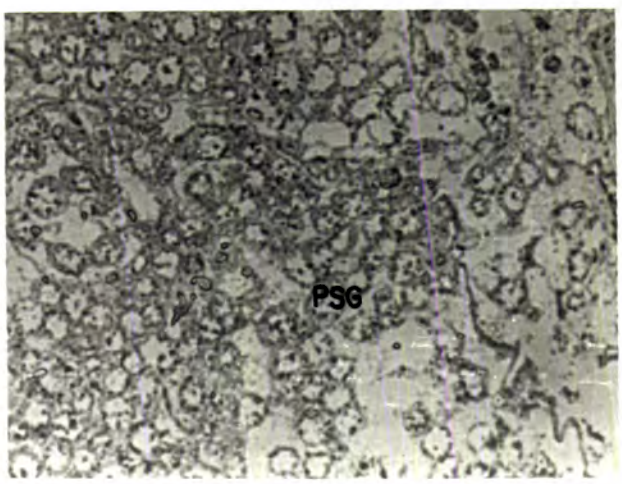

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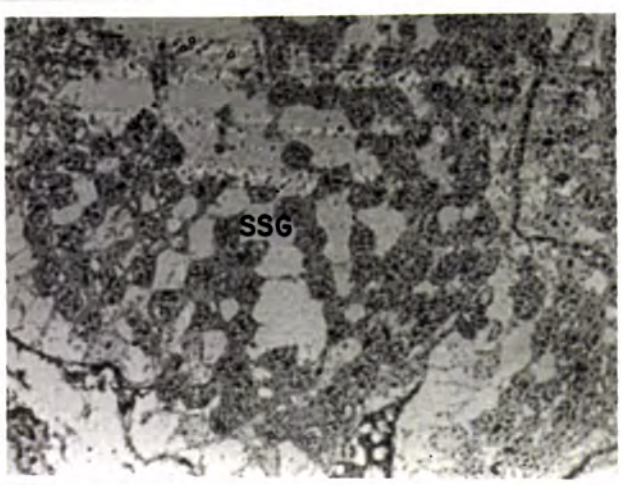

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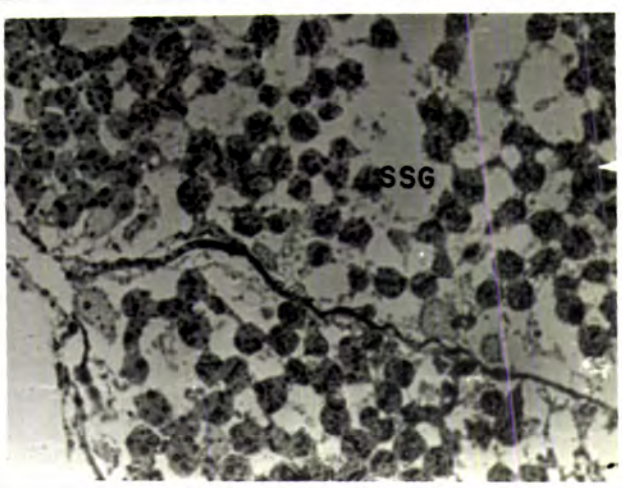

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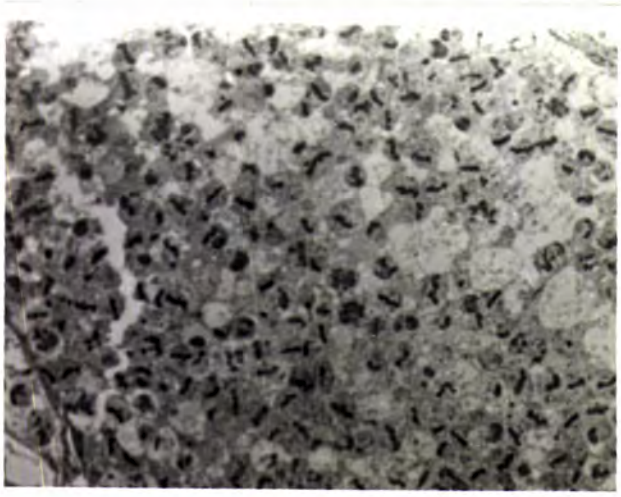

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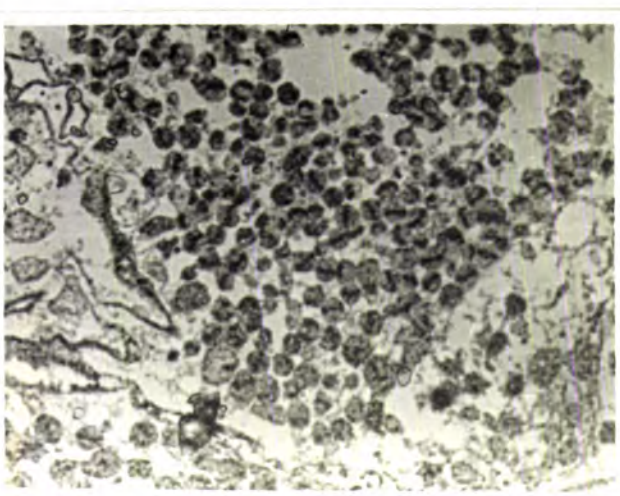


f

PLATE 16

PLATE 17

Transverse section of testis of mud crab species

a. Part of lobule showing primary spermatocytes (PSC) in *S. serrata* (400 x)

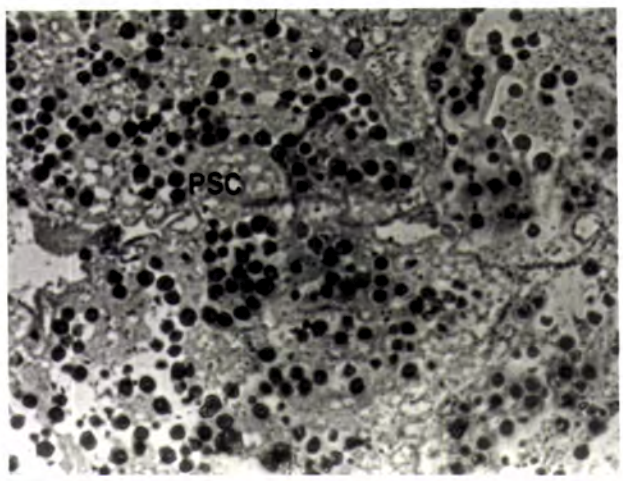
b. Part of lobule showing primary spermatocytes (PSC) in *S. oceanica* (400 x)

c. Part of lobule showing secondary spermatocytes (SSC) in *S. serrata* (400 x)

d. Part of lobule showing secondary spermatocytes (SSC) in *S. oceanica* (400 x)
RSG - Resting spermatogonia

e. Part of lobule showing spermatids (ST) in *S. serrata* (400 x)

f. Part of lobule showing spermatids (ST) in *S. cceanica* (400 x)



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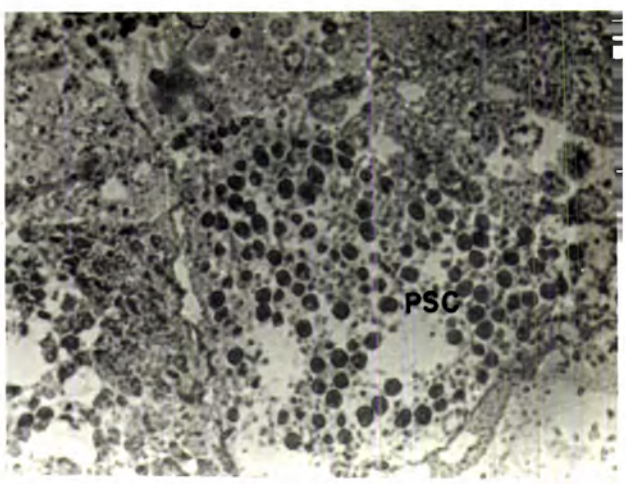

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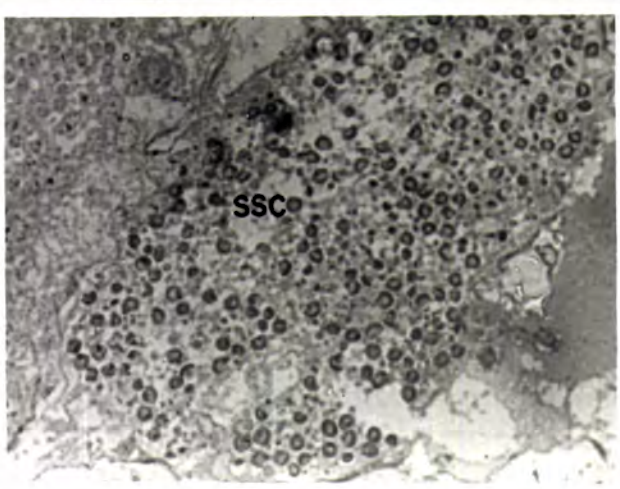

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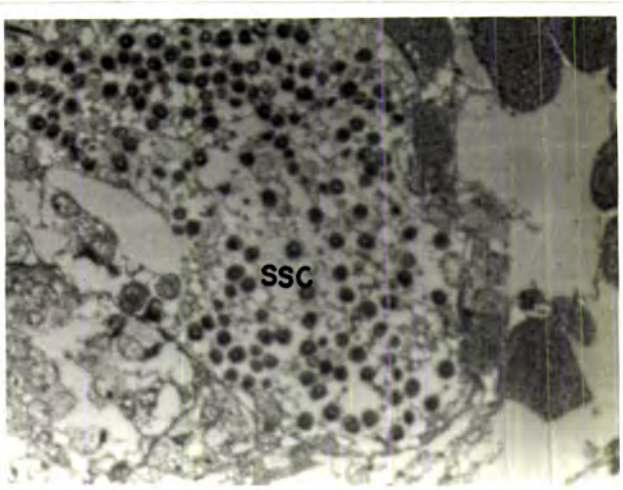

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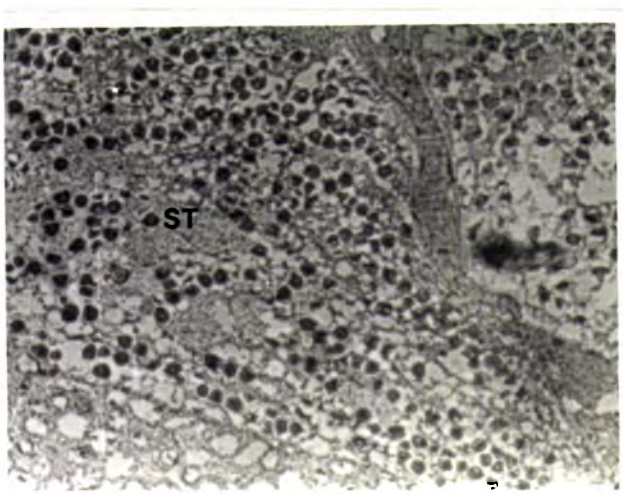

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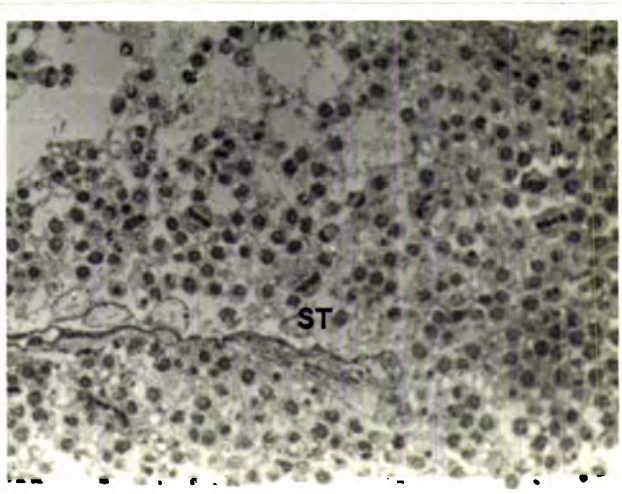

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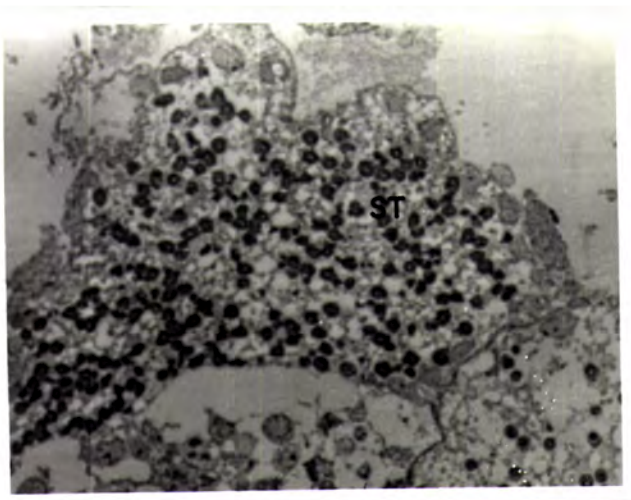
PLATE 17



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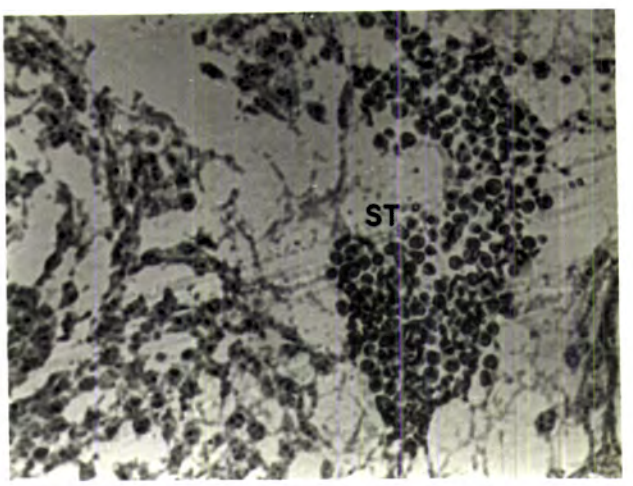

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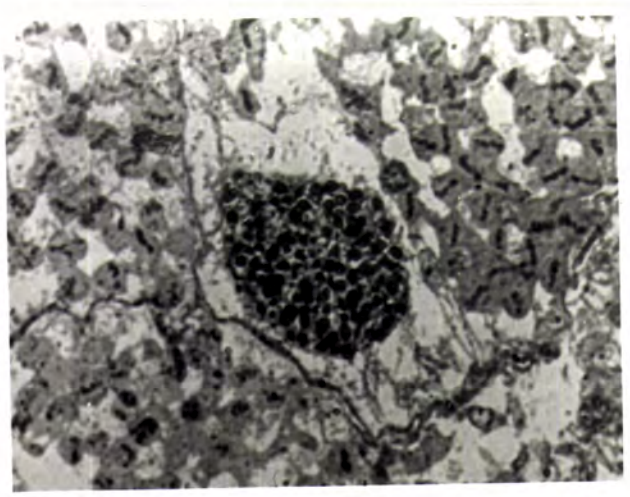

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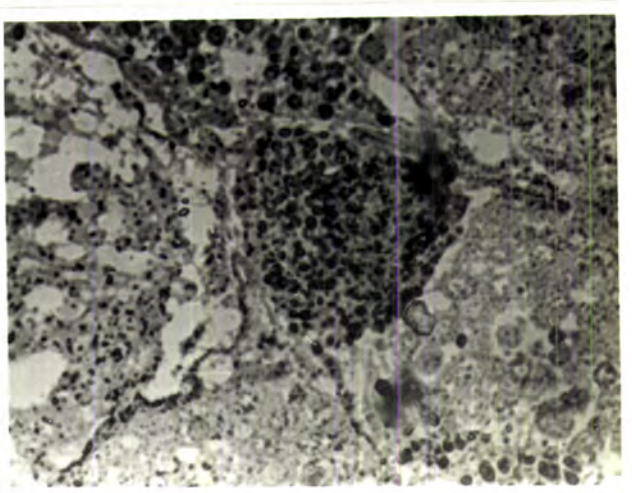

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PLATE 18

Transverse section of testis of mud crab species

a. Condensation of spermatids (ST) in testicular lobule of *S. serrata* (400 x)

b. Condensation of spermatids (ST) in testicular lobule of *S. oceanica* (400 x)

c. Fully formed spermatozoa inside testicular lobule in *S. serrata* (400 x)

d. Fully formed spermatozoa inside testicular lobule in *S. oceanica* (400 x)

half the size of primary spermatocytes (Pl. 17 c, d). The meiotic division occurs synchronously in all the primary spermatocytes of a lobule. This stage is of short duration as cells of all stages of prophase to cytokinesis are found in the same tubule. These secondary spermatocytes divide again meiotically and give rise to spermatids (Pl.17 e, f). The spermatids are smaller than spermatocytes. The round spermatid possesses a deeply staining prominent nucleus and a thin rim of eosinophilic cytoplasm. The spermatids undergo further condensation and transformation to spermatozoa without undergoing any division (Pl 18 a & b).

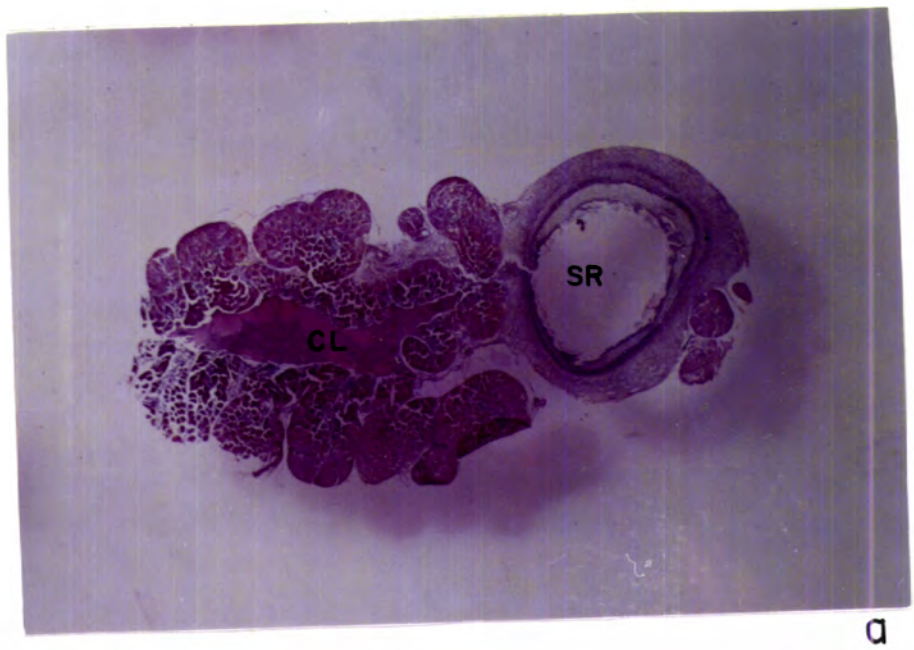
Structure of female reproductive system

The ovaries are paired and occupy the same position as that of testes in male, except that the anterior lobes extent up to the last anterolateral tooth of carapace. They are connected behind the pyloric foregut with a commissure in the shape of the letter "H" (Pl. 23-26). Unlike testes, the ovary extends further posteriorly and the posterior extension lies in a position similar to the vas deferens of the male reproductive system. In most cases these lobes are unequal in size with the left or right lobe longer than the other. In some cases one of the lobes may be further divided into two lobes and in others these lobes are fused to give a ring-like appearance.

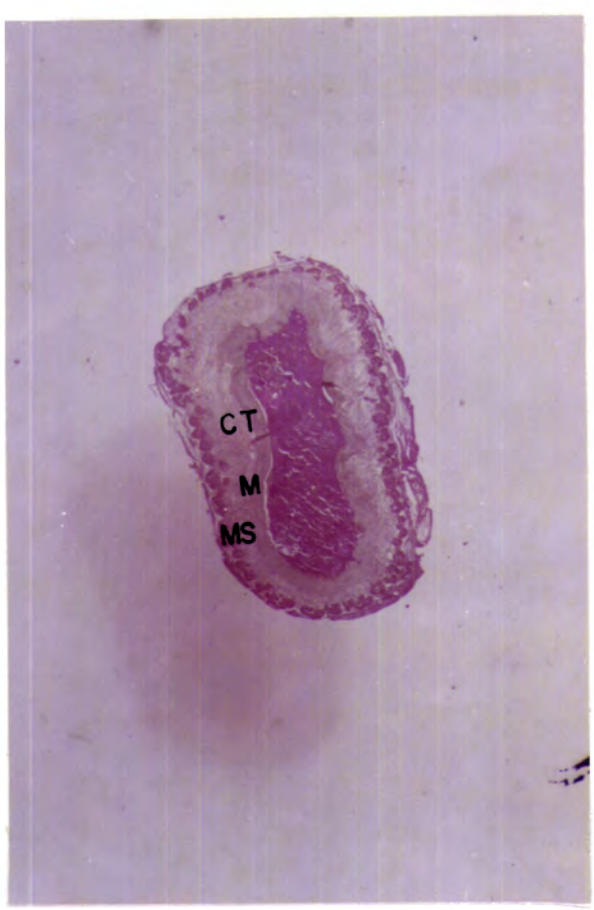
Ovary opens to the exterior on sternite of sixth thoracic segment through seminal receptacle and a small oviduct. The seminal receptacle or spermatheca arises from the midlateral border of the posterior lobe, and is actually an enlarged portion of the oviduct. The duct and lower portion of the receptacle are lined with soft chitin. Spermatheca acts as a storage organ for the seminal products after the copulation. The ovary also showed a similar structure in both the species.

Histology

The histological details are more or less similar in both the species. Structural details are almost similar for the entire length of the ovary including the commissure in each stages of gonadal maturation. The ovary is covered by a double



a



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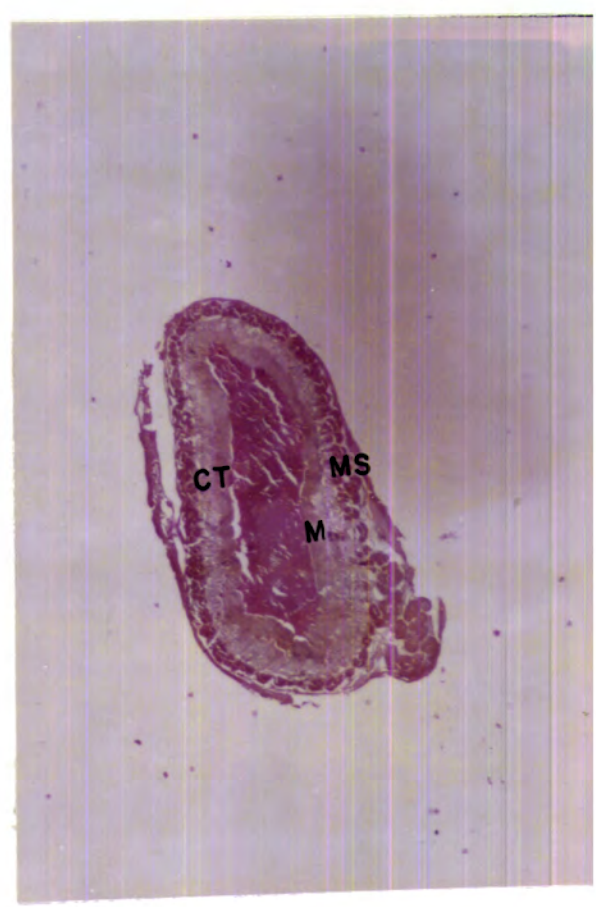


c

PLATE 19

a. Cross section of ovary of *S. oceanica* showing seminal receptacle (SR) and central lumen (CL) of ovary

b. Cross section of oviduct of *S. serrata*

c. Cross section of oviduct of *S. oceanica;*

M - Mucosa; CT - connective tissue; MS - muscles

layered membrane made of connective tissue. This membrane is thicker during early maturing and post-spawning periods, whereas it is extremely thin in immature ovaries. Each lobe is composed of a number of lobules of varying sizes. A central shaft occasionally with an empty lumen, extending along the entire length of the ovary, constituted the germinal zone. As the gonadal maturation progresses, the oogonial cells differentiate from the central germinal zone and proliferate radially outwards (Pl.20 a,b). In mature ovary, the germinal zone becomes greatly reduced and contains a few residual oogonia.

In cross section, the spermatheca shows three distinct layers, an outer connective tissue layer, middle longitudinal muscle layer and an inner lining of mucosa (Pl.19 a). The wall of the oviduct consists of condensed simple muscle running longitudinally and obliquely, and embedded in compact connective tissue. The oviduct is lined by glandular mucosa, with cells arranged in general layers. In both the species of mud crabs oviduct is closed by a gelatinous material (Pl. 19 b, c).

Oogenesis

Serial sections of the ovary of both the species at different maturity stages showed a similar pattern of ovarian development and gamete differentiation.

The oogenesis starts with the proliferation and differentiation of the primordial germ cells into primary oogonial cells. The primary oogonial cells are located in close proximity to the central germinal zone of the ovary. These cells possess relatively large nuclei with a thin rim of cytoplasm (Pl.20 a, b). These mother cells undergo mitotic division and develop into the secondary oogonial cells. The secondary oogonial cells are somewhat similar to the primary oogoniae in structure, except in their sizes (PL. 20 b, c). Each secondary oogonial cell possesses a round vesicular nucleus with deeply stained chromatin granules in their nucleoplasm. As the secondary oogonial cells passes into the zygotene or synaptic stage of meiotic prophase the chromatin materials condense at one side of the

nucleoplasm and forms the synezesis knot (Pl.20 e, f). At the final stage of development, chromatin appears in the form of discrete clumps lying close to the nuclear wall and the nucleolus is not visible. A clear cell boundary separating these cells is not distinct at this stage (Pl. 20 e, f). The secondary oogonial cells grow larger and undergo reduction division to produce primary oocytes or previtellogenic oocytes. The nuclei of previtellogenic oocytes are larger and vesicular. In contrast to oogonia these cells possess deeply stained nucleoli within the nucleus. Though the cytoplasmic volume has increased considerably, (Pl.21 a,b), the yolk formation has not yet begun. The limiting membrane of the cytoplasm becomes clear and distinct in oocytes in this stage of maturation.

The transition from previtellogenic to vitellogenic oocyte is immediately recognized by the changes in the nucleus and cytoplasm. The process of vitellogenesis can be divided into different stages such as primary, secondary and tertiary vitellogenic stages. Marked changes are noticed in the nucleus, nuceolus and ooplasm of the cells during the transitional stages of vitellogenesis.

Primary vitellogenic oocyte: The primary vitellogenic oocyte is characterized by increased cytoplasm/nucleus ratio compared to the previtellogenic oocyte (Pl. 21 c, d). The centrally located round nucleus is solid and did not show any increase in size from that of the preceding stage. Finely granular chromatin materials could be seen inside the nucleoplasm especially at the perinuclear area. The cytoplasm is granular and foamy in nature due to the accumulation of yolk droplets which made its appearance at the peripheral ooplasm of the primary vitellogenic oocytes at its later stages. Folliculogenesis or development of follicular cells begin around the oocytes during this stage of vitellogenesis. It develops as a thin undifferentiated layer in the early stages, however, in the later stages these follicle cells become more conspicuous with glial cell nucleii.

Secondary vitellogenic oocytes: A tremendous increase in the size of the oocyte is observed as the vitellogenesis progresses. Drastic changes are noticed in the

PLATE 20

Photomicrographs of ovary of mud crab species in early maturing stages.

a. Transverse section showing germinal zone (GZ) and oogonia (oo) in *S. serrata* (x 100)

b. Transverse section showing germinal zone (GZ) and oogonia (oo) in *S. oceanica* (x 100)

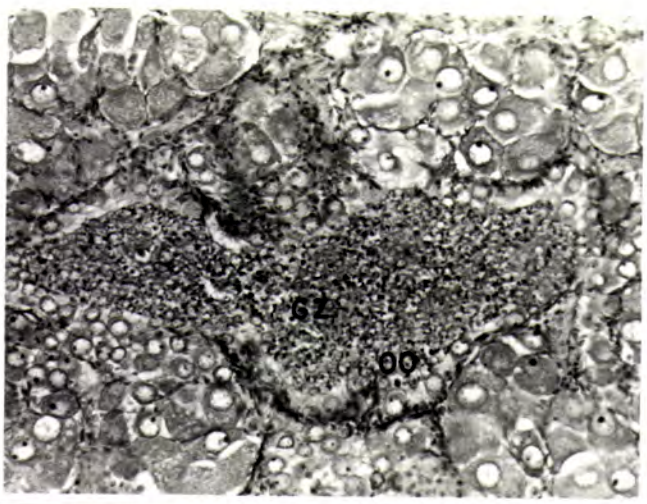
c. Transverse section showing secondary oogonia (SO) cells in *S. serrata* (x 200)

d. Transverse section of early maturing ovary showing secondary oogonia (SO) cells in *S. oceanica* (x 200)

e. Secondary oogonial cells in synaptic stage of meiotic prophase in *S. serrata* (200 x)

f. Secondary oogonial cells in synaptic stage of meiotic prophase in *S. oceanica* (200 x)

SK - Synezesis knot



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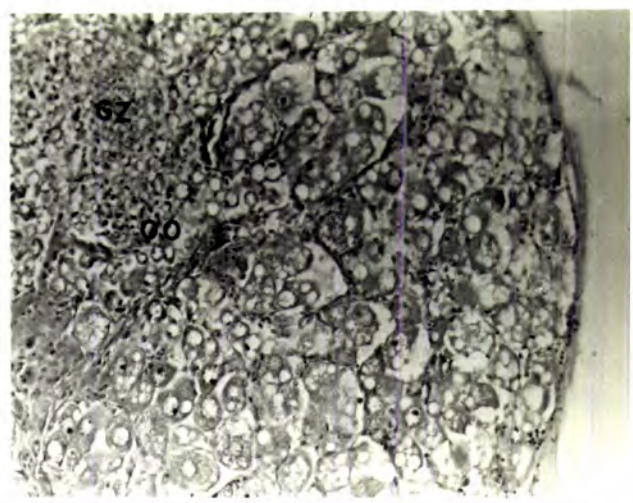

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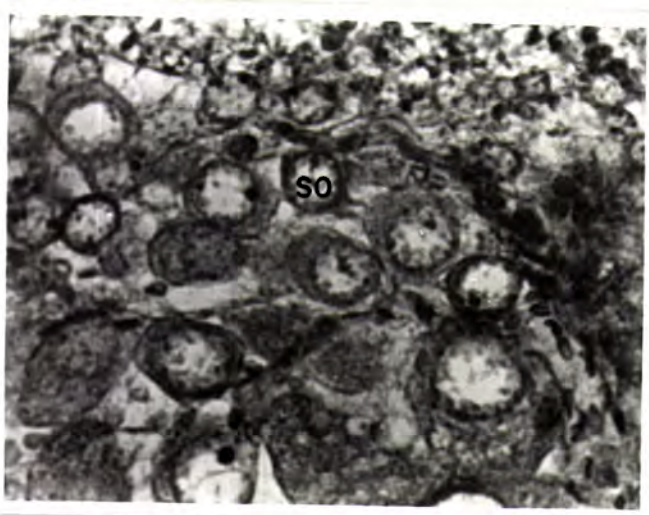

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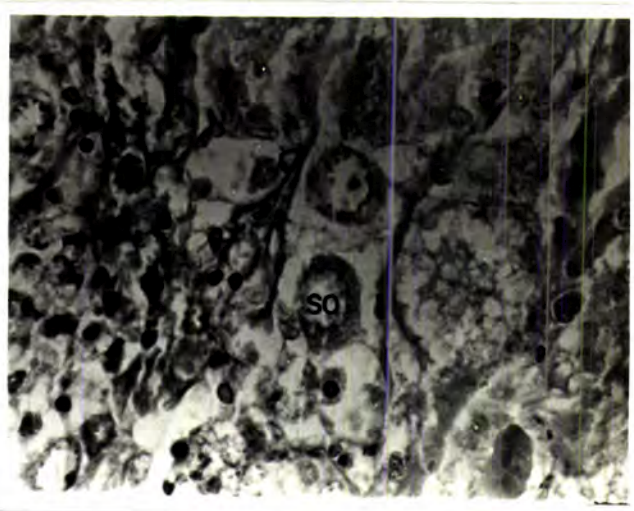

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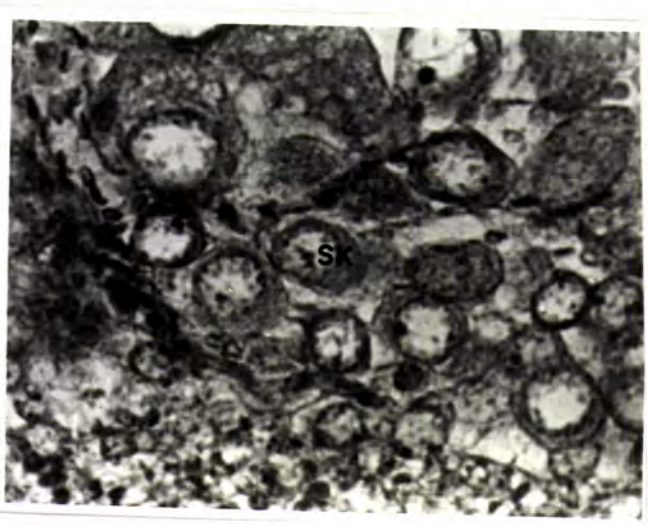

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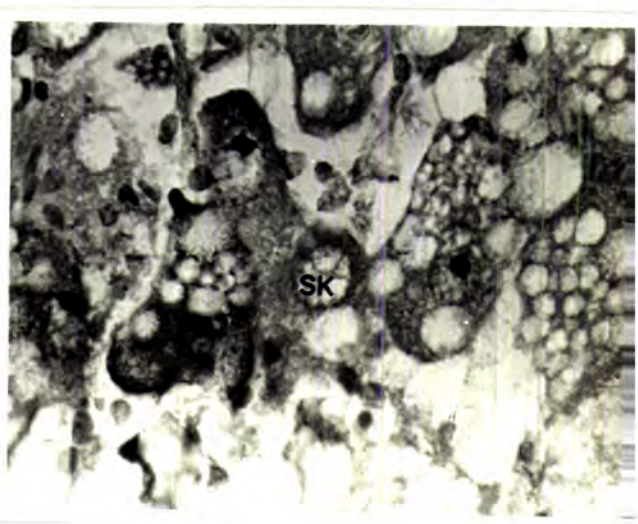
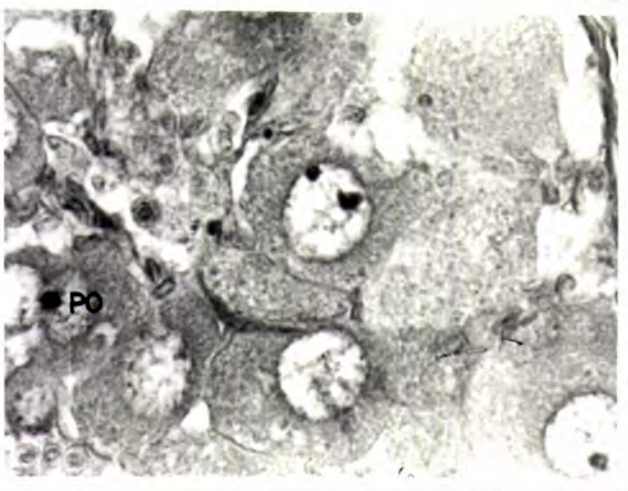


f

PLATE 20

PLATE 21

Photomicrograph of ovary of mud crab species in late maturing stages.
a. Transverse section showing previtellogenic oocyte (PO) in *S. serrata* (200 x)
b. Transverse section showing previtellogenic oocyte (PO) in *S. oceanica* (200 x)
c. Transverse section showing primary vitellogenic oocyte (PVO) with yolk granules (YG) in *S. serrata* (200 x)
d. Transverse section showing primary vitellogenic oocyte (PVO) with yolk granules (YG) in *S. oceanica* (200 x)
e. Transverse section showing secondary vitellogenic oocyte (SVO) in *S. serrata* (200 x)
f. Transverse section showing secondary vitellogenic oocyte (SVO) in *S. oceanica* (200 x).



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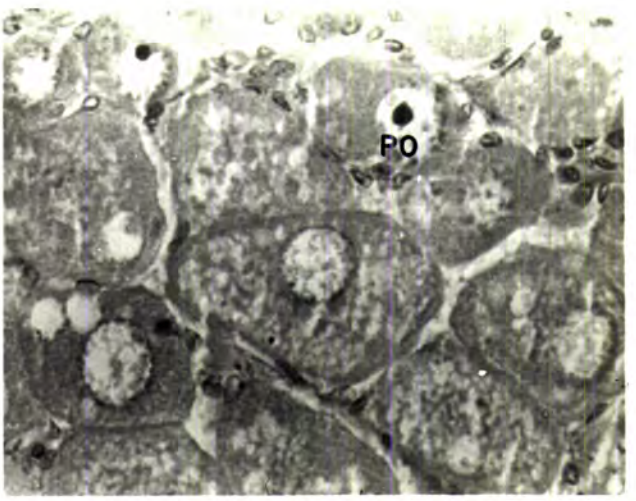

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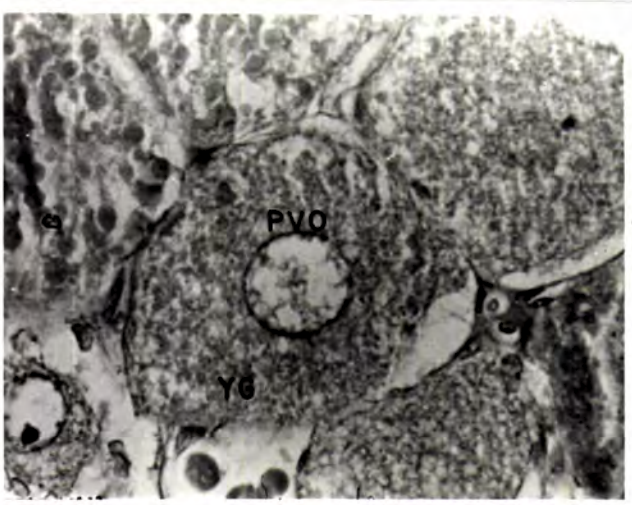

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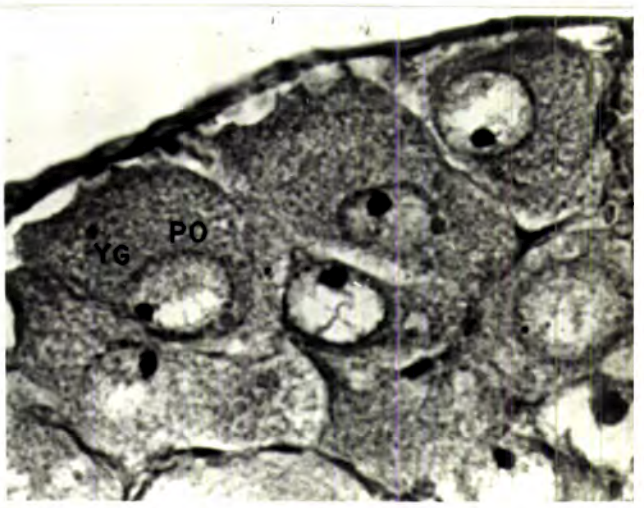

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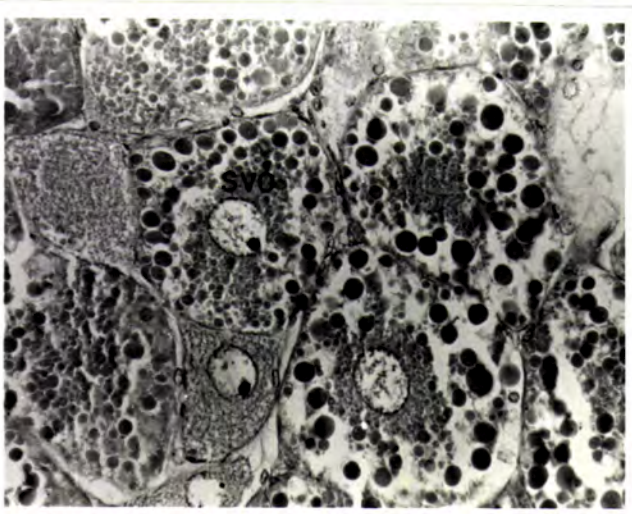

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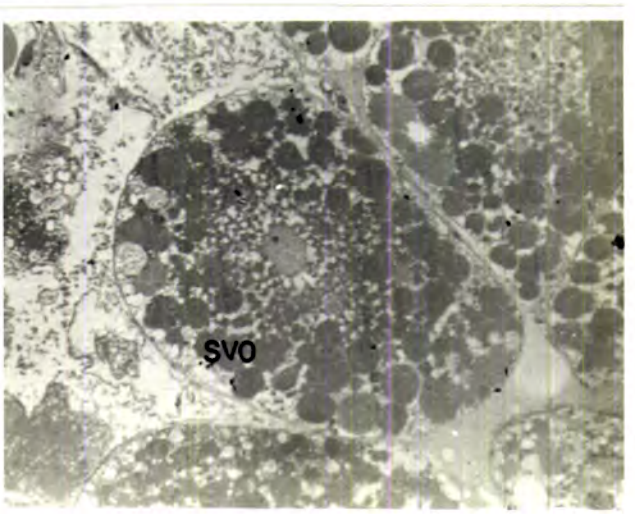


f

PLATE 21

PLATE 22

Photomicrographs of ovary of mud crab species
in ripe and spent stages

a. Transverse section showing teritiary vitellogenic oocyte (TVO) in *S. serrata* (400 x)

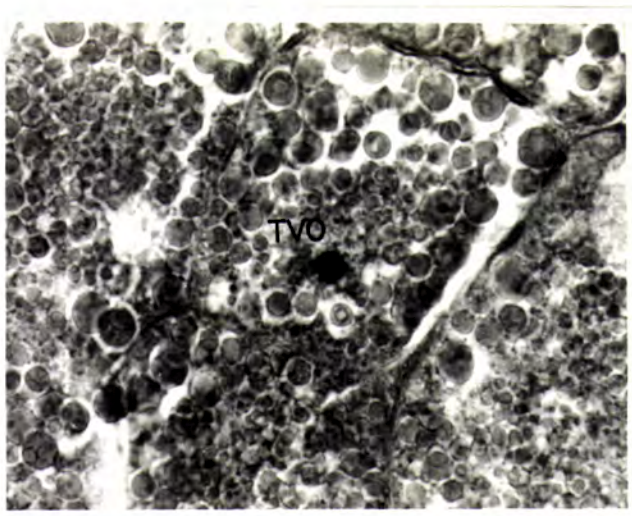
b. Transverse section showing teritiary vitellogenic oocyte (TVO) in *S. oceanica* (400 x)

c. Transverse section of ripe ovary showing nuclear materials completely dispersed in *S. serrata* (400 x)

d. Transverse section of ripe ovary showing nuclear materials completely dispersed in *S. oceanica* (400 x)

e. Transverse section of spent ovary of *S. serrata*. Phagocytic cells (P) and unspawned ova undergoing resorption (RO) can be seen (100 x)

f. Transverse section of spent ovary of *S. oceanica*. Phagocytic cells (P) and unspawned ova undergoing resorption (RO) can be seen (100 x)



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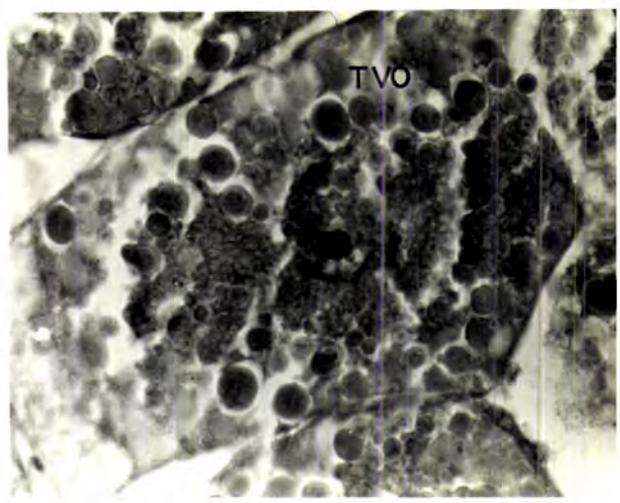
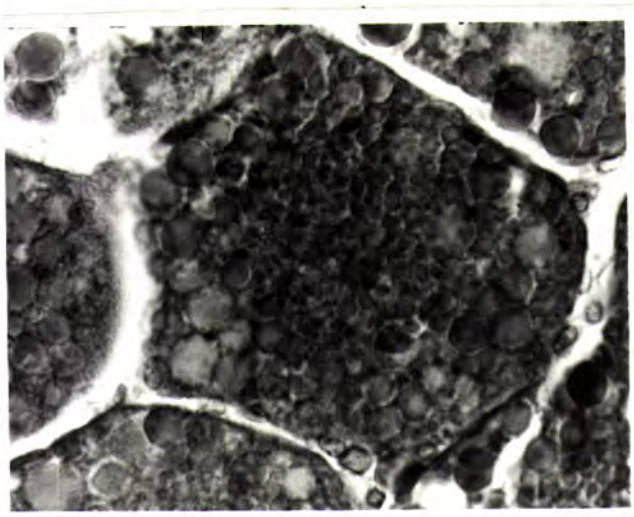


b



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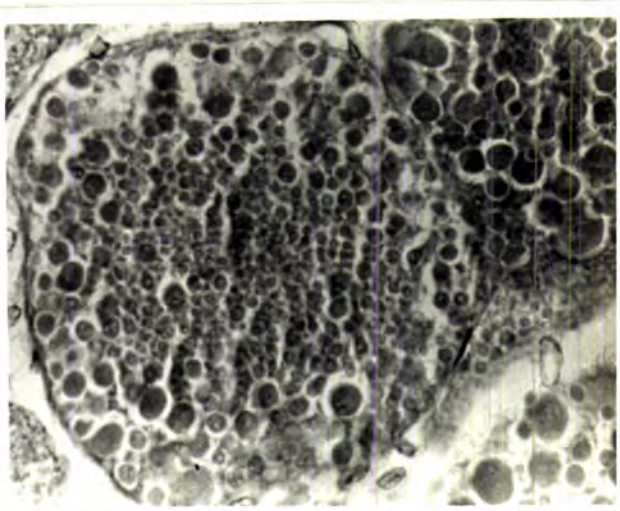

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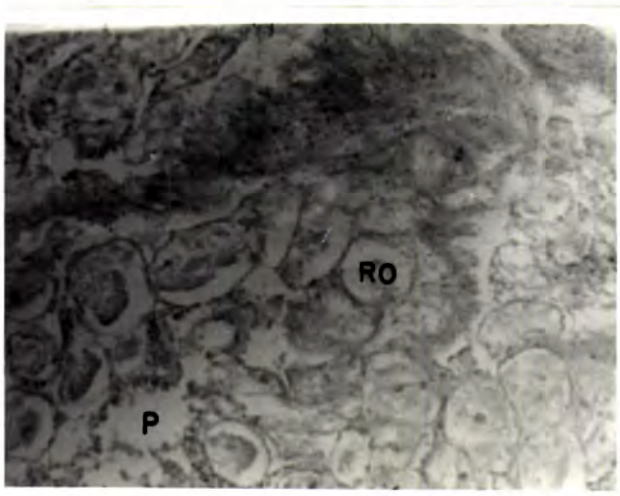
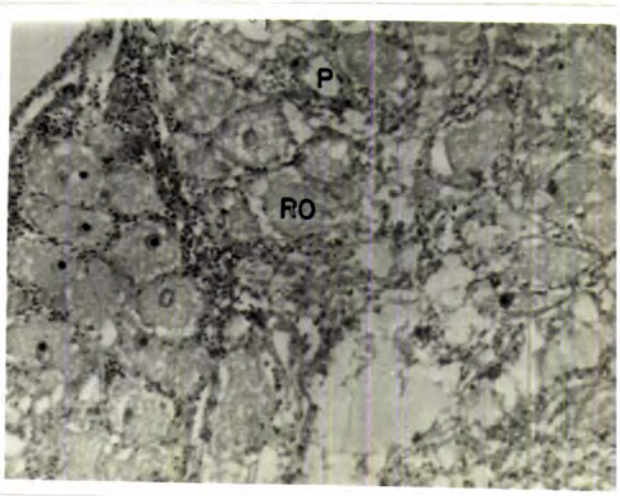


e



f

PLATE 22

nature of the ooplasm as the primary vitellogenic oocytes become secondary vitellogenic stage. The entire cytoplasm contains variously stained round to oval yolk droplets and yolk vesicles (Pl.21 e, f). Cytoplasmic activity is more pronounced in the outer cytoplasm as indicated by the large yolk globules and yolk droplets. However, the limited number of smaller yolk granules in the perinuclear ooplasm shows a lower cytoplasmic activity around the nucleus.

The nucleus does not show any marked change in the secondary vitellogenic oocyte whereas the nucleolus become enlarged and eccentric (Pl. 21 e, f). Oolemma and follicular layers are well distinguishable.

Tertiary vitellogenic oocytes: The tertiary vitellogenic oocytes are characterized by a higher cytoplasmic volume due to the accumulation of yolk materials. Histologically it is noted that as the oocytes mature, the nucleus lost its round appearance and solid structure, and the nuclear/cytoplasmic ratio decreased. Even though the nucleus look considerably smaller, it is still visible (Pl.22 a, b). The cytoplasm immediately surrounding the nucleus at this stage contain yolk granules and droplets of varying sizes. Yolk globules become larger and polygonal and occupy most of the ooplasm including the perinuclear region. Larger granules are seen near the peripheral ooplasm and smaller ones towards the center. Oolemma and follicular cells are distinct. Follicular layer is stretched to a thin membrane and its nuclei become spindle-shaped due to the turgidity of the oocytes as its volume increased.

Ripe or mature oocytes: Ooplasm of the ripe ovary is heavily impregnated with large yolk globules and yolk vesicles. The appearance of these inclusions serve as an indication of the full maturity of ova. The nucleus is not distinguishable in these ripe oocytes (Pl.22 c, d). The yolk appears as a variety of variably staining vacuoles randomly dispersed in the cytoplasmic matrix. The oolemma as well as the highly stretched follicular cells also become apparent in these matured ova.

Spent ovaries: Spent ovary is characterized by the presence of atretic cells and

empty follicle cells (Pl.22 e, f). There is no difference in the structure of spent ovaries of both the species. Germinal zone becomes active in spent ovaries for the regeneration of new set of cells.

Apart from the minor differences due to slight variation in the stages of ovaries from which sections were taken, both the species showed a similar pattern of oogenesis.

Maturity stages of ovary

Ovary undergoes changes in size and colouration during maturation. In crustaceans this is due to the presence of carotenoid pigment linked to the main yolk protein (Nadarajalingam & Subramoniam, 1982). Therefore intensification of colour is an index of accumulation of yolk protein. Based on colour change, external morphology and histology the ovary is classified into 5 maturity stages, namely, immature (stage 0), early maturing (stage 1), late maturing (stage 2), ripe (stage 3) and spent (stage 4).

Immature (stage 0): Ovary thin, colourless and tubular, difficult to locate as it is masked in the hepatopancreatic tissue. Ova diameter ranges from 24 μ to 40 μ.

Early maturing (stage 1): Ovary clearly visible; occupies 1/6th of body cavity; ivory to yellow in colour (Pl.23 a, 25 a); occasionally has a large germinal zone with an empty lumen; ovarian lobules visible. Ova diameter ranges from 34 μ to 110 μ.

Late maturing (stage II): Ovary occupies 1/4 to 1/3rd of body cavity; yellowish orange in colour, opaque in nature; ovarian lobules greatly enlarged (Pl.23 b, 25 b). Ova diameter ranges from 74 μ to 182 μ.

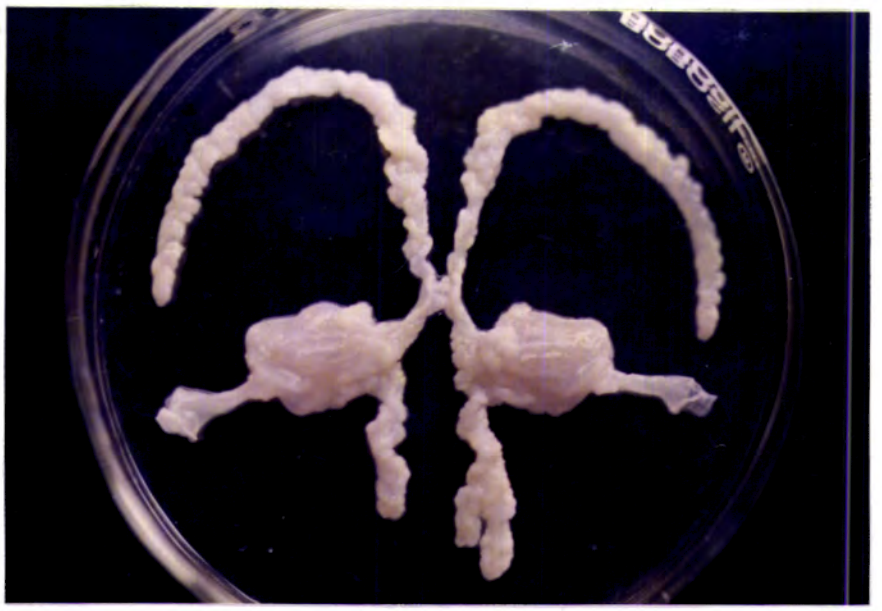
Ripe (stage III): Ovary deep orange in colour; fills up most of the body cavity (Pl.23c, 24a, 25c, 26a). ovarian wall too thin; ova diameter ranges from 89 μ to 267 μ.

Spent (stage IV)_: Ovary greatly reduced in size; creamy white and flaccid (Pl.24

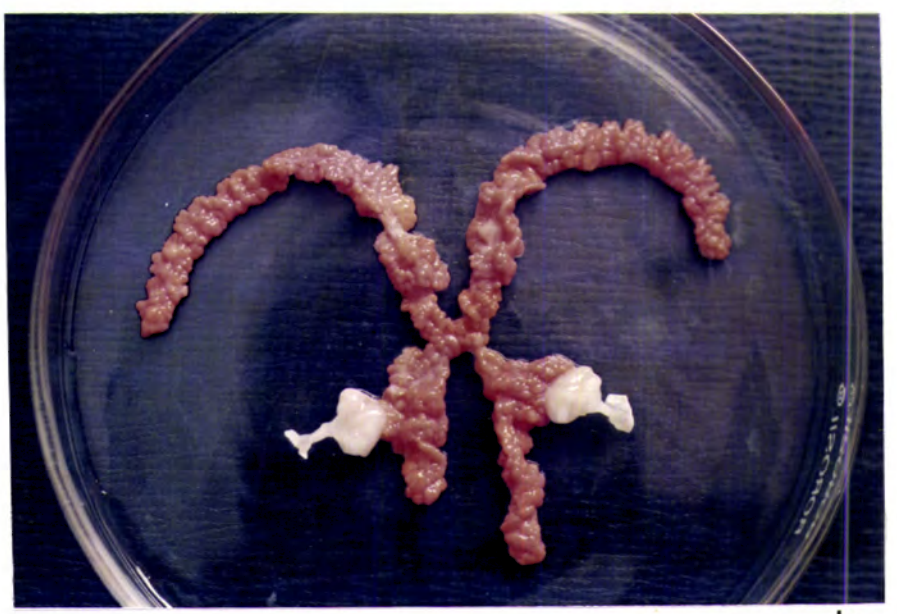
PLATE 23

Ovary of *S. serrata* in different maturity stages

a. Early maturing, b. Late maturing, c. Ripe



a



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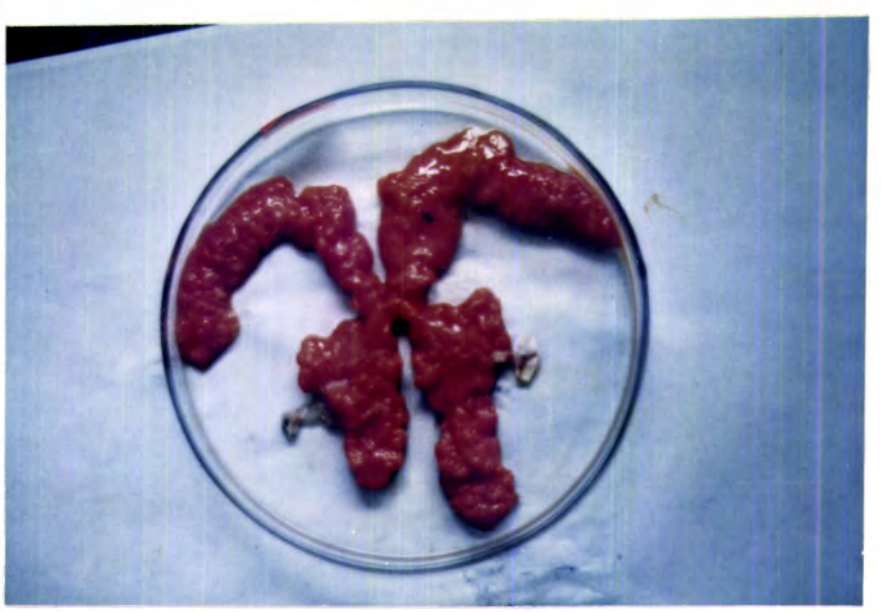
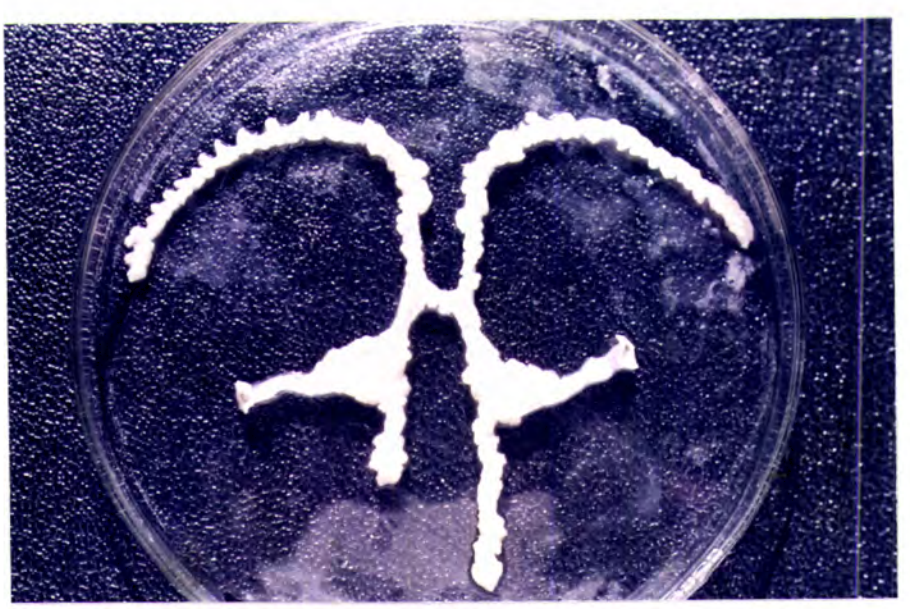


c

PLATE 23

a



b

PLATE 24

Ovary of *S. serrata* in different maturity stages

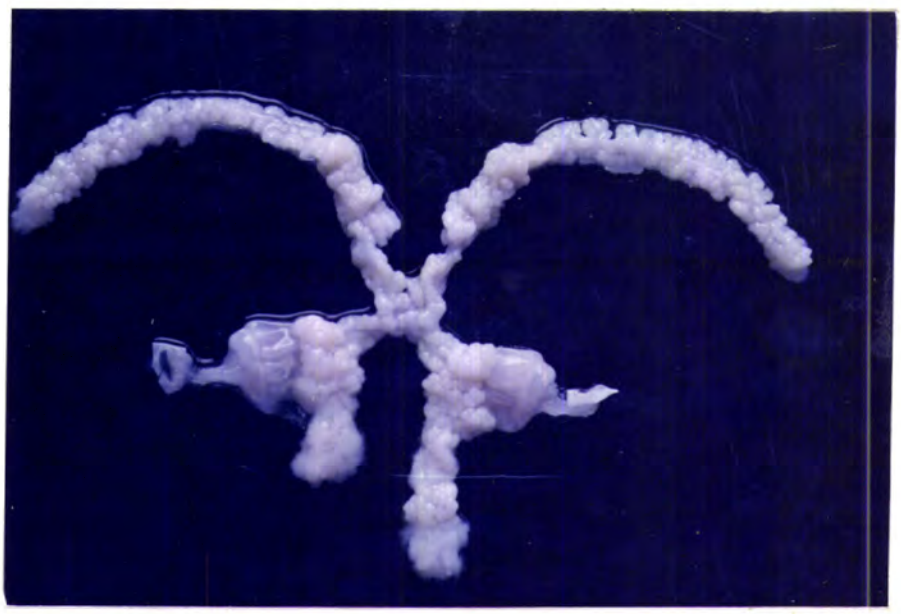
a. Ripe ovary filling the body cavity

b. Spent ovary

PLATE 25

Ovary of *S. oceanica* in different maturity stages

a. Early maturing, b. Late maturing, c. Ripe



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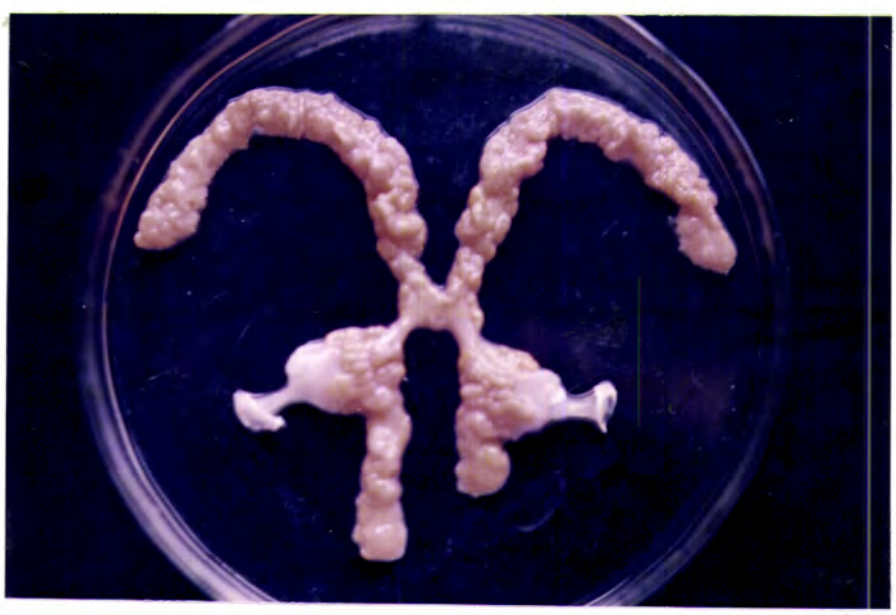

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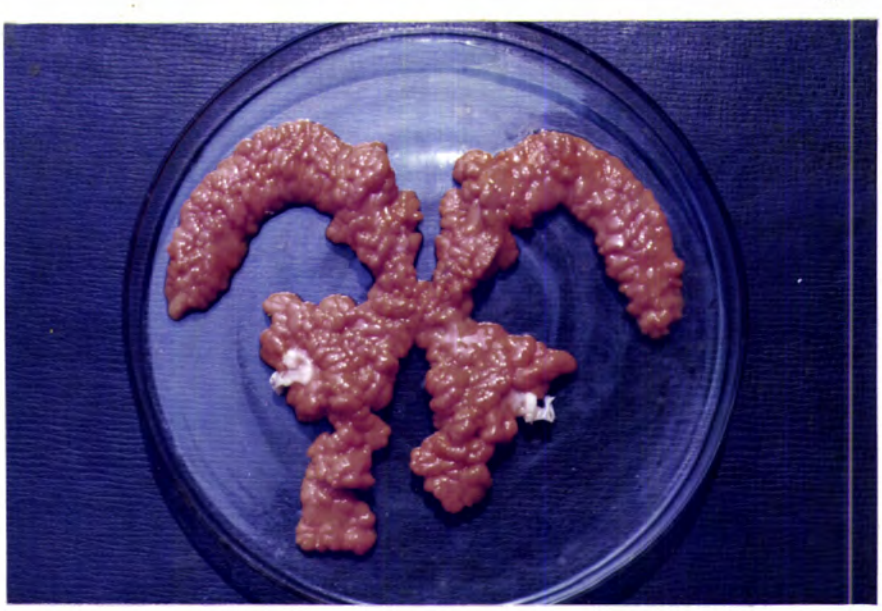


c

PLATE 25

a

b

PLATE 26

Ovary of *S. oceanica* in different maturity stages

a. Ripe ovary filling the body cavity

b. Spent ovary

b, 25 b). Ova diameter ranges from 61 μ to 190 μ.

Minimum size at maturity

The observed minimum size of ovigerous female in Cochin backwater, Ashtamudi lake and Korapuzha estuary measured 8.4 cm, 8.0 cm, 8.7 cm respectively for *S. serrata* and 12.2 cm, 12.4 cm and 12.3 cm CW for *S. oceanica*.

In grow-out pond, where juvenile crabs of 100-200 g size (9-10 cm CW) belonging to the species *S. oceanica* were stocked, the crabs showed "doubler formation" or "premating embrace" where male climbs over female and carries her around. According to crab fishermen, crabs belonging to both the species in `doubler formation' were caught in ring nets from both backwaters and coastal sea. This would indicate that mating may take place in the marine as well as brackishwater environment. Berried crabs were also met with in ponds, backwater and inshore sea. Crabs in advanced stage of incubation (with brown or black coloured berry) is never encountered in open backwater, but they were found in closed brackishwater ponds. Berried animals exhibited a strong tendency to escape from ponds by climbing over the sluice gate.

Berried crabs of both the species were observed in the marine catches through out the year but their frequency was very low during monsoon season. They were also seen in backwaters almost throughout the year except during June to August in the case of *S. oceanica* and June-July in the case of *S. serrata*. The peak occurrence of berried animals was noticed during February-March in the case of *S. oceanica* and January-February in the case of *S. serrata* in both the environments.

Fecundity

Fecundity was examined from 23 specimens of *S. serrata* in the size range 9.5 cm to 12.1 cm CW and the number of eggs carried by an ovigerous individual varied from 1,52,140 to 4,53,344, the average being 3,69,872. In the case of *S. oceanica*, examination of 17 berried specimens in the size range 13.4 cm to 18.2 cm CW gave a total egg-count varying from 25,39,683 to 70,58,823 with an average of

41,23,494. The egg diameter ranged 290-365 micron in the case of *S. serrata* and 330-385 micron in *S. oceanica*.

Incubation and larval development

In female crabs, after the extrusion of eggs during oviposition, the ova get attached to the ovigerous setae present on pleopods 1 to 4 (Ong, 1966). In freshly acquired condition the berry appeared yellowish in *S. oceanica* (Pl. 27) and pinkish yellow in *S. serrata* (Pl.28). The egg mass in both cases was very compact. As the development proceeded the colour of egg mass changed slowly to grayish yellow and finally to brownish black or black in both the species (Pl. 27 b, 28 b). Microscopic examination of ovigerous eggs revealed that they are spherical and the yolk content visible as yellow granules, dividing the surface into large polygonal areas. As the development advanced there was a decrease in yolk volume. The organogenesis and pigmentation of eggs are clearly discernible during the incubation (Pl. 29). Towards the end of the incubation period the egg mass became loosened and the abdomen tilted dorsally without touching the bottom of the rearing tank. The twitching of heart was clearly visible one day before hatching.

The berried animals were sluggish and did not feed regularly during incubation. The actual hatching or release of zoea from the eggs took place in the morning from 6 to 10 A.M. in both the species. They showed vigorous activity during the hatching period. Contraction of the abdomen and movement of pleopods helped in the release of larvae whereas the water current created by the movement of pleopods helped in the dispersal of larvae.

The maximum period of incubation noted during the present study was 13 days for *S. oceanica* and 12 days for *S. serrata*.

S. oceanica larvae were reared through 5 zoeal and one megalopa stage to crab instar (Pl.30-33) whereas *S. serrata* larvae were reared upto the 5th zoeal stage (Pl. 33-35). Frozen *Artemia* nauplii and *Brachionus* were given as feed for first two zoeal stages whereas newly hatched *Artemia* nauplii was given to the other zoeal

a

b

PLATE 27

Egg mass of ovigerous *S. oceanica* female in different stages of embryonic development

a. Early stage, b. Late stage

a

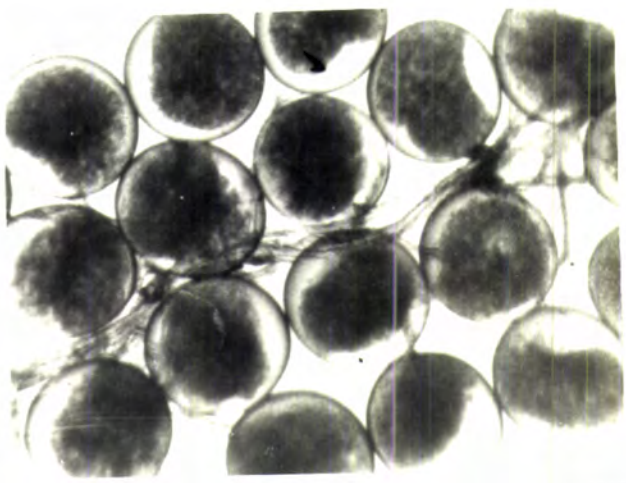
b

PLATE 28

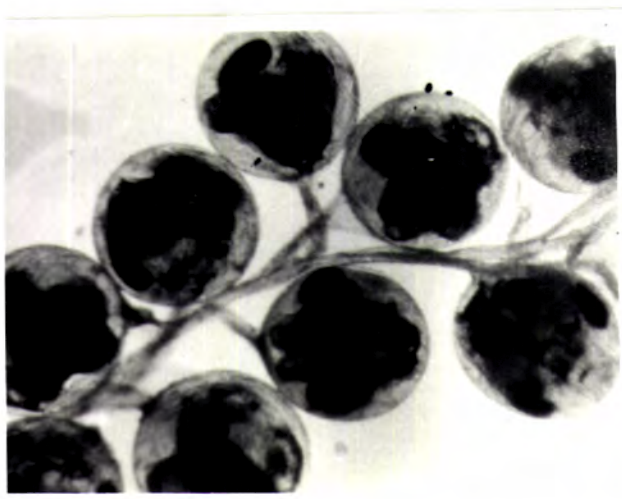
Egg mass of ovigerous *S. serrata* female in different stages of embryonic development

a. Early stage, b. Late stage

a



b



c

d

PLATE 29

Egg of *S. oceanica* in different stages of incubation (45 x)

a. 11 days before hatching, b. 7 days before hatching
c. 1 day before hatching, d. Hatched egg shell

stages. Cut pieces of clam meat and shrimp was given to the megalopa stage. Though the 1st zoea of *S. oceanica* was found feeding on *Artemia* nauplii it was not so acceptable to *S. serrata* larvae. Maximum mortality was observed in zoea I in both the species, but mortality was comparatively very high in *S. serrata* (90%) as compared to *S. oceanica* (about 40%). Thereafter the mortality was gradual. The larval stages, minimum time required for moulting and the size range of different stages in the development of both species of crab are presented in table 3.

The two species showed marked differences in minimum periods required for moulting to successive developmental stages and in the sizes attained by the larvae at every stage. They however resembled closely in the morphological features at the various larval stages. The salient morphological features of different larval stages (both species combined)are given below.

Zoea I (Z1) (Pl.30a, 33b): Eyes sessile, unsegmented antenna; mandible with 2 large teeth and serrated; maxillule with two segmented endopodite; maxilla with unsegmented endopodite; 1st maxilliped with 5 segmented and 2nd maxilliped with 3 segmented endopodite; abdomen 5 segmented, segment 3 to 5 with short lateral spines, telson with 2 pairs of dorsolateral and one pair of dorsal spines, 3 pairs of setae between telson furca and inner most pair of setae with 8-10 setules. Mean sizes 0.96 mm total length in *S. serrata* and 1.25 mm in *S. oceanica*.

Zoea II (Z2) (Pl. 30b, 34a): Eyes stalked, antennule with 4 aesthetes and 2 setae, coxal segment of maxillule with 7 setae and basal with 8 setae; exopodites of maxillipeds with 6 swimming setae; lateral spines on abdominal segments 3-5 longer, a pair of small setae between inner pair of setae of caudal furca. Mean sizes 1.38 mm in *S. serrata* and 1.56 mm in *S. oceanica*

Zoea III (Z3) (Pl 31a, 34 b): Antennal flagellum develops as bud, basal part of maxillule with 8 setae and coxal with 9, basal and coxal part of maxilla with 7 and 8 setae; first maxilliped with 8 swimming setae on exopodite and 9 on exopodite of 2nd maxilliped, buds of remaining thoracic segment visible , abdomen 6 seg-

a

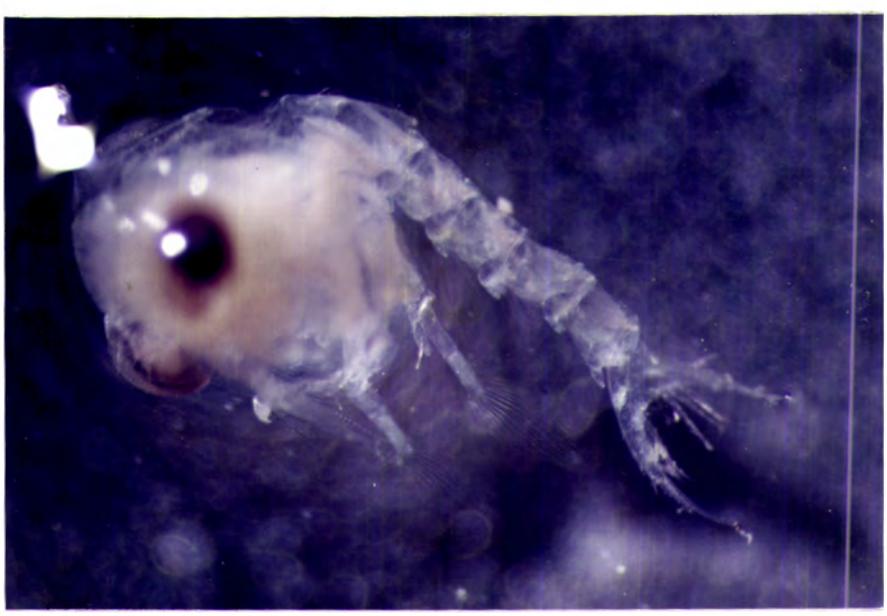
b

PLATE 30

Larval stages of *S. oceanica*

a. Zoea I (100 x) b. Zoea II (50 x)

a

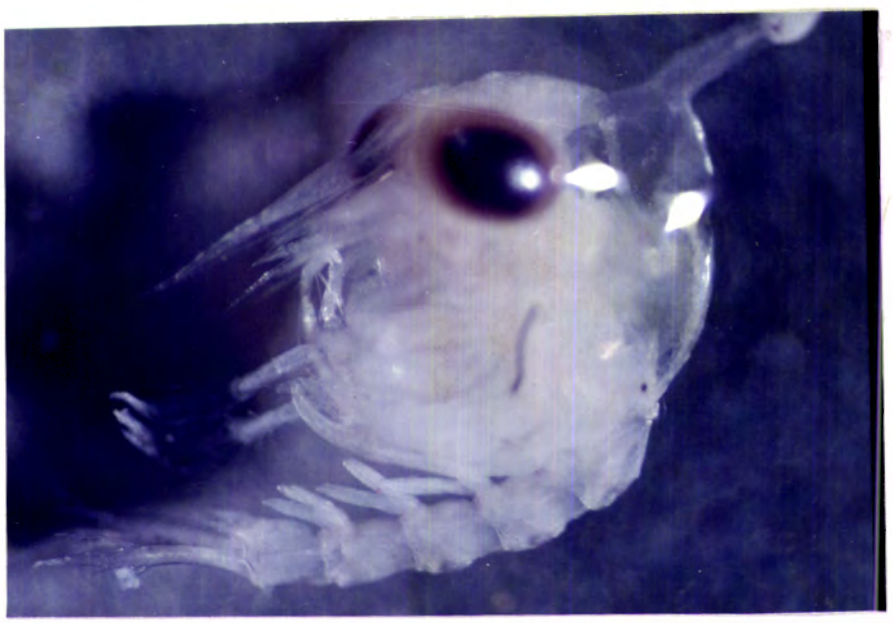


b

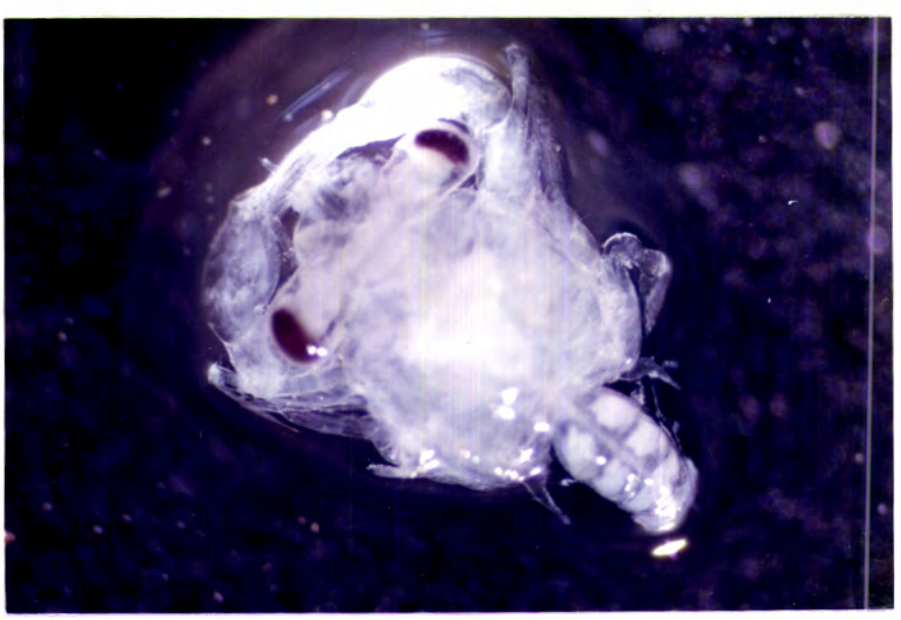
PLATE 31

Larval stages of *S. oceanica*

a. Zoea III (50 x), b. Zoea IV (45 x)



a

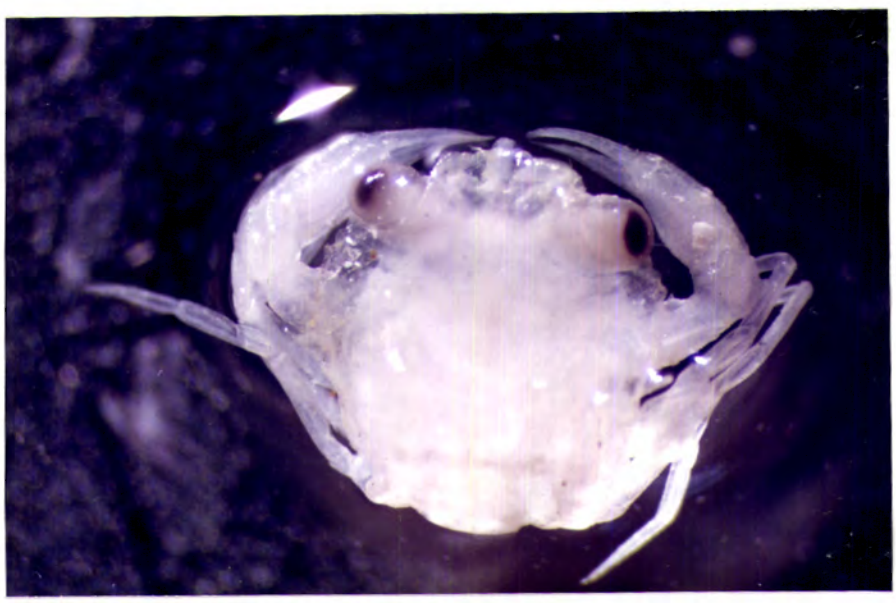


b

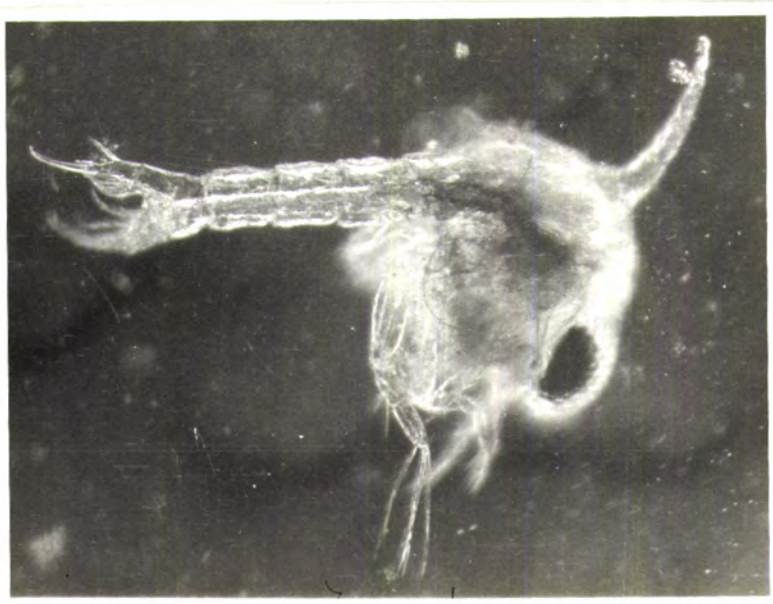
PLATE 32

Larval stages of *S. oceanica*

a. Zoea V (30 x), b. Megalopa (30 x)



a



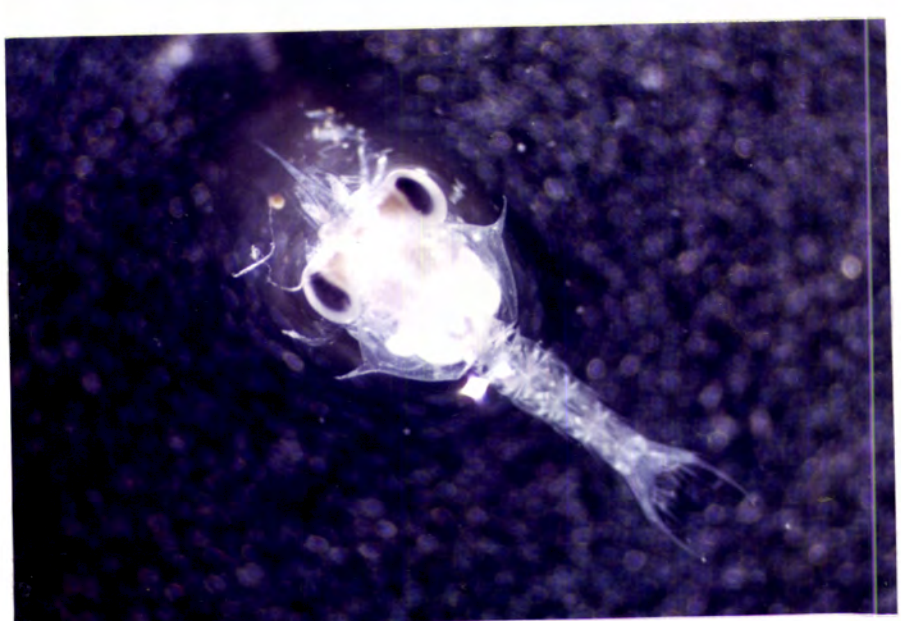
b

PLATE 33

a. Crab Instar-I of *S. oceanica* (30 x)

b. Zoea I of *S. serrata* (100 x)

a



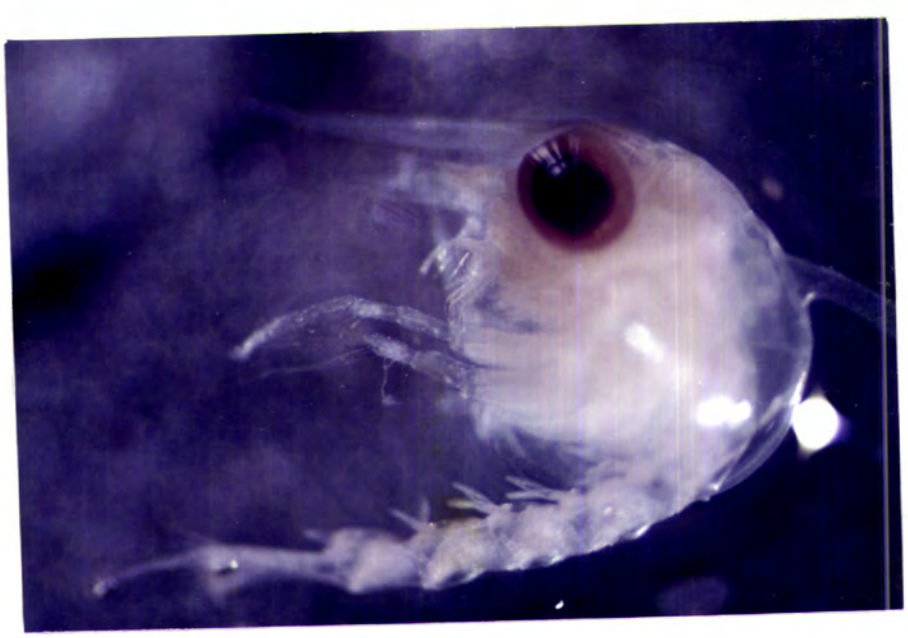
b

PLATE 34

Larval stages of *S. serrata*

a. Zoea-II (50 x), b. Zoea III (45 x)

a.



b

PLATE 35

Larval stages of *S. serrata*

a. Zoea IV (30 x), b. Zoea V (30 x)

TABLE 3: Minimum time taken for moulting and sizes observed during development of mud crabs

Stage	*S.oceanica*		*S. serrata*	
	Min.no.of days for moulting	Size range (mm) (Mean size)	Min. no.of days for moulting	Size range(mm) (Mean size)
Zoea I	4	1-1.3 (1.25)	5	0.9-1.0 (0.96)
Zoea II	3	1.5-1.7 (1.56)	4	1.3-1.4 (1.38)
Zoea III	3	1.8-2.1 (1.94)	5	1.5-1.8 (1.62)
Zoea IV	3	2.4-2.6 (2.53)	6	2.1-2.4 (2.25)
Zoea V	4	3.6-5.1 (4.32)	..	3.2-3.5 (3.38)
Megalopa	6	4.8-5.3 (5.12)	..	..
Crab I	4	3.8-4.0 (3.82 CW)	..	..

mented, lateral spines on segments 3-5 longer. Mean sizes 1.62 mm in *S. serrata* and 1.94 mm in *S. oceanica.*

Zoea IV (Z4) (Pl.31 b, 35 a): Antenna with flagellum, maxillule with 12 setae on coxa and 14 on basis, maxilla with 10 setae on coxa and 12 on basis, maxilliped 1 and 2 with 10 swimming setae, buds of other thoracic segment longer. Pleopod buds on segments 2-6, lateral spines on abdominal segments 3-5 more elongated. Mean sizes 2.25 in *S. serrata* and 2.53mm in *S. oceanica.*

Zoea V (Z5) (Pl. 32a, 35 b): Antennule with endopodite as bud; antennal endopodite elongated to four-fifth the length of spiniform process; periopods elongated, shows segmentation; pleopod buds on abdominal segments well developed, exopodite with setae; lateral spines on abdominal segment 3 extend to about one-third the anterior part of segment 5. Mean sizes 3.38 mm in *S. serrata* and 4.32 mm in *S. oceanica.*

Megalopa (M)(Pl.32 b): Typical portunid megalopa with rostral spine and a pair of long slightly curved spines directed posteriorly from fourth thoracic sternite; first pereiopod modified into cheliped with a curved spine on ventral surface of ischipodite; abdomen with 5 pairs of pleopods. Mean size 5.12 mm in *S. oceanica.*

Crab Instar I (C1) (Pl. 33a): Margin of carapace serrated, including 9 anterolateral spines, frontal part with a median indentation, pereiopods with setae especially on last two segments, propodus and dactylus of last pair of legs with long plumose setae. Mean carapace width 3.82 mm CW in *S. oceanica.*

Growth

Growth is considered to be one of the most important factors for assessing the suitability of a species for aquaculture. During the present study, growth was traced by (1) rearing juveniles in the laboratory, (2) size frequency analysis of commercial catches, and (3) direct observation of grow-out culture.

Growth of juveniles in laboratory conditions

Laboratory produced crab instar-1 of *S. oceanica* with a mean carapace width

TABLE 4: Growth pattern in *S. oceanica* male during juvenile phase in laboratory condition

Crab instar	Days from instar 1	Min.no. of days from preceeding instar	Mean days from preceeding instar	Mean CW (mm)	Av. moult increment of CW (mm)	Av.increment of CW (%)	Mean body weight (g)	Av.increment of weight (g)	Av.increment of weight (%)
1				3.8					
2	4	4	4	5.7	1.9	50.0			
3	9	5	5	7.4	1.7	30.0			
4	14	5	6	9.9	2.5	33.8			
5	20	6	7	12.5	2.6	26.3			
6	28	8	10	15.9	3.6	27.2	0.685		
7	37	9	10	21.5	5.6	35.2	1.356	0.67	98.0
8	49	12	14	28.0	6.5	30.3	2.646	1.29	95.0
9	63	14	16	34.8	6.8	24.4	5.159	2.51	94.9
10	81	18	21	42.2	7.4	21.1	10.06	4.9	94.6
11	105	24	27	52.5	10.3	24.5	18.5	8.44	83.9
12	134	29	32	62.8	10.3	19.6	30.6	12.1	65.4
13	165	31	33	73.1	10.3	16.3	48.7	18.1	59.1
14	202	37	40	83.9	10.8	14.8	78.1	29.4	60.4

TABLE 5: Growth pattern in *S. oceanica* female during juvenile phase in laboratory condition

Crab instar	Days from instar 1	Min.no. of days from pre ceeding instar	Mean days from precee-ding instar	Mean CW (mm)	Av. moult increment of CW (mm)	Av.in-crement of CW (%)	Mean body weight (g)	Av.in-crement of weight (g)	Av.in-crement of weight (%)
1				3.8					
2	4	4	4	5.6	1.8	47.4			
3	9	5	5	7.5	1.9	33.9			
4	14	5	6	9.7	2.2	29.3			
5	21	7	8	12.4	2.7	27.8			
6	29	8	9	16.0	3.6	29.1	0.655		
7	38	9	11	21.9	5.9	36.8	1.3	0.645	98.5
8	49	11	13	28.1	6.2	28.3	2.5	1.2	92.3
9	63	14	15	35.2	7.1	25.3	4.9	2.4	96.0
10	78	15	17	42.8	7.6	21.6	9.6	4.7	95.9
11	98	20	21	52.3	9.5	22.2	17.7	8.1	84.4
12	123	25	28	62.1	9.7	18.7	28.9	11.2	63.3
13	150	27	29	72.8	10.8	17.3	46.8	17.9	61.9
14	180	30	34	84.0	11.2	15.4	75.0	28.2	60.3
15	218	38	43	95.5	11.5	13.7	117.0	42.0	56.0
16	264	46	52	107.6	12.1	12.7	170.0	53.0	45.3

(CW) of 3.8 mm and baby crabs of *S. serrata* with a mean CW of 27.6 mm collected from the wild were used for growth studies. The results obtained are presented in table 4-7. The growth is described separately for each species.

Scylla oceanica (Pl. 36).

Male: During the rearing period of 295 days males moulted 14 times from the initial size of 3.8 mm CW attaining a final mean sizes of 96 mm CW and 120 g body weight. The average growth rate for the period was 10.59 mm CW and 13.3 g weight per month. Average growth/moult increased gradually from 1.9 mm CW in the 1st moult to 12.1 mm CW in the 14th moult during this period the mean percentage increase in CW decreasing from 50 to 14.4. The change in body weight was recorded from instar-6 onwards when the animal had an average weight of 0.685 g. The average weight gain per moult increased from 0.67 g during the 6th moult to 42.5 g during the 14th moult. In terms of percentage the corresponding change decreased from 98 to 54. The intermoult period increased from 4 days to 42 days from the 1st moult to 14th moult.

Female: During the same period of rearing (295 days) females moulted 15 times and reached 16th instar. The mean size of animals increased from 3.8 mm CW to 107.6 mm CW registering an average growth rate of 10.94mm CW and 17.28 g weight per month. The average growth/moult increased from 1.8 mm CW in the 1st moult to 12.1 mm CW in the 15th moult, with the mean percentage increase in CW decreasing from 47.4 to 12.7. The change in body weight was recorded from the 6th moult onwards as in the case of male. The average weight gain per moult increased from 0.65 g during the 6th moult to 53.0g during the 15th moult. In percentage the average weight gain decreased from 98.5 to 45.3. The intermoult period increased from 4 days to 52 days from the first moult to 15th moult.

Scylla serrata

Male: Male crabs moulted six times to grow from an initial size of 27.6mm CW (2.4 g) to 80.8 mm CW (62.4 g) during 263 days of experiment. The increase in

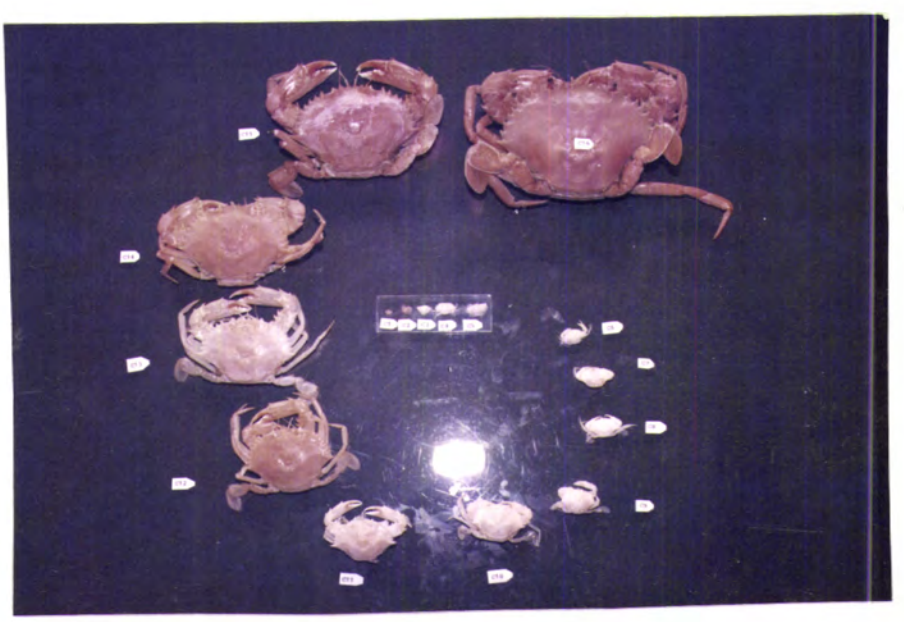


PLATE 36

Pattern of moulting and growth of hatchery produced *S. oceanica*

C1-C15 Moulted shells of crab Instar I to 15

C16 - Crab Instar 16

TABLE 6: Growth pattern in *S. serrata* male during juvenile phase in laboratory condition

Sl No	Days from instar 1	Min.no. of days from pre ceeding instar	Mean days from precee-ding instar	Mean CW (mm)	Av. moult incre ment of CW (mm)	Av.in-crement of CW (%)	Mean body weight (g)	Av.in-crement of weight (g)	Av.in cre-ment of wei ght (%)
1				27.6			2.4		
2	17	17	20	33.8	6.2	22.4	4.76	2.36	98.33
3	44	27	28	40.9	7.1	21.0	9.45	4.69	98.5
4	75	31	38	49.4	8.5	20.8	17.7	8.25	89.3
5	119	44	49	59.6	10.2	20.6	30.4	12.5	70.6
6	177	58	61	70.1	10.5	17.6	44.7	14.3	47.0
7	240	63	67	80.8	10.7	15.2	62.4	17.7	39.6

TABLE 7: Growth pattern in *S. serrata* female during juvenile phase in laboratory conditions

Si No	Days from instar 1	Min.no. of days from pre ceeding instar	Mean days from precee-ding instar	Mean CW (mm)	Av. moult incre ment of CW (mm)	Av.in-crement of CW (%)	Mean body weight (g)	Av.in-crement of weight (g)	Av.in - cre-ment of wei ght (%)
1				27.5			2.45		
2	18	18	21	34.0	7.5	23.6	4.88	2.43	99.18
3	44	26	29	41.1	7.1	20.9	9.51	4.63	94.87
4	75	31	34	49.0	7.9	19.2	17.32	8.81	82.12
5	113	38	43	58.0	9.0	18.3	29.23	11.91	68.7
6	160	47	49	67.5	9.5	16.3	43.51	14.28	48.85
7	211	51	56	77.5	10.0	14.8	60.74	17.23	39.6

mean CW per moult was 6.2 mm in the 1st moult to 10.7 mm in the 6th moult, the mean percentage increase decreasing from 22.4 to 15.2. The average weight gain increased from 2.36 g in the first moult to 17.7 g in the 6th moult, but the percentage weight gain decreased from 98.33 to 39.6 during the same moults. The average growth rate worked out to 9.23 mm CW (7.12 g). The intermoult period increased from 17 days to 63 days between 1st and 6th moult.

Female: Female crabs of mean initial size 27.5 mm CW (2.45g) moulted 6 times during the experimental period of 232 days, and attained a final size of 77.5 mm CW (60.74g). Monthly average growth of the animal worked out to 10.02 mm CW (7.85 g). The increase in mean CW per moult varied from 7.5 mm in 1st moult to 10 mm in the 6th moult, with mean percentage values for the same decreasing from 23.6 to 14.8. The mean weight gain per moult increased from 2.43 g to 17.23 g, but the percentage weight gain decreased from 99.18 to 39.6. The intermoult period increased from 18 day in the first moult to 51 days in the 6th moult.

Combining both male and female the initial mean size of *S. serrata* was 27.55 mm CW with a mean weight of 2.43 g. This increased to 79 mm CW weighing 61.5 g showing a monthly growth rate of 6.27 mm CW and 7.2 g in weight in a period of about 245 days. For the sake of comparison of growth rates between species, an initial size of 28.5 mm CW weighing 2.55 g, arrived at by averaging appropriate size of male (28.0 mm CW and 2.6 g) and female (28.1 mm CW and 2.5 g) was used against the final mean size of 102.8 mm CW and 151 g attained in a period of about 240 days in respect of *S. oceanica*. The monthly growth rate in this case worked out to 9.08 mm CW and 18.02 g for more or less identical size groups.

Growth based on size frequency analysis

The monthly size frequency data collected from commercial catches between August 1992-July 1993 was used for statistical estimation of growth. As availability of adequate samples of both the species was almost regular in Cochin backwaters, the size frequency data collected from this centre was used for this

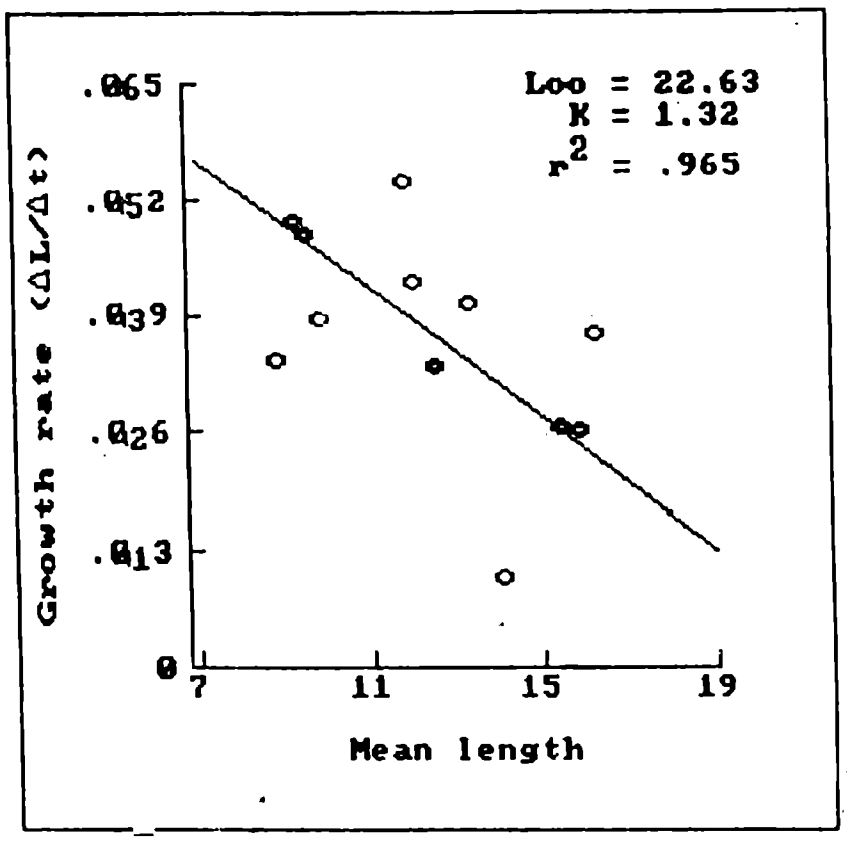


Fig. 2: Gulland and Holt plot of *S. oceanica* male.

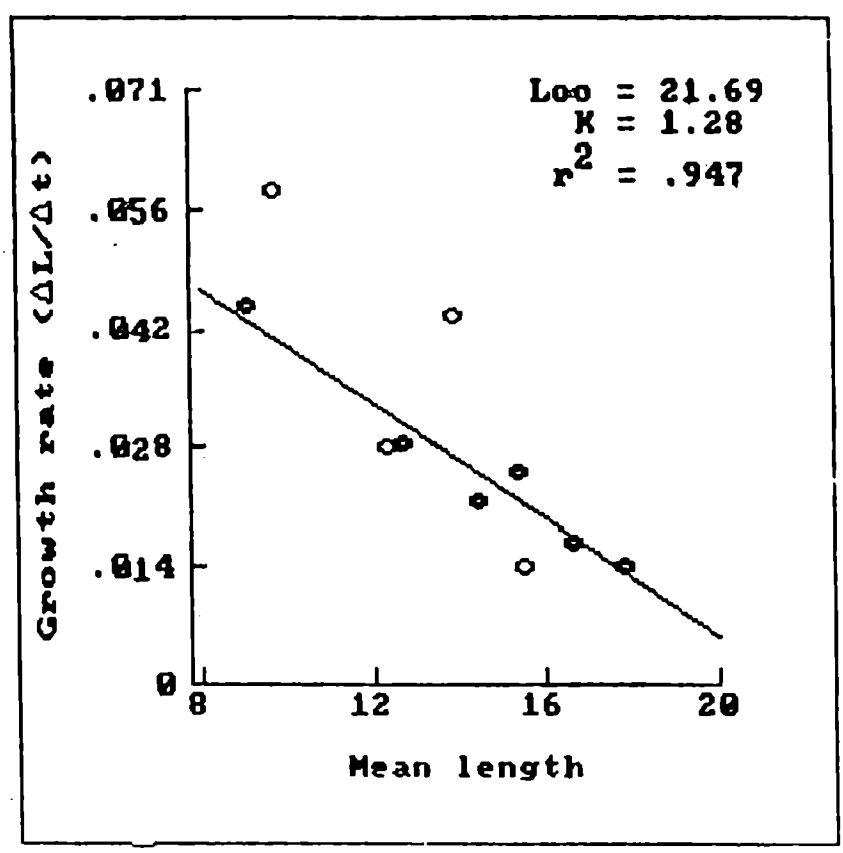


Fig. 3: Gulland and Holt plot of *S. oceanica* female.

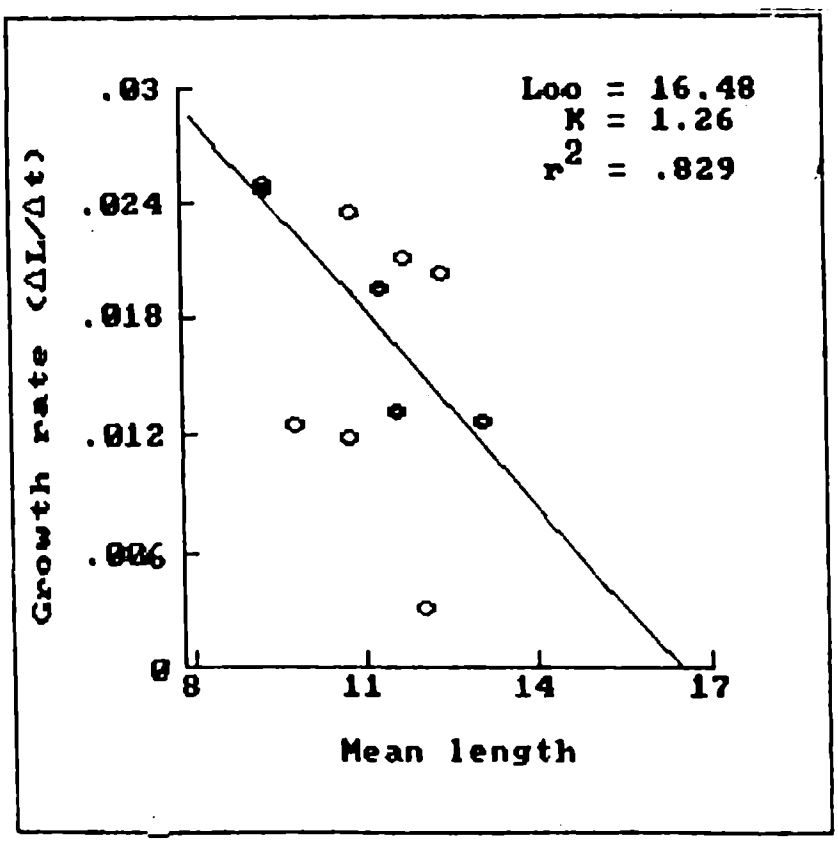


Fig. 4: Gulland and Holt plot of *S. serrata* male.

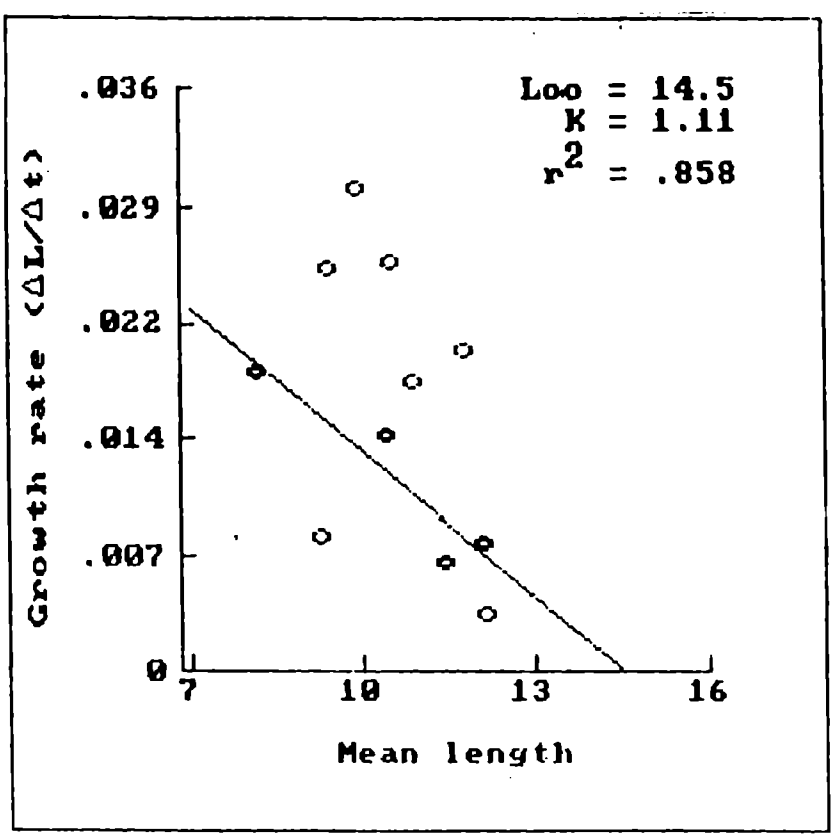


Fig. 5: Gulland and Holt plot of *S. serrata* female.

TABLE 8: Estimated monthly growth of male and female *S. oceanica* based on the fitted growth curves

Months	Carapace width (cm)	
	Male	Female
1	2.36	2.19
2	4.47	4.17
3	6.36	5.94
4	8.06	7.53
5	9.57	8.97
6	10.93	10.25
7	12.15	11.41
8	13.24	12.45
9	14.22	13.39
10	15.10	14.23
11	15.88	14.98
12	16.58	15.66
13	17.21	16.27
14	17.78	16.82
15	18.28	17.31
16	18.74	17.75
17	19.14	18.15
18	19.51	18.51
19	19.83	18.83
20	20.12	19.12
21	20.38	19.38
22	20.62	19.62
23	20.83	19.83
24	21.02	20.01
25	21.18	20.18
26	21.33	20.34
27	21.47	20.47
28	21.59	20.60
29	21.70	20.71
30	21.80	20.81
31	21.88	20.90
32	21.96	20.98
33	22.03	21.05
34	22.09	21.11
35	22.15	21.17
36	22.20	21.22

TABLE 9: Estimated monthly growth of male and female *S.serrata* based on the fitted growth curves

Month	Carapace width (cm)	
	Male	Female
1	1.64	1.29
2	3.12	2.46
3	4.45	3.53
4	5.65	4.51
5	6.73	5.40
6	7.70	6.21
7	8.58	6.95
8	9.37	7.62
9	10.07	8.24
10	10.71	8.80
11	11.29	9.31
12	11.81	9.78
13	12.27	10.20
14	12.69	10.59
15	13.07	10.94
16	13.41	11.26
17	13.71	11.55
18	13.99	11.82
19	14.24	12.07
20	14.46	12.29
21	14.66	12.49
22	14.84	12.67
23	15.01	12.84
24	15.15	13.00
25	15.29	13.14
26	15.41	13.26
27	15.51	13.38
28	15.61	13.49
29	15.70	13.58
30	15.77	13.67
31	15.84	13.75
32	15.91	13.82
33	15.96	13.89
34	16.02	13.95
35	16.06	14.01
36	16.10	14.06

purpose.

Scylla oceanica

The size frequency data of 1127 crabs including 545 males and 582 females in the size range 6.1 - 21.0 cm CW was used for the statistical analysis. Fig. 2 and 3 depicts the Gulland and Holt plot of *S. oceanica* male and female respectively. The estimated L ∞ and K values for male were 22.63 and 1.32 and those of female 21.69 and 1.28. The growth equations so obtained are given below.

$L_t = 22.63\ [1 - \exp(-1.32\ (t-to))]$ - Male

$L_t = 21.69\ \{1-\exp(-1.28\ (t-to)\}]$ - Female

The monthly growth coefficient (K) were 0.11 for male and 0.107 for female. Table 8 shows the computed monthly growth from the growth equation for the two sexes for 3 year period.

It may be seen that in the first year the male attains a size of 16.58 cm CW whereas female attains only 15.65 cm. In the second and third year male attains sizes of 21.02 cm and 22.20 cm respectively while the female reaches sizes of 20.01 cm and 21.22 cm in the same period.

S. serrata

The size frequency data of 1059 crabs including 589 males and 570 females in the size range 6.1-16.0 cm CW were used for the statistical analysis. Fig. 4 and 5 depicts the Gulland and Holt plot of *S. serrata* male and female respectively. The estimated L ∞ and K values of male were 16.48 and 1.26 and those of female 14.5 cm and 1.11. The growth equations so obtained are given below.

$L_t = 16.48\ [1-\exp\{-1.26\ (t0to)\}]$ .. male

$L_t = 14.50\ [1-\exp\{-1.11\ (t-to)\}]$.. female

The monthly growth coefficients (K) were 0.105 for male and 0.0925 for female. Table 9 shows the computed monthly growth from the growth equation for the two sexes for 3 year period.

Male attains a carapace width of 11.8 cm, 15.15 cm and 16.1 cm in first,

second and third year of growth where as female attains only 9.78 cm, 13.0 cm and 14.06 cm during the same period.

Growth in grow-out culture

Experimental grow-out culture of *Scylla oceanica* was carried out over a period of six months from August 1993 to February 1994 .The growth was assessed from size and weight measurements of 20-25 crabs of each sex taken in each month. The monthwise sample size, mean carapace width, mean weight and growth increment are shown in Table 10 for male and Table 11 for female.

Males: From a stocking size of 9.92 cm CW, the males grew to 15.64 cm in 6 months (table 10). The monthly growth increment in terms of percentage gain in CW was maximum during the first month (18.95). However it considerably reduced in the next 3 months (6.44%, 5.10% and 4.70%) and after increasing to 9.33% in the fifth month reduced drastically to 3.5% in the sixth month. The estimated daily growth was the highest in the first month (0.63 mm) which gradually reduced to 0.21 mm in the fourth month. An increased growth rate of 0.43 mm/day was noticed during the fifth month but it reduced to 0.18 mm/day which was the lowest for the entire period.

The mean weight of crab at the time of stocking was 168.15g which increased to 596g in 6 months time. The monthly percentage weight gain indicated that, the weight increased with time at a much faster rate than the carapace width. The weight gain was 30% in the first month and then reduced to 18.29%, 23.21% and 19.62% in the second, third and fourth months respectively. The highest value of 32.19% was recorded in the fifth month and it again decreased to 17.51% in the sixth month. During the first and second months the daily growth in terms of weight was 1.69 g and 1.33g respectively. In the third and fourth months it increased to about 2 g/day. A maximum daily growth rate of 4.19 g was recorded in the fifth month and in the sixth month it was only 2.96g.

Female: The female crabs with a mean initial CW of 10.75 cm grew to 16.4 cm in

TABLE 10: Growth pattern of *S. oceanica* male in culture pond

Time (Month)	Sample size (N)	Mean CW (cm)	Mean weight (g)	Monthly growth		Growth/day	
				length (%)	weight (%)	length (mm)	weight (g)
0	25	9.92 ±1.11	168.15 ±45.31				
1	21	11.8 ± 0.96	218.7 ± 43.24	18.95	30.06	0.63	1.69
2	23	12.56 ± 0.89	258.7 ± 45.17	6.44	18.29	0.25	1.33
3	23	13.2 ± 0.56	319.0 ± 39.5	5.10	23.31	0.21	2.01
4	22	13.82 ± 0.57	381.6 ± 48.9	4.70	19.62	0.21	2.01
5	23	15.11 ± 0.5	507.18 ± 59.72	9.33	32.91	0.43	4.19
6	23	15.64 ± 0.61	596.0 ± 75.9	3.5	17.51	0.18	2.96

TABLE 11: Growth pattern of *S. oceanica* female in culture pond

Time (Month)	Sample size (N)	Mean CW (cm)	Mean weight (g)	Monthly growth		Growth/day	
				length (%)	weight (%)	length (mm)	weight (g)
0	23	10.75 ± 0.86	190.4 ± 39.96				
1	21	12.10 ± 0.69	237.3 ±40.08	12.56	24.63	0.45	1.56
2	23	13.04 ± 0.79	295.3 ± 41.7	7.7	24.44	0.31	1.93
3	20	14.02 ± 0.88	364.66 ± 45.96	7.52	23.49	0.33	2.31
4	22	14.55 ± 0.54	436.3 ±50.58	3.78	19.65	0.18	2.39
5	20	15.24 ± 0.61	501.4 ± 58.55	4.76	14.92	0.23	2.17
6	23	16.4 ± 0.96	574.37 ±57.5	7.61	14.55	0.39	2.43

6 months. It may be seen from Table 11 that the monthly growth rate was maximum in the first month (12.56% CW). Growth rate declined to 7.7%, 7.52% and 3.78% (CW) in the second, third and fourth months respectively which again increased to 4.76% and 7.61% in the fifth and sixth months. The daily growth which was 0.45 mm, 0.31 mm and 0.33 mm in the first, second and third months respectively, showed a decline to 0.18 mm in the fourth month. It again increased to 0.23 mm and 0.39 mm in the fifth and sixth months.

The mean weight of female crabs at stocking was 190.4g which increased to 574.37g in 6 months period. Monthly percentage weight gain was maximum in the first month (24.63%) which showed a gradual decline over the months to 14.55% in the sixth month. It reduced from 23.49% in the third month and 14.92% in the fifth month. Weight gain/day increased from 1.56 g in the first month to 2.17 g in the fifth month. The highest value of weight gain/day was recorded in the sixth month (2.43).

Based on the results obtained on the growth rates of male and female crabs in different months, the average monthly growth rate of *S. oceanica* in terms of carapace width and weight were estimated and the results are depicted in Table 12.

From the table it can be seen that in male crabs the growth rate of 1.88 cm during the first month declined to 0.76 cm during the second month. Further, the growth rates reduced to 0.64 cm and 0.62 cm in the next two months indicating very less variation in the monthly growth rates in these months. An increase to 1.2 cm/month was observed in the fifth month which again declined to 0.53 cm in the sixth month. In terms of weight, the growth rate showed a gradual increase from 50.55 g in the first month to 62.6 g in the fourth month. In the fifth month the highest value of 125.58 g was recorded corresponding to the highest growth in CW, but the weight reduced to 88.82 g in the sixth month. The average growth rate of female for the entire 6 months period was 0.95 cm or 71.31 g body weight/

TABLE 12: Estimated monthly growth rates of *S. oceanica* in culture pond

Particulars	Male		Female	
	CW (cm)	weight (g)	CW (cm)	weight (g)
Mean CW / weight at stocking	9.92	168.15	10.75	190.4
Growth rate				
1st month	1.88	50.55	1.35	46.9
2nd month	0.76	40.00	0.94	58.0
3rd month	0.64	60.30	0.98	69.36
4th month	0.62	62.60	0.53	71.64
5th month	1.29	125.58	0.69	65.10
6th month	0.53	88.82	1.16	72.97
Average monthly growth rate	0.95	71.31	0.94	64.00

month.

Monthly growth rate of female crab was the highest in the first month (1.35 cm) and it declined to 0.94 cm, 0.98 cm and 0.53 cm in the second, third and fourth months. Subsequently a slight increase to 0.99 cm in the fifth month and an increase to 1.16 cm in the sixth month was recorded. The average monthly growth of female for the entire six months culture period was 0.94 cm/month. In terms of weight, the monthly growth rate gradually increased from 46.5 g in the first month to 71.64 g in the fourth month. A slight decline was noticed in the fifth month (65 g) and the highest monthly growth rate of 72.97 g was recorded in the sixth month. The average monthly growth rate for the entire six month period was 64 g.

Carapace width - weight relationship

Under normal conditions, the length-weight relationship of an animal can be expected to conform to cubic relationship of length to weight. There can be difference in length-weight relationship of animal sex-wise due to sexual dimorphism or other biological reasons. Variations can also occur due to biotic and abiotic conditions.

During the present study CW-weight relationships were derived for both the species, sex-wise from all the three centres of study. The regression equations of *S. oceanica* from Ashtamudi lake, Cochin backwater and Korapuzha estuary expressed in the exponential form are given in Table 13.

The exponent values for both the sexes are not significantly different from 3 indicating isometric growth. In male, these values ranged from 3.0771 to 3.1185, whereas in female they ranged from 2.9350 to 2.9999. Table 14 shows the regression equations in respect of *S. serrata* in which male showed exponent values ranging 2.9776-3.22901 and female slightly lower values of 2.5668-2.6992.

To test the carapace width-weight relationship between sexes ANOVA was performed using MSTATC Computer programme. The difference in CW-weight relationship between sexes in *S. oceanica* was found significantly different at all

TABLE 13. Carapace width-weight relationship of *S. oceanica*

Centre	Sex	No.of crabs	CW-weight relationship	r
Ashtamudi lake	Male	527	$W = 0.1110\ CW^{3.1185}$	0.9827
	Female	565	$W = 0.1584\ CW^{2.9392}$	0.9850
Cochin backwater	Male	543	$W = 0.1046\ CW^{3.1425}$	0.9827
	Female	580	$W = 0.2363\ CW^{2.9999}$	0.9847
Korapuzha	Male	538	$W = 0.1235\ CW^{3.0771}$	0.9819
estuary	Female	564	$W = 0.1586\ CW^{2.9353}$	0.9895

TABLE 14: Carapace width-weight relationship of *S. serrata*

Centre	Sex	No.of crabs	CW-weight relationship	r
Ashtamudi lake	Male	301	$W = 0.2068\ CW^{3.2290}$	0.9381
	Female	288	$W = 0.2924\ CW^{2.6992}$	0.9596
Cochin backwater	Male	589	$W = 0.2685\ CW^{3.0422}$	0.9555
	Female	570	$W = 0.3550\ CW^{2.6068}$	0.9751
Korapuzha	Male	331	$W = 0.1875\ CW^{3.9776}$	0.9454
estuary	Female	288	$W = 0.3905\ CW^{2.5668}$	0.9766

three centres with F = 70.75 (df.2,1090, P =0.000) for Ashtamudi lake, F = 71.23 (df 2,1125, P=0.000) for Cochin backwaters and F = 104.96 (df. 2, 1104, p+0.000) for Korapuzha estuary. Similarly the CW-weight relationship between the sexes was found significantly different in *S. serrata* also with F = 153.76 (df.2, 587, P=0.000) for Ashtamudi lake, F = 443.7 (df.2, 1157, P=0.000) for Cochin backwaters and F = 157.8 (df.2, 617, P=0.000) for Korapuzha estuary.

Behavioural observations

The two species of mud crabs showed many differences in their behaviour. *S. oceanica* was found occupying mostly in open waters and wider canals, whereas *S. serrata* was commonly met with in shallow areas and narrow canals where it preferred to live in burrows. *S. oceanica* took shelter in burrows mostly during moulting period. The burrows of *S. serrata* had generally a single opening while those of *S. oceanica* had two. During the course of larval rearing it was observed that larvae of both the species were highly photopositive and seen to swarm at the surface of the rearing medium. However, with every moult the larvae gave up this tendency and by the time they developed into megalopa stage the animal settled at the bottom, occasionally tumbling in the medium. Cannibalism was observed from the megalopa stage onwards and they were more susceptible to the same during moulting. Both in juvenile and adult stages the males showed more aggressive behaviour than the female. Among the two species *S. serrata* was more aggressive than *S. oceanica*.

Discussion

The anatomy of male and female reproductive systems of both the species studied conforms to the pattern reported by Estampador (1949 b) and Gupta and Chaterge (1976) for mud crabs. In both sexes the reproductive systems are 'H' shaped as in other brachyuran crabs (Cronin, 1947; George, 1963; Ryan, 1967a,b; Vasisht & Relan, 1971; Haefner, 1977; Joshi & Khanna, 1982a,b; Melville-Smith, 1987; Wenner *et al.*, 1987). In adult male the internal organ consists of paired

testes which are medially interconnected and the paired vasa deferentia, with 3 distinct regions, the anterior, median and posterior regions. The external sexual organs include paired penes and the first and second abdominal appendages. However, there is no discernible structure representing vas efferens in between testes and the vas deferens. The presence of a distinct vas efferens has been observed in other portunid crabs as a very small tube which is not macroscopically distinguishable (Cronin, 1947; Nishioka, 1959; George 1963). According to Ryan (1967 a) this vas efferens is merely a specialised part of the proximal end of the AVD.

The paired ovaries are elongated, medially interconnected and lobulated in mature condition and they occupy almost the same position as the testes in males. At the postero-lateral border each ovary is connected to the spermatheca which in turn communicates with the exterior by vagina through a short oviduct. The structure in both the spcies of mud crabs closely agrees with that observed by Pearson (1909) in *Cancer pagarus*, Cronin (1942) and Johnson (1980) in *Callinectes sapides*, Estampador (1949 b) in *Scylla serrata*, George (1963) and Ryan (1967 b) in *Portunus sanguinolentus*, Haefner (1977) in *Chaceon quinquedens* and Hinsch (1988 a) in *C. fenneri*. The presence of a short oviduct has been reported by Estampador (1949 b) in species of genus *Scylla* and George (1963) and Ryan (1967b) in *P. sanguinolentus*. George (1963) reports that the oviduct, which is covered by gonadal tissue, runs for a short distance along the anterior inner side of the spermatheca and opens into it at about the middle position. In *Cancer pagarus* Pearson (1909) observed that the two posterior prolongations of the ovary are connected together at the posterior end. In the present study also it is observed that the posterior extremities of the ovary are connected in some specimens of both *S. serrata* and *S oceanica*. A similar condition has also been reported by Estampador (1949b) in the genus *Scylla* (species not specified). In *P. sanguinolentus* George (1963) noticed the posterior prolongation on the right side of the ovary to be shorter and

narrower than on the left side. In the present species, it is observed that there was no consistency in the relative lengths of the lobes of the ovary on the two sides as the posterior extension remained equal or on one side shorter or longer than on the other side.

The histological structure of male and female reproductive organs conforms to the general pattern observed in other brachyuran crabs by Cronin,(1942), George (1963), Ryan (1967a, 1967b). Haefner (1977), Joshi and Khanna (1982a,b), Melville-Smith (1987) and Wenner *et al.* (1987) and in genus *Scylla* by Estampador (1949b) and Uma and Subramaniam (1984). In the case of male *P. sanguinolentus*, Ryan (1967a) observed that subdivision of testicular lobe was only an occasional feature, and whenever noticed it was only incomplete. Joshi and Khanna (1982 a) could not find any lobation in the testes of the freshwater crab *Potamon koolooense*. During the present study both the species showed incomplete lobation and each of the incomplete lobes was divided into many seminiferous tubules.

In the marine crab *P. sanguinolentus*, Ryan (1967b) described two layered connective tissue for the thin wall of ovary. Johnson (1980) observed a thin capsule of fibrous connective tissue on the wall of the ovary of *C. sapides*. Present study indicated thin double layered ovarian wall made of connective tissue, which showed considerable thickening in early maturing and spent stages. The ovarian wall was very thin during ripe condition. According to Joshi and Khanna (1982b) the ovarian walls in *P. koolooense* is continuous with ovarian stroma, and is thicker during post spawning period but becomes thin at maturing and mature stages. This is in conformity with the present finding. Though the crustacean ovary does not possess any strictly compartmentalized germerium and vitellarium as in insects, a germinal zone or germinal epithelium is distinguished during ovarian development (Adiyodi & Subramoniam, 1983). Wide variations are also noticed in the placement of the germinal zone. The germinal zone may be either peripheral as in the shrimp *P. setiferus* (King, 1948) or centrally located as in the brachyuran

crab C. *maenas* (Laulier & Demeusy, 1974). Durint the present study the germinal zone is found to be at the centre of the ovary in both the species. Same is the condition in *P. pelagicus* (Dhas *et al.* 1980) and *P. sanguinolentus* (Ryan, 1967 b). According to Adiyodi and Subramoniam (1983) aggregation of primordial cells in the centre of the ovary may be advantageous for the easy displacement of primary oocytes to the growth zone in later stages.

The process of gametogenesis in the present species did not vary significantly from the general pattern in crustaceans, and both the species exhibited almost similar pattern of development of sperm and ovum. On the contrary, Estampedor (1949 a , b) supported his taxonomic revision of genus *Scylla* based on the differences noticed in the gametogenesis of the four group consisting of three species and one variety. But Stephenson and Campbel (1960) observed that the cytological differences indicated by Estampador were not impressive. Structural and ultrastructural studies of spermatogenesis in crustacean species of different taxonomic groups (King, 1984; Genthe, 1969; Malek & Bawab, 1974 a, 1974 b; Aiken & Vaddy, 1980; Johnson,1980; Durfort *et al.*, 1985; Garcia Valero, 1988) have led to the finding that the process is basically similar in all the species. Binford (1913) observed the presence of both spermatocytes and spermatids in the same seminiferous tubule. Cronin (1947), however, reports that in C. *sapidus* the spermatocytes of a tubule get differentiated at the same time. According to Johnson (1980), mitosis of primary spermatocytes and meiosis of secondary spermatocytes are roughly synchronized so that almost all the germ cells in a tubule are in the same stage of development. In the present study also, except for the resting oogonial cells, all the cells were in the same stage of development in both the species.

The process of oogenesis in both the species of mud crabs is completed after passing through two major developmental phases as is the case of other crustaceans. The first one is proliferative phase in which the primary oogonial cells multiply to form secondary oogonial cells and these in turn transform into pri-

mary oocytes. The second one is the vegetative phase, the first part of which (previtellogenic) involves accumulation of large amount of ooplasm in which yolk formation has not started; and the later part (vitellogenic) involves successive growth of the oocyte with repeated accumulation of yolk material in the cytoplasm as observed by Cronin (1942), Ryan (1967 b) and Johnson (1980) in other species of crabs.

The spermatophore formation in both *S. serrata* and *S. oceanica* during the present study closely followed the pattern described by Uma and Subramoniam (1984) for their *S. serrata*. In crustaceans in general, after spermatogenesis, the spermatozoa move down into the vas deferens (Hinsch, 1988 a). The vas deferens functions as a site of sperm maturation, encapsulation of sperms into spermatophores, production of seminal fluid and storage (Langreth 1969, Hinsch & Mcknight, 1988). Though the process of spermatogenesis is basically similar in all decapod crustaceans (King, 1948, Genthe, 1969; Malek& Bawab, 1974 a, 1974b; Aiken & Waddy, 1980; Johnson, 1980; Durfort *et al.*, 1985; Garcia valero, 1988), the formation of spermatophore does not always follow the same pattern nor is the functional structure same in all. Comparative morphology of decapod spermatophores suggests their relationship with fertilization (Uma& Subramoniam, 1984). In brachyuran crabs with 'internal fertilization' the simplest type of spermatophores are found (Subramoniam, 1991). In the present study non-pedunculate vesicular spermatophores are observed in both the species of crabs. The only difference noticed is in the size of the spermatophores, the maximum size observed in *S. oceanica* being 116 μ whereas in *S. serrata* it was only 93 μ. The double wall of spermatophore was clearly visible in the semi-thin sections of MVD of *S. oceanica* as observed by Uma and Subramoniam (1979) in *S. serrata*. According to Uma and Subramoniam (1984) the proximal portion of AVD in *S. serrata* secretes substance 'A' which agglutinates sperm and forms the spermatophore layer and

its distal part secretes substance B which forms medium for storing spermatophores. The fully formed spermatophores are stored in MVD.

Regarding the number of maturity stages in brachyuran crabs diverging opinions are expressed by different authors. Hzefner (1976, 1977) recorded 6 stages in the rock crab *Cancer irroratus* and 5 stages in *C. quinquedens*. Dhas *et al.* (1980) came across 5 maturity stages in *Portunus pelagicus* while Sukumaran *et al.* (1986) recognized 4 maturity stages in *P. sanguinolentus* excluding spent/regenerating stage. Shanmugam and Bensam (1980) described 3 maturity stages for *S. serrata* viz. immature, maturing, mature. In the present study both the species showed 5 maturity stages including spent stage.

Pillai and Nair (1973a) who studied the breeding biology of several brachyuran crabs along the south west coast of India reported 12 cm CW as the minimum size of egg laiden females of *Scylla serrata,* while Shanmugham and Bensam (1980) reported 12.7 cm from the Tuticorin coast. In both the above cases the correct identity of the species studied is not known. Joel and Raj (1980) while studying the taxonomy of two species of *Scylla* in Pulicat lake reported the minimum size of berried specimen of *S. serrata* as 8.3 cm and that of *S. tranquebarica* as 12.3 cm, Kathirvel (1981) reported 8.5 cm for *S. serrata* and 12.0 cm for *S. oceanica* as the minimum sizes of berried females in Cochin backwaters, whereas Radhakrishnan and Samuel (1982) noted 9.8 cm to be the minimum size for *S. serrata serrata* (= *S. serrata*) and 14.0 cm for *S. serrata* (= *S. oceanica*) in the same ecosystem. A minimum size of berried specimens at 8.4 cm for *S. serrata* and 12.2 cm for *S. oceanica* recorded during the present study conforms well with the observation of Joel and Raj (1960) and Kathirvel (1981).

The possibility of mating of mud crabs in the brackishwater system is evident from the 'doubler formation' which is found to be a common feature in grow-out culture ponds. In the fattening ponds however this was not observed probably due to the fact that the crabs stocked in the fattening ponds are in an ad-

vanced stage of the post moult period. Normally mating is found to take place between hard shelled male and freshly moulted female. Ong (1966) reports that in *S. serrata* the male follows the female which is about to moult and then perform the premating embrace in which the female is passively carried around and the crabs remain in that condition for 3-4 days. Actual mating takes place soon after moulting of female.

Berried females with eggs in advanced stage of development are observed in ponds, which would suggest that normal embryonic development takes place in the brackish water environment which is in agreement with the observation of Marichamy and Rajapackiam (1992) who reported production of berried females in the brackishwater ponds at Tuticorin.

Both *S. serrata* and *S. oceanica* are found to breed throughout the year as evident from the occurrence of berried females when brackishwater and marine population are treated together. In the brackishwater systems berried females were encountered in most of the months of the year except during the south west monsoon period (June-August). Within the monsoon period, the total absence of ovigerous females in the brackishwater systems was observed between June-August in the case of *S. oceanica* and June-July in the case of *S. serrata*. Though ovigerous females contributed a small portion of the crab fishery during the monsoon period this was entirely contributed by catches from the open sea. Sheba (1988), studying the reproductive biology of mud crabs in Cochin backwater during the monsoon period came to the conclusion that mud crabs breed throughout the year including monsoon season.

Pillai and Nair (1973a) observed ovigerous females of *S. serrata* to occur throughout the year with a distinct peak in January and a period of least breeding activity during June-July along the southwest coast of India. A round-the-year breeding with definite peaks has been reported by Arriola(1940) Quinn and Kojis, 1987), Stephenson (1934) demonstrated that the crabs occurring in tropical waters

may exhibit several types of breeding cycles, such as continuous breeding around the year, discontinuous breeding in relation to lunar phases during greater or shorter period of the year, two spawning periods and lastly one single breeding season. A number of littoral and sublittoral crabs of the southwest coast of India are reported to breed throughout the year (Pillai & Nair, 1968). On the east coast of India *P. pelagicus* is reported to breed continuously throughout the year (Rahman, 1967).

According to Pillai and Nair (1973a) the fecundity of *S. serrata* varied between 3,18,720 and 5,21,450 in the size range of 11.5 to 15.0 cm CW, while Kathirvel (1981) reported a range of 6,20,250 to 1,479,680 eggs for crabs of 9.2 to 10.7 cm CW. During the present study fecundity of *S. serrata* varied between 1,52,140 (9.5 cm) and 4,53,344 with an average of 3,69,872 where as in *S. oceanica* it varied between 25,39,683 (13.4 cm) and 70,58,823 (18.2 cm) with an average of 41,23,494 eggs. The high fecundity of more than 7 million is a record for the Indian region. According to Haesman (1980), as quoted by Hill (1984b), mud crabs are highly fecund producing 1-7 million eggs.

Pillai and Nair (1973a) reported the average egg diameter of *S. serrata*(?) as 350 micron and the egg diameter of other 11 species of crabs they studied ranging from 287 micron in *Charybdis hoplites pusilla* to 390 micron in *Dorippe astuta*. During the present investigation the egg diameter ranged 290-340 micron in the case of *S. serrata* and 330-385 micron in the case of *S. oceanica*. According to Marichamy and Rajapackiam (1992) the egg diameter of *S. serrata* ranged from 280-390 micron/dia. Balasubramanian (1993) observed an egg diameter of 595 micron in the deepwater crab *Charybdis (Goniohellenus) smithii*. According to Hines (1988 b) the larger egg size of deep-sea brachyurans is to provide nutritional flexibility to their larvae when compared to the smaller eggs of species inhabiting in neritic regions of the sea where larvae get a more predictable source of food than the deep-oce-

anic region.

During the development of brachyuran eggs, marked changes in the colour of berry have been reported by many authors (Prasad & Tampy, 1953; Haefner, 1978; Erdman & Blake, 1988). According to Duppreez and Mclachlan (1984) the colour variations are due to biochemical changes and embryonic development. Variations in the colour of egg mass have also been noticed between species (Haefner, 1978; Erdman& Blake, 1988). During the present study the colour of the berry was yellowish in the case of *S. oceanica* and pinkish yellow in the case of *S. serrata* in the early stages of incubation which changed to brownish black or black in advanced stages of incubation in both the species of crabs. Among coastal crabs of the southwest coast of India, Prasad and Tampy (1953) noticed a bright yellow colour for the eggs of *P. pelagicus* immediately after oviposition, which subsequently changed to light brown and finally to greenish black at the time of hatching.

Ong (1964) reported an incubation period of 12 days at an average daily temperature range of 24.5 to 31.3°C. Brick (1974) also reported 12 days at an average ambient temperature of 25-26°C. Heasman and Fielder (1983) observed an inverse relationship between incubation period and temperature, and in his trials incubation period varied between 20 to 30 days in the temperature range of 26 and 20°C. During the present study the maximum incubation period was 13 days for *S. oceanica* and 12 days for *S. serrata* at an average temperature of 29°C.

According to Ong (1964) it takes about 18 days for the first 5 zoeal stages to complete at 31 $\pm$ 2 ppt salinity and 7-8 days for megalopa to metamorphose to crab stage at 24 $\pm$ 2 ppt salinity. During the present study *S. oceanica* took a minimum period of 17 days to complete all the five zoeal stages whereas *S. serrata* larvae took 20 days to reach zoea five and total mortality of zoea 5 occurred on 22nd day of rearing and none of them moulted to megalopa stage. Megalopa of *S. oceanica* took 6 days to moult to crab stage at a salinity of 21 $\pm$ 2 ppt and the first crab stage was obtained on 23rd day whereas it took 24 days in Ong's experi-

ment.

The changes in larval morphology were similar in both the species of crabs and closely followed the description given by Ong (1964). Brick (1974) took a minimum of 17 days and a maximum of 26 days to produce megalopa and 9-11 days more to reach the crab stage. In the experiments conducted by Haesman and Fielder (1983) it took 18-20 days to reach megalopa at 30 $\pm$ 2ppt salinity and 7-8 days to reach crab stage at 26-28 ppt salinity and 24.8-27.4°C temperature. Marichamy and Rajapackiam (1984, 1992) reported 18-20 days for zoea to reach megalopa and 8-11 days for megalopa to reach crab Instar I at 32 $\pm$ 2 ppt salinity and 26-30°C temperature, whereas Jamari (1992) reported 25-28 days from zoea through megalopa to crab stage at 28-30°C temperature and 25-30 ppt salinaty. During the present study the period taken by 1st zoea to reach the 5th zoea stage varied considerably in both the species. The minimum period taken at successive zoeal stages, were 4, 3, 3 and 4 days for 2nd, 3rd, 4th and 5th zoeal stage, adding upto 17 days in the case of *S. oceanica* and 5, 4, 5 and 6 days adding upto 20 days in the case of *S. serrata*. This was probably due to the fact that larvae of *S. oceanica* were able to accept frozen *Artemia* given on account of their larger size and capability to capture the feed than the larvae of *S. serrata*. In the case of *S. oceanica* in which the larval rearing could be continued upto crab stage, the total duration for transformation from zoea 1 to megalopa stage varied from 17 days to 21 days and megalopa stage to crab 1 stage took 6-9 days. In most of the experimental trials the period ranged from 18-20 days for the phase upto megalopa and 8-11 days for megalopa to crab stage. This observation is in conformity to the findings of most of the earlier workers (Ong, 1964; Haesman & Fielder, 1983 ;Marichamy & Rajapackiam, 1984,1992). While *S. oceanica* took a minimum of 17 days to attain the megalopa stage, the zoea stage of *S. serrata* did not develop beyond the fith zoeal stage even after 21 days of rearing under the same environmental conditions. The factors responsible for such type of protracted larval life of closely re-

lated species of mud crabs are posers of future research.

The laboratory rearing of early juvenile stages of the crabs showed more or less a similar growth pattern in both species. The minimum moult period increased gradually from initial to final. Though the percentage increment in carapace width and weight decreased with successive moults, the average moult increment in CW and weight increased gradually. Significant increase in weight was observed from 14th moult onwards in the case of *S. oceanica*. In this species the average increment in CW decreased from 47.4 % in the 1st moult to 12.7 % in the 15th moult in female and from 50% in the 1st moult to 14.4% in the 14th moult in male. According to Hartnoll (1965) the moult increment generally varies between 44% and 3%, whereas Ong (1966) reported the same to be between 50 and 6.3% in the 1st moult and 16th moult respectively.

The percentage increment in weight was almost 100 in the initial growth phases in both sexes, which decreased gradually to 54 in male in the 14th moult and 45.3 in female in the 15th moult in *S. oceanica*. Marichamy and Rajapackiam (1992) reported that the percentage increment in weight decreased from 98.4 in the 3rd moult to 76.7 in the 14th moult in *S. serrata* (?) juveniles. During the present study, *S. serrata* showed a faster decrease in percentage moult increment by weight, changing from 99% in the initial moult to 39% in the final moults of six successive moults observed.

The monthly growth recorded for *S. oceanica* was 10.74 mm CW (17.28 g) for female and 10.59 mm (13.3 g) for male, whereas *S. serrata* showed a lower growth rate of 10.02 mm (7.8 g) for female and 9.23 (7.12 g) for male. This would indicate a faster growth rate for *S. oceanica* even in the juvenile phase. Ong (1966) reported a lower growth of 6.8 mm/moult for *S. serrata*(?) in a rearing period of 532 days, whereas Marichamy and Rajapackiam (1992) recorded a growth of 9.3 mm CW/month, which is similar to the present observation on *S. oceanica*. The lower growth rate in Ong's experiments could have been due to the prolonged rearing

of crabs for more than one and a half years in small containers possibly resulting in stunted growth of the animal. Srinivasagam (MS) as quoted by Srinivasagam and Kathirvel (1992) observed monthly growth of 5-14mm (5-23 g) for a rearing period of 50-67 days with initial sizes of 61-81 mm CW. This large variation in the estimation of growth rates could be due to the difference in moult stage of seed obtained from the wild and also possibly due to mixing of more than one species in the growth experiments.

The estimated monthly growth of both the species based on the fitted growth curve indicate a better growth rate in natural conditions than in the laboratory. The average monthly growth of *S. oceanica* was 18.2 mm and 13.8 mm for 6 and 12 months respectively in the case of male and 17.0 mm and 13.0 mm in the case of female. The data indicate a comparatively lower growth for the female in the advanced stages. This reduced growth may be due to the large amount of energy being spent for gonadal development and also probably due to the extension of intermoult period during spawning and incubation. *S. serrata* also showed difference in growth between male and female at a greater degree, the male showing growth of 12.8 mm/month and 9.8 mm/month for the 6 and 12 months period and the female showing growth of 10.03mm and 8.1 mm for the same periods respectively.

The average sizes attained by *S. oceanica* (both sexes combined) work out to 16.1 cm, 20.5 cm and 21.6 cm CW at the end of the 1st, 2nd and 3rd year respectively. Mercy Thomas *et al.* (1987) recorded an estimated growth of 11.25-11.8 cm, 15.1-15.6 cm and 18-18.7 cm CW for the 1st, 2nd and 3rd year in the case of *S. serrata* (=*S. oceanica*). But Wildman (1974) has reported a growth of 0.5-0.7 kg by the end of the 1st year (which corresponds to 15-16 cm CW of *S. oceanica*), which is in agreement with the present results. The estimated growth rate of *S. serrata* was lower than in *S. oceanica*, the sizes attained by the former at the end of the 1st year, 2nd year and 3rd year being 10.8 cm, 14.7 cm and 15.5 cm CW respectively. Mercy

Thomas *et al.* (1987) reported a much lower growth for *S. serrata serrata* (=*S. serrata*) as compared to the present estimate. The poor sample sizes of these authors could have been a possible reason for the variation in growth.

During the present study the maximum growth rate was recorded in the 1st year and the prime export size of 500-550 g weight could be attained in 10-11 months period in the case of *S. oceanica*. Hill (1975 a) also noticed that growth is faster during the first 12-15 months by which time the crab attained a size of 80-160 mm CW. The present study revealed that *S. oceanica* attains a size of 160 mm CW and *S. serrata* attains 98-118 mm CW at the end of the first year. During the 2nd and 3rd year, the growth is comparatively less. It would therefore appear that in culture operations, harvesting crabs at the end of the 1st year will be more advantageous than harvesting after a later period.

The growth obtained for *S. oceanica* in the grow-out culture was almost similar to the growth estimated by length-frequency analysis of commercial catches. During the culture experiment the size of the crab increased from 9.92 to 15.64 cm in male and 10.7 to 16.4 cm in female in 6 months whereas the estimated growth from growth curve was 10.95 cm to 16.58 cm in male and 10.25 to 15.65 cm in female for the corresponding sizes in 6 months period.

Even though the average initial size of male was smaller than in females the monthly average growth in terms of carapace width was similar in both sexes (0.95 cm in male and 0.94 cm in female). But the average monthly growth in terms of weight showed that male (70.31 g) grows at a faster rate than female (64.00). As in the case of juvenile phase the percentage growth decreased with age of the animal, ie. from 12.56% to 7.61% of CW and 24.63 to 14.55% of body weight in female and 18.95 to 3.5% of CW and 30% to 17.5% of body weight in male in 6 months. There were also some deviations from this general trend in which sudden increase or decrease in growth was evident. Earlier workers have also reported that sudden increase in size can occur which may be upto 30-40% in adults

and upto 100% in juveniles in terms of weight and from 6% to 50% in terms of carapace width (Hartnoll, 1965; Ong, 1966; Marichamy & Rajapackiam, 1992).

The growth per day recorded during the present study ranged from 1.56 to 2.43 g with an average of 2.13 g in female and 1.33 g to 4.19 g with an average of 2.64 g in male. Samarasinghe *et al.* (1992) reported an increase in weight of 290g in 115 days which works out to 2.51 g/day. Prinpanapong and Yonngwanichsaed (1992) reported a growth of 52.3 g/month which compares well with the present observation for the initial stage. Srinivasagam (MS) as quoted by Kathirvel and Srinivasagam (1992 a) obtained an average growth of 127 g/month (from 472 to 790 g in 75 days). During the present study also monthly growth upto 125 g has been recorded at the final stage of the experiment.

Behavioural differences between two groups of mud crabs have been reported by many workers like Estampador (1949a), Joel and Raj (1980), Kathirvel (1981) and Radhakrishnan and Samuel (1982). According to Estampador (1949 a), the 'mamosain' group which included *S. serrata* were distinctly 'hole dwellers' in contrast to the decided propensity of 'banhawin group' towards rowing life. Similar observations were also made by Joel and Raj (1980) and Radhakrishnan and Samuel (1982) for their respective species. Joel and Raj (1980) noticed burrowing habit among both the species, *S. serrata* making a single opening and *S. tranquebarica* two opening, for their burrows. These authors have also pointed out that the former species was more agile and fierce, whereas the latter was sluggish. The present study conforms to the observations of Joel and Raj (1980) as regards the burrowing habits and aggressive nature of the crabs. Cannibalistic tendency was noticed in both the species, and in the case of *S. oceanica* it was observed from the megalopa stage onwards. Ong (1964), Marichamy and Rajapackiam (1984) and Jamari (1992) also reported cannibalism from the megalopa stage onwards for the species they reported as *S. serrata*.

In the grow-out culture of *S. oceanica* more than 50% mortality was ob-

served for which cannibalism was considered to be an important reason. Many authors have reported that cannibalism was the biggest problem in mud crab culture (Escritor, 1970; Marichamy *et al.*, 1980; Chen, 1990; Srinivasagam & Kathirvel, 1992; Chong, 1992). Hence control of cannibalism has been pointed out to be one of the important steps needed for enhancing production in grow-out culture and in hatchery operation. Some of the important methods suggested to reduce cannibalism are providing shelters, timely feeding in proper quality and quantity, stocking the pond at optimum level and proper water exchange and other farm management practices (Babu & Manjulatha, 1995; Suseelan *et al.*, 1995, Suseelan & Anil, 1995 and Suseelan, 1996a).

SECTION 3

CAPTURE FISHERY

The mud crabs of genus *Scylla* lend themselves to easy exploitation as they live in shallow estuarine and coastal areas which are easily accessible to small fishing units. They support traditional fisheries in many South East Asian countries like Philippines, Thailand, Indonesia etc. In India, the mud crabs form a major constituent of the crab fisheries of the brackishwater regions (Rao et al., 1973; Trivedi & Patel, 1975; Shanmugam & Bensam,1980). The average annual landing of crabs from the inshore waters of India during 1981-1995 amounted to 246420 t forming about 10% of the crustacean landings (Anon, 1982b, 1983b, 1986, 1989; Suseelan, 1996b). There is no reliable statistics of the total mud crabs landed in the country and whatever little information available pertains to only local fisheries of some of the major estuarine systems (Trivedi & Patel, 1975; Ansari & Harkantra, 1975; Ram & Chandramohan, 1978; Kathirvel, 1981). Among the 15 species of edible crab contributing to the fishery (Kathirvel & Sreenivasagam , 1992a), it is estimated that the mud crab *Scylla serrata* (Forskal) (and probably other species too) may form about 4.5%. (Banerji, 1969).

In early Eighties the mud crab fishery of India emerged as an export oriented trade with considerable development potential. The fast growing export trade for live mud crabs since mid Eighties (Raj, 1992) is indicative of the quantum of exploitation of this resource in the country. A close monitoring of the rate of exploitation and stock characteristics are essential prerequisites for proper management and conservation of the fishery to ensure sustainable yield. The present study is an attempt to generate a baseline data on mud crab fishery in Kerala coast

which has come up as one of the major Indian sources for live crab export to the South East Asian countries.

Fishing methods and seasons

The methods employed for catching mud crabs in the estuaries and back-waters are more or less the same throughout the Kerala coast. The important gears used are ring nets, gill nets and long lines which are operated with the help of non-motorised dug out canoes of about 2.5-3 m OAL. Beside these, skin diving is also practised in the fishery in some places.

Gill net: Bottom set gill nets of 200-300 m length made of nylon or polyester monofilament, with mesh sizes 6-14 cm (stretched) are used for entangling the crabs (Pl. 38a). The mesh size is relatively smaller (6-8 cm) when polyester ('Pattuvala') is used. No.6 nylon twine is used as head rope for mounting the net. The foot rope is often reinforced with coir rope of 1 cm diameter. Disc shaped PVC floats are attached to the head rope at 5-15 m intervals. Two sealed kerosene tins or polystyrene floats are connected to the ends of head rope and two stone sinkers at the ends of foot rope. In Cochin backwaters near the bar mouth where tidal force is very strong, stone weights upto 10 kg are used to prevent drifting of the net. Fishing is generally more active during the hightide period during day or night. Each unit of dugout canoe is manned by two persons, one for paying or hauling the net and the other for rowing the canoe. In each fishing trip the nets are lifted 5 to 6 times at intervals of 1 to 2 hours during day time or at lesser intervals during night time. In the beginning of monsoon season, however, hectic fishing is carried out throughout the day due to the strong influx of flood water and the resultant heavy catches of crabs especially in Cochin Backwaters.

Ring net (Umbrella net): The most popular gear used for catching mud crabs in Cochin backwaters, the ring net is more advantageous than gill net as the chances of damage to the crab is almost negligible. The chance of escape of crab also is

a

b

PLATE 37

a. Ring net made of steel rod and operated in Cochin backwater

b. Ring net made of cycle rim and operated in Korapuzha estuary

a

c

b

PLATE 38

a. Crab caught by gill net

b. Long line with hooks used in Korapuzha estuary. Scoop net and aluminium float are also seen

c. crab diver wearing goggles

much less in this gear when compared to long lines. The net consists of an iron ring of 75-100 cm diameter fabricated out of 7-10mm diameter mild steel rod and a loose circular nylon net piece of 2-3 cm mesh size attached to it along the circumference (Pl. 37a). In Korapuzha estuary old cycle rims are used as the frame (Pl. 37b). Three to four bridles made of nylon strings are attached to the ring equidistantly and the free ends tied to a nylon rope of 6-8 m length by which the nets are set and hauled back. A thermocol piece or a sealed oil-can is attached to the free end of the rope which acts as float and marker. One or two pieces of bait are attached at the centre of the ring by means of two strings tied to the ring crossing each other at the centre. Small pieces of fish (eel, cat fish or mackerel head) are used as bait. Usually two fishermen go in a dug out canoe for fishing, with 10-14 rings. A single person can also operate this gear usually with 6-7 rings. These nets are operated at day time during high tide. On reaching the fishing ground baited nets are placed a few meters apart and lifted at regular intervals.

Long line: Long line of about 450-600 m in length with 150-350 branch lines, each about 15 cm long, is used in Ashtamudi lake. The baits are tied to the free ends of the branch line. In Korapuzha estuary, the main line is about 150-200 m long with 100-125 branch lines each of 20 cm length. The free end of the branch line is provided with a hook (No. 7/8/9)(Pl. 38b). Two PVC or aluminium floats are tied to the ends of the line. The line is weighted down by attaching rock pieces at either ends of the mainline (Korapuzha estuary) or by using lead sinker at every 15th branch line (Ashtamudi lake). Fresh or salted eel meat is used as bait. The gear is operated mostly in day time during high tide. After setting the line, the line is lifted at intervals of approximately 30 minutes and crabs clinging to the bait are collected by scoop net.

Skin diving: Divers using goggles to cover their eyes (Pl. 38c) undertake skin diving at depths upto 7 m for catching mud crabs especially in Ashtamudi lake.

The buried crabs are identified from the eyes and antennae visible over the mud and caught from behind. The best season for this type of fishing is summer when the water is very clear.

Among the different types of gears described above gill nets and long line are the most common gears operated in the Ashtamudi lake. In Cochin backwaters and adjoining tide fed regions of Vembanad lake ring nets and gill nets are the predominant gears operated. In Korapuzha estuary line fishing is the most common gear employed with restricted operation of gill nets and ring nets. In all the above brackishwater systems, in addition to the aforesaid dominant gears involved in the crab fishery, mud crabs are also caught as bycatches in several other types of nets like stake nets, dip nets, cast nets, seines etc.

Although crab fishing is practised throughout the year, the peak fishing season extends from December to June. For gill nets, however, exceptionally good catches are recorded soon after the onset of monsoon rains and with the commencement of freshwater run off.

Landings

The landing data of mud crabs were collected from all the three brackishwater systems by monthly visits at the fixed observation Kavanadu, centres Palliport and Elathur. Both the species of mud crabs were landed at all these centres in varying proportions throughout the year. At the landing centres the crabs landed were graded as 'big', 'big water', 'medium', 'water', 'small' 'red' and 'local' on the basis of shell condition, weight and species and sold them to the middle men. The merchants distinguished both the species of mud crabs and priced them differently. *S. oceanica* was known by the local trade name 'green crab' or 'white crab', whereas *S. serrata* was known as 'red'. Shell condition or hardness which was an arbitrary measure of meat quality was assessed by pressing the sternites of the crabs. Animals which yielded to pressing was the

TABLE 15 : Commercial grades of mud crabs and their prices

GRADES	SPECIES	WEIGHT (g)	SHELL CONDITION	PRICE (Rs/kg)
Big	*S. oceanica*	>=550	Hard	200.00
Big-water	*S. oceanica*	>=550	Soft	80.00
Medium	*S. oceanica*	>=350-550	Hard	75.00
Water	*S. oceanica*	350-<550	Soft	45.00
Small	*S. oceanica*	250-<350	Hard	45.00
Red	*S. serrata*	>=250	Hard	45.00
Local	*S. oceanica*	<250]	Hard	
"	*S. oceanica*	<350]	Soft	14-20
"	*S. serrata*	250]	Soft & hard	

postmoulted crabs with a soft shell having poor quality watery meat and hence known as 'water crabs'. The 'water crabs' were again graded into 'big water' and 'water' according to their body weight. Those with hard shell were graded as 'big', 'medium' and 'small' in the case of *S. oceanica* whereas in the case of *S. serrata* they were treated as a single grade called 'red'. The term 'local' included underweighed and damaged crabs of both species which were not used for export. Table 15 shows details of the different grades and their prices offered at the landing centres.

Landing at Kavanadu: The total estimated crab landing for the one year study period amounted to 27,189 kg of which 75% was contributed by *S. oceanica* and 25% by *S. serrata*. Both the species recorded minimum and maximum catches in August and June respectively. The average monthly catch of *S. oceanica* worked out to 1,732 kg with the maximum of 2785 kg in June. In the cases of *S. serrata* the average monthly catch amounted to 534 kg with a maximum of 1085 kg in the same month. In the overall crab landing, *S. oceanica* formed about 80% and *S. serrata* 20% in terms of number.

Fig.6 shows the monthly variations in the landing of different commercial grades. The catch of 'big' remained at a low ebb during August-October, and it gradually increased to a maximum of 1,221 kg in March and thereafter declined. Relatively higher catches of 'medium' were recorded during December and June, 'small' during November and May-June, 'big crabs' during February-June, 'water' during November and May-June and 'red' during November-December and May-June.

Landing at Palliport: The total crab landing for the one year period was 24,144 kg, of which 18,225 kg(75%) was constituted by *S. oceanica* and 5919 kg (25%) by *S. serrata*. In terms of number, *S. oceanica* formed 81% and*S . serrata* 19%. The highest catch of *S. oceanica* was recorded in June (3101 kg) and that of *S. serrata* in may

Monthly trend in grade wise catch of mud crabs at Kavanadu (Ashtamudi lake)

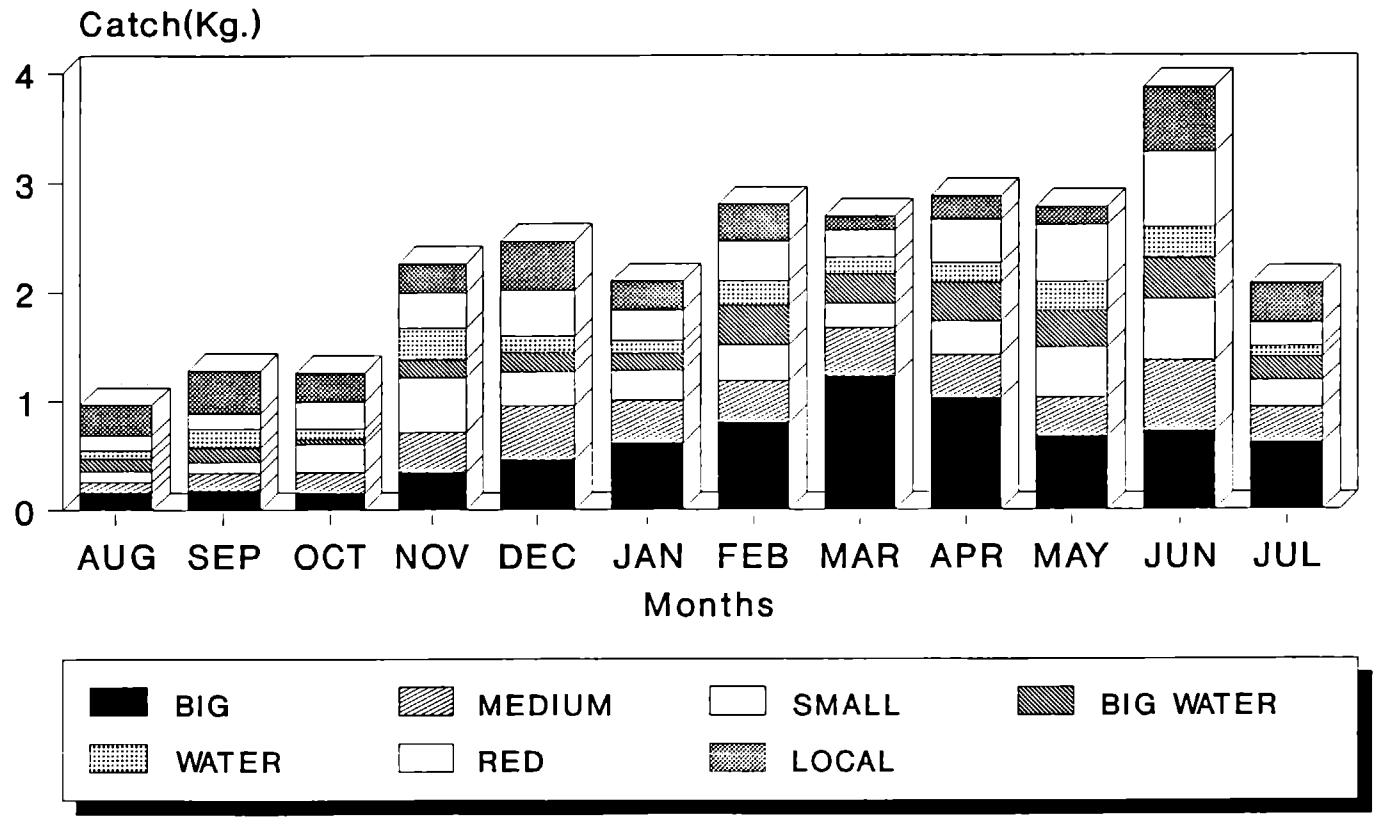


Fig. No.6

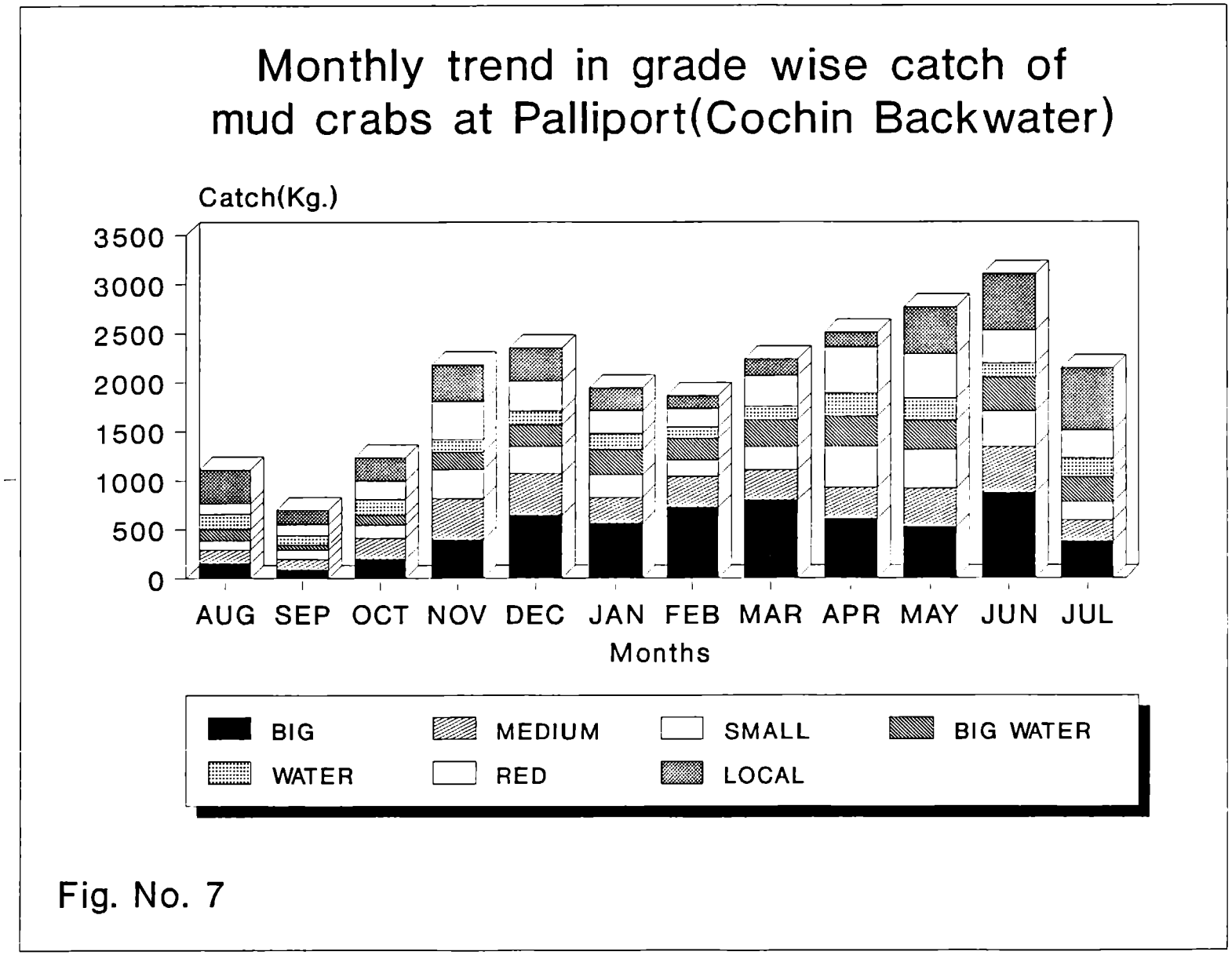

Monthly trend in grade wise catch of mud crabs at Palliport(Cochin Backwater)
Catch(Kg.)
3500
3000
2500
2000
1500
1000
500
0
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
Months
BIG
MEDIUM
SMALL
BIG WATER
WATER
RED
LOCAL

Fig. No. 7

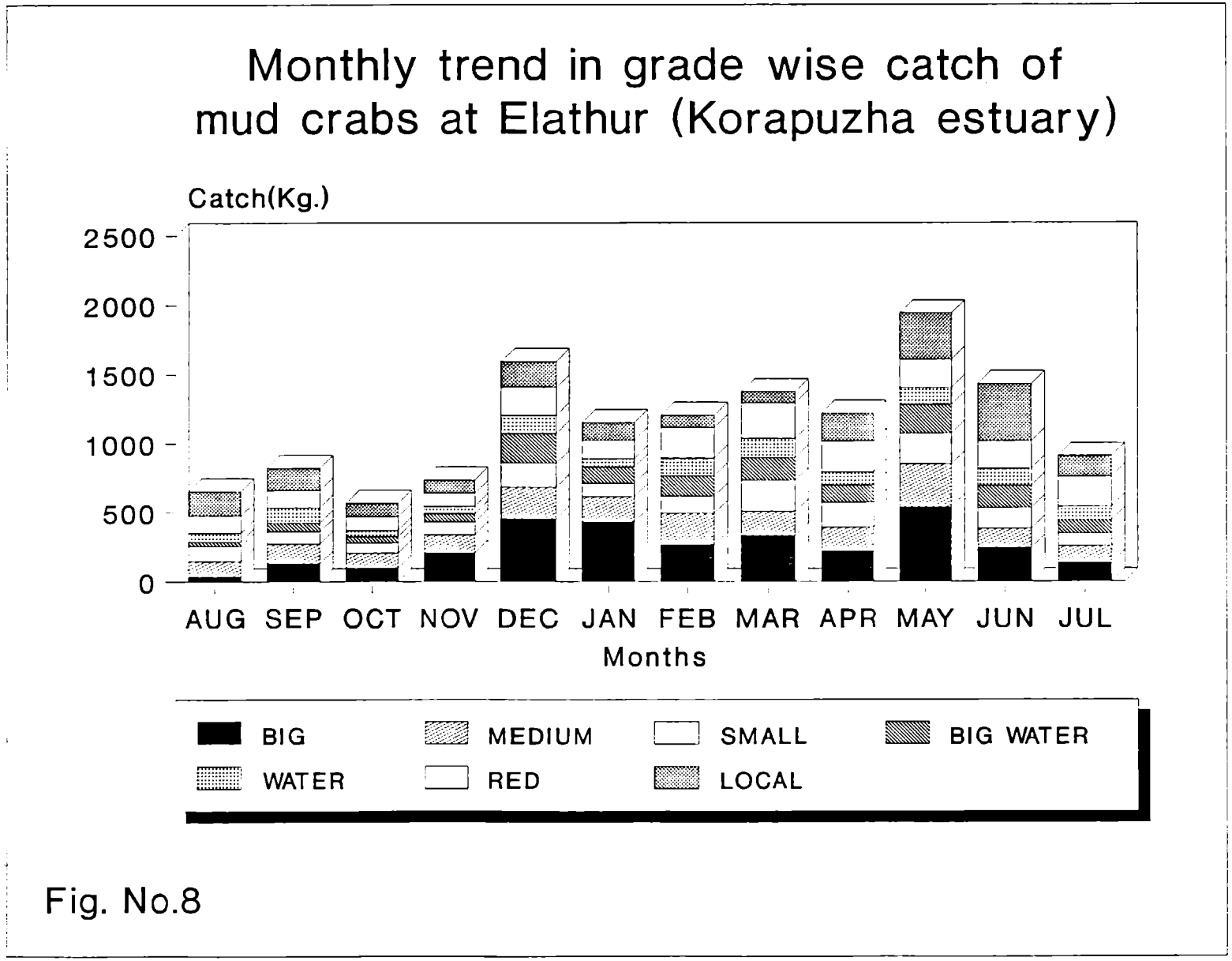

Monthly trend in grade wise catch of mud crabs at Elathur (Korapuzha estuary)
Catch(Kg.)
2500
2000
1500
1000
500
0
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
Months
BIG
MEDIUM
SMALL
BIG WATER
WATER
RED
LOCAL

Fig. No.8

Trend of yearly price variations of mud crabs grade wise at Kochi(1987-'95)

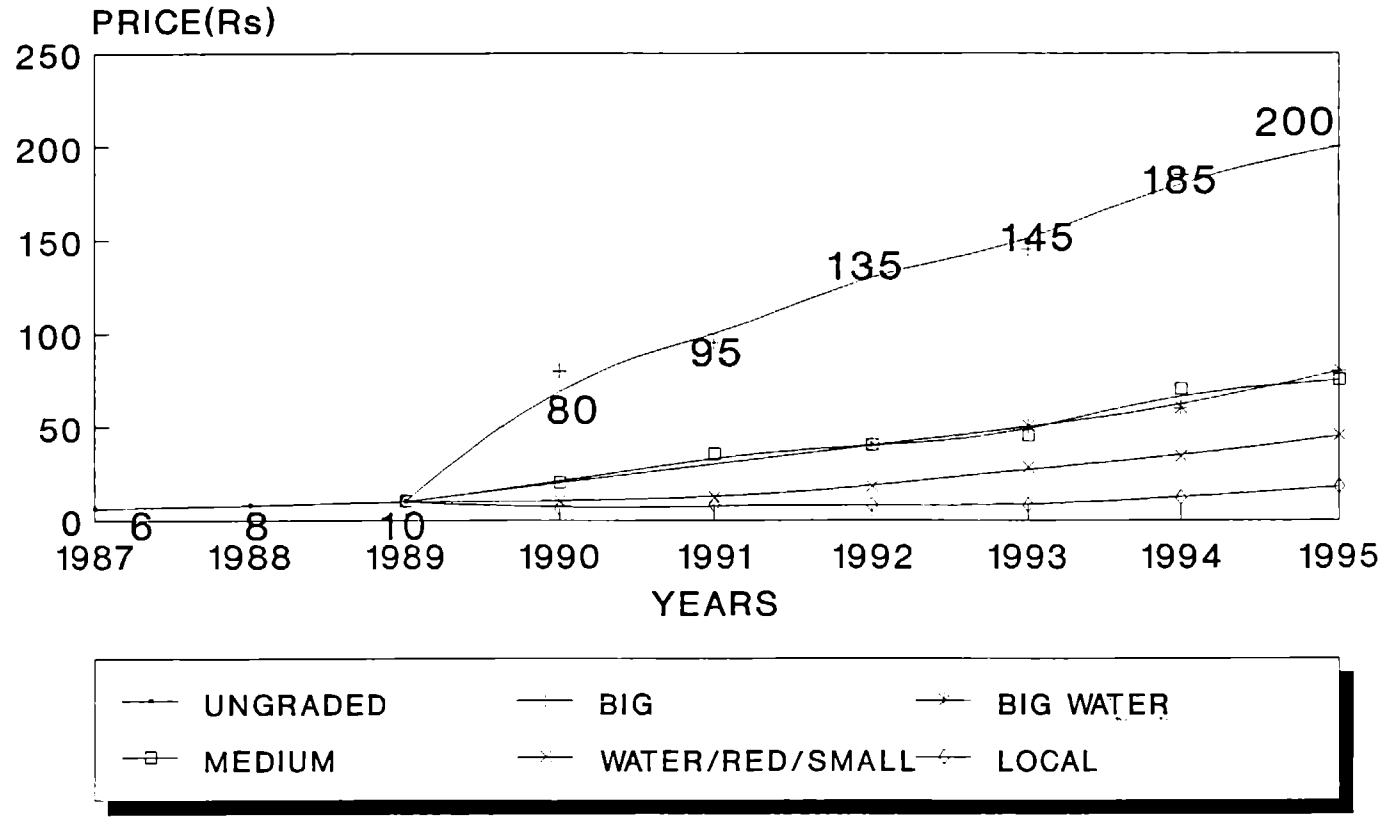


Fig. No. 9

(771 kg).

The catch of 'big' was low during August-October (Fig.7) and comparatively high during the rest of the months. Its peak abundance was noticed in June (872 kg). Relatively higher catches of 'medium' were recorded during November-December and May-June, 'small' during April-June, 'Big water' during June-August, 'water' during April-May and 'red' during November-December and March-May.

Landing at Elathur: A total of 13,607 kg of crabs was registered at this centre, of which 10,107 kg (73%) was contributed by *S.oceanica* and 3,500 kg (27%) by *S. serrata.* In terms of number *S. oceanica* accounted 78% and *S. serrata* 22%. The monthly catch of *S. oceanica* was maximum in May (1516 kg) and that of *S. serrata* in June (474 kg).

With an average monthly production of 358 kg, the landing of 'big' showed two peaks, one in December and the other in May (Fig.8). Relatively higher abundance of 'medium' was observed in the fishery during December-February, 'small' during March-April, 'Big water' during February-March, 'water' during February-March and June and 'Red' during February, April and July.

In order to study the price variation for mud crabs in the earlier years, the price records maintained by the crab merchants at Cochin were examined for the period 1987-1995 and the trend in annual price variation is depicted in Fig.9. It may be seen that, the price of crabs at the landing centres remained at a very low level of Rs.6-10/kg till 1987. In the subsequent years the price shot up as a result of the unusual demand of live crabs for export. The price increase was very rapid in the case of grade 'big' as it was the prime commodity for the export trade. The price of this grade took a sudden leap to Rs.80/kg in 1990 and thereafter considerably increased to reach a level as high as Rs.200/kg by 1995. The price increase for the other grades was relatively of a low order.

Population charecteristics

Size distribution

The commercial fishery of mud crab was formed by both the species in varying proportions in all the three brackishwater systems. The size composition of these species in varying proportions in the catches of the different ecosystems is described below.

Ashtamudi lake

In the case of *S. oceanica*, examination of 1183 crabs including 527 males and 656 females spread over 12 months from August 1992 to July 1993 indicated a size range of 6.1-21.0 cm CW for male and 6.1-20.0 cm CW for female. The fishery was predominantly constituted by the size group 9.1-15.0 cm for male and 8.1-14.0 cm for female. The overall size frequency was of unimodal pattern with the mode at 13.1-14.0 cm for male and 12.1-13.0 cm for female (Fig.10,11). The mean CW worked out to 12.3 cm for male and 12.2 cm for female.

The measurements of *S. serrata* numbering a total of 591 crabs, including 305 males and 286 females, showed a size range of 6.1 to 15.0 cm CW. Nearly 88% of males and 82% of females belonged to the size group 8.1-13.0 cm. The size frequency distribution of this species was also unimodal in nature, with modes at 11.1-12.0 cm for male and 10.1-11.0 for female (Fig.12, 13). Male showed an annual mean size of 10.5 cm and female 10.4 cm CW.

Cochin backwater

S. oceanica ranged in size between 6.1 and 21.0 cm CW in male and 6.1 and 20.0 cm in female. Then size frequency distribution of a total of 1127 crabs, including 545 males and 582 females, showed that nearly 70% of the former and 67% of the latter belonged to the size group 9.1-15.0 cm and 8.1-14.0 cm respectively. In the unimodal size frequency, the mode was noted at 13.1-14.0 cm in male and 11.1-12.0 cm in female (Fig.14, 15). The mean size worked out to 12.5 cm for male

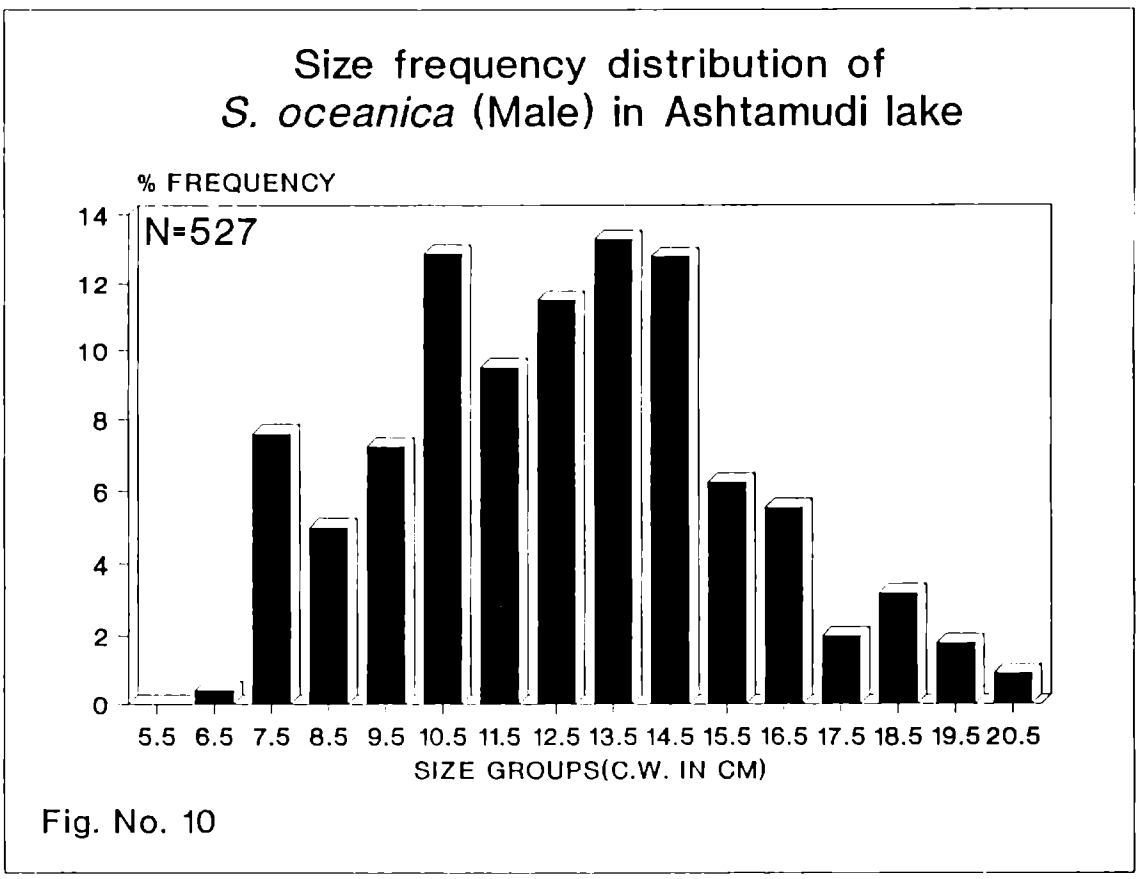


Fig. No. 10

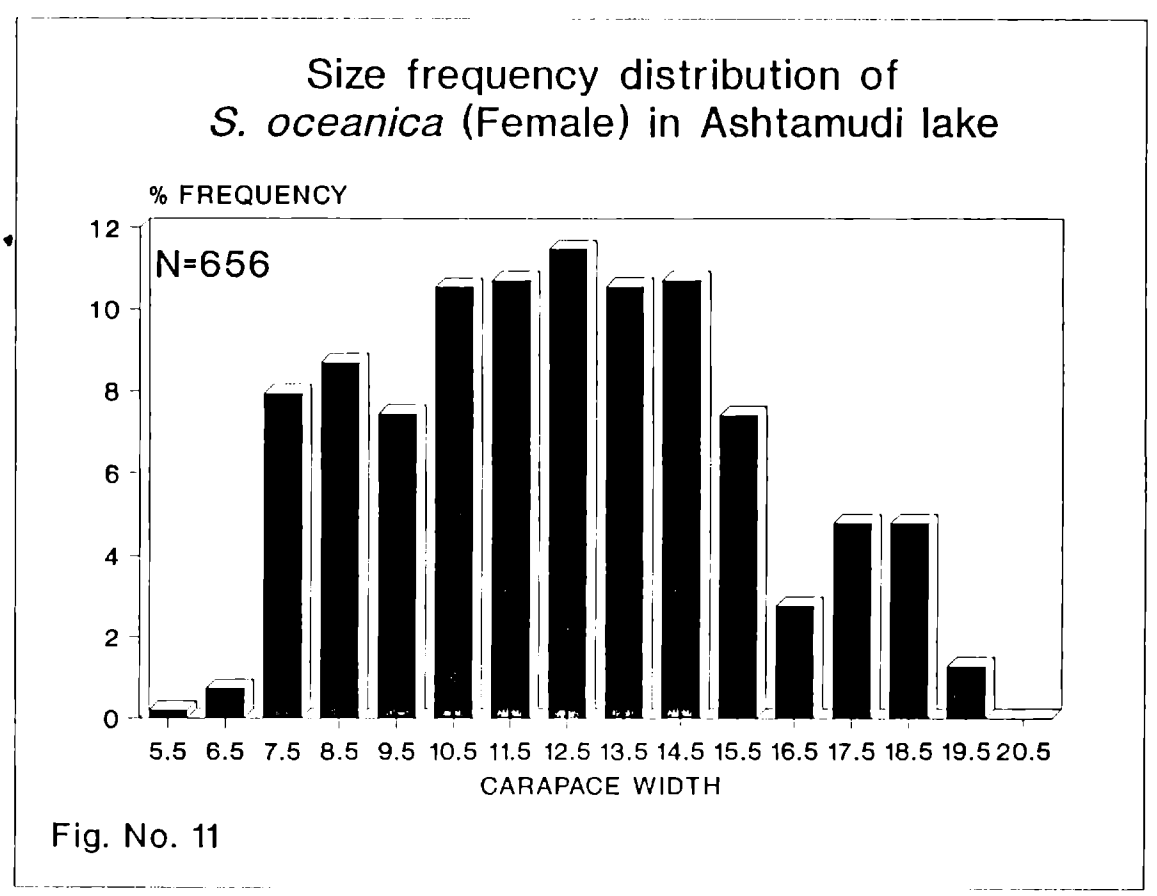


Fig. No. 11

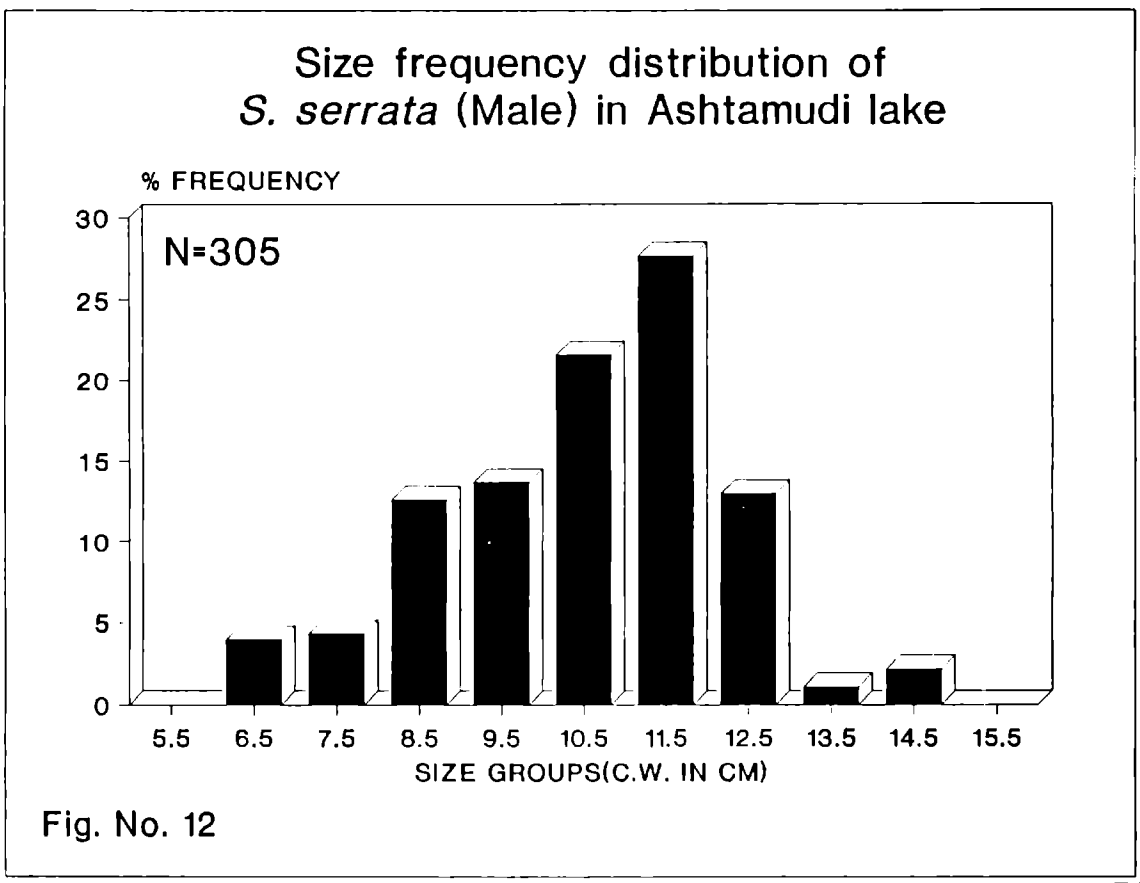


Fig. No. 12

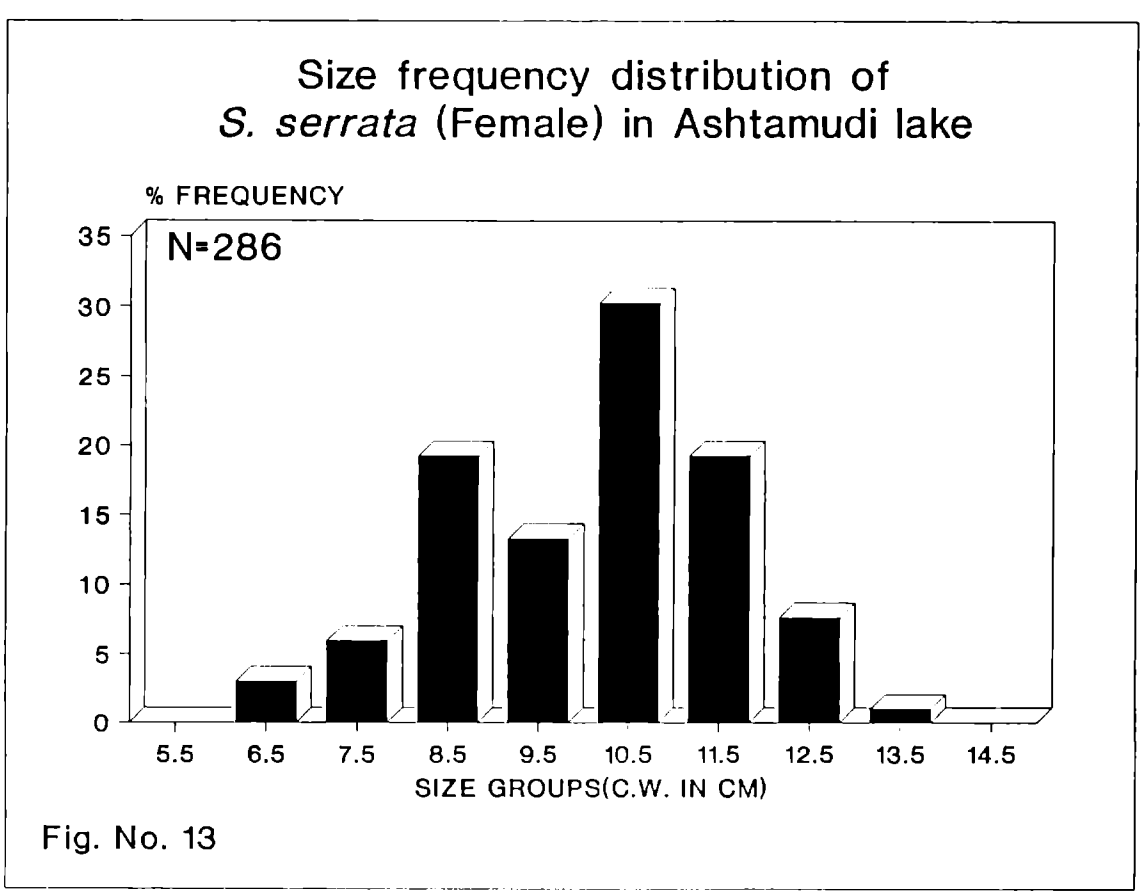


Fig. No. 13

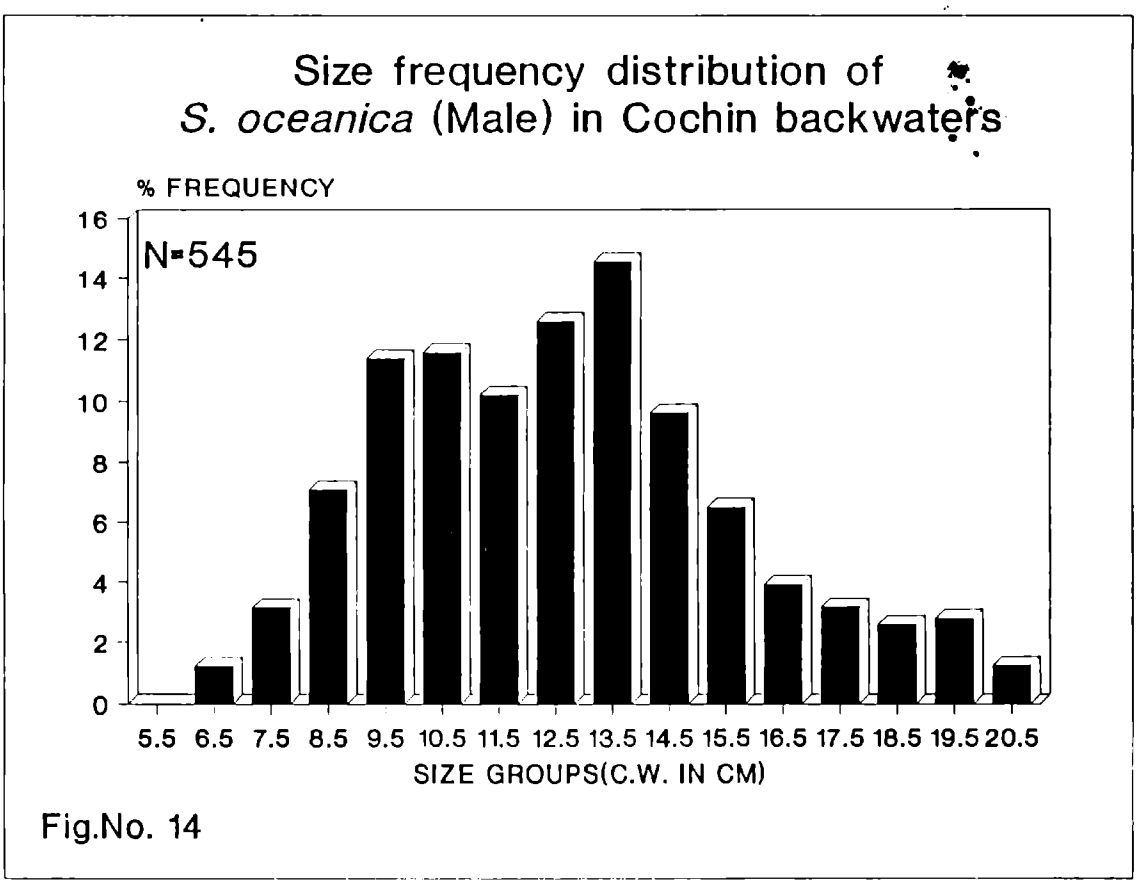
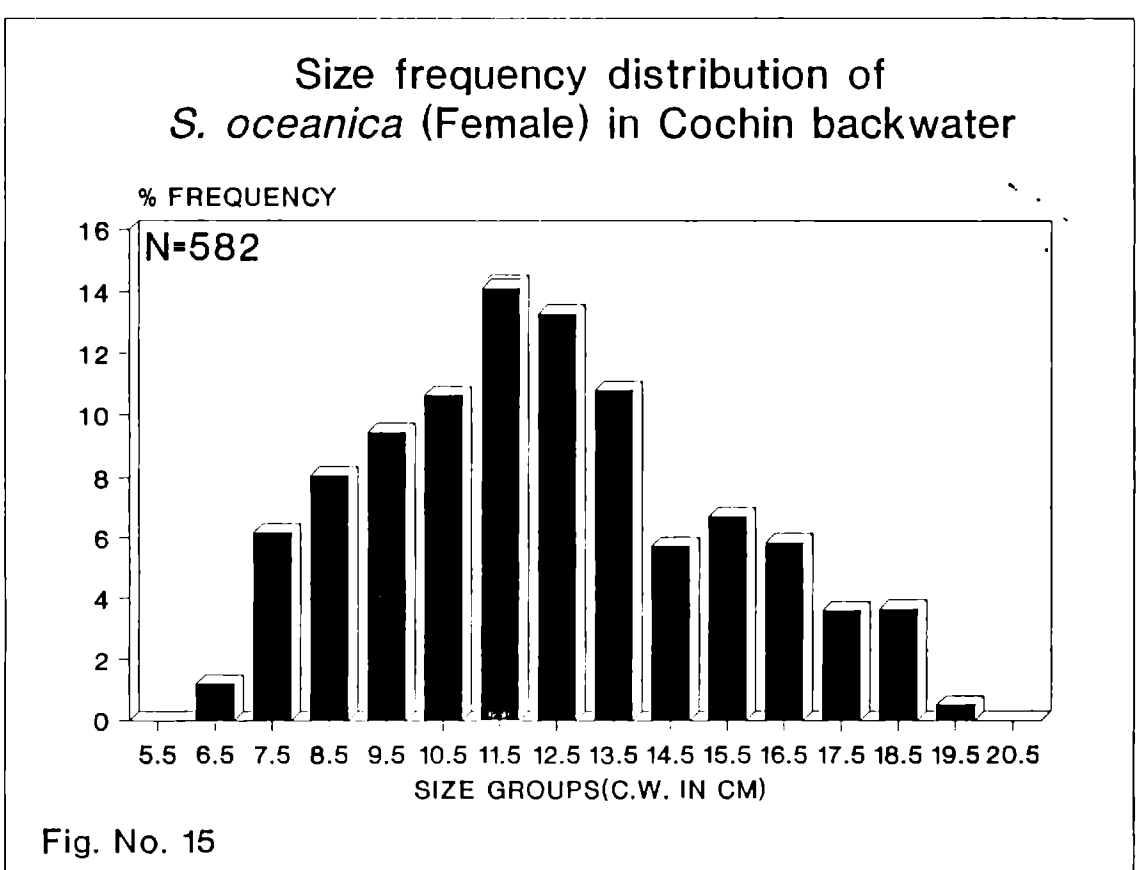


Fig.No. 14



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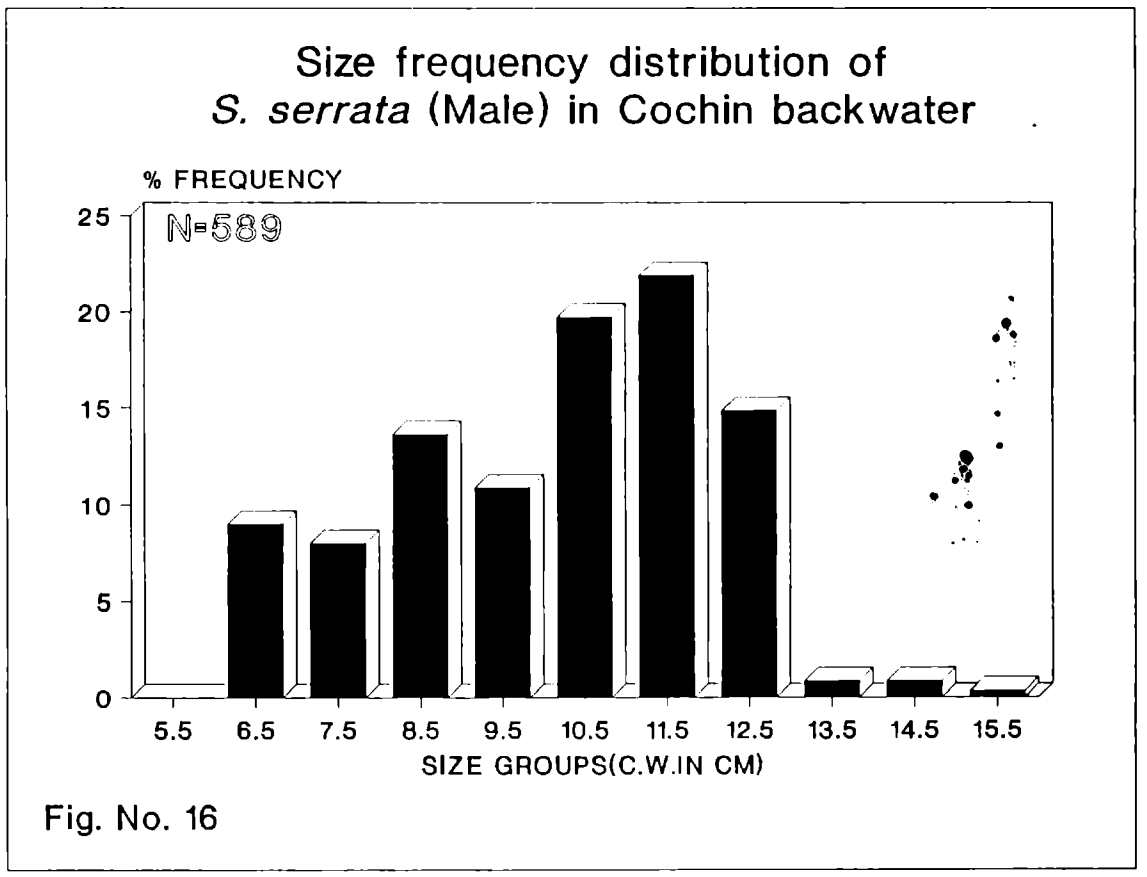

Fig. No. 16

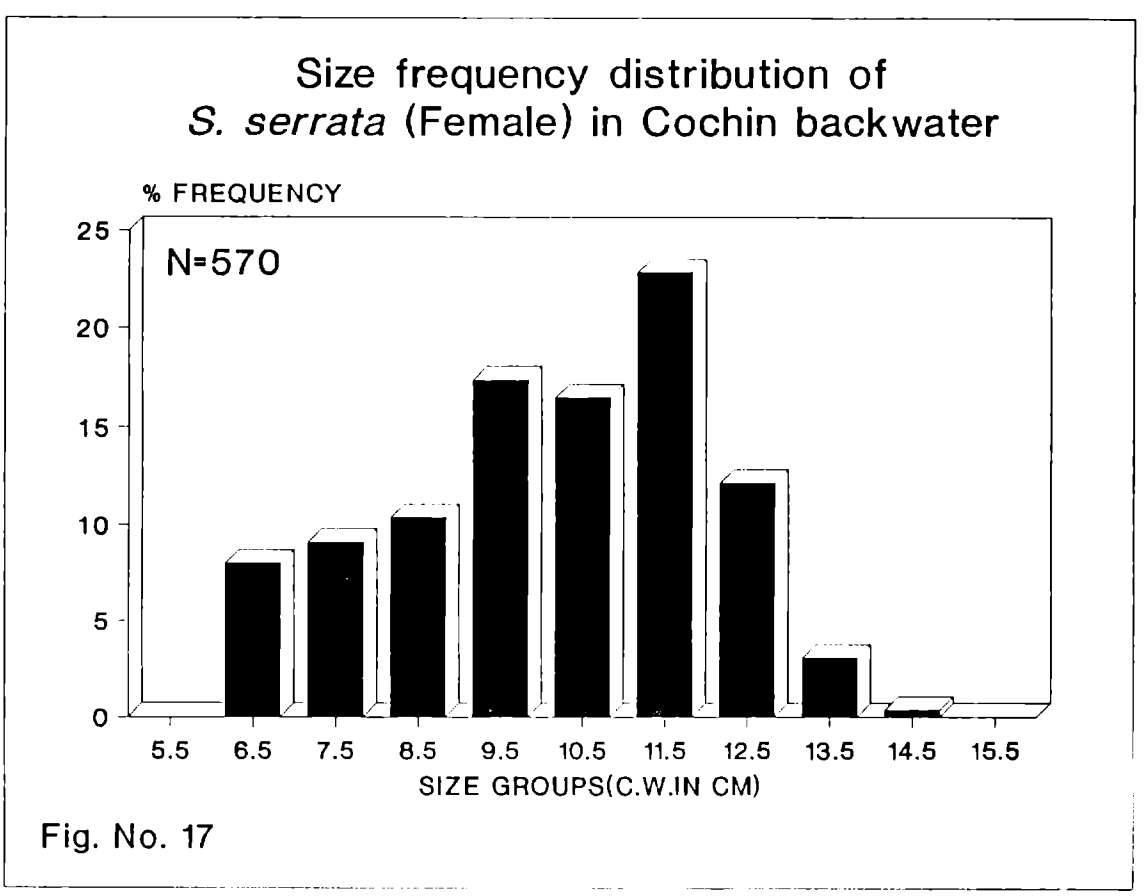

Fig. No. 17

Size frequency distribution of
S. oceanica (Male) in Korapuzha estuary

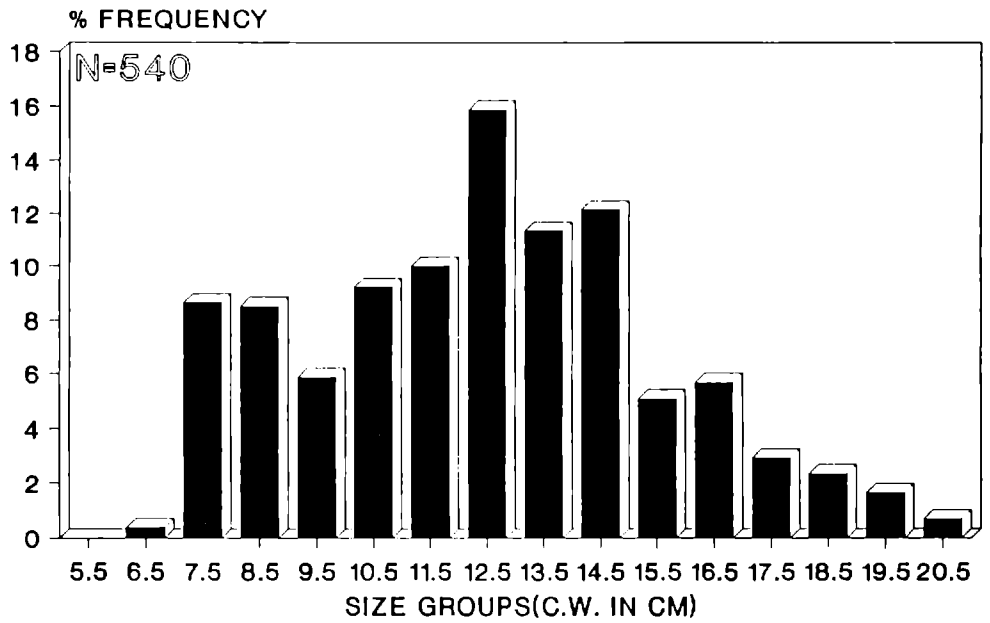

Fig. No.18

Size frequency distribution of
S.oceanica (Female) in Korapuzha estuary

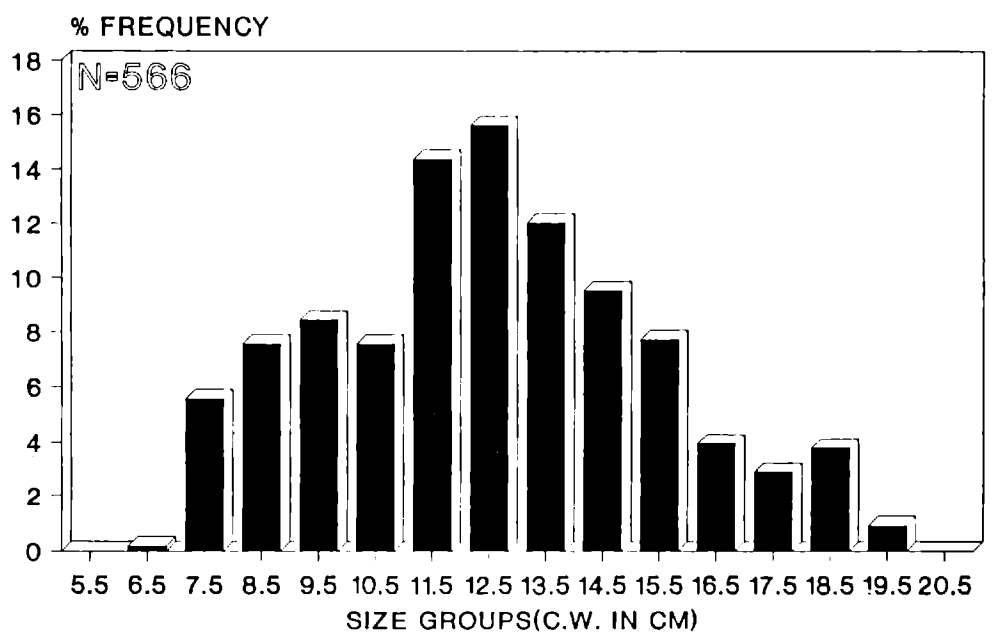

Fig. No.19

Size frequency distribution of
S. serrata (Male) in Korapuzha estuary

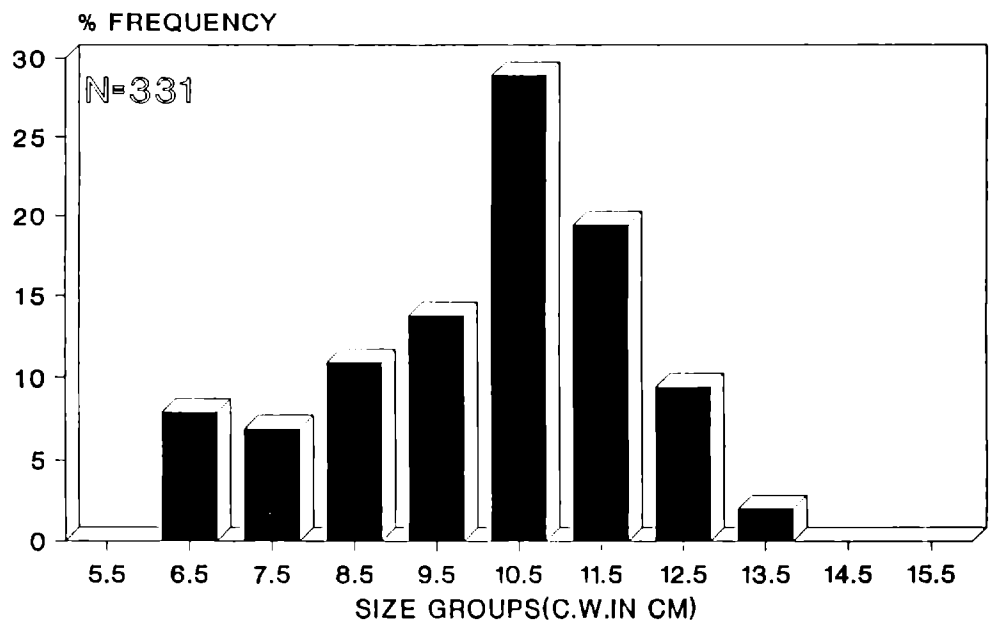

Fig. No.20

Size frequency distribution of
S. serrata (Female) in Korapuzha estuary

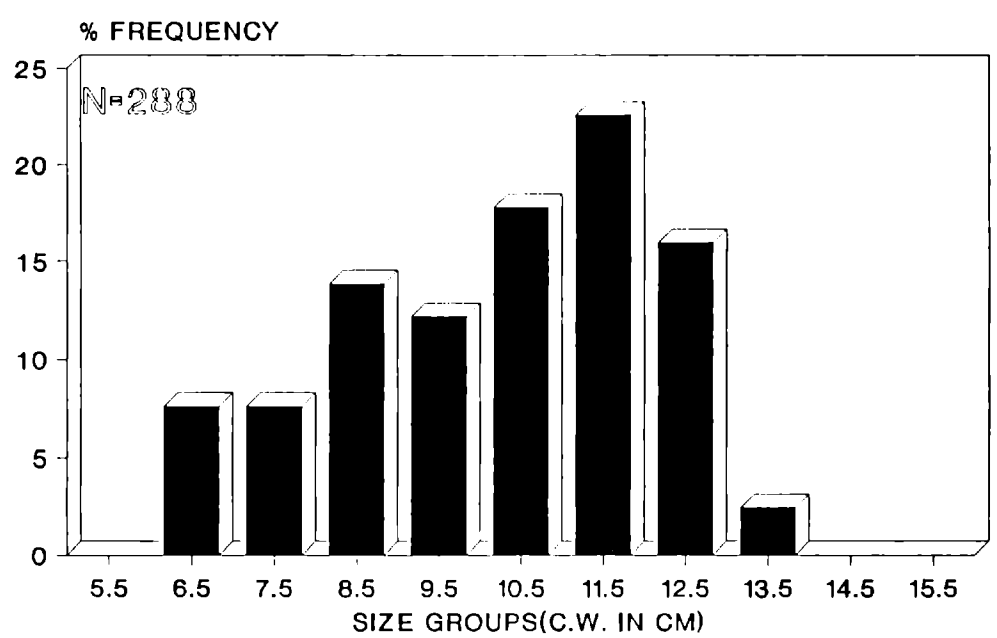

Fig. No.21

and 12.2 cm for female.

In *S. serrata* a total of 1059 crabs measured, including 589 males and 570 females, indicated a size range of 6.1-16.0 cm CW for male and 6.1-16.0 cm CW for female. The fishery was predominantly constituted by the size groups 8.1-13.0 cm for male and 9.1-13.0 cm for female. The annual size frequency distribution was unimodal, with mode at 11.1-12.0 cm in both sexes. (Fig.16, 17). The mean sizes 10.1 cm for male and 10.0 cm for female.

Korapuzha estuary

A total of 1106 crabs including 540 males and 566 females of *S. oceanica* were measured. The species showed a size range of 6.1-21.0 cm CW, with about 60% belonging to the size group 10.1-15.0 cm in male and 11.1-16.0 cm in female. (Fig.18, 19) The overall size frequency was unimodal with the mode at 12.1-13.0 cm in both sexes. The mean sizes worked out to 12.4 cm in male and 12.2 cm in female.

In *S. serrata*, measurements of a total of 619 crabs including 331 males and 288 females indicated a size range of 6.1-14.0cm CW for both sexes. The fishery was mainly constituted by the size group 8.1-13.0 cm for male as well as female. The overall size frequency was unimodal in nature, with modes at 10.1-11.0 cm for male and 11.1-12.0 cm for female (Fig.20, 21). The mean size of male worked out to 9.8 cm and that of female 10.1 cm in CW.

Recruitment

Smaller crabs of *S. oceanica* in the size range 9.5-11.5 cm were observed during June to November with peak recruitment during August-September. In the case of *S. serrata* the size at recruitment ranged from 9.5 to 10.5 cm CW and the same was encountered throughout the year with peak abundance in October-December.

Breeding population

An important aspect considered for the purpose of capture fishery man-

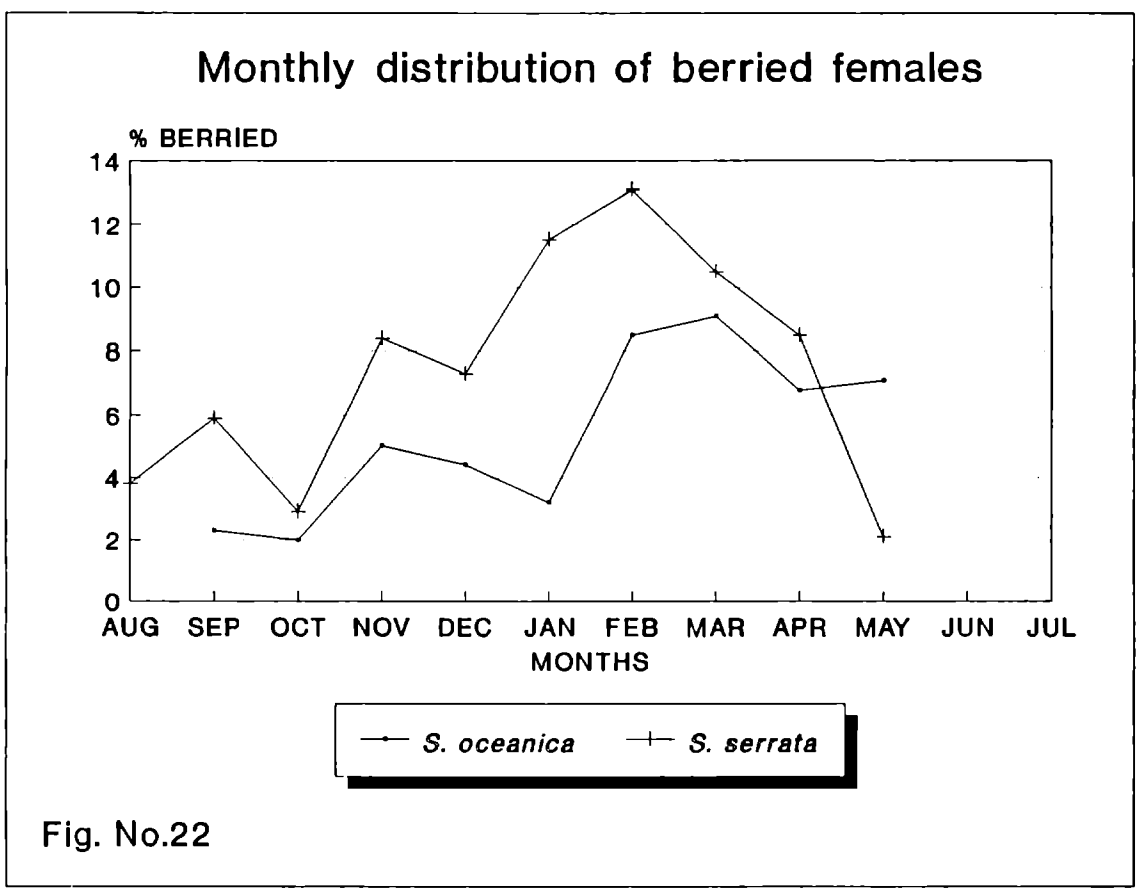
Monthly distribution of berried females
% BERRIED
14
12
10
8
6
4
2
0
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
MONTHS
S. oceanica
S. serrata

Fig. No.22

agement is the relative abundance of breeding population in the fishery over space and time as it gives indication of recruitment potential in the fishery. A knowledge on the seasonal abundance of the breeding stock is also essential for the procurement of breeders for hatchery purpose. In the present study the abundance of breeding population of the two species of mud crabs was studied on the basis of the occurrence of ovigerous (berried) females in the landings. The incidence of occurrence of berried crabs in the commercial catches was extremely low in the Korapuzha estuary. Out of 1723 crabs observed from this system for various studies only 11 females of *S. oceanica* and 17 females of *S. serrata* were found in berried condition during the entire period of study. In the Ashtamudi lake, berried crabs were better represented in the catches with 24 out of 1092 crabs of *S. oceanica* and 32 out of 591 crabs of *S. serrata*. Although berried females occurred almost throughout the year their peak abundance was observed during January-March.

In the Cochin backwater, berried specimens of both the species were encountered in most of the months of the year although their monthly abundance in the landings varied considerably. Most of the berried specimens of *S. oceanica* were in the size range of 15-17 cm CW and those of *S. serrata* in the size range of 10-12 cm CW. The monthly percentage composition of berried specimens in the catches for the one year study period in this backwater is depicted in Fig. 22. The peak occurrence of berried crabs was observed during January-April. Out of the total of 1127 specimens of *S. oceanica* examined for the entire study period 44 berried crabs were encountered of which as many as 19 crabs (43%) were recorded during February-March. In the case of *S. serrata*, out of the total number of 85 berried crabs 24 (28%) were recorded during January-February. Berried individuals were not encountered in the fishery during monsoon period (June-August) in the case of *S. oceanica* and during the early part of monsoon period in (June-July)

in the case of *S. serrata*. During the monsoon season berried crabs were observed only in the trawl catches taken from the sea.

Incidentally berried crabs of both the species were observed in the brackishwater shrimp farms of Vypeen Island during the monsoon period when the salinity of the farms was above 15 ppt. From the inshore sea also the shrimp trawlers operating from Cochin were found to land 50-60 crabs of *S. oceanica* daily, during February-April, 1993, in which more than 40% of female crabs were in berried condition.

Sex ratio

The distribution of sex ratios over space and time have been studied from a total of 3324 crabs of *S. oceanica* and 2369 crabs of *S. serrata*. In general, the proportion between male and female in the population was almost equal for both the species and this feature was noticed throughout the year in all the three brackishwater systems (Tables.16-21).

In the monthly distribution of sex ratios, the heterogeneity chi-square values of *S. oceanica* were 5.234 (df. 11; $P>0.9$) for Ashtamudi lake, 10.639 (df.11, $P>0.470$ for Cochin backwaters and 3.106 (df.11, $P>0.98$) for Korapuzha estuary. In the case of *S. serrata* the corresponding values were 10.61 (df.11, $P>0.48$) for Ashtamudi lake, 3.33 (df. 11; $P>0.98$) for Cochin backwaters and 4.071 (df.11; $P>0.97$) for Korapuzha estuary. All these values indicated that the sex ratio was homogeneous over the months. The individual Chi-square values showed that they were not significantly different from the expected 1:1 ratio in both the species.

In the size wise analysis of sex ratios, the heterogeneity chi-square values of *S. oceanica* for Ashtamudi was 23.065 (df.14; $P>0.05$) which did not indicate significant difference in sex ratio over sizes. The chi-square values in respect of the size group 8.1-9.0 cm showed that the sex ratio was significantly different from the expected 1:1 ratio but this individual case may not represent a general trend in

TABLE 16: Monthwise sex ratios and Chi-square values of *S. oceanica.*

Month	Ashtamudi lake					Cochin backwater					Korapuzha estuary				
	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.
Aug	88	53.4	46.6	0.049	>0.05	94	53.2	46.8	0.383	>0.05	92	48.9	51.1	0.044	>0.05
Sep	83	48.2	51.8	0.108	>0.05	100	46.0	54.0	0.640	>0.05	98	50.0	50.0	0.000	>0.05
Oct	91	45.1	54.9	0.890	>0.05	96	54.2	45.8	0.667	>0.05	98	51.0	49.0	0.041	>0.05
Nov	88	47.7	52.3	0.182	>0.05	87	48.3	51.7	0.103	>0.05	99	49.5	50.5	0.010	>0.05
Dec	100	53.0	47.0	0.360	>0.05	92	41.3	58.7	2.783	>0.05	88	47.7	52.3	0.182	>0.05
Jan	102	52.9	47.1	0.353	.0.05	95	40.0	60.0	3.800	>0.05	101	48.5	51.5	0.089	>0.05
Feb	88	46.6	53.4	0.409	>0.05	90	53.3	46.7	0.400	>0.05	94	48.9	51.1	0.042	>0.05
Mar	92	46.7	53.3	0.391	>0.05	94	43.6	56.4	1.532	>0.05	93	47.3	52.7	0.269	>0.05
Apr	95	42.1	57.9	2.368	>0.05	93	51.6	48.4	0.097	>0.05	87	50.6	49.4	0.012	>0.05
May	94	45.7	54.3	0.681	>0.05	102	52.9	47.1	0.353	>0.05	81	46.9	53.1	0.309	>0.05
Jun	79	50.6	49.4	0.017	>0.05	88	51.1	48.9	0.046	>0.05	83	54.2	45.8	0.590	>0.05
Jul	92	46.7	53.3	0.391	>0.05	96	44.8	55.2	1.042	>0.05	92	42.39	57.61	2.130	>0.05
Total	1092	48.3	51.7	1.322	>0.05	1127	48.4	51.6	1.215	>0.05	1106	48.8	51.2	0.611	>0.05

TABLE 17: Monthwise sex ratios and Chi-square values of *S. serrata.*

Month	Ashtamudi lake					Cochin backwater					Korapuzha estuary				
	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.
Aug 92	51	56.9	43.1	0.961	>0.05	97	51.6	48.5	0.093	>0.05	51	52.9	47.1	0.177	>0.05
Sep	45	60	40.0	1.8	>0.05	98	51.0	49.0	0.041	>0.05	60	55.0	45.0	0.600	>0.05
Oct	55	56.4	43.6	0.891	>0.05	92	55.4	44.6	1.087	>0.05	49	53.1	46.9	0.184	>0.05
Nov	51	49.0	51.0	0.020	>0.05	86	51.8	48.2	0.106	>0.05	48	54.2	45.8	0.333	>0.05
Dec	45	48.9	51.1	0.022	>0.05	86	46.5	53.5	0.419	>0.05	61	50.8	49.2	0.016	>0.05
Jan93	64	40.6	59.4	2.250	>0.05	97	53.6	46.4	0.505	>0.05	53	54.7	45.3	0.047	>0.05
Feb	44	54.6	45.4	0.364	>0.05	108	49.1	50.9	0.037	>0.05	52	55.8	44.2	0.692	>0.05
Mar	52	42.3	47.7	1.231	>0.05	103	53.4	46.6	0.476	>0.05	49	63.3	36.7	3.450	>0.05
Apr	45	51.1	48.9	0.022	>0.05	96	45.8	55.2	0.666	>0.05	53	54.7	45.3	0.472	>0.05
May	50	54	46	0.320	>0.05	97	50.5	49.5	0.010	>0.05	49	51.0	49.0	0.020	>0.05
Jun	43	36.5	53.5	0.209	>0.05	106	49.1	50.9	0.038	>0.05	47	51.1	48.9	0.021	>0.05
Jul	46	63.0	37	3.13	>0.05	94	52.1	47.9	0.170	>0.05	47	44.7	55.3	0.532	>0.05
Total	591	51.6	48.4	0.611	>0.05	1159	50.8	49.2	0.312	>0.05	619	53.5	46.5	2.987	>0.05

TABLE 18: Analysis of heterogeneity Chi-square (month-wise) of mud crabs

Species	Station	Source	df	Chi-square
S. oceanica	Ashtamudi lake	Deviation	1	1.322
		Heterogenity	11	5.234
		Total	12	6.556
	Cochin backwaters	Deviation	1	1.215
		Heterogenity	11	10.630
		Total	12	11.845
	Korapuzha estuary	Deviation	1	0.611
		Heterogenity	11	3.106
		Total	12	3.718
S. serrata	Ashtamudi lake	Deviation	1	0.611
		Heterogenity	11	10.61
		Total	12	11.22
	Cochin backwaters	Deviation	1	0.312
		Heterogenity	11	3.336
		Total	12	3.648
	Korapuzha estuary	Deviation	1	2.987
		Heterogenity	11	4.071
		Total	12	6.968

TABLE 19: Size wise sex ratios and Chi-square values of *S. oceanica.*

Size groups (cm)	Ashtamudi lake					Cochin backwater					Korapuzha estuary				
	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	p.
6.1-7.0	9	44.4	55.6	0.000	>0.05	13	46.2	53.8	0.000	>0.05	5	8020	0.800	>0.05	
7.1-8.0	84	47.6	52.4	0.107	>0.05	54	33.3	66.7	5.351	<0.05	72	56.9	43.1	1.125	>0.05
8.1-9.0	76	35.5	64.5	5.802	<0.05	85	44.7	55.3	0.752	>0.05	90	52.2	47.8	0.100	>0.05
9.1-10	91	41.8	58.2	2.154	>0.05	115	52.2	47.8	0.139	>0.05	80	40	60	2.813	>0.05
10.1-11	125	52.8	47.2	0.288	>0.05	144	42.4	57.6	3.063	>0.05	92	53.3	46.7	0.272	>0.05
11.1-12	109	45.0	55.5	0.917	>0.05	116	46.5	53.5	0.422	>0.05	134	39.5	60.5	5.440	>0.05
12.1-13	123	48.0	52.0	0.130	>0.05	126	52.4	47.6	0.198	>0.05	171	48.5	51.5	0.094	>0.05
13.1-14	125	52.8	47.2	0.288	>0.05	139	54.7	45.3	1.036	>0.05	129	47.3	52.7	0.278	>0.05
14.1-15	117	58.1	41.9	2.769	>0.05	96	53.1	46.9	0.260	>0.05	120	55	45	1.008	>0.05
15.1-16	75	44.0	56.0	0.853	>0.05	80	43.7	56.3	1.013	>0.05	75	38.9	61.1	3.125	>0.05
16.1-17	48	64.6	35.4	3.521	>0.05	61	44.3	55.7	0.590	>0.05	54	57.4	42.6	0.907	>0.05
17.1-18	43	34.9	65.1	3.349	>0.05	39	46.1	53.9	0.103	>0.05	33	51.5	48.5	0.00	>0.05
18.1-19	46	39.1	60.9	1.761	>0.05	36	41.7	58.3	0.694	>0.05	35	40.0	60.0	1.029	>0.05
19.1-20	16	56.3	43.7	0.063	>0.05	19	84.2	15.8	7.579	<0.05	14	64.3	35.7	0.643	>0.05
20.1-21	4	100	0	2.250	>0.05	4	100	0	2.250	>0.05	5	100	0	3.2	>0.05
Total	1091	48.3	51.7	1.188	.0.05	1127	48.4	51.6	1.145	>0.05	1106	48.8	51.2	0.565	.0.05

TABLE 20: Size wise sex ratios and Chi-square values of *Scylla serrata.*

Size groups (cm)	Ashtamudi lake					Cochin backwater					Korapuzha estuary				
	Spl. size (N)	Sex ratios(%) (M)	(F)	Chi-sq. values	3p.	Spl. size (N)	Sex ratios (%) (M)	(F)	Chi-sq. values	p.	Spl. size (N)	Sex ratios (%) (M)	(F)	Chi-sq. values	p.
6.1-7.0	21	66.7	33.3	1.714	>0.05	94	52.1	47.9	0.096	>0.05	48	54.2	45.8	0.188	>0.05
7.1-8.0	31	48.4	51.6	0.000	>0.05	100	47.0	53.0	0.250	>0.05	45	51.1	48.9	0.000	>0.05
8.1-9.0	94	40.4	59.6	3.075	>0.05	148	59.5	40.5	4.926	<0.05	74	48.7	51.3	0.013	>0.05
9.1-10	80	51.3	48.7	0.013	>0.05	162	38.9	61.1	7.562	<0.05	83	55.4	44.6	0.771	>0.05
10.1-11	151	41.7	58.3	3.814	>0.05	210	55.2	44.8	2.100	>0.05	150	66.0	34.0	14.72	<0.05
11.1-12	136	58.8	41.2	3.890	<0.05	256	49.6	50.4	0.004	>0.05	129	49.6	50.4	0.000	>0.05
12.1-13	60	65.0	35.0	4.817	<0.05	157	55.4	44.6	1.631	>0.05	77	40.3	59.7	2.546	>0.05
13.1-14	9	66.7	33.3	0.444	>0.05	24	29.2	70.8	3.375	>0.05	13	46.2	53.8	0.000	>0.05
14.1-15	9	100	0.00	7.111	<0.05	8	62.5	37.5	0.125	>0.05					
Total	591	51.6	48.4	0.548	>0.05	1159	50.8	49.2	0.280	> 0.05	690	53.5	46.5	2.850	>0.05

TABLE 21: Analysis of heterogeneity Chi-square (month-wise) of mud crabs

Species	Station	Source	df	Chi-square
S. oceanica	Ashtamudi lake	Deviation	1	1.188
		Heterogenity	14	23.065
		Total	15	24.253
	Cochin backwaters	Deviation	1	1.150
		Heterogenity	14	22.302
		Total	15	23.452
	Korapuzha estuary	Deviation	1	0.565
		Heterogenity	14	20.834
		Total	15	21.399
S. serrata	Ashtamudi lake	Deviation	1	0.565
		Heterogenity	8	24.330
		Total	9	24.878
	Cochin backwaters	Deviation	1	0.280
		Heterogenity	8	19.788
		Total	9	20.068
	Korapuzha estuary	Deviation	1	2.850
		Heterogenity	7	15.394
		Total	8	18.244

sex ratio with reference to size of the animals. The heterogeneity Chi-square values for Cochin backwaters (22.30, df.14; P>0.07) and Korapuzha estuary (20.834, df. 14; P>0.14) did not show any significant variation of sex ratio over sizes. But there was a trend of dominance of male over female in the higher size groups, as evident from the size group 19.1-20.o cm in Cochin backwater, which was significantly different from the 1:1 ratio (Chi-square - 7.58, df.1, P< 0.006).

In the case of *S. serrata*, the heterogeneity Chi-square values were 24.33 (df.8; P=0.002) for Ashtamudi lake, 19.79 (df.8, P = 0.011) for Cochin backwater and 15.39 (df.7, P< 0.03) for Korapuzha estuary. These Chi-square values indicated significant differences in the sex ratios size wise, but here also individual chi-square values did not show any trend in sex ratios against size except for the largest size groups in which case males dominated over females.

DISCUSSION

The mud crab fishery of India in general, and Kerala in particular, is based on traditional craft and gears and it is in the hands of artisanal fishermen. A perusal of the available literature on the fishing methods employed in the fishery over the past five decades would reveal significant changes in the same brought about by the increased exploitation and utilization of mud crab as a commodity for export. Around the middle of the present century, the common gears employed for catching crabs included long lines, scoop nets, iron rods, hooked iron and steel rods in most of the brackishwater systems (Hora, 1935; Jones & Sujansinghani, 1950; Chhapgar, 1962; Rao et al., 1973; Pillai & Nair, 1973a ; Devasia & Balakrishnan, 1985). Mud crabs were also caught as bycatches in gill nets, stake nets, cast nets, seine nets, boat seines and trawl nets. Examination of the crab fishery of Kerala during the present study has indicated that many of the above mentioned fishing implements have almost vanished from the capture fishery and in their place innovative gears such as ring nets and crab gill nets made of

polyester and nylon twines have been introduced. The advantage of ring net is that it is cheapest, easy to operate, durable and the chances of damage of crabs are very less. Since this net yields better catch of crabs in undamaged condition, it is apprehended among fishermen that the increased use of this net would lead to unhealthy competition and overexploitation of the available stocks. Therefore its operation is objected to in Ashtamudi lake and some parts of Korapuzha estuary, where the traditional by operating gears like long lines are still in vogue.

According to Devasia and Balakrishnan (1985) the crab fishery was seasonal in Cochin backwaters, the main season being May to August. The present study reveals that mud crab fishing has become a regular practice at present and the fishery exists throughout the year with peak season from December to June in all the three brackishwater systems studied. The maximum catch for both the species is observed in the month of June which is the beginning of monsoon season. This could be attributed to the mass migration of crabs from the low saline upper reaches to the high saline lower reaches of the brackishwater system where they get caught in large quantities. Devasia and Balakrishnan (1985) reported that among the various hydrographic parameters, salinity plays a vital role in the distribution and abundance of mud crabs, lower the salinity lesser will be the density of population.

Only very little quantitative information is available regarding mud crabs from the brackishwater areas of Kerala. Devasia and Balakrishnan (1985) observed that during the active fishing season 3000-4000 crabs weighing about 800-1000 kg are processed at Cochin. According to Raj (1992), about 3 t of live mud crabs of exportable size arrive in Madras every day, out of which about 2 t come from Cochin backwaters and 100-200 kg from Ashtamudi lake. During the present study, a total catch of 27 t of mud crags was landed at Kavanadu (Ashtamudi lake), 18 t at Pallipuram (Cochin backwaters) and 13 t at Elathur (Korapuzha Estuary), of which

75-80% was constituted by *S. oceanica* and the rest by *S. serrata*. Both the species occurred in peak abundance in May-June period coinciding with the commencement of south west monsoon.

Stringent specifications are in force as regards species, sizes, shell hardness and health of crabs in the live crab trade at Cochin and the other centres. The crabs are graded on the basis of the above criteria and prices are offered according to the grade. Only animals weighing above 200 g are accepted by the buyers. The grading system is strictly followed at Cochin because of the competition among the middlemen. The middle men often pay money to the crab fishermen well in advance so that their catches are committed to them. They also advance money to the crab fishermen during lean season, including monsoon period when sustenance becomes difficult. Thus the crab fishermen are often economically tied to the middle men.

The data on monthly grade distribution (Fig. 6-8) shows that the recruitment of younger crabs (9.5-11.5 cm) into the fishery is an year-round process with distinct peaks which vary between species. The peak season for recruitment of the younger population into the fishery is August to September for *S. oceanica* (9.5-11.5 cm CW) and October to December in *S. serrata* (9.5-10.5 cm CW). Both the species show more or less the same trend in all the three brackishwater systems studied.

A wide range of sizes have been reported in the capture fishery of mud crabs with major size groups appearing inconsistently in space and time due to the mixing of more than one species in the fishery which went on unnoticed in most of the crab producing countries of the Indo-Pacific region (Khan & Alam, 1992; Jayamma, 1992; Povachiranon, 1992). The present study reveals that the two species, *S. oceanica* and *S. serrata* which coexist in the same habitats of Kerala coast, show distinct variations in their individual size distribution pattern and other as-

pects of population *S. oceanica* grows to a much langer size then *S. serrata*, the observed maximum sizes of the two species being 20.9 cm CW and 16.0 cm CW respectively. In both the species male attains slightly higher sizes than female which is in conformity with the observation of Sreenivasagam and Raman (1985). Kathirvel (1981) noticed 20.2 cm as the maximum CW for male and 19.8 cm CW for female of mud crabs in Cochin backwaters. Sheeba Tharyan (1988) recorded a maximum carapace width of 21.0 cm for *S. serrata* (=*S. oceanica*) and 140 cm for *S. serrata serrata* (=*S. serrata*).

Taking into account the growth rate estimated for the juvenile population (vide chapter III Section 2), the approximate age of *S. oceanica* at the time of its peak recruitment into the fishery during August-September could be 6-8 months, and that of *S. serrata* 11-12 months at the time of its peak recruitments in November-December. These recruits may possibly belong to the February-March brood in the case of *S. oceanica* and January-February brood in the case of *S. serrata*.

The data on size distribution of the two species of mud crabs in the capture fishery shows that in most cases over 60% of the catch in the case of *S. oceanica* and 75% in the case of *S. serrata* are constituted by the size group 8-15 cm CW for the former species and 8-12 cm CW for the latter. Within this size range *S. oceanica* is predominantly represented by the size group 12-14 cm CW and *S. serrata* by the size group 10-12 cm. As the minimum size at maturity of *S. oceanica* has been found to be 12.2 cm CW the major sizes contributing in the fishery are in the initial phase of reproduction. In contrast to this situation, the size distribution of *S. serrata* depicts a pattern in which the dominant size groups belong to an older age class, which has gone far ahead in the reproductive activities when considering the size at maturity which is 8.4 cm CW. This situation points to the possibility that the fishing pressure on *S. oceanica* stock is relatively more when compared to the same on *S. serrata* in all the three brackishwater system with a strong possibility of

overexploitation of larger individuals which are in greater demand for live crab export. The persistence of larger individuals in the fishery in the case of *S. serrata* may be attributed to its lesser vulnerability to capture because of its burrow dwelling habit when compared to the free living nature of *S. oceanica*. This suspected 'growth overfishing' in the case of *S. oceanica* calls for regulatory measures on the mud crab fishery of Kerala by restricting capture of smaller sizes below 15 cm CW, especially in the case of the above species. In Queensland (Australia) such fishing restrictions are in vogue, where female crabs are totally banned from fishing and the capture of males below 15 cm CW is prohibited (Lee, 1992).

The data on distribution of ovigerous females in the fishery indicates occurrence of breeding population almost throughout the year except during the monsoon period of June-July in *S. oceanica* and June-August in the case of *S. serrata* when the salinity of the environment is very low. The abundance of berried crab is noticed during February to March in the case *S. oceanica* and January-February in the case of *S. serrata* which coincides with active fishing for crab in Cochin backwaters. During the peak period of abundance the breeding population constitutes 9.1% of the total crab landed in the case of *S. oceanica* and 13.1% in the case of *S. serrata*. Poovachiranon (1992) reports that in tropical estuaries, the period of peak spawning of *S. serrata* coincides with high nutrient input associated with monsoon or cyclonic rain fall. During the present study the peak breeding period of *S. oceanica* and *S. serrata* is found to be outside the monsoon period and hence the correlation put forward by Poovachiranon (1992) between spawning habit and nutrient input associated with the rainfall does not hold good in the case of present fishery.

The distribution of sex ratios in the fishery indicates almost equal proportion between the two sexes of both the species of mud crabs. This situation is evident in the fishery of all the three brackishwater systems. Size wise sex ratio

also depicted almost 1:1 ratio between males and females except in the case of the highest size group in which male dominated in both the species. According to Fisher's theory of sex ratio, natural selection favours a 1:1 parental expenditure on offspring of the two sexes (Fisher, 1930; Kolman, 1960). Mohanty (1975) reported preponderance of male in the crab population of Chilka lake where as Srinivasagam and Raman (1985) noticed higher proportions of females in Pulicat lake.

SECTION 4

MUD CRAB CULTURE

GLOBAL STATUS

For centuries, mud crab constituted an important secondary crop in the traditional culture systems of Asian countries. In the beginning there was no intentional stocking and the crop entirely depended on auto-stocking through the incoming tide which brought juvenile crabs along with fish and prawn seed. In some countries farmers even considered mud crabs a nuisance that had to be removed from culture ponds (Ahmed, 1992; Larda, 1992). The traditional farming practices existed in countries like Philippines, Malaysia, Indonesia, China and Taiwan, where the culture operations were entirely restricted to the artisanal sector. As the price of crabs increased, both in the local and export markets, the farmers started supplementing the crop by stocking juvenile crabs collected from the wild in traditional ponds in which milk fish, penaeid shrimp and/or seaweeds were cultured. The area of such ponds ranged from 0.2. to 20 ha. At present, in countries like Taiwan, mud crab farming comprises different operations such as nursery, grow-out and fattening.

The technology of mud crab farming practised around the world can be broadly categorised into two, viz. 'grow-out culture' and 'fattening'. Grow-out culture refers to farming of undersized crabs for comparatively longer period, usually 3 to 6 months, to produce marketable sizes, whereas fattening is holding of market-size crabs for 2 to 4 weeks time to acquire certain desired biological characteristics (Chong, 1993). During grow-out culture the stocked animals moult several times before they attain the market size, while during fattening, the animals are harvested before they moult atleast once. In the latter-case, therefore, there is hardly any change in the size of the animal at the time of harvest. Short-term

culture involving moulting of the animal is sometimes wrongly referred to as fattening, but as per the definition given by Chong (1993) it does not come under 'fattening'.

The aim of fattening is either to produce female crabs with ripe gonads or to convert post-moult soft crabs to hard shelled crabs. Crabs with well developed ovary or 'roe' filling the body cavity is considered a delicacy in many countries. Such animals fetch very high prices in restaurants and markets. Therefore female crabs with immature ovary are fattened by giving proper feed until their ovary develops and fills up the body cavity. Experienced farmers can identify the crabs with fully developed ovary by looking through the carapace, holding the crab against sun light or a bright light source.

During and soon after moulting the crabs absorb large amount of water through the soft skin, which results in the growth of the body. During the intermoult period the excess water is slowly replaced with meat. The newly moulted crabs, therefore, have soft shell and watery meat and hence are known as 'water crabs'. The crabs in this condition fetch very low prices compared to hard shelled crabs of the same size. The soft-shelled crabs are fattened by proper feeding for two weeks to one month, and by this time their flesh becomes firm and shell hardened. Hardness of the shell is judged by pressing the sternites of the cephalothorax. Those animals with hard shell are sorted out and marketed at a higher price.

Grow-out culture is practised traditionally in coastal polyculture ponds of size 0.2 to 20 ha. But more recently monoculture of crabs is carried out in smaller ponds of size 0.05 to 1 ha size. Fattening operations are done in small ponds, pens or cages to facilitate close monitoring.

Mud crab farming is mainly practised in countries like Philippines, Malaysia, Taiwan, China, Thailand, Indonesia and India. A brief account of the status of mud crab farming in each of these countries is given below.

Philippines: Mud crab is a secondary product in milkfish ponds of Philippines. Stocking is entirely by tidal effect where there is no control over the stocking density and yield. Usually the crabs are reared for 6 months and harvested along with milkfish and prawns. Some farmers resort to management measures such as additional stocking of crab seed of 2-3 cm size at the rate of 1000/ha , fencing of the pond and providing shelters to improve the yield. Milkfish/prawn/crab polyculture pond produces on an average 577 kg of fish, 52 kg of prawn and 111 kg of crab/ha. Wherever monoculture is practised, the average yield amounts to 339 kg/ha/yr (Lapie& Librero, 1976). Recently crabs are being fattened in cement tanks, ponds, pens and cages. Bamboo cages of size 140 x 70 x 25 cm subdivided into 18 compartments are used for fattening crabs individually (Larda, 1992). Where as in ponds, the stocking rate used is 2-3 crabs/sq.m. Feed used include kitchen refuse, trash fish, animal entrails and African-snails, the rate of feeding being 5 to 10 % of body weight. Samonte and Agbayani (1992) analysed the economics of pond culture of mud crabs at SEAFDEC Legenes Research Centre and found that mud crab monoculture is highly profitable at stocking densities of 5000/ha and 10,000/ha using seed of 25 g average size, with an yield of 1019 kg and 1022 kg/ha/3 months respectively.

Malaysia: In this country both grow-out culture and fattening are practised since 1970's. Pond culture is mostly of subsistence nature in smaller ponds of less than 0.5 ha and the duration of culture is 2-3 months or 6 months depending on the size of seed stocked. Floating net cages are used for crab fattening in which soft shelled crabs or female crabs with immature ovary are fattened for about 20 days. Fattening cages are of the size 3 x 3 x 2 m made of wooden rectangular frame floated by plastic drums and covered by polythene netting or rigid extruded plastic mesh of 2-5 cm. In some areas, 2 x 2 x 0.6 m wooden frame closed by double layer of netlon is also used. A crab fattening farm may have 40-200 cages. Stocking density ranges 30-60 kg/cage and the crabs are fed with trash fish, fish offal or

fish stored by salting or sun drying (Chong, 1992). In monoculture using hatchery produced seed after one month nursery rearing, the crabs reach marketable size of 300-350 g in 5 months with a survival rate of 35-40 % (Chong 1993).

Taiwan: Crab culture has a long history in this country. It originated in polyculture manner with milkfish, shrimp and/or seaweed (*Gracilaria*) ponds, and later developed into monoculture due to increase in demand. Mud crab farming is either raising the seed crab to marketable size or fattening unripe female to one with fully developed gonad. Fattening of soft shelled crabs to hard shelled ones is also practised some times.

Crab seeds of size 2-3 cm CW are obtained from estuarine areas round the year with peak in June-July. In addition to this, megalopae are collected using seine nets during evening hours or by trapping against currents. They are stocked in 15 x 20 m concrete tanks lined with 3-4 cm sand on the bottom. Tanks are filled with sea water of 30-35 ppt salinity, and a stocking density of 2000/sq.m is usually used. They are fed with chopped shrimp and fish meat during morning and evening and water exchange of 200-300 % is given daily. Megalopa metamorphoses into crab in 3-5 days time. Thereafter 10% of sea water is replaced with freshwater at the time of water exchange. Crab reaches 1.5 to 1.8 cm in one month with a survival of 40 to 60%. At this stage crabs are transported sandwiched between 2 layers of seaweeds in wooden boxes.

Grow-out culture is practised in earthen ponds of size 0.3 to 0.5 ha with sandy substrate. A water column of about 1.5 m is usually maintained and the salinity ranges from 20 to 30 ppt. A fencing made up of bamboo or Fiberglass panels of 80 cm height surrounds the pond. Stocking density ranges from 2 to 5 crabs/sq.m and feeding is by trash fish at the rate of 5% of body weight. Market size of 200-350 g is obtained in 5-6 months with a survival of 30-70 % depending on the size of the seed and nature of management. Survival is better in polyculture ponds with *Gracilaria*. A polyculture pond of 0.5 ha stocked with 10,000 to 16,000

crabs may also contain 150,000 to 250,000 PI-25 of *P. monodon* seed. They are fed with trash fish, horse-mussel and pelleted shrimp feed. Taiwanese use brick walled ponds of size ranging from 200 to 1000 sq.m with a depth of about 1 m for fattening purpose. Fattening is mainly to produce female crabs with fully mature ovary locally known as 'Arn-jim'. Crabs are stocked at the rate of 1-5/sq.m and fed with trash fish and hornshell snail. The rearing period is 20 to 50 days with average survival rate of 80-85% (Chen, 1990).

China: Crab culture is practised in China since 1890's. They are cultured in about 1340 ha, with a total production of around 2000 tons. Crabs of 200 g are reared for 15-50 days or small crabs below 100 g are reared in brick or concrete or earthen ponds to marketable size. Crabs are cultured singly or in polyculture manner with shrimp/crab, fish/crab or shrimp/crab/seaweed (*Gracilaria*) combination as in Taiwan. Crabs are fed according to their sizes; crabs of 2-4 cm CW being fed at the rate of 8-12 % of body weight and 6 cm CW and above are fed with 5% of body weight daily with trash fish, small shrimp and crabs. Crab pond is usually fenced with asphalt felt, plastic cloth, polythene netting and brick or concrete walls (Yalin & Qingsheng, 1994). Recently crabs are cultured in pens and cages also.

Thailand: Here crab farms are generally of small size, never more than 1600 sq.m each. Ponds are usually earthern type fenced with bamboo. There are about 100 farms in Thailand. Pens and cages are also used for crab farming (Harvey, 1990). Here crab farming is a short term culture cum fattening operation in which undersized crabs of 200-300 g body weight caught from the wild are stocked in ponds at the rate of 2-4/sq.m and reared for about a month till they attain 400-500 g. Female crabs with well developed ovary are also produced during this rearing period, which forms the fattening part of the culture. Mud crabs are usually fed with trash fish for 20 days, thereafter horse mussel is also included in the diet. Feeding rate varies from 7 to 10% of body weight (Suresh, 1991). In Surat Thani province of Thailand, the area under crab culture has declined since 1985 due to non avail-

ability of stocking material (Rattanachote & Dangwatanakul, 1992).

Indonesia: Though crab culture is of recent origin fattening as well as grow-out culture of seed crab to marketable size are practised. According to Cholik and Hanafi (1992), for the production of female crabs with roe, floating bamboo cages of 2 x 1.5 x 1 m size each with an opening of 30 sq.cm on the top are used. Stocking density varies from 70 to 110 crabs/cage in the case of crabs with 150 g body weight. They are fed with trash fish at the rate of 3-5 % of body weight for one month until 70-80% of the crabs are harvested ripe. Fattening of post-moulted soft crabs are carried out in cages, pens or ponds and its duration is 3-4 weeks. Bamboo cages of size 2 x 0.5 x 0.2 m divided into compartments of 30 sq.m or plastic cages of 60 x 40 x 20 cm partitioned into 9 compartments or floating net cages of 2.5 x 2.5 x 1 m with wooden frame at the top are used for fattening. In floating net cages, male and female crabs are kept separately to reduce cannibalism. Fattening ponds are usually small with a size of 20 x 50 m with bamboo fencing and peripheral canals of 30-40 cm width. Stocking rate is 2 crabs/sq.m for a crab of size 150-200 g weight and the crabs are fed at the rate of 10 to 15% of their body weight/day. Pens are of size 4 x 4 x 2.5 m made up of bamboo fencing are set in lagoon. Crabs of about 150 g size are stocked in a pen at the rate of 100 crabs/pen and fed with trash fish, fresh or dried. In 3-4 weeks time, the crabs attain an average weight of 200 g each and are harvested with a mortality upto 5 %, evidently indicating that some animals would have moulted atleast once during the rearing period. So it must be called a short term culture as per the definition given by Liong (1994).

Grow-out culture is carried out in an extensive manner in ponds upto 0.5 ha area with bamboo fencing driven to the bottom to a depth of 70 cm, leaving a width of 20 cm above the water surface (Cholik & Hanafi, 1992). Best stocking in terms of production is 2/sq.m and survival rates of 77.3, 49.17 and 32.06% were achieved at stocking rates of 1 crab, 3 crabs and 5 crabs/sq.m respectively (Gunarto & Cholik, 1990).

India: A perusal of the available literature would reveal that crab farming in India before 1990 was restricted to experimental culture and growing of crabs trapped in the traditional shrimp culture (prawn filtration) ponds. Most of the farmers considered crabs a menace as they made burrows in bunds. Culture experiments were conducted by many workers in the laboratory or field in order to study growth, production and survival (Kathirvel, 1980; Srinivasagam *et al.*, 1988; Natarajan & Thangaraj, 1983; Bensam, 1986; Marichamy *et al.*, 1986). Experiments conducted by the Central Marine Fisheries Research Institute showed a production upto 1116 kg/ha in 210 days (Anon., 1983-84) in the case of monoculture of mud crabs, and 690 kg of mud crabs, 324 kg of *Chanos chanos* and 630 kg of *Liza macrolepis* per ha in 300 days from polyculture ponds (Anon., 1983-84).

During 1990's mud crab culture started gaining importance in states like Kerala, Andhra Pradesh and Tamil Nadu as a result of increased demand and price for mud crabs for live crab export. In Andhra Pradesh and Tamil Nadu, the crab culture is mainly fattening/hardening of 'water' or soft crabs and growing under-sized crabs of 100-200 g to marketable size which takes 4 to 6 months.

In Kerala the grow-out culture practices include supplementing the crab population in the traditional prawn filtration ponds with crabs of size 2-200 g. These ponds are of sizes ranging from 0.1 to several hectares and no definite stocking density is followed. There are also monoculture ponds where grow-out culture of crab is practised. The size of the seed ranges 100-200 g and the stocking density is 1 crab/m^2. The pond size is generally 0.1 to 2 ha and culture period is 6 months. Fattening/hardening of post-moulted crabs are practised in smaller ponds of size 0.5 to 1 ha and continuous stocking and harvesting is usually followed. In Cochin backwater, cages, (pl. 39a) are used for fattening/hardening of water crabs. The cages are rectangular measuring 2.5 m length, 2.5 m breadth and 2 m height. Arecanut splits of 2 cm thickness and 3-4 cm width are used for making the cages. Usually a maximum of 25-30 crabs are stocked in a cage and the stocking and

a

b

PLATE 39

a. Cage used in Cochin backwaters for crab fattening
b. Pen used in Korapuzha estuary for crab fattening

harvesting is continuous. In Korapuzha estuary (Kozhikode) rectangular pens of size 3.5 x 4 x 3 m (pl. 39b) made up of palmyra palm wood are used for fattening of crabs. Top of the pen is covered with nylon netting to prevent crabs from escaping. There is no definite stocking density, and stocking and harvesting are continuous. In all the above cases the feed used is trash fish and in some cases slaughter house waste is used as a supplement.

Experimental culture

Despite high market value mud crabs were generally not considered ideal for aquaculture because of some biological and behavioral peculiarities associated with these animals. The cannibalistic tendency noticed among them is one of the most important factors that can adversely affect the survival and thereby the overall production. In addition to this they have the habit of burrowing and destroying the bunds. Unlike fishes and prawns they may escape from the pond by climbing over the bund. Around the world, grow-out culture as well as fattening is seriously constrained by the non-availability of stocking material or seed. In Thailand the area which was under mud crab culture dwindled because of the non-availability of stocking material (Rattanachpote & Dangwatanakul, 1992). In spite of the decline in catches due to overfishing and destruction of mangrove areas which form their natural habitat, the fishing pressure on the resource is ever on the increase all over the world because of very high price of the commodity. One of the ways of protection of natural stock is by satisfying the demand through aquaculture. Keeping the above point in mind, fattening and grow-out experiments were conducted to study the feasibility of crab farming in brackishwater ponds and the results are described below.

FATTENING

Experimental fattening of *Scylla oceanica* was conducted in a brackishwater pond of 0.05 ha area (Pl. 40a) as described in detail in chapter III with the objective of fattening soft shelled crabs with watery meat to hard shelled crabs of firm whole-

some meat during August 1992 to April 1993.

The pond was first conditioned by adding lime at the rate of 600 kg/ha after reducing the water level to the minimum. Next day water was let in during high tide. The incoming water was screened using a nylon net screen to avoid entry of competitors. Soft crabs weighing above 550 g. in body weight were purchased from local fishermen and active crabs with all the appendages in tact were used for stocking. The carapace length of the crabs raged from 15 to 20 cm.

The crabs were fed with either trash fish, slaughter house waste or clam meat at the rate of 7% of body weight. Boiling of slaughter house waste before feeding was found to reduce water pollution. When trash fish was available in bulk, it was salted and stored and used for feeding when fresh fish were scarce. Water exchange was done by tidal flushing.

Four fattening trials were conducted and the experimental details are summarised in the Table 22.

In the first trial, 125 soft crabs ('water crabs') weighing 95.75 kg were stocked and the stocking density was 0.25/sq. m. Among the stocked crabs, 30 crabs were individually tagged using numbered plastic tags. These tags were tied to the base of the last leg of the animal after noting the weight and number of the tag. During the first trial, salinity was low, ranging between 5.0 ppt and 7.5 ppt. The water temperature, pH and dissolved oxygen values were 25-26.7°C, 7.2-7.5 and 2.1-6.7 ml/l respectively.

Partial harvesting started from 20th day onwards using baited ring nets described in section 3 (chapter III). All the crabs thus caught were individually tested for their shell condition by pressing the sternites of the cephalothorax (Plate 40b). Those with hardened shells were segregated and marketed. The crabs whose shells were not hardened properly were returned to the pond for further fattening. Total harvesting was done on the 45th day after completely draining the pond, by hand picking or using scoop nets locally called 'bols'. All the tagged

a

b

PLATE 40

a. Final harvesting of crabs in fattening pond

b. Testing shell hardness of mud crab

TABLE 22: Details of fattening experiments on *S. oceanica*

Particulars	Trial-1	Trial-2	Trial-3	Trial-4
Area of pond(ha)	0.05	0.05	0.05	0.05
Duration (days)	45	45	45	60
Stocking density (No./sq.m)	0.25	0.35	0.35	0.5
Number of water crabs stocked	125	175	175	250
Total weight of water-crabs stocked	95.75	140.8	145.7	192
No.of hard shelled-crabs harvested	98	142	154	183
Total weight of hard-shelled crabs harvested (kg)	75	114	128	143
No.of soft shelled crabs at harvest	18	22	17	36
Total weight of soft shelled crabs at harvest (kg)	13	17.5	13	28
No.of dead or missing crabs	6	6	2	22
No.of damaged crabs	3	5	2	9
Survival rate (%) including damaged crabs	95.2	96.6	98.9	91.2
Crabs used for sale* (in %)	92.8	93.7	97.7	87.6

* Both soft and hard shelled

crabs were carefully cleaned of mud and algae attached to the tags and weighed. Though a maximum individual weight increase up to 30 g/crab was noticed, majority of the crabs showed little change in weight even after a period of 45 days of experiment.

Out of the 125 crabs stocked, 98 crabs weighing 75 kg were sold as hard-shelled meat crabs and 18 crabs as water crabs. Apart from this, 3 crabs were caught severely damaged and 6 crabs were either dead or missing. Survival rate was 95.2 % which included hard shelled crabs, soft crabs and damaged crabs at the time of harvesting. The percentage of crabs suitable for sale (undamaged hard or soft shelled ones) was 92.8.

During the second trial, stocking density was increased to 0.35/m^2 and altogether 175 soft crabs were stocked within a week time. Salinity recorded at the beginning of the experiment was 6.5 ppt which gradually increased to 24.2 ppt by the end of the trial period. The pH and temperature values ranged from 6.8 to 7.8 and 25.2 to 28.3°C respectively. Dissolved oxygen varied between 2.1 and 7.0 ml/l.

Out of the 140.8 kg of soft crabs stocked, 114 kg numbering 142 crabs was harvested in hard shelled condition. Twenty two crabs remained in soft condition, making the survival rate of marketable individuals as 93.7 %. Five crabs were caught in highly damaged condition which were unsuitable for sale. Actual survival rate of the animal was 96.57%.

In the third fattening trial, stocking density remained the same as that of the second trial but the feeding schedule was changed from once a day to twice a day. Only 30% of daily ration was given in the morning, the remaining 70% given in the evening. During the experimental period the salinity varied narrowly ranging 24.2-27.5 ppt. Dissolved oxygen varied between 2.9 and 7 ml/l. Water temperature and pH were in the range of 27.3-29°C and 7.3-7.8 respectively.

During the third trial the total weight of soft crabs stocked was 145.75 kg.

Out of this 128 kg numbering 154 crabs was harvested in hard shelled state and 17 crabs weighing 13 kg remained in soft condition. Total mortality was 2 and another 2 crabs were caught in damaged condition. Actual survival rate worked out to 98.85 % of which percentage of crabs suitable for sale formed 97.7%.

During the fourth trial, the stocking density was increased to 0.5/m^2 and 250 crabs weighing 192 kg were stocked. It took two weeks to stock the crabs in the pond. During this cycle salinity ranged 27-29 ppt, temperature 28-29.7°C and pH 7.2-8.1. Harvesting began from the 20th day onwards. A total of 183 crabs weighing 142.75 kg was harvested during the fattening period of 60 days and 36 crabs weighing 28 kg remained in soft condition. Dead and damaged crabs were maximum in this trial which numbered 22 and 9 respectively. Actual survival rate worked out to 91.2%. The rate of recovery of animals suitable for disposal was the lowest, being 87.6% among all the four fattening trials.

Biochemical changes during fattening

In order to assess the change in biochemical composition during fattening, the proximate composition of the crab meat was studied before and after fattening and the results are presented in Table 23.

The values of the different biochemical constituents in the two different conditions of crab body would reveal that considerable change occurs in the contents of moisture and crude protein during the transformation period. The protein content was 7.282-9.143% in the soft shelled condition and 13.93-16.03% in fattened condition with average values of 8.33% and 14.93% respectively. As the protein content increased, the water content showed a reduction from the average value of 87.15% in 'water crab' to 80.93% in fattened crab. The differences in protein and water contents were found statistically significant. Other parameters analysed, such as, ash content, fat and NFE did not show any statistically significant difference between soft and fattened crab. The crude fibre was negligible in both type of crabs indicating very low content of non digestible carbohydrate in

TABLE 23: Proximate composition of meat of soft shelled an hard shelled (fattened) crabs (standard deviation of mean given in parenthesis).

Constituents	Percentage of wet meat weight	
	Soft crab	Fattened crab
Moisture	87.15	80.925
	(1.371)	(1.9105)
Crude protein	8.328	14.93
	(0.663)	(0.7156)
Ash	3.559	3.415
	(0.2411)	(0.3427)
NFE	0.6488	0.724
	(0.0512)	(0.0452)
Fat	0.293	0.2873
	(0.019)	(0.021)
Crude fibre	Negligible	Negligible

their meat.

Economics of crab fattening

Based on the results obtained from the fattening experiments, the economics of crab fattening has been worked out for a 0.05 ha farm for one year separately for each type of the experimental trials with varying stocking densities and feeding schedule. The comparative cost and earnings arrived at are shown in the table 24.

As the fattening period was 45 days for the first 3 trials each, the annual expenditure and income were calculated assuming that at least 6 such fattening operations could be carried out in a year. However in the case of the 4th trial, computations were made on the assumption that 5 trials could be taken in a year since the duration of operation lasted for 60 days.

The initial investment of fattening operation included cost of land, cost of construction of watchmen's shed, cost of construction of pond, cost of sluice gate and expenditure for perimeter fencing. Total initial investment was Rs.37750, which remained the same for all trials since all the trials were carried out in the same pond.

Annual fixed cost was calculated taking 10% of the cost of land as its opportunity cost, 20% as depreciation on the initial investment and interest at the rate of 20% of initial investment. The calculated value of initial investment for all the 4 trials was Rs.12600.

Operating cost included cost of pond preparation, cost of stocking material (soft crabs), cost of feed and labour charges. Charges toward pond preparation included cost and transportation charges of lime,labour charges for strengthening the bund etc. Feed material such as trash fish, slaughter house waste etc. were purchased at Rs.3-4/kg. Cost of salt used for storage of trash fish also included under the cost of feed. Cost of stocking material was the most dominant variable among the operating cost. Consequently the operating cost/crab was lowest in

TABLE 24 : Economics of mud crab fattening in 0.05 ha farm at Vypeen Island

(Values in Rs.)

Particulars		Trial-1	Trial-2	Trial-3	Trial-4
I. Initial investment					
1. Cost of land	:	25000	25000	25000	25000
2. Watchman's shed	:	5000	5000	5000	5000
3. Pond construction	:	4000	4000	4000	4000
4. Sluice gate	:	3000	3000	3000	3000
5. Fencing	:	750	750	750	750
Total	:	37750	37750	37750	37750
II. Annual fixed cost					
1. Opportunity cost of land (@ 10%)	:	2500	2500	2500	2500
2. Depreciation (20% of initial investment excluding land cost)	:	2550	2550	2550	2550
3. Interest (20% of initial investment)	:	7550	7550	7550	7550
Total	:	12600	12600	12600	12600
III. Operating cost					
1. Pond preparation	:	300	300	300	300
2. Cost of soft crab (@80/kg)		7660	11280	11660	15360
3. Feed	:	777	1134	1182	1555
4. Labour charges	:	3000	3000	3000	4000
Total (operating cost /crop)	:	11737	15714	16142	21215
5. Annual working cost (6/5 crops/year)	:	70422	94284	96852	106075
IV. Annual expenditure(II+III)		83022	106884	109452	118675
V. Annual income					
1. Income from sale of hard shelled crabs @ 200/kg	:	15000	22800	25600	28550
2. Income from sale of soft shelled crabs @ 80/ kg	:	1040	1400	1040	2240
Total	:	16040	24200	26640	30790
3. Annual income from 6/5 crops	:	96240	145200	159840	153950
VI. Gross profit (V-IV)		13218	38316	50388	35275

the first trial (Rs.11737) and highest in the fourth trial (Rs.21215) corresponding with the lowest and highest stocking densities. The operating cost/crop of the third and fourth trials were Rs.15714 and 16142 respectively.

Annual working cost was calculated for 6 crops in the case of first three trials and five crops in the case of the fourth trial and the values worked out to Rs.70442, Rs.94284, Rs.96852 and Rs.106075 respectively.

Annual expenditure was calculated by adding the annual fixed cost and annual working cost. Income/crop included the revenue obtained from the sale of the hard shelled crabs or meat crabs harvested during the trial and the income from the sale of soft crabs at the time of the final harvest of each trial. The meat crabs were sold at Rs.200/kg and the soft crabs at Rs.80/kg. Income per crop was the highest in the fourth trial (Rs.30790) and the lowest in the first trial (Rs.16040). There was no significant difference in the income/crop for the third and fourth trials (Rs.24200 and Rs.26640). Though the stocking densities were different for the last two trials, the annual income realised from these trials did not show significant variation (Rs.159840 and Rs.153950) because of the lesser number of cycles/year in the last trial. In the second trial the annual income was Rs.1,45,200 which was lower than that of the third trial with an annual turnover of Rs.1,59,840.

The gross profit was calculated by substracting the annual expenditure from the annual income. It is seen that the profit was the highest in the third trial (Rs.50388/annum) as against the decreasing profits realised for the 2nd (Rs.33316), 4th (Rs.35275) and 1st (Rs.13218) trials.

GROW-OUT CULTURE

Experiment on grow-out culture of *S. oceanica* was conducted in a pond of approximately 0.1 ha located in Vypeen Island (As described in chapter III) for a period about 6 months from August 1993 to February 1994. This period was chosen for the experiment due to the fact that smaller crabs of the species were available in maximum abundance in the backwater during this period. The procedure

adopted for the pond preparation was more or less same as in the fattening experiment. The pond was first drained off completely and the black slushy material accumulated at the bottom was removed manually to the maximum possible extent. Lime (Calcium oxide) was applied at the rate of 600 kg/ha. The pond was allowed to dry up for a week in order to mineralise the organic matter accumulated at the pond bottom. Water was let in through the sluice gate. A close meshed screen was kept in the sluice gate to prevent the entry of competitors into the pond. Daily water exchange was effected by tide.

Juveniles of *S. oceanica* ranging 100-200 g body weight were purchased locally at the rate of Rs.3/animal or Rs.18-20/kg depending on size and were brought to the site with their chelate legs tied to the body. Only active animals with all the appendages were selected for stocking. The animals were immediately released into the water after untying the legs. Table 25 shows monthly values of salinity, temperature, dissolved oxygen and pH of the farm during the experimental period.

The details of the grow-out trial are summarised below:

Area of pond	0.1 ha.
Stocking density	1/sq.m.
No.of crabs stocked	1000
Total weight of crabs stocked	180 kg
Average initial weight	180 g
Duration of culture	192 days
Total number of crabs harvested	520
Survival rate	52%
Total weight of crabs harvested	308 kg
Average final weight	592 g
Number of undamaged crabs harvested	487
Percentage of crabs used for sale	48.7

TABLE 25: Monthly variation in salinity, temperature, dissolved oxygen and pH of the grow-out system

Months	Salinity (ppt)	Temperature (°C)	Diss.O_2 (ml/l)	pH
Aug	27.1	28.4	4.2	7.8
Sep	24.3	29.3	4.0	7.6
Oct	26.4	28.5	3.9	8.0
Nov	23.8	27.6	4.8	7.7
Dec	24.6	29.0	4.7	7.6
Jan	26.7	28.7	5.1	7.9
Feb	27.0	28.0	4.7	7.8

a

b

PLATE 41

a. Grow-out culture pond. Sluice gate reinforced with bamboo matting is also seen

b. Tying harvested crabs for sale

Weight of undamaged crabs harvested (kg)	291
Number of damaged crabs harvested	33
Weight of damaged crabs harvested (kg)	17.00 kg

At the rate of 1 crab/m^2, a total of 1000 crabs weighing about 180 kg were stocked within a period of about one week. The average weight of male crab (9.92 CW) at the time of stocking was 168.15 g and that of female (10.75 CW) 190.4 g. At the time of harvest the males attained an average size of 574.4 g (16.4 cm CW) and the females 596 g (15.6 cm CW) whereby indicating a growth increment of 427 g (5.79 cm CW) and 383.9 g (5.65 cm CW) for males and females respectively.

Biomass production

Based on the mean initial weight, mean final weight, rearing period, stocking density and survival rate, the biomass production (New, 1976) in the grow out culture system was calculated and the same is presented in the table 26. The results show an average biomass production of 0.665/sq.m/day at a stocking density of 1 crab/sq.m. During the culture period of 192 days, the biomass of crabs increased from 180 kg to 308 kg recording a net biomass increase of 128 kg in the 1000 sq.m culture pond. The estimated production/ha for the period of 192 days culture works out to 1280 kg.

Economics

The economics of the grow-out operation worked out on the basis of data obtained is given in the Table 27.

The total initial investment for the 0.1 ha farm was Rs.700000 and the annual fixed cost worked out to Rs.23000. The operating cost per crop including the cost of seed (@ 1820/kg) worked out to Rs.25700 and annual working cost (assuming two crops could be taken in an year) to Rs.51400. The annual expenditure was Rs.74400 which included annual fixed cost and annual operating cost.

Income from the crop included price of 291 kg of crab constituted by 284 kg 'Big' (above 550 g) and 7 kg 'Medium' (350-550 g). Annual income was calculated

TABLE 26: Biomass production of *S. oceanica* in the experimental grow-out culture system

Particulars		Estimated values
Average initial weight of crab (g)	(b)	180.12
Average final weight of crab (g)	(a)	592.00
Increase in average weight (g)	(a-b)	411.88
Length of the trial (days)	(x)	192
Average daily gain (g/day)	*(A)	2.15
Stocking density (No.sq.m)	(z)	1.00
Survival %	(y)	52.00
Biomass increase (g/sq.m)	**(C)	127.72
Biomass increase/day (g/sq.m)	(C/x)	0.665
Total area of the culture system (sq.m)		1000
Total biomass production in the culture system/192 days (kg)		128.00
Production/hectare/192 days (kg)		1280.00

* $A = \frac{(a-b)}{x}$

** $C = \frac{(azy)}{100} - bz$

TABLE 27: Economics of grow-out culture

Particulars	Value in Rs.
I. Initial investment	
1. Cost of land	50000
2. Watchman's shed	5000
3. Pond construction	8000
4. sluice gate	5000
5. Fencing	1500
Total	70000
II. Annual fixed cost	
1. Opportunity cost of land (@ 10%)	5000
2. Depreciation (20% of initial investment excluding land cost)	4000
3. Interest (20% of initial investment)	14000
Total	23000
III Operating cost	
1. Pond preparation	500
2. Cost of seed crabs	3500
3. Feed	8700
4. Labour charges	13000
Total (Operating cost per crop)	25700
5. Annual working cost (2 crops/year)	51400
IV. Annual expenditure (II+III)	74400
V. Annual income	
1. Income from sale of crabs	57325
2. Annual income from 2 crops	114650
VI. Gross profit (V-IV)	40250

assuming that two crops can be taken in an year. The calculated value of annual income was Rs.1,14,650. Gross profit was calculated by deducting annual expenditure from annual income, which worked out to Rs.40250.

LARVAL FEEDING AND EXPERIMENTAL SEED PRODUCTION.

Unlike prawn farming for which hatchery technology is well developed crab farming depends entirely on seed obtained from wild. The diminishing seed abundance in natural nursery areas will be an impediment for the development of crab farming in India (Suseelan, 1996a). Realising the imperative need, development of hatchery technology for mud crabs has been given top priority in most of the crab culturing countries in the world (Chong, 1992, Cowan 1984). Experiments on rearing larval stages to juveniles under controlled conditions have been conducted in Malaysia, Hawaii, Australia, Taiwan and Japan (Ong, 1964; Brick, 1974; Haesman & Fielder, 1983; Cowan; 1984; Jamari, 1992) with varying degrees of success and practical techniques for commercial production of juveniles in hatcheries have been developed in Taiwan and Japan (Cowan, 1984).

In India experimental work on larval rearing and seed production of mud crabs was initiated as early as 1984 at the Tuticorin Research Centre of the Central Marine Fisheries Research Institute (Marichamy & Rajapackiam, 1984). Mass rearing of larvae of *S. serrata* could be successfully carried out during the above experiments. Since no information is available on these aspects specifically for *S. oceanica,* a series of experiments carried out on incubation and larval development upto instar I have been dealt with in detail in chapter III. As larval feed is an important factor for better survival for evolving seed production technololgy, two series of experiments were conducted to study the ability of different food items, individually and in combination to support development and survival of the larvae of *S. oceanica* and the results are described below. In the first series of experiments, food items such as *Chlorella, Artemia, Brachionus,* microencapsulated feed and egg custard were given individually. In the second series, feeding with different com-

binations of the above food items was attempted. The experimental set up, methods of live feed production and preparation and composition of particulate feeds are described in detail in Chapter II . In all the experiments, larval density was maintained at 50 numbers/litre. Experiments were conducted at salinity 34-35 ppt, pH 7.8-8.2 and temperature 27-30°C. Megalopa was reared at a reduced salinity of 23 ppt.

Results of the first series of experiments are graphically represented in Figs. 23-28. The first food item tried was *Chlorella salina*. A concentration of 50,000 cell/ml was maintained in the culture medium throughout the rearing period with 100% water exchange daily. Larvae were very active during the first day but on the second day morning only 34.3% of them were alive. Even among the live ones some of the larvae were not active and seen lying at the bottom with limited movements. On the third day morning, only 11.7% of larvae were alive but a greenish tinge was seen in the alimentary canal of the live larvae indicating intake of the algae. On the fourth day, 3.7% of the larvae were alive and most of them remained at the bottom of the container with limited movements. Total mortality was observed on the fifth day of rearing.

In the second treatment egg custard was given as feed. The feeding rate was 70 mg/larvae/day in four split doses at six hourly interval. Larvae were active during the first day of rearing but only 12% of them survived on the second day morning. The live ones were also not active. Total mortality occurred on the second day night and none of them showed any sign of activity on the third day morning when viewed under the microscope.

Microencapsulated feed was used as the third treatment and the feeding rate was 50 mg/larval/day in four split doses at six hourly interval. Survival rates recorded were 22.7, 13.3, 5 and 1.7 on the second, third, fourth and fifth day of rearing and the larvae did not survive beyond that. From the second day onwards a greenish tinge was noticed in the alimentary canal of the larvae indicat-

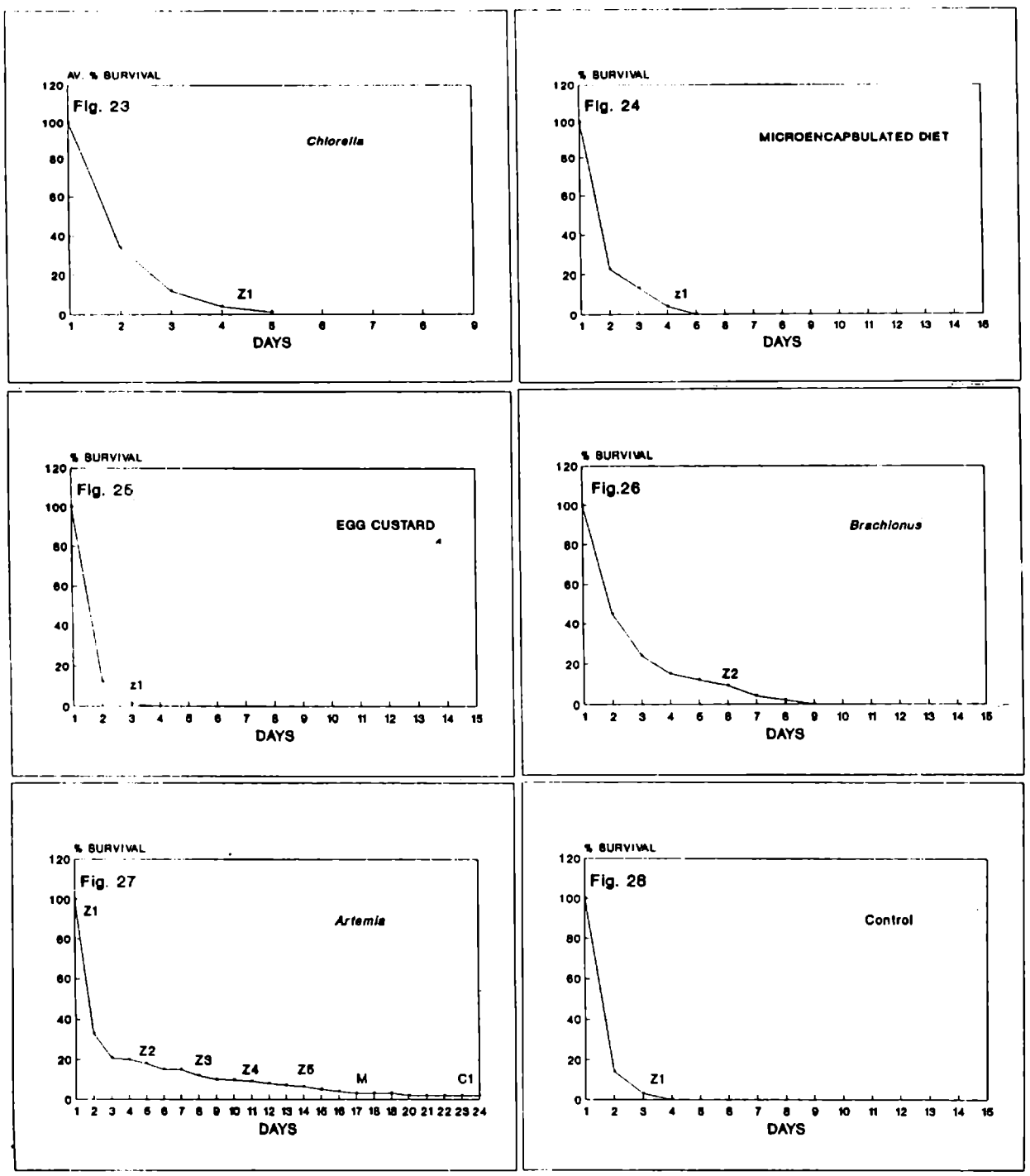

Fig. 23-28: Survival rates of developmental stages in different feed trials

ing the presence of feed in the stomach. Even among the surviving larvae only 1/3rd of them were active and the others were totally inactive and the movements could be recognised only on close examination of the larvae.

In the fourth treatment, the rotifer *Brachionus* was used as food at a feeding rate of 20 numbers per ml. The second zoeal stage was noticed on the sixth day of rearing but the survival rates were low with 26.3, 18.7, 10.3 and 5.7% of larvae surviving on the 2nd, 3rd, 4th and 5th day respectively. Only 2.3% of the larvae metamorphosed in to zoea-II. Total mortality was observed on the 10th day of rearing with no further moulting.

In the fifth treatment newly hatched and frozen *Artemia* nauplii was given as feed at the rate of 10/ml for the first and second zoeal stages and from the third zoeal stage onwards newly hatched *Artemia* nauplii was given at the rate of 10/ml. The zoea were seen nibbling the nauplii on the first day itself. This treatment supported the zoea through all the five zoeal stages, the megalopa stage and the crab stage. After the first stage, successive zoeal stages were observed on the 5th, 8th, 11th and 14th day of rearing. Maximum mortality (67%) was recorded on the second day of rearing and after that the mortality was gradual. The percentage survival was 18.3, 9.7, 5 and 2 on the 5th, 10th, 15th and 20th day of rearing. Percentage of larvae reaching Zoea-II, Zoea-III, Zoea-IV, Zoea-V and megalopa and crab stages were 13, 8, 6, 4, 2 and 2 respectively. Megalopa stage was observed on 17th day and the crab stage on 23rd day of rearing.

In the control set in which no feeding was done, 85% mortality was recorded on the second day of rearing and 3% of larvae survived on the third day. Total mortality was observed on the 4th day.

In the second series of experiments consisting of three treatments, namely, A, B, and C, combinations of feed used in the first series were tried. In the treatment A, a combination of frozen *Artemia* nauplii, *Brachionus* and microencapsulated

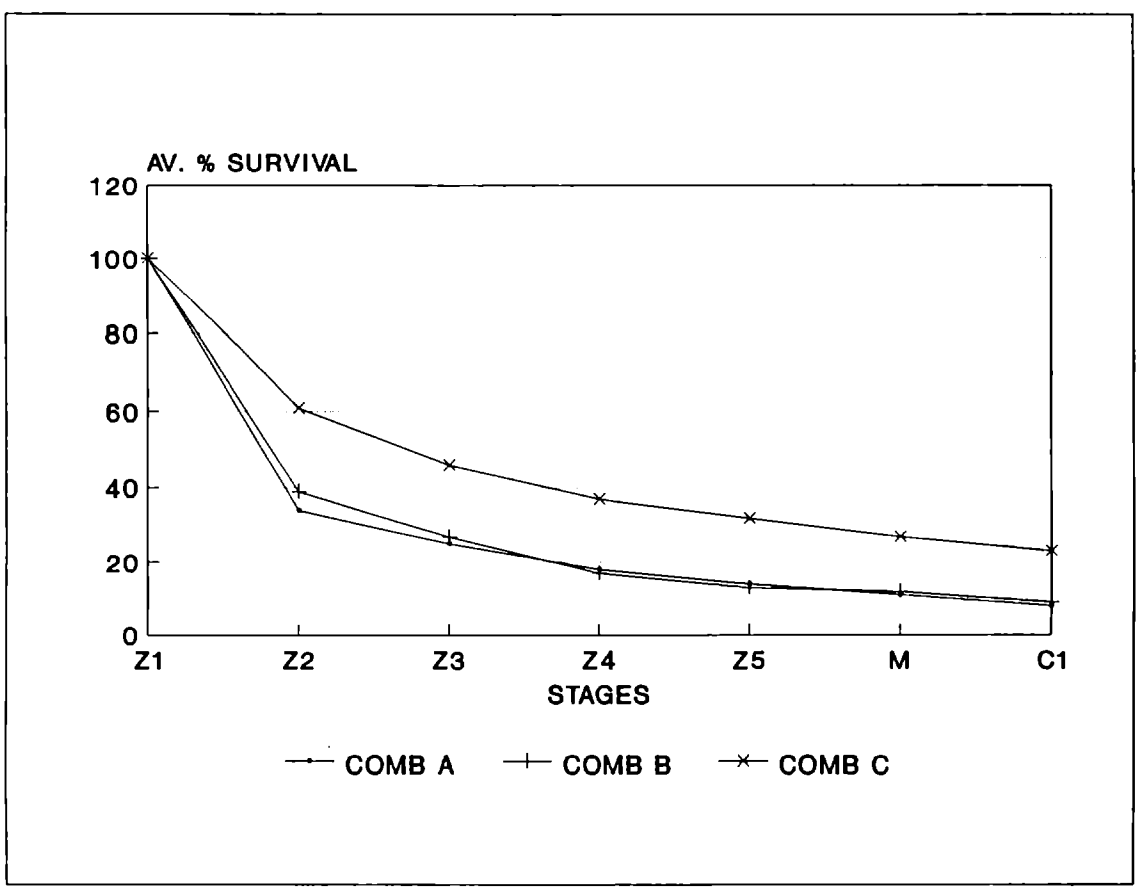

Fig. 29: Survival rates of developmental stages in different feed combinations

feed was used, while in treatment B, combination of frozen *Artemia* nauplii, *Brachionus* and *Chlorella* and in treatment C, combination of *Artemia* nauplii suspension and *Brachionus* were used. An antibacterial chemical prefuran was also used in the treatment C to avoid bacterial contamination. In this treatment, from Zoea-III onwards, *Artemia* nauplii suspension was supplemented with freshly hatched nauplii at the rate of 15/ml which was increased to 20/ml at Zoea-V stage. Rotifer *Brachionus* was given at the rate of 20/ml till Zoea-IV. Microencapsulated feed was given at the rate of 50 mg/larva/day which was increased by 10 mg at every moult and approximately 90-100 mg given at Zoea-V stage. *Artemia* nauplii suspension was given at the rate of 70 mg/larva/day. Live feeds were given in two split doses; one each in the morning and evening. Particulate feeds were given in four split doses at six hour interval. From megalopa stage onwards prawn meat suspension was given.

Results of the second series of experiments are graphically represented in Fig. 29. In these experiments also maximum mortality was recorded in the first zoeal stage. Average percentage mortalities during the first zoeal stage were 66, 61 and 31 in the case of treatments A, B and C respectively. The mortality was gradual after the first zoeal stage (Fig.29). Treatment C showed statistically significant higher rates of survival at all the successive larval stages compared to treatments A and B, with average percentage survival of 46, 37, 32, 27 and 23 at Z-3, Z-4, Z-5 megalopa and crab stages respectively. Among combinations A and B, the latter showed better survival rates at Z-2 and Z-3 with average percentage survival of 39 and 27 as compared to the survival of 34 and 25 percent in the case of treatment A. The differences noticed between the two treatments, however were not statistically significant. From Z-3 onwards the percentage survival was almost similar in the case of treatments A and B. The average production of megalopa with feed combination A, B and C were 11%, 12% and 27% and that of

crabs 8%, 9% and 23% for the three treatments respectively. Cannibalistic tendency was observed from megalopa stage onwards and it was the main reason for mortality from that stage. Shelters such as oyster shell and untwisted nylon rope were placed in the container and they were found effective in reducing cannibalism.

The results indicated that the period of transformation between different development stages did not vary significantly with treatments. The minimum time taken to attain the megalopa stage was 17 days in treatment A and B and 18 days in treatment C. The crab stage was reached in 23 days in treatments A and B and 24 days in treatment C.

Discussion

An important problem associated with mud crab farming is the inherent tendency of crabs to escape from the farming system during the period of culture operation. In order to prevent the escape of crabs, different management measures such as fencing the pond, reinforcing the dyke with concrete/bricks, proper feeding schedule, adequate water exchange etc. are resorted to. Of these fencing is done invariably and for this various kinds of materials are used. In Taiwan, the fattening ponds are constructed with vertical brick walls (Chen ,1990) whereas in Indonesia the farmers use bamboo stakes for fencing the pond (Cholik & Hanfi, 1992). De silva (1992) tried wire mesh fencing in Sri Lanka, while in Surat Thani province of Thailand different materials like bamboo poles, asbestos sheets or knotless netting are used (Rattanchote and Dangwatankul, 1992).

During the present study the culture pond was provided with nylon netting which proved to be very effective to prevent the escape of crabs and is comparatively cheaper than other materials like wire mesh, asbestos sheet or bamboo

fencing. Further, the installation of fencing made of nylon netting was much easier and less time consuming than by other materials. The use of nylon nets for fencing is found to have a number of other advantages apart from the low cost of construction. As in the case of the export of processed fishery products wherein quality assurance is an essential aspect, the live crab export which is becoming more and more lucrative in the recent years also demands quality assurance like healthy and disease free condition for trade. In the event of crabs attempt to escape from the ponds by climbing over the dykes and fencing, injuries are bound to occur on the ventral side of the crab leading to infections. As the presence of scratches on the body or shell breakage in the crabs would disqualify their acceptability to exporters, care has to be taken to prevent occurrence of scratches or shell breakage during culture operation. It is observed that the chances of such damages on the body of crabs are extremely low when the fencing is done with nylon netting. Since nylon netting is cheaper the cost of fencing can be brought down to very low level. Another advantage is that, instead of new nylon netting for this purpose even old fishing nets could also be used thereby reducing the cost of fencing further.

The mud crabs are well known for their burrowing habits and the tendency for burrowing is more pronounced during moulting in order to ensure safety from the attack of predators and also to escape from the ponds in the event of unfavorable environmental conditions. During the present study crabs showed strong tendency to burrow into the bund especially near the sluice gate. This part of the pond therefore appeared to be more vulnerable for escape of crabs. Hence this area of the bund was covered with strong bamboo matting which proved to be effective to check the incidence of burrowing during crab farming. In the fattening experiments assorted sizes of crabs falling between 550 g-2000 g were used in all the four trials since the preference for live crab export was for those above

550 g and also because there was no consistency in the availability of any particular sizes between this size range in the backwater capture fishery which formed the source of material for the experiment.

As there are no studies reported in the literature on fattening of large size crabs above 550 g, the present study was a maiden attempt to find out the ideal stocking density yielding the maximum economic returns. The stocking density was 0.25/sq.m in the first trial, 0.35/sq.m in the 2nd and 3rd and 0.5/sq.m in the fourth trial. The duration of fattening was uniformly 45 days for the first 3 trials and 60 days for the 4th trial (Table 22). The percentage survival at the time of final harvest varied significantly between different trials. In the first experiment the survival was 95.2%, which increased to 96.6% in the 2nd trial and 98.9% in 3rd trial. The final survival rate in respect of 4th trial went down drastically to 91.2%. The rate of survival of crabs remained appreciably good in spite of the fact that the salinity of the pond was at a very low level ranging 5.0-7.5 ppt in the first trial. The most favourable salinity for mud crab farming is reported to be 15-35 ppt (Liong, 1994). Although the fattening commenced with low salinity condition (6.5 ppt) in the second trial the salinity values increased gradually to as high as 24.2 ppt, and it remained more or less at constant level of 27-29 ppt in the 3rd trial. It is possible that the higher survival rate recorded for these two trials could have been favourably influenced by the higher salinity regime prevailing in the pond as most of the other environmental factors and pond management procedures remained more or less the same. The high survival rate of 98.7% was recorded in the 3rd trial in which the only variable factor that could be attributed to this is the difference in the feeding schedule during that experiment. The feeding schedule during the 3rd trial was changed from once a day to twice a day, about 30% of the daily ration was given in the morning and the remaining 70% given in the evening. Many workers reported that feed utilisation is more effective in multiple feeding

rather than one time feeding.

In the 4th fattening trial though higher salinity condition (27-29 ppt) prevailed in the pond, mortality was maximum. The percentage of marketable crabs was also lower than in all other experimental trials (87.6%). This poor performance coincided with deteriorated water conditions on several occasions as evident from the smell of water caused by the excess metabolic wastes released by the denser population and the lack of adequate water exchange. The temperature of the pond water was also higher than in all the previous trials because of the summer season (April), which could have adversely affected the crabs as was evident from the sluggish nature of the animals and fouling of epiphytic algae on crabs body. Taiwanese crab farmers, who stock crabs of 8-12 cm in CW corresponding to about 200-250 g in weight use one crab/m^2 as optimum stocking density in summer (Sivasubramoniam & Angell, 1992). In the present study, 0.5/m^2 stocking density corresponds to about 400 g/m^2 assuming that the average weight of crab stocked was about 800 g. The Taiwanese use pump sets for water replenishment as and when required whereas in the present study the water exchange was by tidal action only which would not have ensured adequate water replenishment commensurate with the crab biomass. From the above observation it can be presumed that the optimum stocking density of crab of about 800 g average weight during summer period could be around 0.35 crab/m^2 under tide fed conditions. This works out to 3500 crabs/ha water area for fattening in tide fed brackishwater condition.

The food given to the crabs consisted of fresh trash fish, salted fish and slaughter house waste. A feeding rate of 7% of body weight was adopted for trash fish and slaughter house waste while a slightly reduced rate of 5% of body weight was used when salted fish was offered. The crab showed varying preferences for different food items when three types were offered together. The first preference

was given to trash fish, then to salted fish and finally to slaughter house waste. Chen (1990) reported a feeding rate of about 1% of body weight with trash fish and sometimes with freshwater hornshell snail during fattening of female crabs of 220-250 g size. Snail meat is added in the diet to facilitate development of gonads, as the fattening is aimed at producing crabs with well developed roe rather than converting 'water crabs'to meat crabs in Taiwan.

According to Rattanchote and Dangwatankul (1992) a higher rate of feeding is practised in Thailand where trash fish and horse mussel are given at the rates of 7-10% of body weight once or twice a day. De Silva (1992) used offal, clam meat and fish for feeding mud crabs and found that first preference was for clam meat and then for offal. Cholik and Hanafi (1992) reported the use of dried trash fish at higher feeding rates of 10-15% of body weight. The feeding rate of 5-7% of body weight followed during the present experiment appears to be reasonable considering the prevailing environmental conditions of the brackishwater farms of Kerala coast which are tide fed. The slaughter house waste when offered in fresh condition was found to pollute the water as evident from the sudden change of water quality recognisable from the colour change and foul odour . Though this problem could be partly overcome by half cooking of meat before use, regular use of slaughter house waste in crab fattening pond is considered undesirable from the view point of environmental safety.

Fattening in cages or pens is considered more advantageous as the stocking rates in such systems could be considerably high (Marichamy *et al.*, 1980; Raman *et al.*, 1980; Natarajan & Thangaraj, 1983; Bensam, 1986; Marichamy *et al.*, 1986). In Philippines as many as 18 crabs are stocked in a cage of 140 x 70 x 25 cm size with 18 compartments, keeping one crab in each compartment (Larda, 1992). In Indonesia crabs are stocked in individual compartments at the rate of 40 crabs/m^2 in which condition the mortality rate is less than 5% (Cholik & Hanafi, 1992). This is

in contrast to a stocking rate of 2 crabs/m^2 for crabs of 150-200 g size in pond systems. Observations on crab fattening in wooden cages (2.5 x 2.5 x 2 m) (Plate. 39 a) which was commenced on small scale in Cochin backwaters in recent years have shown that as many as 25-30 'water crabs' of size 550 g and above are successfully raised at a time without any mortality. This high stocking density is possible since the cages facilitate constant water replenishment in the open backwater providing very ideal living conditions for the crab. From this it would appear that the optimum stocking density of 0.35 crabs/m^2 worked out for fattening ponds could be further increased by resorting to frequent water exchange and constant aeration coupled with appropriate feeding as practised for shrimps in the semi-intensive systems. Further under such improved environmental conditions a denser population can be raised safely since no moulting takes place during fattening period which would make the animals vulnerable for cannibalism and consequent mortality.

A clear change was noticed in the biochemical composition of meat during fattening. The average moisture content decreased from 87.15 % to 80.93% whereas the crude protein increased from 8.33 to 14.93% during the transformation. This would indicate that the water profusely absorbed during moulting gets replaced with protein during fattening apparently with little change in the body weight.

As regards the grow-out culture experiment, a stocking rate of 1 crab/m^2 was used since the size of the crab was less (100-200g). The survival rate recorded at the end of the experiment was only 52% which was remarkably low when compared to the survival rate (>90%) recorded in the fattening experiments. The reason for the low survival rate could be the protracted nature of the culture operation using smaller crabs of wide ranging sizes which moult several times during the culture period making the smaller ones susceptible to predation by the larger crabs in freshly moulted condition. Low survival rates during the grow-out

culture was reported by several workers. Samarasinghe *et al.* (1992) culturing juvenile crabs of 50 g average weight for 175 days in Sri Lanka, observed a mortality rate of 56.3% which is comparatively more than the mortality rate observed in this study. These authors also observed that considerable mortality occurred at the stocking stage itself when the crablings were in highly stressed condition due to poor handling during collections and transport. Chen (1990) reported 30-70% survival in grow-out culture system in Taiwan from stocking to harvesting depending upon the size of the seed and scheme of management. He also observed that crabs in polyculture with *Gracilaria* fair much better, giving survival of 50-60% in 6-8 months culture period, probably because the *Gracilaria* acts as shelter minimizing cannibalistic loss.

Analysis of biomass production during the grow-out experiment indicates an average daily gain of 2.15 g and an average biomass production of 0.665/sq.m/day. Studies conducted by Samarasinghe *et al.* (1992) showed an increase in weight from 50 g to 340 g in 115 days and the daily growth rate worked out to 2.52 g/day (species not specified). These authors obtained a production of 1011 kg/ha/115 days whereas in the present study it was 1280 kg/ha/192 days. Chaiyakam and Parnichsuka (1977) reported average growth rates of 1.22 to 1.41 g/day in cages. Earlier Indian studies (Kathirvel, 1995) yielded production rates of 494 to 600 kg/ha in monoculture and 690 kg/ha in polyculture with milk fish and mullets. The low yields in those experiments could have been due to stocking of mixed species and multiple sizes whereas in the present study *S. oceanica*, the fast growing species, alone was used for the culture.

Economic analyses of mud crab farming practised in most of the East Asian countries (Anon, 1992a; Kathirvel, 1993; Viswakumar, 1993) and in India (Suseelan *et al*, 1995) have established that crab culture is highly profitable when compared with other forms of aquaculture due to the increasing price live mud crabs of

crabs in the international markets.

In the crab fattening experiments the initial investment and fixed cost were the same for all the four trials as they were conducted in the same pond. Among the operating costs, cost of soft crabs was the most important variable since the stocking size was very big compared to the sizes used in the grow-out culture. The operating cost per crop was lowest in the first trial (Rs.11,737) corresponding to the lowest stocking density and highest in the fourth trial (Rs.21,215) corresponding to the highest stocking density tested. The operating cost of the second and third trials did not differ much because of the uniformity of stocking density and the meagre variation in the weight of animals. Feed, which was given according to the biomass of the stocked animals also showed a similar pattern with respect to its cost.

The lowest income per crop was obtained in the first trial and the highest in the fourth trial corresponding to the lowest and highest stocking densities used in these trials, but the annual income was higher in the third (Rs.1,59,840) and second (Rs.1,45,200) trials. Even though the income per crop was the highest in the fourth trial, the annual income worked out for this trial was lower than that of the third trial because of the lesser number of trials in the former case. The gross profit from trial four amounted to Rs.35,275 which was less than the gross profit from the third (Rs.50,388) and second (Rs.38,316) trials as the operating cost was the highest in the fourth trial. This would indicate that stocking density of $0.5/m^2$ or above cannot be recommended under the present level of management. The higher gross profit obtained in the third trial as compared to the second trial shows that even at the same stocking density profit can be increased significantly by adopting better management techniques. The lowest profit (Rs.13,218) obtained at the stocking density $0.25/m^2$ shows the under utilization of the pond.

Results of the grow out culture during the present study indicated a gross

annual profit of Rs.40,250 for two crops, which is very less compared to the annual profit recorded for fattening in which the mean annual profit works out to Rs.88,714 when the average annual profit of trials 2 and 3 (which gave the best results) are raised in a corresponding pond size of 0.1 ha. Crab fattening is more remunerative because of the fast turn over, low operating cost, high survival rate and good market demand for the end product. According to Viswakumar (1993) out of the capital investment required for construction of 1 ha farm, cost of pond construction formed about 59% and perimeter fencing cost formed 28%. Out of the operating cost feed represented 37.4%, labour 26.4%, seed 10.7% depreciation 11.4% and interest on capital, marketing, fertilizer and maintenance formed the rest.

The profitability of crab farms can be improved by reducing the incidence of mortality by cannibalism through various methods as practised in most South East Asian countries (Chen, 1990; Chong, 1992). Stocking uniform sized crabs and regular feeding in appropriate quantities are the best management procedures for achieving this. Closer observations during the present experimental culture revealed that monosex culture can be a possible method of reducing mortality. Placing sufficient shelters like roofing tiles, cut bamboo pieces, concrete/ asbestos pipe etc. in pond together with proper water quality management will ensure higher survival rates and better economic returns.

In the first series of experiments in which five larval feeds viz. *Chlorella*, egg custard, microencapsulated feed, *Brachionus* and frozen *Artemia* nauplii were given individually, only *Brachionus* and *Artemia* nauplii supported moulting of zoea. Even though *Chlorella* did not support moulting of zoeae it enhanced their survival period as compared to the control (Fig. 23-28). Simon (1974) observed that mixed diatom culture given to early zoeal stages favoured good survival, but did not moult. According to Haesman and Fielder (1983) the better survival with *Chlorella*

and antibiotics is due to reduced risk of bacterial infection and/or build up of potentially harmful metabolites or breakdown products thereof. In the case of microencapsulated feed also survival was better than in the control, and this may also be attributed to the antibacterial properties of algal fractions which was indicated in the manufacturer's label. But both *Chlorella* and microencapsulated feed failed to support moulting of zoea. Jamari (1992) successfully used 5-10 rotifers/ml in the morning and evening supplemented with artificial shrimp larval feed. Studying the development and survival of the larvae of *S. serrata* in Hawaii, Brick (1974) observed that rotifers and wild zooplankton as a food source failed to support zoeal survival to the onset of metamorphosis. Marichamy and Rajapackiam (1992) however, was able to raise the first two zoeal stages by feeding rotifer (*Brachionus plicatilis*). During the present study *Brachionus* supported one moulting, but very few larvae could reach the 2nd zoeal stage. *Artemia* nauplii (10-15/ml) supported the larvae through all the zoeal stages, but the production of crab was as low as 2%. Ong (1964) and Du plessis (1971) reported survival rates of 1% and 4% respectively for crab and megalopa stage with *Artemia* nauplii as feed. Haesmen and Fielder (1983) achieved the best survival rate of 26% of first zoea using a specially designed recirculatory system in which the larvae were fed exclusively with newly hatched San Francisco brine shrimp (*Artemia salina*). The residual brine shrimp nauplii were selectively flushed from the rearing vessel each day by exchanging the 142 micron filter sleeve with 939 micron substitute for 300 micron. These authors could maximise the survival rate by increasing the artemia nauplii concentration from 5 to 30/ml.

In the second series of experiment the Combination-C with *Artemia* nauplii suspension and *Brachionus* along with antibacterial chemical prefuran (0.5 ppm) gave best production rate of 23% at crab stage as compared to Combination-A (Frozen *Artemia* nauplii, *Brachionus* and micro-encapsulated feed) with a produc-

tion rate of 8% and Combination-B (Frozen *Artemia* nauplii, *Brachionus* and *Chlorella*) with a production rate of 9%.

In all the three feed combinationsmaximum mortality was noticed during the 1st zoeal stage with mortality rates of 66%, 61% and 39% for Combinations A, B and C respectively. Thereafter the mortality rate remained steady in all the three cases. Several authors have reported maximum mortality in the first zoeal stage (Ong, 1964; Brick, 1974; Haesman & Fielder, 1983; Jamari 1992; Marichamy & Rajapackiam, 1984, 1992). Several reasons were assigned to the low survival of larvae. According to Ong (1964) the most important reason for this mortality was the failure to supply natural food for feeding the larvae. He opined that *Artemia* nauplii were too fast and big for majority of the early zoeae. During the present study also *Artemia* nauplii were found to be too big and fast that the zoeae could not feed them easily. Because of this only frozen nauplii were given in the initial stages but the dead nauplii were found to pollute the rearing medium very fast. According to Jamari (1992) sudden death of larvae occurred due to the inability to moult. The zoeae were killed occasionally by the chitin destroying bacteria attacking near the carapace spine (Ting *et al.*, 1981). In the case of *P. pelagicus*, Raman *et al.* (1987) recorded a survival rate of 35.7 % at megalopa stage which was attained in seventeen days from first zoea, by feeding different items like *Tetraselmis* sp., egg custard suspension, *Brachionus plicatilis*, egg & mussel tissue and minute particles of trash fish flesh at different stages of development.

The highest production rate obtained with feed combination C can be attributed to the *Artemia* nauplii given in suspension form and the presence of antibacterial chemical in the medium. Artemia suspension would have given better accessibility of feed to the zoea and the antibacterial chemical helped in reducing the bacterial contamination.

Brick (1974) observed that antibiotics enhanced premetamorphic survival of zoea while leaving the rate of zoeal development and the success of metamorphosis to megalopa unaltered. He used the antibiotics such as carbonate buffered potassium penicillin-G at 40 ppm and Polymyxin-B sulphate at 10 ppm, and observed that water filtration and ultraviolet sterilization did not significantly affect larval survival.

During the present study cannibalism was encountered from megalopa stage onwards and the mortality recorded from this stage was mainly due to cannibalism. Similar observations were also made by Ong (1964), Marichamy and Rajapackiam (1984) and Haesman and Fielder (1983) in *S. serrata*. According to Jamari (1992) mortality upto 60% occurred at crab stage due to cannibalism within the initial few days at a stocking density of 10 pcs/litre. He further pointed out that cannibalism continued even when adequate food was given. During the present study the mortality due to cannibalism was controlled by giving shelters such as oyster shells, untwisted nylon rope etc. Marichamy and Rajapackiam (1992) also found that providing shelters would reduce cannibalism to some extent.

CHAPTER IV
SUMMARY

SUMMARY

1. The thesis embodies the results of a detailed study of the taxonomy, distribution, biology, fishery and culture prospects of mud crabs of the genus *Scylla* along the Kerala coast based on observations from the Ashtamudi lake (Kollam), Cochin backwaters (Kochi) and Korapuzha estuary (Kozhikode) and the contiguous inshore waters during 1992-'95.

2. The identity of species of mud crabs occurring in the study area has been critically examined on the basis of morphological characters, colour variations and electrophoretic evidences and in comparison with specimens obtained from the east coast of India. It is found that the mud crab population of Kerala as well as Tamil Nadu coast is represented by two distinct species, a smaller one *Scylla serrata* (Forskal) and a larger one *Scylla oceanica* (Dana), which coexist throughout the coast in the marine and brackishwater environments.

3. Comparative study of the biology and larval development of the two species of mud crabs has been undertaken for the first time which showed distinct variations between species in many respects.

4. The gross morphology, anatomy and histology of the reproductive systems have been described. The reproductive systems of the two species resemble closely and conform to the general pattern of portunid crabs.

5. The male reproductive system consists of paired testes, vasa deferentia, ejaculatory ducts and external penes. The mature testis has the appearance of white convoluted tube and is incompletely divided into lobes. The vas deferens is differentiated into a coiled

anterior vas deferens (AVD), a massive median vas deferens (MVD) and a thin posterior vas deferens (PVD).

6. Spermatogenesis is initiated from the peripheral germinal zone of testis and it involves a progressive reduction of cytoplasm and condensation of chromatin material in developing cells. The pattern of spermatogenesis is similar in both the species. Spermatophore formation takes place in different parts of the AVD and the fully formed spermatophores are stored in the MVD, which are spherical or ovoid in shape and measure 28-93 μ in *S. serrata* and 33-116 μ in *S. oceanica.*

7. The female reproductive system consists of paired ovaries, spermatheca and oviduct. The 'H' shaped ovary fills the body cavity in mature stage. Histologically the ovary shows a medially placed germinal zone. Oogenesis involves three broader phases in both the species, namely, proliferative phase, previtellogenic phase and vitellogenic phase. During proliferative phase, the oogonial cells multiply in the germinal zone and develop into primary oocytes. In previtellogenic phase, the oocytes increase in size. In vitellogenic phase, the oocytes undergo further growth attaining a diameter of 267 μ when the ooplasm becomes fully flooded with yolk granules. Nucleus is not visible in ripe ova.

8. Ovarian maturation is accompanied by distinctive colour changes and increase in the volume of the ovary. Based on the colour and size of the ovary five maturity stages are recognised namely, immature, early maturing, late maturing, ripe and spent. The different maturity stages are described.

9. The minimum size of berried female measured 8.0 cm CW for *S. serrata* and 12.2 cm CW for *S. oceanica.* The diameter of eggs in the berry measured 290-365 μ for the former

and 330-385 μ for the latter.

10. The newly acquired berry is pinkish yellow in *S. serrata* and yellowish in *S. oceanica*. It changes to brownish black or black in the final stage of incubation. The maximum period of incubation observed is 12 days for *S. serrata* and 13 days for *S. oceanica*.

11. The fecundity ranges from 1,52,140 (9.5 cm CW) to 4,53,344 (12.1 cm CW) for *S. serrata* and 25,39,683 (13.4 cm CW) to 70,58,823 (18.2 cm CW) for *S. oceanica*.

12. Both the species breed in the brackishwater systems where peak breeding is noticed during January-February for *S. serrata* and February-March for *S. oceanica*. Though ovigerous females occur throughout the year in the inshore waters, the same are not encountered in the brackishwater systems during June-August in the case of *S. oceanica* and June-July in the case of *S. serrata*..

13. *S. oceanica* egg was reared through five zoeal and one megalopa stages to crab instar I. It took a minimum of 17 days for first zoea to become megalopa which inturn took 6 days to metamorphose into crab instar I. *S. serrata* egg was reared through five zoeal stages and it took 20 days to reach the fifth zoeal stage. In both the species maximum mortality was observed in the first zoeal stage, *S. serrata* showing 90 % mortality as against 40 % mortality in *S. oceanica*. Except for size variations, larval stages of both the species showed close similarity in their morphological features.

14. During a rearing period of 295 days with laboratory raised crab instar I of *S. oceanica*, the male moulted 14 times to reach the 15th instar attaining a size of 9.6 cm CW and 120.6 g wt, while the females moulted 15 times to reach the 16th instar attaining a size of 10.76

cm CW and 170.0 g wt. A mean monthly growth of 10.59 mm CW and 13.3 g wt was recorded for male and 10.94 mm CW and 17.28 g wt for female. The minimum intermoult period ranged from 4 days for 1st instar to 42 days for 14th instar in the case of male and 4 days for 1st instar to 52 days for 15th instar in the case of female.

15. During a rearing period of 9 months using baby crabs of *S. serrata* collected from the wild, the males with an initial size of 2.76 cm CW and 2.4 g wt attained a size of 8.08 cm CW and 62.4 g wt showing a monthly growth rate of 9.23 mm CW and 7.12 g wt. The females with an initial size of 2.75 cm CW and 2.45 g wt attained a size of 7.75 cm CW and 60.7 g wt showing a monthly growth rate of 10.02 mm CW and 7.85 g wt.

16. Based on statistical analysis of the size frequency data from commercial catches, the $L\infty$ and K (annual) have been estimated to be 22.63 cm CW and 1.32 respectively for male and 21.69 cm CW and 1.28 for female in the case *S. oceanica* and 16.4 cm CW and 1.26 for male and 14.5 cm CW and 1.11 in the case of *S. serrata*. The estimated sizes attained in the first, second and third year of life of *S. oceanica* are respectively 16.58 cm, 21.02 cm, and 22.20 cm CW for male and 15.65 cm, 20.01 cm and 21.22 cm CW for female. The estimated sizes attained by *S. serrata* are 11.8 cm, 15.8 cm and 16.1 cm CW for male and 9.78 cm, 13.0 cm and 14.0 cm CW for female during the corresponding periods.

17. In the grow-out culture experiment, *S. oceanica* male grew from a mean initial size of 9.92 cm CW (168.15 g) to 15.64 cm CW (596 g) in six months indicating a mean monthly growth rate of 0.95 cm (71.31 g) whereas female grew from a mean initial size of 10.75 cm CW (190.4 g) to 16.4 cm (544.37g) showing a monthly growth rate of 0.94 cm CW (64.0 g).

18. Comparison of carapace width-weight relationship between sexes showed statistically significant difference in both the species.

19. The two species of mud crabs showed notable differences in their behavioural pattern, *S. serrata* being more 'burrow dwelling' in character as compared to the 'free living' nature of *S. oceanica*. Further, the former species is more agile and fierce than the latter.

20. Observations on the fishery of mud crabs indicated marked changes over the years in the gears used in the fishery. Modern gears such as ring nets and gill nets made of synthetic twines have almost replaced the traditional gears like hand lines, long lines, iron rods and shore seines. Crab fishing which was seasonal earlier has become a regular practice with peak fishing from December to June catching maximum crabs in June with the onset of rain and the consequent influx of freshwater. In the commercial catches *S. oceanica* accounts more than two-third and *S. serrata* the rest.

21. The peak recruitment of crabs into the fishery takes place during August-September in the case of *S. oceanica* when they are approximately 6-8 months old and during October - December in the case of *S. serrata* when the crabs are about 11- 12 months old. As the bulk of the fishery of *S. oceanica* is supported by sizes close to the size at first maturity (12-14 cm CW), it is suspected that growth-overfishing is taking place in this species which call for regulatory measures to protect the wild stock. In the smaller species *S. serrata*, on the other hand, such damaging situation of stock is not observed.

22. Short term crab fattening experiments conducted using postmoulted soft crabs ('water crabs') of *S. oceanica* in the sizes of 550 g and above have shown that 45 days fattening with a stocking density of 1 crab / 3 sq. m and a feeding rate of 7 % of biomass per day

in two split doses is ideal for better survival and economic returns in tide-fed conditions. During fattening no significant change was observed in the total weight of the animal, but the average protein content of meat increased from 8.33% to 14.93 % while the moisture content decreased from 87.15 % to 80.93 %.

23. In the grow-out culture experiment, *S. oceanica* juveniles with a mean weight of 180 g was raised at a stocking density of 1 crab/sq.m in a 0.1 ha pond for 192 days. The biomass of crabs increased from 180 kg to 308 kg. The estimated biomass production / ha worked out to 1280 kg.

24. Economic analysis of the two types of crab farming experiments showed that fattening would yield over 150 % more profit than grow-out culture on the assumption that six operations are possible for fattening or two for grow-out culture in a year.

25. In the seed production experiments, among the five larval feeds attempted, namely, *Chlorella*, microencapsulated feed, *Brachionus*, frozen *Artemia* nauplii and egg custard, only *Brachionus* and frozen *Artemia* nauplii supported moulting of zoea. Among these two, *Brachionus* supported larvae upto zoea II and frozen *Artemia* nauplii upto crab instar with a production rate of 2 % . In the experiments in which three combinations of larval feeds were tried, Combination-C formed of *Artemia* nauplii suspension and *Brachionus* along with antibacterial chemical prefuran (0.5 ppm in the medium) gave the best production rate of 23% at crab stage as against Combination-A (frozen *Artemia* nauplii, *Brachionus* and microencapsulated feed) which gave a production rate of 8% and Combination-B (frozen *Artemia* nauplii, *Brachionus* and *Chlorella*) which gave a production rate of 9% at crab stage.

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