

**STUDIES ON THE DEEP-WATER CRAB
CHARYBDIS (GONIOHELLENUS) SMITHII MACLEAY
FROM THE SEAS AROUND INDIA**

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BY

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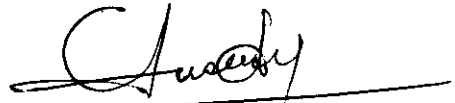
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DEDICATED TO MY PARENTS

C E R T I F I C A T E

This is to certify that this thesis entitled **Studies on the deep-water crab Charybdis (Goniohellenus) smithii Macleay from the seas around India** embodies the bonafide original research work conducted by Shri. C.P. Balasubramanian, under my supervision and guidance. 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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D E C L A R A T I O N

I hereby declare that this thesis entitled **Studies on the deep-water crab Charybdis (Goniohellenus) smithii Macleay from the seas around India** 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, associate-ship, fellowship or other similar recognition.

Kochi-682014,
September, 1993.


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P R E F A C E

The declining growth rate in marine fish production coupled with the rising human population is widening the gap between the supply and demand of fish which continues to be an important source of animal protein for the growing world population. It is universally believed that the conventionally exploited fish stocks of marine sector are no longer in a position to yield any substantial increase in the coming years as they have already reached stage of stagnation. At this juncture, the only alternative one can foresee to augment fish production from the sea is to tap the hitherto unexploited or under-exploited fish resources of the deeper waters. The government of India have given top priority for development of deep-sea fishing and many programmes are underway to fulfil this national priority during the current 5 year plan (Sukumaran, 1992). These programmes have been set by the Government in the light of encouraging results obtained during the past exploratory surveys in the deep-sea/offshore regions of Indian coasts. The swarming crab, Charybdis (Goniohellenus) smithii is one of the potential species which have been identified to be candidates for future exploitation. The increasing demands for crabs in some of the Southeast Asian countries in the recent years has given a fillip to the export of ^{this} resource from the country and greater foreign exchange earnings. Though the occurrence of C. (G.) smithii in Indian waters has been increasingly reported for the past two decades under the name C. edwardsi, no serious attempt has been made so far to study the resource characteristics and biology of the species. A sound knowledge of these aspects is an essential prerequisite for proper exploitation, conservation and management of the resource. Considering the

paucity of information on this potentially important crustacean and the growing demand for crabs in the country, an attempt has been made to carry out a comprehensive study of the species and the results are presented in this thesis.

The thesis is presented in three chapters. The first chapter deals with a general introduction which outlines the objective of the study providing an exhaustive review of works on crabs with particular reference to deep-sea forms. The second chapter describes the material and methods used for the study.

Chapter III includes the results and discussion which are presented in three sections. In the first section, Taxonomy and Geographical distribution of the crab are dealt with. The species is described in detail based on several male and female specimens obtained from the pelagic and bottom collections, and its identity in Indian waters is established. It is also distinguished from a closely allied species so far not reported from Indian waters. The second section comprises the biology of the species and it is dealt with under four subheadings, namely, Habit and Habitats, Reproduction, Food and feeding and Proximate composition. The different habitats occupied by juveniles, subadults and adults of the species have been described and discussed in the light of available information on differential distribution of other related species. The reproductive biology is described in various details touching on gross anatomy and histology of the reproductive systems, spermatogenesis, oogenesis, size at maturity, ovarian maturation process, fecundity, egg carriage and breeding. The food and feeding habits of the species have been studied with reference

to the different life stages such as juveniles, subadults and adults during the different phases of life based on stomach content analysis. The percentage of meat recovery and protein, carbohydrate and lipid content of meat have been described in the section dealing with proximate composition. In section 3 the distribution and abundance of the crab for the entire Indian EEZ and some contiguous areas have been described and illustrated in detail separately for pelagic and benthic realms. The size frequency distribution, sex ratios, length weight relationship and relative abundance of breeding population in the experimental catches have been dealt with in detail and discussed.

A summary of the important findings of the study is given at the end, which is followed by a detailed list of references on the subject matter.

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C P Balasubramanian

CHAPTER 1
INTRODUCTION

CHAPTER 1

INTRODUCTION

It is an established fact that the world population swells at an alarming rate year after year, and over half of the same is believed to suffer from malnutrition. At the present rate of population explosion it is likely that the global population may ^{go} up from the present level of 5 billion to about 8 billion by the close of the present century (Becker, 1992). The food from land is so limited that it may not be able to satisfy even the basic requirement of the ever increasing population. One of the alternative to overcome this problem of food shortage is to tap the vast resources of the ocean which could nourish the human population many times more than its present level. According to FAO fishery Statistics the world fish production in 1990 amounted to about 97 million tonnes of which 95.8 million tonnes have come from the sea. Crustaceans comprising of prawns lobsters and crabs accounted for about 4.4% of this, which are the most highly valuable commodities by virtue of their pivotal role in the seafood industry of the world. In India, the marine fishery is mostly export oriented and among the seafood items exported from the country, the crustaceans account for about 45% in terms of volume and 75% in terms of value. According to the latest export figure, this amounts to about 14,000 million rupees annually (Sukumaran, 1992). Among edible 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 markets. Crab meat is considered as a delicacy in many

parts of the world and within the country it is an important source of protein rich food for the less affluent society of coastal areas. Besides its immense nutritive value, the crab meat also carries many therapeutic properties. Crab shells are rich source of chitin and its chitosan content which have numerous industrial and medicinal applications, particularly in the manufacture of artificial fabrics, printing inks, photographic emulsions adhesive cosmetics, dialysers and anticoagulants (Mendenhall, 1971, Muzzarelli and Pariser, 1978, Sambasivan, 1992). It is estimated that the world export earnings from chitin would be about 200 crores dollars by the end of 2000 AD (Girish Babu, 1990).

A perusal of fishery statistics for the past few years would reveal that the annual crab production of the world ranged between 0.8 million tonnes and 1.1 million tonnes with an average annual production rate of about 0.9 million tonnes (FAO, 1990). During 1990, the crab production accounted for 50% of the total world crustacean landing (FAO, 1990). This was mainly comprised of four categories namely blue, dungeness, tanner and King crabs. In developed countries where organized crab fishery exists, the crab industry mainly relies on species caught from the coastal waters. Presently the catches of tropical crabs account for about 74% of the total crustacean landing. The supply however is not commensurate with the increasing demand of crabs and crab products mainly due to less efforts for directed fishing on this resource in most regions of the world. Further, commercial exploitation is mostly restricted to the near-shore waters where the fishing pressure has reached the optimum level in the major fishing areas (Haefner, 1985 a). Many workers have pointed

out the possibility of tapping underexploited stocks of crabs in the tropical and subtropical countries, which have been often hidden by inadequate catch statistics (Alverson and Patterson, 1974; Haefner, 1985a).

The seas around India are blessed with a rich fauna of brachyuran crabs as could be evident from the several faunistic reports published over the past hundred years or more. This includes a number of edible crabs which support sustenance fishery throughout the Indian coasts (Rao, et al., 1973; Kathirvel, 1993). In most areas of the coast the crabs are taken as incidental catches, while an intensive fishery is restricted to only selected centres (CMFRI, 1992). The average annual crab landing from the marine sector during 1980-1990 amounted to 22,000 tonnes which form 8.4% of the total crustacean landing. Bulk of this catch is utilized for local consumption in the coastal areas. This forms only about 50% of the potential crab resources of 44,000 tonnes estimated by Rao et al. (1973) for the Indian seas including brackishwater sector. In this assessment, the authors have not included the vast potential of unexploited deep-water crab resources which have been located in some parts of the Indian coast during the exploratory fishery surveys conducted in the past (Silas, 1969, Mohamed and Suseelan, 1973). The deep-water swarming crab Charybdis (Goniohellenus) smithii, which is so far known in Indian literature as Charybdis edwardsi, is one of the most common deep-sea/off shore species which have been reported during the exploratory surveys. Though the possibility of exploiting this resource on commercial scale has been pointed out by several workers (Losse, 1969, Silas, 1969, Mohamed

and Suseelan, 1973; Prasad and Nair, 1973; Rao et al., 1973; Sulochanan et al., 1991) no serious attempt has been made so far to investigate on the biology and population characteristics of the species or any other deep-sea crabs in Indian waters. Besides being an important potential resource for human consumption, C. (G.) smithii is also reported to play an important role in the trophic structure of Indian Ocean (Losse, 1969; Zamorov et al., 1991). It forms an important forage of scombroid fishes and deep-sea sharks (Losse, 1969; Silas, 1969; Zamorov et al., 1991).

The importance of crab as a source of protein-rich food for the growing population of India especially in the coastal sector, and also as an excellent raw material for seafood products for export purpose is increasingly recognized in the country in recent years. At present, though major portion of the crab catch from the inshore waters is utilized for local consumption, some quantities are exported to foreign countries like Belgium, U.S.A., Japan, Singapore and Malaysia in the frozen and canned form. A perusal of trends in the export of crab products from the country since sixties (Kathirvel, 1993) would reveal that the export has increased tremendously over the past two decades. The average annual foreign exchange earned by exporting crab product for the period 1989-91 is Rs. 23 million, which is mainly obtained from frozen crab meat (Kathirvel, 1993). Demand of live crabs in some of the South-East Asian countries like Malaysia and Singapore has given greater impetus to the crab export industry of the country. The live crab export which commenced with 36 tonnes during 1987-1988 period increased to 654 tonnes during 1991 registering an eight-fold increase in the export of this new product during the past 3 years (Kathirvel, 1993). The above development in the fishery sector

would clearly indicate that the importance of crab is ever on the increase in the country. This shows the need for serious efforts for the exploitation and utilization of the untapped crab resources existing in the deeper waters of Indian EEZ. A proper understanding of the biology, distribution and population characteristics is highly imperative for proper exploitation, conservation and management of any resource.

The swarming crab Charybdis (Goniohellenus) smithii has not received any serious attention for systematic scientific studies so far obviously due to the difficulties for samples. The commissioning of the research vessel FORV Sagar Sampada for resource surveys in the Indian EEZ and contiguous waters has given an excellent opportunity to make a comprehensive study of this little known resource from Indian coast and the results are presented in this thesis.

Review of Literature

Although study of brachyuran crab has been initiated from the time of Linnæus (1758), investigations on these animals in India commenced only from the middle of 19th century. Initially the studies were mainly on the taxonomic aspects as could be evident from the classical works of Wood-Masson (1871) and Alcock (1895, 1896, 1898, 1899a, 1899b, 1899c, 1900). Later, many authors have also contributed greatly to the systematics of Indian Brachyura,, particularly from the mainland, the notable contribution being those of de Man (1908), Kemp (1915, 1923), Chopra (1931, 1933, 1935), Chopra and Das (1937), Pillai (1951), Chhapgar (1958), Sankarankutty (1966), Joel and Sanjeevaraj (1980) and Radhakrishnan and Samuel (1982).

Faunistic accounts of brachyuran crabs of the Lakshadweep Islands have been extensively dealt with by Borradaile (1902). Subsequently Sankarankutty (1961a), Meiyappan and Kathirvel (1978) and Suresh (1991) also added information on the crab fauna of these islands. Alcock (1899a), Chopra (1935), Sankarankutty (1961b), Premkumar and Daniel (1971) and Kathirvel (1983) reported on the crabs of Andaman-Nicobar 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 coasts. Later, Chopra (1936, 1939) furnished details of the crab fishery of Indian coast in general, Chidambaram and Raman (1944), Prasad and Tampi (1952) and Chacko and Palani (1955) on the crab fishery of the east coast, Menon (1952), Vasudeo and Kewalramani (1960), George and Nayak (1961) and Chhapgar (1962) on the crab fishery of the west coast. An annotated bibliography of the fishery and biology of edible crab of India was published by George and Rao (1967). The crab fishery of India reviewed in greater detail by Rao et al. (1973). Since then many authors have reported on the regional crab fisheries of India which included the accounts of Ansari and Harkantra (1975) from Goa, Dhawan et al. (1976) from Zuary estuary (Goa) Manonararam and Chandramohan (1978) from Mangalore, Ameerhamsa (1978a) from Palkbay and Gulf of Mannar, Shanmugam and Bensam (1980) from Tuticorin, Lalitha Devi (1985) from Kakinada and Sukumaran et al. (1986) from the south Kanara coast on important coastal species occurring in the respective region.

Various accounts on the biology of Brachyuran crabs have been documented from about the middle of this century. The reproductive biology of portunid crabs has been dealt with by many workers, some of the notable contributions being those of Chhapgar (1956), George (1963), Rahman (1967) Krishnaswamy(1967), Chandran (1968), Pillay and Nair (1968, 1971, 1973), Srikrishnadhas and Ramamoortny (1976) Simon and Sivadas (1978, 1979), Joel and Sanjeevaraj (1982), Sethuramalingam et al. (1982), Mercy Thomas (1985), Chaudhuri and Chakrabarti (1989), Jeyalectumie and Subramoniam (1989), Trinathababu et al. (1989), Jacob et al. (1990), Prasad and Neelakantan (1990) and Sarojini et al. (1990). The food and feeding habits of the crabs have been studied by few orkers like Chopra (1939), Patel et al. (1979), Joel and Sanjeevaraj (1986) and Prasad et al. (1988). The proximate composition and nutritive value of edible crabs of Indian coasts have been evaluated by several workers some of the notable contributions being those of Chinnamma George and Arul James (1971), Radhakrishnan and Natarajan (1979), Ameerhamsa (1978b), Srinivasagam (1979), Mukundan et al (1981) and Mercy Thomas (1985). Larval development of brachyuran crabs of India has been extensively worked out beginning with pioneering investigations of Menon (1933, 1937 1940) followed by Prasad (1954) and George (1958) based on plankton collections. Later many workers have attempted to trace out the larval history of brachyuran crabs by rearing the berried females in the laboratory (Prasad and Tampi, 1953; Naidu 1955, 1959, Sankolli, 1961; Noble, 1974; Kakati 1977; Kannupandi et al., 1980; Mercy Thomas, 1985).

When compared with the above mentioned works on coastal crabs, information on the resource characteristics and biology of deep-sea/

offshore crabs are extremely meagre from Indian waters although considerable works have emerged from other parts of the world during the past two decades. Systematic investigations on deep-sea brachyuran crabs can be said to have commenced with the pioneering work of Miers (1886) based on the valuable collections made during the great oceanic expeditions of HMS CHALLENGER during the 19th century. The collections made in the subsequent years by DANA (1928-1930) VALDIVIA (1898-1899) SIBOGA etc. formed the basis of a number of other taxonomic accounts of deep-sea crabs of the world oceans. The works of Chace (1951), Dell (1963), Pequegnat (1970), Soto (1978), Manning and Holthuis (1981, 1984, 1989) are some of the later contributions in this line. According to Attrill et al. (1990), the brachyurans are less represented in deeper waters when compared to other members of Reptantia. However, many members of the family Geryonidae, Majidae and Portunidae are known to inhabit the deeper waters of the ocean. The family ~~G~~^eryonidae, an ally of Portunidae, is generally found to occupy 200-2000 m in the Atlantic, Indian and Pacific oceans (Manning and Holthuis, 1984, Manning 1990). Some of the members of this family like Chaceon (= Geryon) quinquedens, C. fenneri and C. maritae are extensively studied on account of their commercial importance. Among these, C. quinquedens is the most important crab occurring in the western Atlantic ocean from Nova Scotia to Argentina (Rathbun, 1937, Scelzo and Valentini 1974). Chace (1940) reported the distribution of this species in his work on brachyuran crabs collected during the Atlantis Expedition. A serological analysis of the systematic relationship of C. quinquedens was carried out by Leone (1951).

Detailed studies on the depth distribution and fishery potential of the species in the north eastern coasts of United States and Gulf of Mexico have been conducted by many workers like Schroeder (1955, 1959) Haefner and Musick (1974), Ganz and Hermann (1975), Wigley et al. (1975), Gerrior (1981) and Soto (1985). The fishery and technological and economic aspects of harvesting of the species along the coasts of United States have been documented by Holmsen (1968), Meade (1970), Meade and Gray (1973) and Holmsen and McAllister (1974). Lux et al. (1982) under took marking studies and McElman and Elner (1982) made trap surveys on this coast and provided valuable information on migratory pattern and abundance of the crab. Lockhart et al. (1990) made comparative study of the distribution and population characteristics between this species and C. fenneri. Population density of this crab in the north east Atlantic waters was studied by Patil et al. (1979).

Reproductive biology of C. quinquedens has been studied by a number of workers from the West Atlantic regions. Gray (1969) studied the basic life history of the species and commented about the reproductive cycle. Gross morphology and histology of ovarian development and seasonality of reproduction were studied by Haefner (1977, 1978). Elner et al. (1987) examined the mating behaviour of C. quinquedens. Ultra structure of sperm and spermatophore of the species was reported by Hinsch (1988a). She found out a typical brachyuran type and ellipsoidal spermatophore with varying number of sperms for this crab. Hines (1988) estimated a relatively low fecundity and large sized eggs. Annual reproductive cycle

of C. quinquegens in the Gulf of Mexico was studied by Erdman et al. (1991), whereas Perkins (1973) traced its larval history by rearing berried females in the laboratory. The latter author described four zoeal and one megalopa stage. Kelly et al. (1982) derived a model of larval dispersal for this crab, who noticed that the Gulf stream played an important role in the dispersal of larvae. Ecological and evolutionary significance of nutritional flexibility of larvae was studied by Sulkin and Van Hevkelem (1980). Many workers have studied the physiological and biochemical aspects of C. quinquegens. Grelg et al. (1976) investigated the heavy metal content, whereas Kuo et al. (1976) reported on the carotenoid content of this crab. George (1979) worked out the daily cycle of metabolic rates and compared the same with the coastal portunid crab Callinectes sapidus. Henry et al. (1990a, 1990b) studied the gill morphology and haemolymph ionic concentration, and Walsh and Henry (1990) the activities of metabolic enzymes.

The golden crab C. fenneri, which has emerged as a new fishery in the Gulf of Mexico, has been subjected to various investigations in recent years. This species is an inhabitant of upper continental slopes between 200 and 800 m depths in these waters (Wenner, et al. 1987; Lindberg and Lockhart, 1988). The taxonomic identity of this species as established by Manning and Holthuis (1984). Soto (1985) studied the distribution pattern of this crab in the straits of Florida and discovered that the species enjoyed a continental pattern of distribution. Its depth distribution and ecology in the Gulf of Mexico was investigated by Lockhart et al. (1990). Gerrior (1981) has summarized its commercial fishery off

New England. Otwell et al. (1984) demonstrated the exploratory trapping and processing technique, and Lindberg and Lockhart (1988) the development of the fishery in the Gulf of Mexico. Wenner et al. (1987) demonstrated the reproductive biology, adult life history, catch rates, size and sex composition in the south Atlantic Bight, whereas Erdman and Blake (1988b) reported on the fishery of the crab in the south eastern Florida.

Detailed information on the reproductive biology and physiology of this species has been attempted by a few workers who furnished information on the morphology of reproductive tract (Hinsch, 1988b), reproductive ecology in the south eastern Florida (Erdman and Blake, 1988a) fecundity (Hines, 1988), ultrastructure of sperm and spermatophore (Hinsch, 1988a) gill morphology and haemolymph ionic concentration (Henry et al., 1990a) action of metabolic enzymes (Walsh and Henry, 1990) and respiratory and cardiovascular response (Henry et al., 1990b).

C. maritae is a west African species, which support an active trawl fishery in Angola since 1970 (Dias and Machado, 1973; Le Loueff et al., 1974). It is known from the localities between Spanish Sahara and Valdivia Bank in the depth range 100-936 m (Manning and Holthuis, 1981). The taxonomic identity of this species has been established by Manning and Holthuis (1981). They have also given a description of the biology and fisheries of the species. A preliminary report on the distribution and abundance of C. maritae (as C. quinquedens) in the deep-waters of Angola has been furnished by Dias and Mechado (1973) whereas Intes and

Le Loeuff (1974) reported the results of exploratory fishing on the Ivory coast. Beyers and Wilke (1980) made a quantitative survey of this species off southwest Africa. They also commented on the biological and morphometric characteristics of this species. Detailed studies on the resource distribution, abundance, commercial exploitation, growth, reproductive biology and population dynamics of this species were carried out by Melville-Smith (1983, 1985, 1987a, 1987b, 1987c, 1988, 1990). Melville-Smith and Bailey (1989) investigated on the possible causes of depth zonation of this crab.

Geryon trisipinosus (= G. tridens) is a small unexploited species of family Geryonidae known to occur in the north-east Atlantic at depth ranging from 40 to 2200 m (Clark 1986). A preliminary note on this species has been provided by Hepper (1971) based on samples collected from deeper waters of West Ireland. Brattegard and Sankarankutty (1967) described the pre-zoea and zoeal stages by rearing the species in the laboratory. More recently, Attrill et al. (1990) reported on the bathymetric distribution, population structure and biomass of the species in Porcupine Seabight.

Members of the family Majidae such as Chionoecetes japonicus and C. tanneri are also reported to occur in commercial concentration in the Pacific ocean (Tsuchiya and Fujii, 1972; Pereyra, 1966). C. japonicus has been fished in Japan since 1970. Ho and Ikehara (1970) described the distribution of C. japonicus whereas Tsuchiya and Fujii (1972) summarized

its commercial utilization. Ito (1976) studied the maturation and spawning, and Moto (1976) the larval history of this species in the seas around Japan. Trapping of this species was studied by Koike and Ogura (1977), whereas fishery biological aspects and processing were studied by Gong et al. (1978) and Suh and Park (1979). The distribution pattern of this crab was studied by Fujikura et al. (1990).

Pereyra (1966) studied the bathymetric and seasonal distribution of C. tanneri off northern Oregon Coast together with some information on reproductive aspects such as incubation, development of egg mass and mating.

Studies on deep-sea brachyuran crabs from Indian waters are extremely poor and limited to only some taxonomic aspects. A pioneering attempt in this regard was made by Alcock (1899a, 1899c) and Alcock and Anderson (1899) who provided fairly good amount of faunistic information on this group based on the collections of 'Investigator'. There was a long gap in our knowledge on the deep-sea brachyurans of the Indian coast in the subsequent years. With the commencement of exploratory resource surveys in the deeper waters along the Indian coasts around sixties paved the way for greater understanding of this group and its fishery potentialities. Based on the results of bottom trawling conducted by the Govt. of Indian vessels Silas (1969) and Mohamed and Suseelan (1973) added to the faunistic list of brachyurans occurring on the continental shelf edge and upper continental slope of the southwest coast of India, indicating the magnitude and economic value of the individual species. Systematic deep-water surveys conducted in the subsequent years have

brought to light the existence of commercial quantities of the swarming crab, Charybdis (Goniohellenus) smithii in this depth region in some parts of Indian coasts as could be evident from the reports of Suseelan et al. (1990) and Sulochanan et al. (1991). Although the occurrence of C. (G.) smithii has been very often reported from the Indian waters in recent years, only fragmentary information is on record regarding its biological aspects. Della Croce and Holthuis (1965) and Daniel and Chakrapani (1984) made mention of the surface swarming behaviour of this species, while Silas (1969) provided notes on its sizes and fecundity observed in the trawl catches of R/V Varuna. More recently Zamorov et al. (1991) indicated migratory behaviour of this species during its pelagic existence.

CHAPTER II
MATERIAL AND METHODS

CHAPTER II

MATERIAL AND METHODS

The material for the present study was obtained from the cruises of the Fishery Oceanographic vessel FORV Sagar Sampada (Plate 1) in the Indian EEZ and contiguous waters (Lat. 05° 00'N to 23° 30'N and Long. 65° 00' to 77° 30' on the west coast, Lat, 05° 00'N to 21° 30'N and Long. 77° 30'E to 95° 30'E on the east coast) from February 1985 to December 1991. The results of experimental trawling conducted during 75 cruises undertaken by the vessel in the different regions of the Arabian sea and Bay of Bengal have been used. Details of the cruise tracks, positions of stations, depth, time, duration of trawling and other operational details have been collected from the Skipper's log and cruise reports of FORV Sagar Sampada published by the Central Marine Fisheries Research Institute (CMFRI) on behalf of the Department of Ocean Development, Govt. of India (Anon., 1986a, 1986b, 1987, 1988a, 1988b, 1989, 1990). Besides this microlevel data on catch, effort and biological details of the crab under study and associated organisms represented in the experimental trawl catches have been collected by personal participation of the candidate in nine cruises covering the entire area of investigation for more authenticity of information. These cruises, of which two were on the west coast, six on the east coast and one around Andaman-Nicobar Islands, extended for 10-28 days each. Several crab samples maintained in the Crustacean Fisheries Division of CMFRI in frozen/formalin preserved condition were also used for biological studies.



PLATE 1

FORV Sagar Sampada

Three types of nets, namely, Isaacs-Kidd Midwater Trawl (IKMT), pelagic trawl and bottom trawl were used during the cruises. The Isaacs-Kidd mid water trawl (Isaacs and Kidd, 1953) is made up of a conical net attached to a wide 'V' shaped diving vane. At each end of the diving vane and from a spreader bar at the top forepart of the net comes the bridles, arranged so that the net takes up a catching position during towing. The net had 2.5 m total length and 4 m vertical opening with a mesh size of 1.5 mm (stretched) at the cod-end. This net sampled the planktonic organisms found in the Deep Scattering Layers (DSL) which occupied the upper strata of the ocean upto a maximum depth of 600 m from the surface. (Suseelan and Nair, 1990). The net was operated at the appropriate depth of DSL recorded by echosounders at a frequency of 38 khz and 120 khz. A total of 433 IKMT hauls were examined for the present study, of which 261 were taken on the west coast, 128 on the east coast and 44 around Andaman-Nicobar islands. The pelagic trawl operated had a total length of 100 m, head rope length of 46.4 m and foot rope length of 26 m with a uniform mesh size of 40 mm (stretched) at the cod end. Of the total number of 334 pelagic trawl operations considered, for the present study, 165 were taken on the west coast, 85 on the east coast and 84 around Andaman-Nicobar Islands. The bottom trawling operations were undertaken using mainly the High Speed Demersal Trawls (HSDT) developed by the Central Institute of Fisheries Technology, Cochin (Panicker, 1990). The nets were basically two seam or four seam type of demersal trawls of 44.5-46.5 m total length and 23.2-28.0 m head rope length.

The mesh size at cod-end was uniformly 40 mm (stretched). A total of 445 bottom trawl hauls were examined during the present investigation of which 243 hauls were taken on the west coast, 178 on the east coast and 24 around Andaman-Nicobar Islands.

The operational particulars for the different types of gears are described in greater detail in section 3 of chapter III. The taxonomic and biological studies of the crab were carried out based on 126 samples obtained from the three types of gears, which included several juvenile subadult and adult stages. In the case of IKMT catches the entire samples obtained in each of the positive hauls were examined, whereas in the catches of pelagic trawl and bottom trawl operations the sample size ranged between 200 to 600 crabs/haul or the entire catch if it was smaller than 100 crabs/haul. All the crab samples thus obtained were analysed in fresh condition when they were drawn while onboard vessel by the candidate or in frozen/formalin preserved condition when they were obtained from the Crustacean Fisheries Division of CMFRI. Onboard vessel, the crab samples were taken to the wet fish laboratory and weighed in fresh condition using the Eilerson, electric balance available in the vessel. After preliminary observation the samples were frozen in cold storage at -20°C or preserved in 5% seawater formalin for detailed studies in the shore laboratory.

The samples were analysed in detail for sexwise size frequency. The size refers to carapace width (cw) measured between the sixth anterolateral teeth to the nearest 0.1mm using vernier calipers. For individual

weight of the crab, after taking measurement of carapace width, the animal was weighed to the nearest 0.01 mg using 'Mettler' electronic balance in fresh condition in the shore laboratory. The methods adopted for studying the various aspects of biology, biochemical composition, population characteristics and distribution of stock are described below.

REPRODUCTION

The crabs were first sexed based on the shape of abdomen, number of pleopods and convexity of carapace. In the case of female crabs, the pleopods and vulvae were examined to determine if mating/extrusion of eggs had taken place. Presence of eggs or egg remnants or their absence on pleopods, colour of egg mass and condition of vulvae were 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 histological studies, gonads and other parts of the reproductive systems were cut and fixed in Bouin's fluid from live crabs onboard vessel.

For studying maturation process, the ovaries were classified into five maturity stages by modifying the methods suggested by Haefner (1977) for the study of deep-sea crab C. quinque-dens. The Gonado Somatic

Index (GSI) was calculated by using the formula $GSI =$

$\frac{\text{Wet weight of ovary}}{\text{Wet weight of animal}} \times 100$ as proposed by Giese and Pearse (1974).

Histology: All 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 shaving 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 rotoring 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 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 hematoxyline 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 canadabalsm of neutral pH. Mounted slides were examined under a monocular research microscope.

Micrometric measurement of oocyte in different stages of maturation were taken using an ocular 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 Optical, U.S.A.) and with a camera unit. Appropriate projection eye piece was used and the photographs were taken using 24x36 mm ORWO NP 22 (125 ASA, Panchromatic) black and white negative film. The prints were taken on soft, glossy, single weight contrast paper.

Fecundity: The fecundity was calculated by counting the number of eggs present on the pleopod in ovigerous condition. As it was not known how many eggs were lost during incubation, 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.

$$F = P/P^1 \times n$$

where P = the weight of egg mass; P^1 = the weight of the sub sample and n = the total number of eggs in the subsample.

STOMACH CONTENT ANALYSIS

The food and feeding habits of the crabs were studied based on qualitative and quantitative analysis of stomach contents of three major size groups namely juveniles (<20mm cw) subadults (21-45mm) and adults (>45mm cw) sexwise. The food contents present in the foregut only were used for the present study for easier identification of various food components. The intensity of feeding was determined based on the degree of distension of stomach wall and the amount of food contained in it, and classified as full, 1/2 full and empty as suggested by Hynes (1950) and Pillai (1952). The food items were identified into the various taxonomic groups and the relative abundance of each of the groups was estimated by the 'frequency of occurrence method' and 'volumetric method' as recommended by Williams (1981) for the study of food and feeding habits of portunid crabs.

In each animal examined, after grading the stomach, the stomach contents were carefully flushed into a petridish with distilled water and observed them under a dissection microscope at 20x magnification. As characteristic of decapod crustaceans, most of the food items were found to be in highly crushed form and hence only the hard structures that could be recognized were relied upon for qualitative evaluation. The major items recognized included foraminifera, molluscs, arthropods and

pisces. Foraminifera were identified from entire shells, molluscs from hinge of shells, spats and cuttle bone, arthropods from pigmented remains of exoskeleton, appendages and carapace of amphipods, crabs and shrimps, external gills of euphausiids etc and pisces from remains of bones, eyeballs, scales and otolith. Many stomach contained food remains that were highly pulverized or digested and such items were included under amorphous material.

PROXIMATE COMPOSITION

Frozen samples brought to the laboratory were cleaned and after noting the carapace width, total body weight of individual crab was weighed accurately to the nearest 0.1 mg with an electronic balance Mettler, PC 440 Switzerland. The carapace was then removed and meat of all parts including chelate legs was separated and transferred to a petridish. The separated meat content was weighed and its percentage worked out. The method of estimation of water content, protein, fat and carbohydrate are given below.

Water content: Pre-weighed wet samples of meat was kept in a hot air at 60°C till constant weights were obtained. The loss in weight was taken as the moisture content and expressed as percentage (AOAC, 1965).

Total protein: The Folin-Ciocalteu Phenol method of Lowry et al. (1951) was adopted for estimation of total protein in the tissue.

A sample of 25 mg of muscle tissue was added to 1 ml of 10% trichloro acetic acid. The sample was centrifuged for 20 minutes at 3,000 rpm. The supernatant obtained in the individual tubes was used for the estimation of total carbohydrate. The protein precipitate in each tube was dissolved in 5 ml 1 N NaOH and to 1 ml of this solution, freshly prepared 5 ml alkaline mixture (50 ml of 2% Na_2CO_3 in 0.1 N/NaOH + 1 ml of 0.5% $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in 1% sodium tartrate) was added and kept at room temperature for 10 minutes. After this 0.5 ml 1 N Folin-Ciocalteu's reagent (diluted the 2N stock solution with double distilled water) was added and mixed rapidly.

A standard stock solution was prepared using bovine serum albumin crystals at a concentration of 25 mg/5 ml 1N NaOH. Different dilutions in the range 0.25-2.5 mg/ml were prepared from this stock solution, and the alkaline mixture and Folin-Phenol reagent were added as in the case of tissue samples. A blank was prepared with 1 ml 1 N NaOH and treated the same way as above.

All the test tubes were kept for 30 minutes at room temperature and the optical density of the blue colour developed was measured against 660 nm.

Total carbohydrate: The phenol sulphuric acid method of Dubois et al. (1956) was followed to estimate the total carbohydrate in the samples.

The supernatant obtained during protein estimation procedure was used for analysis. To 1 ml of supernatant of tissue, 1 ml of 5% phenol (5.5 ml of 90% liquid phenol added to 94.5 ml water) was added and mixed well. One ml of concentrated sulphuric acid was added rapidly and carefully to each tube and mixed well.

A standard stock solution was prepared using D-glucose (concentration 20 mg/100 ml saturated solution of benzoic acid) different dilutions of working solution with the concentration of glucose ranging from 10-100 μ g/ml were prepared and the procedure adopted for the tissue was followed. A blank solution with 2 ml of 5% phenol was prepared and the above procedure was followed.

All the tubes were kept for 30 minutes at 30°C and the optical density of orange colour developed was measured at a wave length of 490 nm.

Total lipid: The total lipid was quantitatively determined by sulpho-phosphovanilline method of Barnes and Black Stock (1973).

About 10 mg of dried tissue was sparately homogenized well in 1 ml of chloroform: methanol. (2: 1 V/V) and kept over night at 4°C for

complete extraction. A sample of 0.1 ml of serum was thoroughly mixed with 1 ml 2:1 V/V chloroform: methanol and left overnight in the refrigerator. The mixture taken in glass stoppered centrifuge tubes was then centrifuged for 15 minutes at 3,000 rpm and the clear supernatant containing all lipid was transferred to clean dry glass tubes. Samples of 0.5 ml of lipid extract of the tissue were taken separately in clean glass tubes and dried in vacuo over silica gel in a desiccator. To each dried sample, 0.5 ml of concentrated sulphuric acid was added and shaken well. The tubes were then plugged with non absorbent cotton wool and heated at 100°C in a boiling water bath exactly for 10 minutes. The tube was rapidly cooled to room temperature under running tap water. To 0.1 ml of this acid digest, 2.5 ml of phosphovanilline reagent was added and mixed well on a cyclomixer.

Stock solution was prepared fresh by dissolving 80 mg of cholesterol in 100 ml of chloroform:methanol (2:1 V/V) mixture (equivalent to 100 mg of total lipid in 100 ml Chloroform methanol mixture). Working solution of different concentrations were prepared from the stock solution in the range 50-500 μ /0.5 ml and the procedure adopted for tissue samples were followed. 0.5 ml of 2:1 V/V chloroform: methanol mixture was treated as blank.

All tubes were kept at room temperature for 30 minutes. The intensity of pinkish red colour developed was measured against blank at 520 nm.

The optical density of the colour developed for total protein, carbohydrate, lipid were measured using a senior spectrophotometer (ECL G6865D), with the samples taken in silica cuvettes. Standard graphs were plotted with concentration of each biochemical parameter in different dilutions of the working standard solution, in the 'X' axis and the optical density in the 'Y' axis. The concentrations of different parameters in samples were calculated (in mg%) by comparing the optical density (O.D.) obtained for the sample with the values in the standard graph and also using the formula.

Concentration in mg/100 mg dry tissue =

$$\frac{(\text{O.D. of sample} - \text{O.D. of the blank})}{(\text{O.D. of standard} - \text{O.D. of the blank})} \times \text{Concentration of standard} \times \frac{100}{\text{wt of sample in mg}}$$

DISTRIBUTION, ABUNDANCE AND POPULATION CHARACTERISTICS

The distribution and abundance of crabs were studied over space and time based on the average catch rates worked out for the positive hauls of three types of nets. The spatial distribution has been studied separately for the pelagic and bottom habitats based on the catch data

from the IKMT and pelagic trawl hauls respectively. The bathymetric distribution and abundance of the benthic population were studied by analysing the bottom trawl catches after dividing the depth regions into the following four depth zones.

Depth zone 1 : less than 150 m

Depth zone 2 : 151-200m

Depth zone 3 : 201-300

Depth zone 4 : 301-400

For temporal distribution, the catch and effort of individual months of the different years were pooled and average catch/hour worked out year wise separately for the west and east coasts and computed for the three seasons namely premonsoon (February-May) monsoon (June-September) postmonsoon (October-January). The catches recorded between 0600 hrs and 1800 hrs were considered as day samples and those recorded between 1800 hrs and 0600 hrs as night samples for the study of day night variation in abundance.

The measurements of carapace width were grouped into 5 mm size classes and mid points of the same were plotted for size frequency distribution and other aspects of population. The numerical data of sex ratios were tabulated sample wise, size wise and gear wise and the same tested by Chi-Square (X^2) test (Snedecor and Cochran, 1967).

The length weight relationships of the form $w=AL^b$ was fitted by the method of least squares using the equation: $\text{Log } w=a+b \text{ log } L$ where w =weight in gm, L =carapace width in mm and a and b are constants derived empirically (Pauly, 1983).

CHAPTER III
RESULTS AND DISCUSSION

SECTION 1. TAXONOMY AND GEOGRAPHICAL DISTRIBUTION

Most of the commercially important or potentially important brachyuran crabs of different parts of the world belong to the family Portunidae. According to the checklist of this family published by Stephenson (1972), there are as many as 210 valid species existing under this family in the Indo-west Pacific region. Being an important family, the species of which occupy predominantly the coastal waters, extensive taxonomic studies of this family have been carried out all over the world and more particularly in the Indo-Pacific region. The works of Alcock (1899a), 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 (Alcock, 1899a, 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.

The great majority of crabs of this family are easily recognized by the paddle-like fifth pair of walking leg which is adapted for swimming.

In the Indian ocean, the crab fauna of family Portunidae is included under subfamilies Podophthalminae (Borradaile), Catoptrinae (Sakai), Portuninae (Rafinesque), Caphyrinae (Alcock), Carcininae (Macleay) and Polybiinae (Ortmann). Majority of the species contributing to commercial fishery in the region belong to the subfamily Portuninae. Members of the subfamily have the typical portunid shape with very broad carapace bearing 4-9 antero-lateral teeth. The basal joint of antennae is usually broad and its antero-external angle sometimes lobulated. Chelipeds are longer than all legs and the last pair typically paddle shaped.

In the seas around India, five genera of subfamily Portuninae have been reported by various authors. These are Charybdis, Lupocyclus, Portunus, Scylla and Thalamita. Members of all these 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 of the carapace and structure of chelipeds. The five genera can be easily 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 | - | <u>Portunus</u> |
| | Surface of carapace with ill-defined regions; hand of cheliped inflated and smooth | - | <u>Scylla</u> |

3. (1) Antero-lateral teeth alternately large and small, carapace front protruding, Chelae 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 CHARYBDIS DE HAAN, 1833

This genus is represented only in the Indo-Pacific region. So far 44 valid species have been reported under this genus. All the species are known to occur only in the Indo-Pacific except one species, namely, Charybdis (Charybdis) hellerii A. Milne Edwards reported from the Mediterranean (Leene, 1938; Stephenson, 1972). In the seas around India, as many as 16 species of this genus have been recorded by various workers. The genus has the following diagnostic characters.

Carapace more or less regularly hexagonal, transverse ridges fairly distinct, front cut into six teeth (excluding inner orbital teeth), antero-lateral border usually with six teeth including outer orbital teeth, postero-lateral and hind margin either evenly curved or meeting in a distinct projecting angle; chelipeds massive, longer than all other legs; arms with spines, inner angle of wrist usually spiniform, outer angle usually armed with spines and palm prismatic.

Members of this genus have considerable fishery significance in the Indo-West Pacific region in general and in the Indian waters in particular. They contribute to the commercial catches from the coastal as well as offshore waters. The various species belonging to this genus are grouped under five subgenera namely Charybdis (de Haan), Goniohellenus (Alcock), Gonioneptunus (Ortmann), Goniosupradens (Leene) and Gonioinfradens (Leene). Of these, the first four subgenera are represented in Indian waters, and can be distinguished by the following key.

Key to Indian subgenera of genus Charybdis

- | | | | |
|-------|---|---|-----------------------|
| 1. | Antennal flagellum not excluded from orbital hiatus | - | <u>Gonioneptunus</u> |
| | - Antennal flagellum excluded from orbital hiatus | - | 2 |
| 2 (1) | Posterior border of cephalothorax curved, forming curved post-lateral junction | - | 3 |
| | - Posterior border of cephalothorax straight forming angular or eared post-lateral junction | - | <u>Goniohellenus</u> |
| 3 (2) | Six antero-lateral teeth, of which atleast five are large | - | <u>Charybdis</u> |
| | - more than six antero-lateral teeth, of which five large and two or three very small | - | <u>Goniosupradens</u> |

All the commercial species of genus Charybdis belong to the subgenera Charybdis and Goniohellenus. The species of former group occupy generally coastal waters within the 100m line of continental shelf on both the coasts of India. Members of the subgenus Goniohellenus occupy the continental shelf as well as the upper continental slope, some of them swarming in large numbers occasionally in the surface waters.

SUBGENUS GONIOHELLENUS ALCOCK, 1899.

The diagnostic features of this subgenus as revealed from the descriptions of Alcock (1899^a and Leene (1938) are: (1) the posterior border of carapace is straight, forming an eared junction with the postero-lateral borders, (2) four median frontal teeth are dissimilar to the lateral frontal teeth, (3) the antero-lateral border is cut into 6 teeth, and (4) the posterior border of the arm of chelipeds ends in a spine distally.

This subgenus contains a total of nine valid species, namely, C. (G.) truncata, C. (G.) padangensis, C. (G.) hongkongensis, C. (G.) vadorum, C. (G.) longcollis, C. (G.) curtidentata, C. (G.) noplites, C. (G.) omanensis and C. (G.) smithii recorded from the different parts of Indo-Pacific. Of these, C. (G.) noplites, C. (G.) omanensis, C. (G.) smithii and C. (G.) truncata are known to occur in Indian waters. All these species, except C. (G.) truncata occupy relatively deeper waters on the continental shelf and some parts of the upper continental slope (Stephenson, 1972).

CHARYBDIS (GONIOHELLENUS) SMITHII MACLEAY, 1838

(Plate 2, 3a, 3b; Fig. 1)

SynonymyCharybdis smithii Macleay, 1838, p. 61.Charybdis smithii Krauss, 1843.Goniosoma truncatum Milne Edwards, 1861, p.380, Pl. 34, Fig.4.Charybdis smithii Stebbing, 1910, p. 307.Charybdis (Goniohellenus) edwardsi, Leene and Buitendijk, 1949, p. 296, Fig. 3, 4C.

- Gonioneptunus smithii, Barnard, 1950, p. 163, Fig. 31j.
- Charybdis (Goniohellenus) edwardsi, Sankarankutty and Rangarajan, 1962, p. 311.
- Charybdis (Goniohellenus) edwardsi, Della Croce and Holtnuis, 1965, p. 33-37, Pl. 1.
- Charybdis edwardsi, Stephenson, 1967, p. 9.
- Charybdis smithii, Stephenson and Rees, 1967a, p. 9.
- Charybdis smithii, Stephenson and Rees, 1967b, p. 285.
- Charybdis (Goniohellenus) edwardsi, Silas, 1969, p. 26, Fig. 11, Pl. III A & B
- Charybdis smithii, Griffin and Stanbury, 1970, p. 123.
- Charybdis (Goniohellenus) edwardsi, Health, 1971.
- Charybdis (Goniohellenus) smithii, Stephenson, 1972, p. 10, 13, 15.
- Charybdis (Goniohellenus) edwardsi, Mohamed and Suseelan, 1973, p. 619.
- Charybdis (Goniohellenus) smithii, Balasubramanian and Suseelan, 1990, p.385.
- Non Charybdis (Goniohellenus) truncata, Alcock, 1899a, p. 69.

Material examined

918 males, carapace width 11-72 mm and 879 females, carapace width 11-69 mm collected between February, 1985 and December, 1991.

Description

Carapace: Slightly convex, more or less hexagonal, widest at antero-lateral teeth, regions fairly demarcated, surface absolutely smooth and highly polished, breadth 1.4 times the length in adults and 1.3 times in juveniles; front cut into 6 median teeth excluding the inner orbital angle (Fig. 1a), teeth generally small and spiniform, median teeth triangular, sharp and granular at inner margin and with a wide 'V' shaped incision

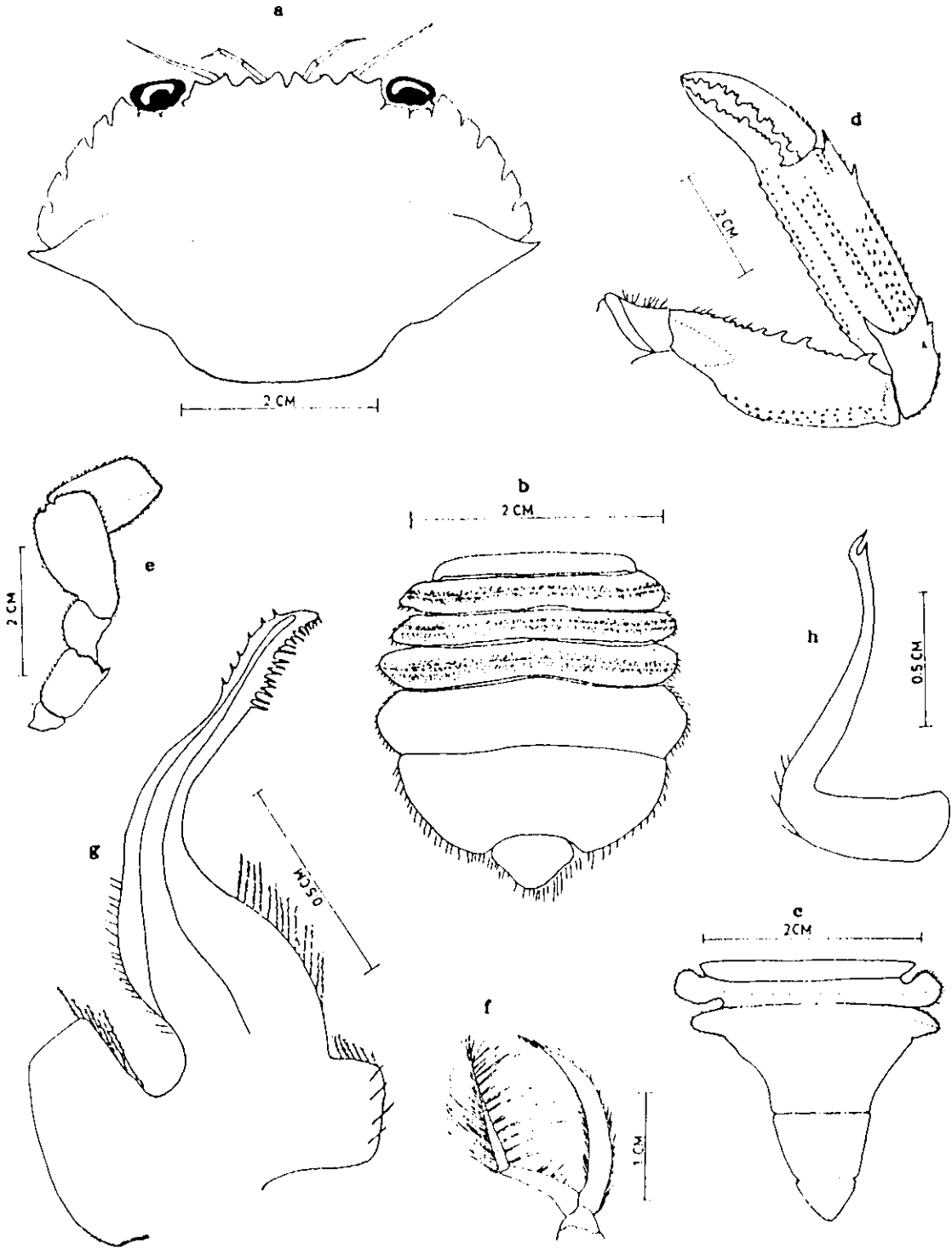


FIGURE 1. *Charybdis (Goniohellenus) smithii* Macleay, 1838 a, Carapace of adult male; b. Abdomen of adult female; c. Abdomen of adult male; d. Male cheliped; e. Fifth walking leg; f. Female pleopod; g. First male pleopod; h. Second male pleopod.

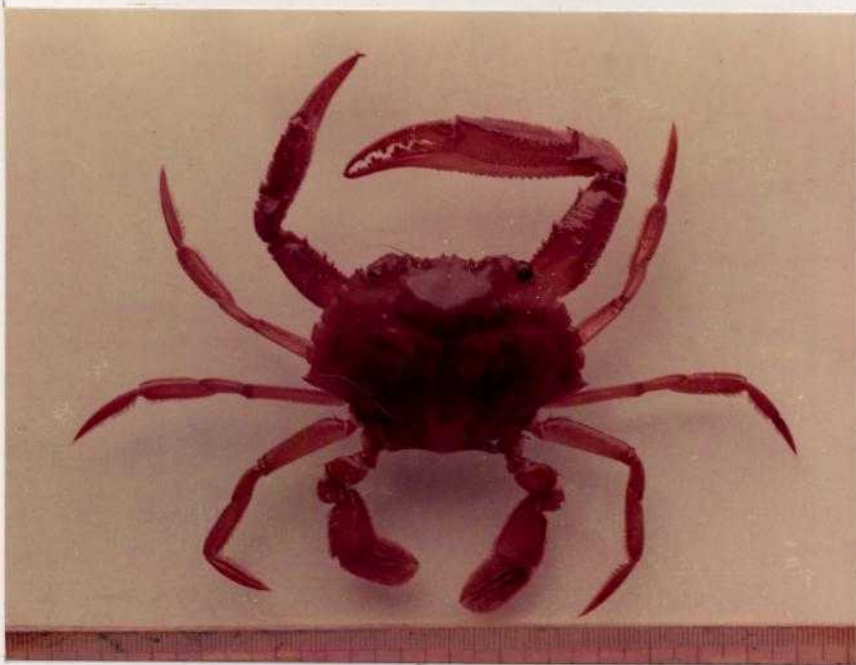


PLATE 2

Charybdis (Gonionhellenus) smithii Macleay,
adult male dorsal view.

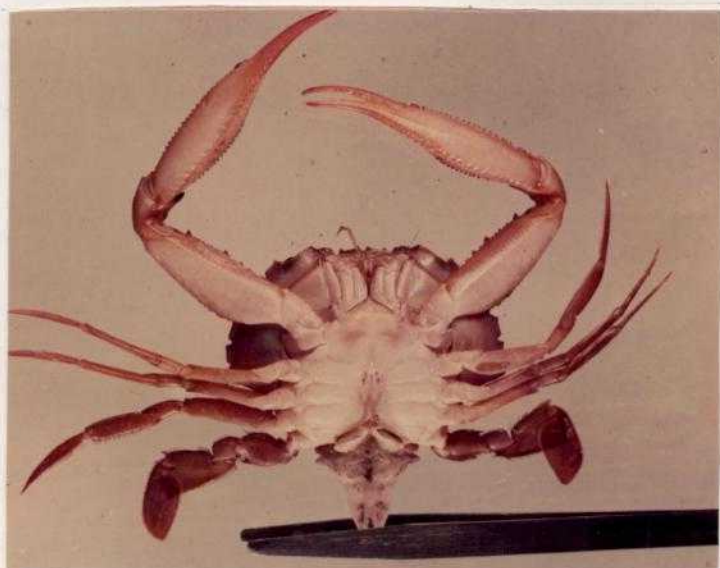
between the two, median teeth and submedian teeth separated by a shallow but broader granular curve, submedian and last teeth separated by a fairly deep 'V' shaped incision making lateral teeth distinct from the median pairs, outer and inner margin of lateral teeth granular, incision between lateral tooth and inner supraorbital angle not so deep as between median and lateral teeth.

Antero-lateral borders cut into 6 teeth, first five more or less same shape, subquadrate with the free edges minutely serrated, sixth tooth triangular in shape, more spine-like and anterior border granular, first tooth slightly larger in size than second, third largest, fourth and fifth slightly larger than first, and sixth little longer than fifth (Fig. 1a).

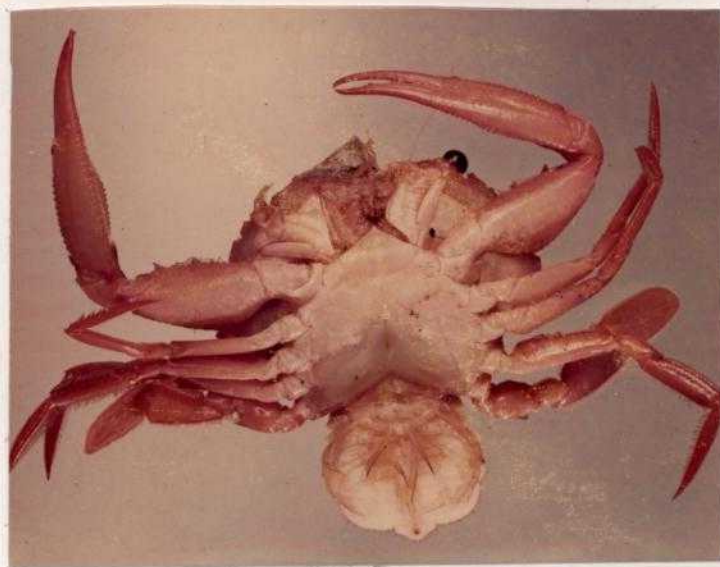
Posterior border more or less straight, granular, forming a feebly eared junction with the postero-lateral border; orbit with a strong dorsal inclination, upper border granular and cut into 3 parts by 2 narrow incisions

Abdomen: Tucked up beneath posterior sternal region of cephalothorax, female abdomen broad, constituted by six movable somites and a telson (Fig. 1b) second, third and fourth somites with carinate ridges; male abdomen inverted 'T' shaped constituted by four movable somites and a telson (Fig. 1c) second and third somites with carinate ridges.

Appendages: Antennules folded transversely; protopodite with 3 segments, proximal segment shortest, second joint comparatively narrow and half the length of entire appendage, distal joint $\frac{2}{3}$ length of second segment; exopodite and endopodite segmented; segments of endopodite few and short; a tuft of setae present on inner side of exopodite.



a



b

PLATE 3

- a. C. (G.) smithii adult male ventral view.
- b. C. (G.) smithii adult female ventral view (Abdomen in both cases opened to indicate the position and arrangement of pleopods).

Antenna with stout protopodite measuring $1/6$ of entire appendage, proximal and fixed to the front of carapace and hence the appendage excluded from orbital hiatus; endopodite forming nearly $5/6$ of entire length of appendage with two large proximal segments and a number of short rings; outer side of basal segments with numerous plumose setae, other segments with olfactory setae.

Mandible powerful with an elongated strongly calcified structure and mandibular palp, calcified structure with jaw and apophysis, jaw stout, curved sharply with blade-like prominence, anterior and rounded, posterior end pointed; middle of apophysis hinged; mandibular palp with 2 segments arising from anterior inner side of apophysis, fringed with sensory hairs and lying bent near to anterior side of jaw, approximately of same length as jaw.

Protopodite of first maxilla two segmented, proximal coxopodite narrow, distal basipodite large, both fringed with setae, plumose setae present at the base of protopodite, endopodite with proximal broad and distal narrow regions, inner margin of proximal region and tip of distal region bearing bristle-like setae.

Exopodite of second maxilla developed into scaphognathite, endopodite rudimentary, basipodal and coxopodal segments divided distally to form four separate endites, each endite tipped with setae.

Coxopodite of first maxilliped less than half the size of basipodite and fringed with setae; basipodite with two row of setae; endopodite

separated in the middle in two halves, proximal region of first half with plumose setae, distal half flattened laterally ending in three lobes, middle one largest, tips of all bearing plumose setae, exopodite two times longer than endopodite, two segmented, proximal segments one-fifth longer than endopodite; the distal multi-articulated segment forming flagellum with long membranous epipodite on outer side.

Endopodite of second maxilliped with five segments, meropodite longest, ischiopodite triangular, carpo, pro and dactylopodite small with thick growth of setae; exopodite two segmented, basal segment longer than distal; epipodite short, rod-like, distal end slightly swollen and fringed with hooked setae; podobranch large arising from coxopodite.

Third maxilliped covering mouth parts externally, basi and ischiopodite fused to form basiischium, basiischium largest of all segments, flattened dorsoventrally and rectangular in shape extending upto three-fourth length of proximal longer segment of exopodite, meropodite placed in front of basischium, dorsoventrally compressed, articulated distally with carpopodite, propodite and dactylopodite covered with long setae; basal segment of exopodite with setae on its entire length; epipodite forming a long curved blade, segmented, bearing long hairs; podobranch relatively small.

Chelipeds about two-and-half times as long as carapace width in adult males and one-and-half times as long as carapace width in adult females and juveniles, anterior border of merus rather sharply granular with 3-4 large spines, posterior spine smallest (Fig. 1d), upper surface

granular and inner surface smooth, inner angle of wrist with a large spine and outer angle with 3 spinules, outer angle with 3 granular ridges and a cluster of granules; palm with 6-7 granular costae and 3-4 spines of which one located at the base, one near the finger and one or two at about middle region, chelae larger in adult males than in females, inner margin with 7-8 stout teeth-like projections on both fingers, movable fingers as long as palm; basiischium triangular one-sixth the size of meropodite; inner margins of coxopodite, basiischium and meropodite with plumose setae.

Second to fourth pereopods of same length and shape, dactylopod with two hinges - one dorsal and the other ventral, joints of pereopods smooth, anterior margin of propodus and dactylus with plumose setae.

Fifth pereopods (Fig. 1e) highly modified as an oar-like structure, basiischium triangular, propodus and dactylus flattened very much dorso-ventrally to form oar-like structure, meropodite and carpopodite stout and round, meropodite larger than carpopodite, posterior border of meropodite with a spine, anterior margin of basiischium, merus and carpus with plumose setae, propodus and dactylus with setae all along the margins.

Female pleopod (Plate 3b, Fig. 1f) with exopod and endopod of same length, margins of endopodite fringed with long fine setae and exopod with plumose setae, size of pleopod decreasing proportionally from first to fourth, first male pleopod (Plate 3a, Fig. 1g) stout at base, gently curved, tapering towards tip, distal aperture situated at the tip of pleopod, shaft covered with small spinules, proximal aperture wider at base, posterior

surface of apex with few rows of spines, second male pleopod (Fig. 1h) with two parts, a protopodite and an endopodite, tip of endopodite slightly swollen, transparent and forked into two blunt equal parts.

GEOGRAPHICAL DISTRIBUTION

Indian Ocean: Offshore waters of South Africa, East Africa, Gulf of Aden, Eastern Arabian Sea, Bay of Bengal, Martaban Bay.

D I S C U S S I O N

Charybdis (Goniohellenus) smithii was originally described under the name Charybdis smithii by Macleay (1838) based on a single dried female specimen measuring 55.5 mm carapace width collected from the coast of South Africa (Cape of Goodhope). The holotype is preserved in the Macleay Museum, University of Sydney (Griffin and Stanbury, 1970). The same species was recorded subsequently from many other parts of Indian Ocean by various authors under different names. Milne Edwards (1861) described and figured the species based on materials obtained from Malabar coast, south west coast of India and from Port Natal (Durban, Natal), South Africa under the name Goniosoma truncatum. This author does not seem to have examined the holotype of the species deposited in the Macleay Museum nor has referred to the original description of Macleay. Subsequently, Leene and Buitendijk (1949) reviewed the identity of the species based on a male specimen of 'Charybdis (Goniohellenus) smithii' obtained from the Martaban Bay (Burma), which was deposited

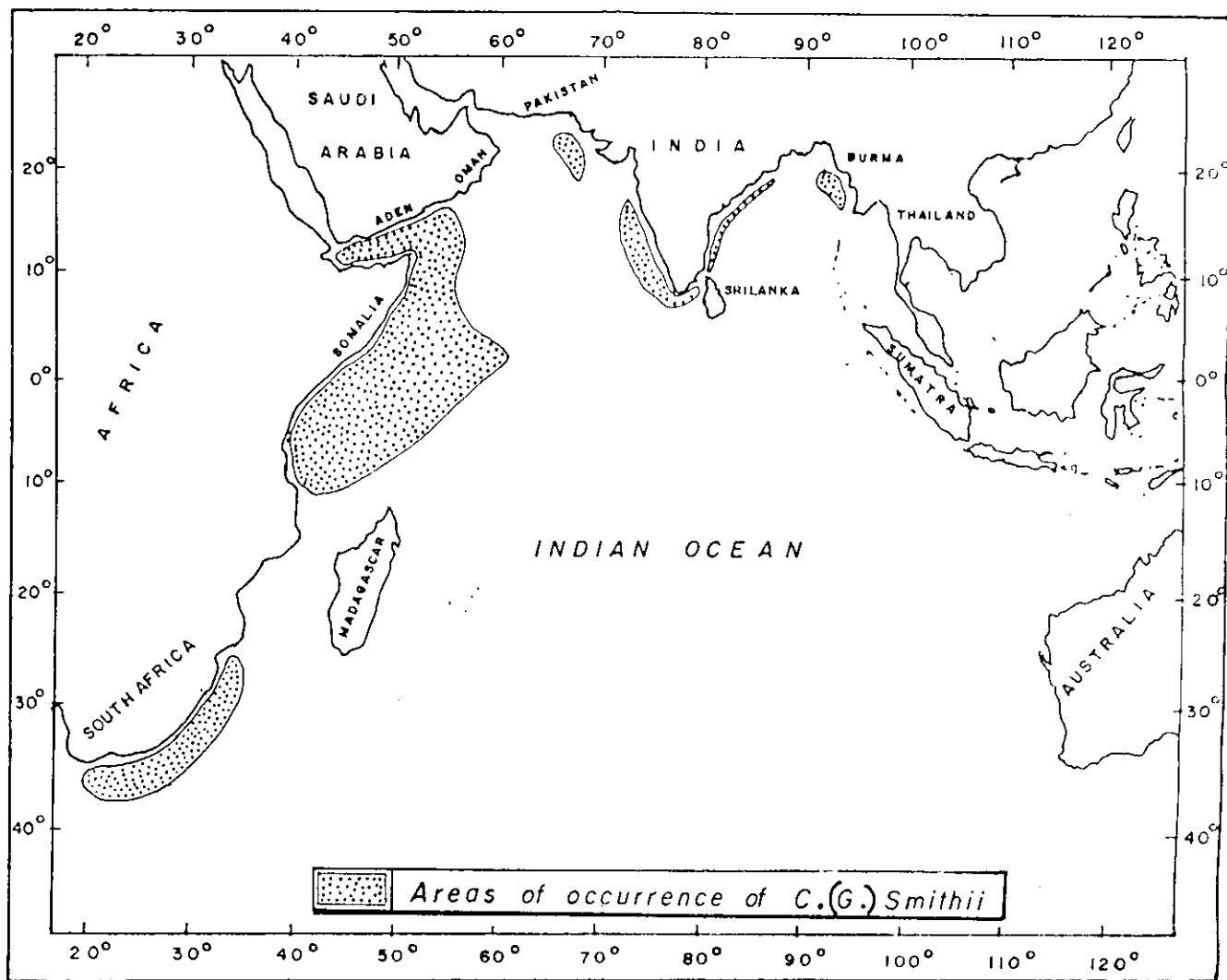


FIGURE 2. Known geographical distribution of *C. (G.) smithii* in Indian ocean.

in the British Museum (Natural History). These authors have found that the material examined by them was, in most characters, identical with the G. truncatum of Milne Edwards (1861) and named the same as Charybdis (Goniohellenus) edwardsi. According to these authors this species (C. (G.) edwardsi) "is most easily recognized by its small and sharp frontal teeth and by its large and truncate antero-lateral teeth". They, however, did not compare their lectotype, C. (G.) Edwardsi with the original description of Macleay (1838).

Barnard (1950) reported on this species under the name Gonioneptunus smithii based on a photograph of the type of Macleay specimen given by Mr. Melbourne Ward who was of opinion that Macleay's species (C. smithii) was identical with Goniosoma truncatum A.M. Edw.(Della Croce and Holthuis 1965).

Sankarankutty and Rangarajan (1962) recorded this species from the oceanic waters of Arabian sea based on two male specimens collected during the cruises of the research vessel R/V VARUNA. A little later, large swarms of this species were reported by Della Croce and Holthuis (1965) from the East African Coast during the International Indian Ocean Expedition (IIOE) and provided brief accounts on the systematics and biological features of the species. Stephenson and Rees (1967b) examined the holotype of C. smithii and unambiguously established that C. (G.) edwardsi of Leene and Buitendijk and C. smithii of Macleay are identical species.

From the descriptions given for the species by all the previous workers it appears that the following are the most diagnostic characters

of the species.

1. The front margin of carapace is cut into six small sharp teeth.
2. The antero-lateral border of carapace is cut into six large subquadrate teeth of which the free edges are minutely serrated, and
3. Carapace is smooth and highly polished. The cardiac and meso-branchial regions are without any perceptible granulation.

The materials examined during the present study fully agree with the descriptions given by the earlier workers (Leene and Buitendijk, 1949; Della Croce and Holthuis, 1965; Stephenson, 1967) in regard to the structure of carapace. Examination of several specimens of the different life stages including juveniles, subadults and adults of both the sexes during this study has revealed very little variation in the structure of carapace as compared to the descriptions given by earlier workers. Some of the minor variations observed were (1) the anterior border of merus of cheliped carries 3-4 spines of which the posterior one is the smallest, (2) the palm of cheliped has 6-7 granular costae and (3) the spines on palm number 3-4. According to Leene and Buitendijk (1949) there are only 3 large spines on the anterior granular costae and 3 spines on the palm.

Barnard (1950) reported that the carapace of the species showed very faint fine granular transverse lines and patches of granules on cardiac and inner branchial regions. In the present study, it is observed that the carapace of the species is absolutely smooth with no indication of granulation. The variation in Barnard's observation as regards the nature of carapace surface could be due to the fact that the observation was only based on a photograph and no direct observation was made of the actual material.

Though Sankarankutty and Rangarajan (1962) made mention of the record of Alcock (1899a); the latter author treated the species (Charybdis (Goniohellenus) truncata (de Haan) as a synonym of Goniosoma truncatum of A. Milne Edwards. However, C. (G.) truncata (de Haan) recorded by Alcock (1899a) does not find a place in the list of synonyms of C. (G.) smithii Macleay given by Stephenson (1972). A scrutiny of the description given by Alcock (1899a) for his "INVESTIGATOR" material (C. (G.) truncata) exhibit considerable variations which does not permit synonymising the same with the present material.

Besides C. (G.) smithii Macleay, two more species, namely, C. (G.) hoplites Wood-Mason and C. (G.) omanensis Leene, which occur in the deep/oceanic waters, have also been reported from the Indian Seas (Stephenson, 1972). These three species can be easily distinguished as follows.

- | | | | |
|-------|--|---|--------------------------|
| 1. | Post-lateral junction distinctly angular,
last antero-lateral tooth long or of
moderate length | - | <u>C. (G.) hoplites</u> |
| | - Post-lateral junction obscurely angular | | |
| | last antero-lateral tooth relatively short | - | 2 |
| 2 (1) | Cardiac and mesobranchial areas of
carapace strongly granular | - | <u>C. (G.) omanensis</u> |
| | - Cardiac and mesobranchial areas of
carapace without granular patches or
ridges | - | <u>C. (G.) smithii</u> |

During the present survey, it has been possible to collect a few specimens of C. (G.) omanensis also along with the present species in

the bottom trawl catches of southwest coasts of India. Examination of the morphological features of this material of C. (G.) omanensis (Suseelan and Balasubramanian, M.S.) have shown that the species could be easily distinguished from C. (G.) smithii by the presence of distinct granular patches on the cardiac and mesobranchial region in the former species (Plate 4). Apart from this important character, a few other morphological features, which appeared to be of taxonomic importance, have also been noticed. The Table below gives a comparative statement of the important morphological characters of these two closely allied species.

<u>C. (G.) smithii</u>	<u>C. (G.) omanensis</u>
1. All frontal teeth arranged at the same level	Median frontal teeth are situated slightly above the other frontal teeth
2. Second and third male abdominal segment of male sharply and transversely keeled	Second, third and partly fourth male abdominal segment of male keeled.
3. Carapace absolutely smooth and highly polished	Carapace with granular ridges in the gastric region and granular patches in the cardiac and mesobranchial region.
4. The fissure separating submedian and lateral frontal teeth narrow	The fissure separating submedian and lateral frontal teeth wide.

Stephenson (1967, 1972), while assigning a species status to C. (G.) omanensis, expressed doubt about the validity of the same. The concurrent collection of specimens of both the species during the present study and detailed examination of their morphological features clearly reveal that C. (G.) smithii and C. (G.) omanensis are two distinct valid species which co-exist in the outer continental shelf and upper continental slope of southwest coast of India.



PLATE 4

Charybdis (Goniohellenus) omanensis Leene, male
dorsal view.

SECTION 2. BIOLOGY

An understanding of the behaviour 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 growth, reproduction and food and feeding under different environmental conditions. The species under study being a deep-water one and considering the paucity of information on its biology, an attempt has been made to gather as much data as possible on the life history of the species. As the fishing operations were exploratory in nature, regular time series data could not be obtained from any particular region and hence it has not been possible to trace out the growth rate and estimate the age of the species. However, the collections obtained from the different types of experimental nets operated in the pelagic and benthic regions have enabled to make detailed observations on the biology of different life stages of the species.

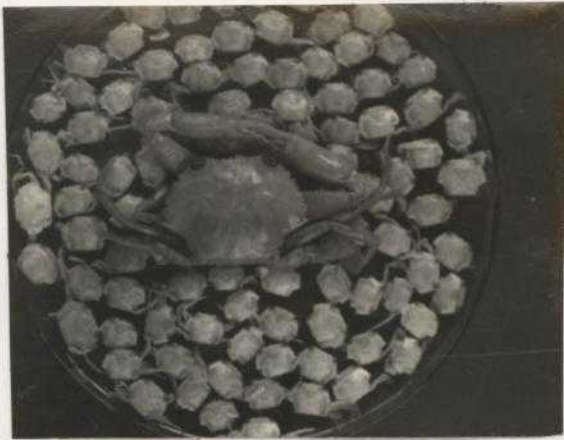
HABIT AND HABITATS

Juveniles: Juvenile stages of the species (Plate 5a) measuring 11 mm carapace width (cw) onwards are observed to be pelagic in existence. They formed more or less a regular component of the micronektonic community taken by the Isaacs-Kidd midwater trawl (IKMT) and contributed an average of about 0.3% of the Deep Scattering Layer (DSL) population in terms of number. Out of 433 IKMT samples examined, the juvenile crabs occurred in 33 samples, most of them belonging to the size group 11-20 mm cw. In some of the trawling operations made in the DSL, the crab collections were exceptionally high (862 no/haul) and almost

exclusively constituted by the above size group. This would suggest that the species has swarming tendency from the very early stage of its life.

Adults: Subadult and adult crabs were observed to occupy both the pelagic and benthic realms. During pelagic trawl operations these stages were caught in large numbers with majority of them belonging to the size groups 31-72 mm cw which are above the minimum size of maturity. Out of 334 pelagic trawl operations examined during the present study the adult crabs were recorded in 72 hauls, some of them containing large quantities numbering about 54,000/haul. This would suggest distinct swarming tendency for these stages as exhibited by the juveniles. Visual observations on surface swarms during day time and evening have shown that these crabs swim in isolation or in groups upto about 10 feet apart. During night time, they were found to be attracted by light from ship's deck lamp. The maximum size of the crab recorded in the pelagic samples was 72 mm cw for male and 69 mm for female, which weighed approximately 55 gm and 34 gm respectively.

Subadult and adult crabs were taken in varying quantities by bottom trawl (Plate 5b) from the outer continental shelf and the upper continental slope. The minimum size recorded at the bottom was 31 mm cw. The fact that still smaller sizes of crabs belonging to other species/genera in the same fishing ground during the bottom trawling operations of FORV Sagar Sampada precludes any possibility of the existence of juvenile stages of the species smaller than 31 mm cw in this habitat. It can



a



b

PLATE 5

- a. C. (G.) smithii a collection of juvenile crabs along with an adult female.
- b. A catch of adult crabs from bottom trawl.

therefore be inferred that the size at which the crab settles at the bottom and assumes benthic life is around 31 mm cw. Although a wide range of size has been encountered at the bottom, specimens in the size range 31-45 mm were relatively poor. The maximum size recorded at the bottom measured 72 mm for males and 69 mm females, which weighed 64 gm and 43.5 gm respectively, thereby indicating a clear difference in weight between the similar sized crabs occupying the pelagic and benthic habitats. The crab is found to prefer soft muddy substratum as evidenced by their abundance in such areas on the upper continental slope off Quilon-Alaphey and the outer continental shelf off Ponnani-Mangalore coast.

REPRODUCTION

Information on reproductive biology throws light on the generative potential, recruitment and sustainability of exploitable resources. These are of great value in fishery prediction and formulating management and conservative measures. The reproductive biology of brachyuran crabs have been extensively studied from different parts of the world (Arriola, 1940; Spalding, 1942; Cronin, 1947; Estampador, 1949; George, 1963; Ryan, 1967b, 1967c; Knudsen, 1960, 1964; Hartnoll, 1968; Hinsch and Walker, 1974; Hafner, 1977; Johnson, 1980; Diesel, 1991). Hartnoll (1968) distinguished two basic patterns of vaginal structure in brachyura (simple and concave) and later correlated with structure and copulatory behaviour (1969). The brachyura 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, 1991). The thelyca are paired or unpaired sternal invaginations, without any connection to ovary, that open on the coxa of third pereopod (Gordon, 1963). The seminal receptacles of *Eubrachyurans* are enlargements of paired female genital ducts (Ryan, 1967b; Hartnoll 1968; Johnson, 1980; Hinseh, 1988b, Adiyodi and Anilkumar, 1988; Beninger, et al., 1988; Diesel, 1989).

Although a number of species of genus *Charybdis* contribute to commercial fishery in the Indo-Pacific region, information of reproductive aspects of this group is restricted to only a few coastal species, notably from Indian waters. Nath (1942) described the spermatozoa of *Charybdis cruciata* in his classical paper on decapod sperms. Breeding habit, breeding season and larval stages of *C. (Goniosoma) callianassa* have been studied by Chhapgar (1956) from Bombay coast. Chandran (1968) investigated on the reproductive cycle of *C. variegata* from the east coast of India, while Pillay and Nair (1968) threw light on the breeding seasons of related species *C. cruciata* and *C. hoplites pusilla* from the southwest coast of India. Padayatti (1990) reported on the fecundity and size at maturity of *C. (G.) feriatius* in the inshore waters of Cochin.

Sexuality:

Sexes are separate and distinguishable even at 11 mm cw, the minimum size encountered during the present study. Male crabs are characterized by the inverted 'T' shaped abdomen, while in female the abdomen is semicircular (Plate 3a, 3b). In addition, the male has a relatively larger chela and a general trimness for body contour than the female. Male has pleopods 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 possess setae for attachment of eggs for brooding.

Male Reproductive System:

Anatomy :

The male reproductive organ is bilateral and roughly in the form of English alphabet 'H' (Plate 6). It is composed of paired testes, vasa deferentia, ejaculatory duct and external penis. The first and second abdominal appendages are highly modified to function as copulatory organs.

Testes: In immature crabs the testis is rather inconspicuous and difficult to make out on dissection. Mature testis has the appearance of slender white convoluted tube 2 to 3 mm in average width (Plate 6). It is sandwiched between the hypodermis of carapace and the hepatopancreas. The organ is opaque with irregular surface and the spermatic artery is visible almost throughout its length. The distal portion on either side is bent along the antero-lateral border of carapace. A short cross-bar joins the testes of the two sides a little ahead of the middle of the carapace.

Vas deferens: The vas deferens has three distinct regions, the anterior vas deferens (AVD), median vas deferens (MVD) and posterior vas deferens (PVD) (Plate 6). The anterior vas deferens are white, tightly coiled and lying on either side of the median line of cephalothorax posterior to the dorsal part of the stomach. The AVD of each side rests on the respective

median vas deferens. The anterior most coils are slender, translucent and delicate. They are bound together by a thin but strong membrane and cannot be separated or straightened by dissection. The coils increase in size posteroventrally. Here they are thicker, white and quite opaque. The coils lead into median vas deferens. The MVD is more massive than the AVD. It is a loosely coiled opaque white tube. The posterior vas deferens is massive for its proximal part, but it gradually narrows before opening to the ejaculatory duct.

Ejaculatory duct (Plate 6): The ejaculatory duct arises behind the PVD as a narrow tube which passes through the musculature of the fifth walking leg and opens at the base of coxal segment through the penis.

Penis (Plate 6): The penis is a slender weak tube which arises from the ventromedian border of the coxopodite of the 5th pereopod. Its diameter varies from 1.6 to 1.8 mm and has a length of 6-8 mm. Its basal portion is surrounded by fine setae. The gonoduct can be seen as a white opaque tube at the centre. Each penis passes into the anterior proximal foramen of the first pleopod.

Pleopod 1 and 2: The structure of pleopod 1 and 2 of adult male is shown in Fig. 1. The first pair is larger than the second, and it may serve as the functional intromittant organ. In related species of portunids, it is reported that the first pleopod receives spermatophores and sperms from the small penis and acts as a tube of transport in copulation, carrying these materials into the paired vagina and the seminal receptacle of adult female. The second pleopod is inserted into

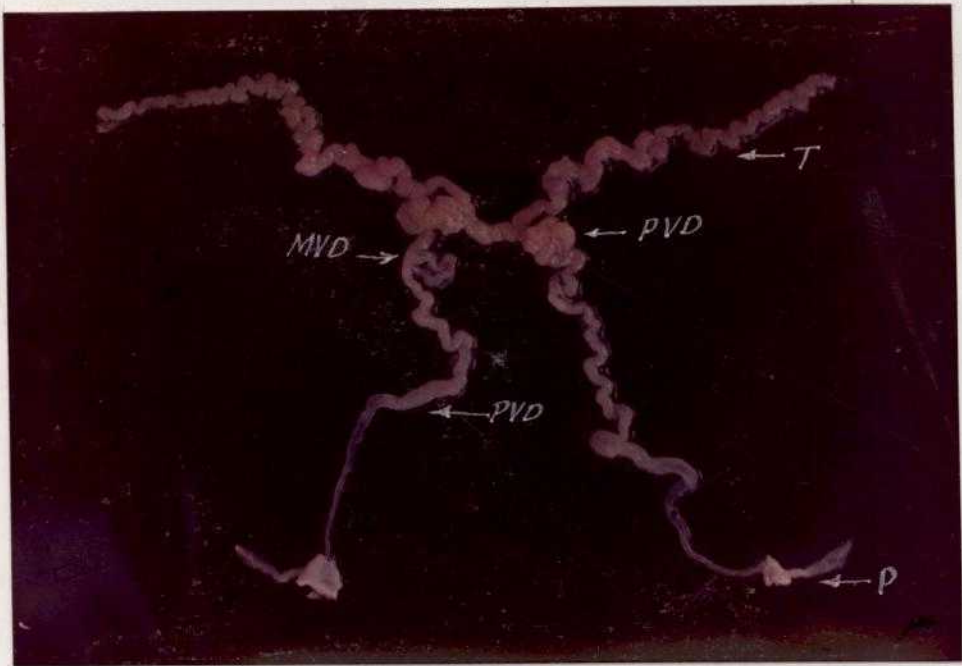


PLATE 6

Male reproductive system of C. (G.) smithii

T - Testis

AVD - Anterior vas deferens

P - Penis

MVD - Median vas deferens

PVD - Posterior vas deferens

the posterior foramen of the first pleopod and forces semen and spermatophores through the tube like intromittent flagellum of the first pleopod (Stephensen, 1946; Cronin, 1947; Ryan, 1967c; Hartnoll, 1969, 1975; Bauer, 1976, 1986; Elner et al., 1985).

Histology:

Histological study of the male reproductive system showed that the testis is incompletely divided into lobes, each of which consisting of a group of seminiferous lobules. The wall of the testis has two layers - a delicate surface membrane and a crenated layer of fibrillar connective tissue (Plate 7a). The seminiferous lobule has a wall of connective tissue around most of its periphery but always shows confluence of its contents with neighbouring lobules or ducts. All the lobules have access to the seminiferous ducts (Plate 7a) either directly or through others. The seminiferous duct varies from 0.15 to 0.40 mm in diameter and is lined with columnar epithelial cells. In a section of testis many portions of the seminiferous ducts are observed (Plate 7a). The duct is essentially tubular with the width varying from 40 to 300 μm . It opens to receive sperms from the surrounding testes lobules. There is no indication of ciliation in the duct.

A cross section of the coiled mass of AVD is shown in the Plate 7b. As can be seen in the figure, the different portions of the AVD which have come in the plane of section are represented by many closed circles, each one enclosing a number of closely packed spermatophores or sperm packets. At the proximal part of AVD, the wall is lined with cuboidal

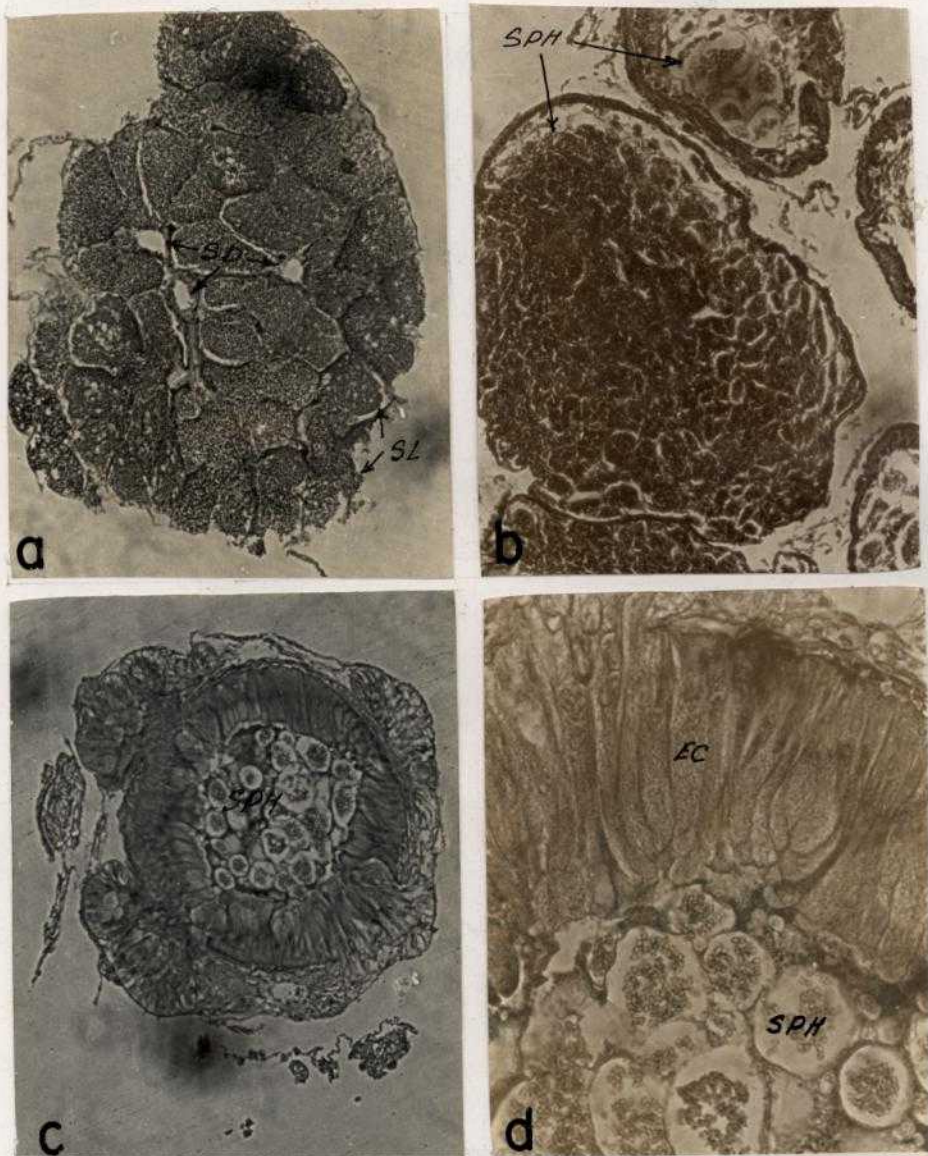


PLATE 7

Photomicrographs of testis and Anterior vas deferens of C.(G.) smithii

- a. Transverse section of testis showing seminiferous lobules (SL) and seminiferous duct (SD) (X100)
- b. Transverse section of anterior vas deferens, proximal region (X100)
- c. Anterior vas deferens distal region, lumen is filled with spermatophore (SPH) (X100)
- d. Section of distal region of anterior vas deferens showing the columnar epithelial cells (EC) (X400)

epithelium surrounded by thin strata of muscle and connective tissue. The lumen appears to be filled with viscous fluid in which spermatophores are lodged (Plate 7c). The distal portion of the wall of AVD is lined with tall columnar epithelial cells having a central nucleus in each (Plate 7d)

Spermatogenesis:

Spermatogenesis or formation of mature spermatozoa takes place in the seminiferous lobule. In the immature crab, the whole testis is occupied by spermatogonia. In maturing/mature stages of the gonad, the spermatogonial cells can be seen in groups in the periphery of the seminiferous lobule (Plate 8a). These spermatogonial cells found in the germinal zone undergo quick growth to become primary spermatocytes (Plate 8b). These divide again to produce subsequent stages resulting in the formation of secondary spermatocytes (Plate 8c) and spermatids. The spermatids develop into spermatozoa. In a particular lobule, almost all germ cells belonged to the same stage of development.

Since spermatogenesis involves progressive reduction of cytoplasm and condensation of chromatin to produce spermatocytes, the spermatogonial cells are found to be larger than spermatocytes. The spermatocytes in turn are larger than spermatids. It is seen from histological sections that each spermatogonial cell has a round vesicular nucleus with diffused chromatin matter (Plate 8a) which stained weakly with hematoxylin. Cytoplasm is represented by thin eosinophilic covering. The spermatocytes are observed to have a more condensed nucleus, which are often seen in dividing stages (Plate 8c). The spermatozoa which are slightly smaller

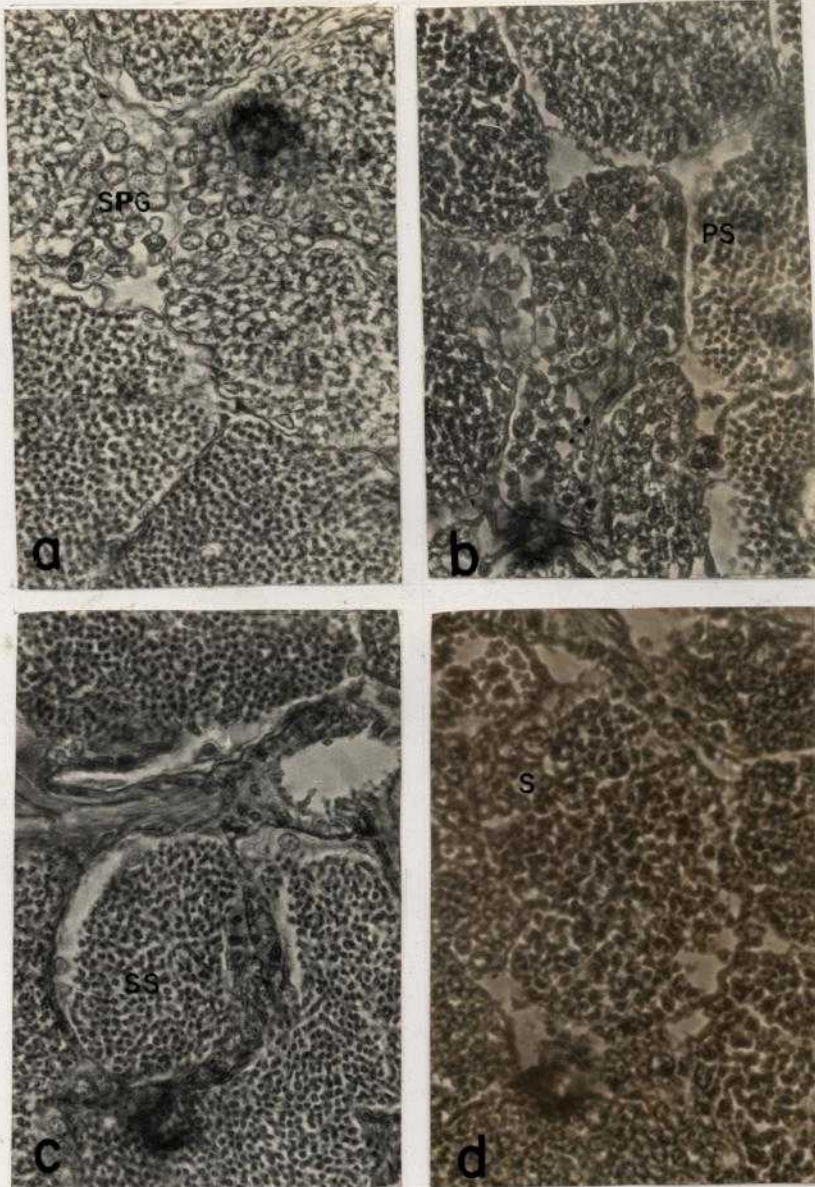


PLATE 8

Transverse sections of testis showing developmental stages of male germ cells such as spermatogonia (SPG), primary spermatocytes(PS), secondary spermatocytes (SS) and spermatozoa (S) (X400)

in size are developed from the spermatids and found occupying most part of the seminiferous lobule in fully ripe condition (Plate 8d).

Female Reproductive System:

Anatomy:

The female reproductive system consists of a pair of ovaries, a pair of spermatheca or seminal receptacle and a pair of vagina (Plate 9). The entire ovary is bound by a fibrous connective tissue which serves to separate the organ from surrounding haemocoel. The ovary is 'H' shaped and located dorsally just beneath the carapace. The horns of ovary extend anterolaterally from either side of the gastric mill and dorsal to the hepatopancreas. At the posterolateral border of gastric mill, near the origin of posterior mandibular muscle bundles, the anterior horns are joined by a commissure. Two posterior horns which lie ventral to the heart, extend posteriorly on either side of the intestine. The posterior prolongation of ovary is subequal, one of the horns being larger and extending further for about 5 to 6 mm beyond the other. The seminal receptacles arise from the mid lateral border of the posterior horns. Each seminal receptacle leads into a narrow vaginal tube which further opens outside through a small circular gonopore (vulva) situated on the 6th thoracic sternite (Plate 13a, 13b). The stage of spermatheca varies according to the reproductive condition of the animal.

Histology:

Transverse sections of ovary in various stages of maturation are shown in Plates 10 and 11. The entire ovary is enclosed by a thin capsule

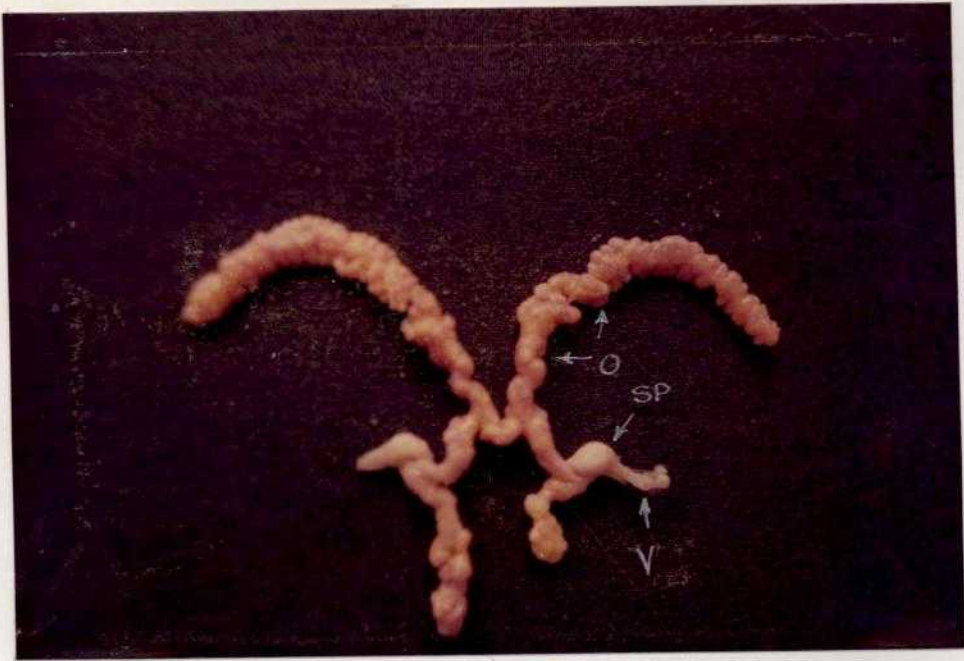


PLATE 9

Female reproductive system of C. (G.) smithii

O - Ovary

SP - Spermatheca

V - Vagina

of fibrous connective tissue (Plate 8a). The capsule separates the ovary from general haemocoel. A germinal zone is present along the middle region of the ovary (Plate 8a). During early phases of maturation, the germinal zone consists of oogonia and young oocytes, the later getting displaced towards the outer region of ovary as development progresses. As maturation advances germinal zone becomes greatly reduced and it contains only a few residual oogonia, the major part of the ovary being filled with maturing oocytes.

Oogenesis:

Oogenesis is said to be a dynamic process (Nadarajalingam and Subramoniam, 1982) which consists of a generative/proliferative phase and vegetative/growth phase. The generative phase refers to the mitotic multiplication of primary oogonial cells into secondary oogonial cells that transform to the primary oocytes. The primary oocytes with diploid number of chromosomes enter into the prophase of meiotic division. However, the meiotic division is arrested at the pachytene stage and the ooplasm starts accumulating yolk material. This process is known as vegetative phase.

During the present study an attempt has been made to trace out the oogenesis of C. (G.) smithii by histological examination of different maturity stages of ovary. The cytological changes presented by oocytes during ovarian maturation enabled to distinguish three broad developmental phases, namely, proliferative phase, previtellogenic phase and vitellogenic phase.

Proliferative phase: The oogonial cells multiply in large numbers in the germinal zone of ovary and this multiplication process can be observed at all stages of maturation of the ovary (Plate 10a). The oogonial cells have a large nucleus and small amount of ooplasm. In the nucleus of these cells patches of clumped chromatin can be seen (Plate 10b). The nucleus lacks stainable material. The primary and secondary oogonial cells are not distinguishable under light microscope. Oogonia develop into primary oocytes (Plate 10c). The primary oocytes remain in groups close to the germinal zone. The nucleus of these oocytes continues to be large, with uniformly distributed chromatin. The nucleus exhibit different meiotic stages.

Previtellogenic phase: The oocytes enters a rapid growth stage. The nucleus increases in volume and appears vesicular containing peripherally arranged chromatin clumps. A centrally placed nucleolus, which stain blue black with hematoxyline is observed inside the nucleus and appears solid. The oocyte at this stage acquires a large amount of basophilic cytoplasm (Plate 10d) in which the yolk formation has not yet begun. The oocyte has a diameter of about 85 μ m.

Vitellogenic phase: Oocyte further increases in the amount of basophilic ooplasm and the volume of its nucleus and nucleolus (Plate 11a). The nucleus is solid and centrally placed. Chromatin clumps become finely granular arranged into a net work in the nucleoplasm. Small yolk droplets appear in the peripheral region of ooplasm. The yolk droplets stain purple to black with hematoxylin. In the subsequent stage of development, the oocyte grow further, and unstainable vacuoles appear in the ooplasm.

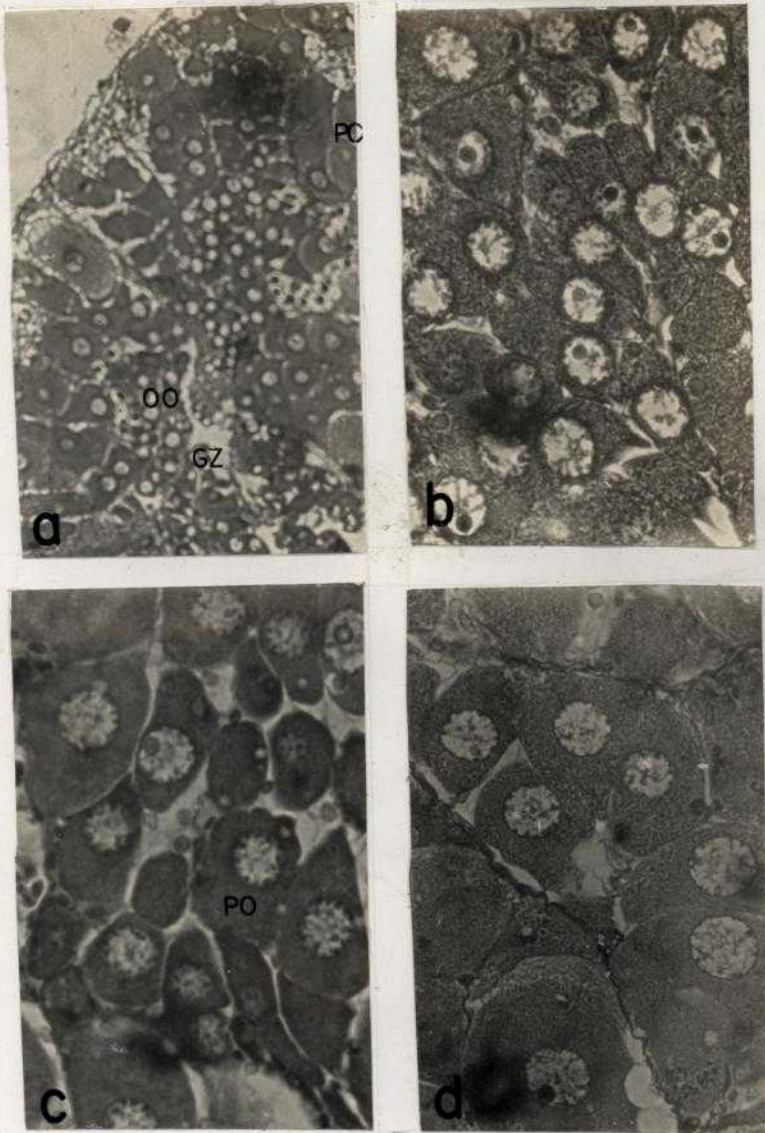


PLATE 10

Photomicrographs of ovary of *C. (G.) smithii* in early and late maturing stages

- a. Transverse section of early maturing ovary showing germinal zone (GZ), oogonia (OO) and primary oocytes (PO) (X100)
- b. Enlarged view of early maturing ovary. Oogonia with clumped chromatin can be seen (X400)
- c. Transverse section of late maturing ovary showing primary oocytes (PO) (X400)
- d. Transverse section of late maturing ovary showing increased size of oocytes due to accumulation of basophilic cytoplasm (X400)

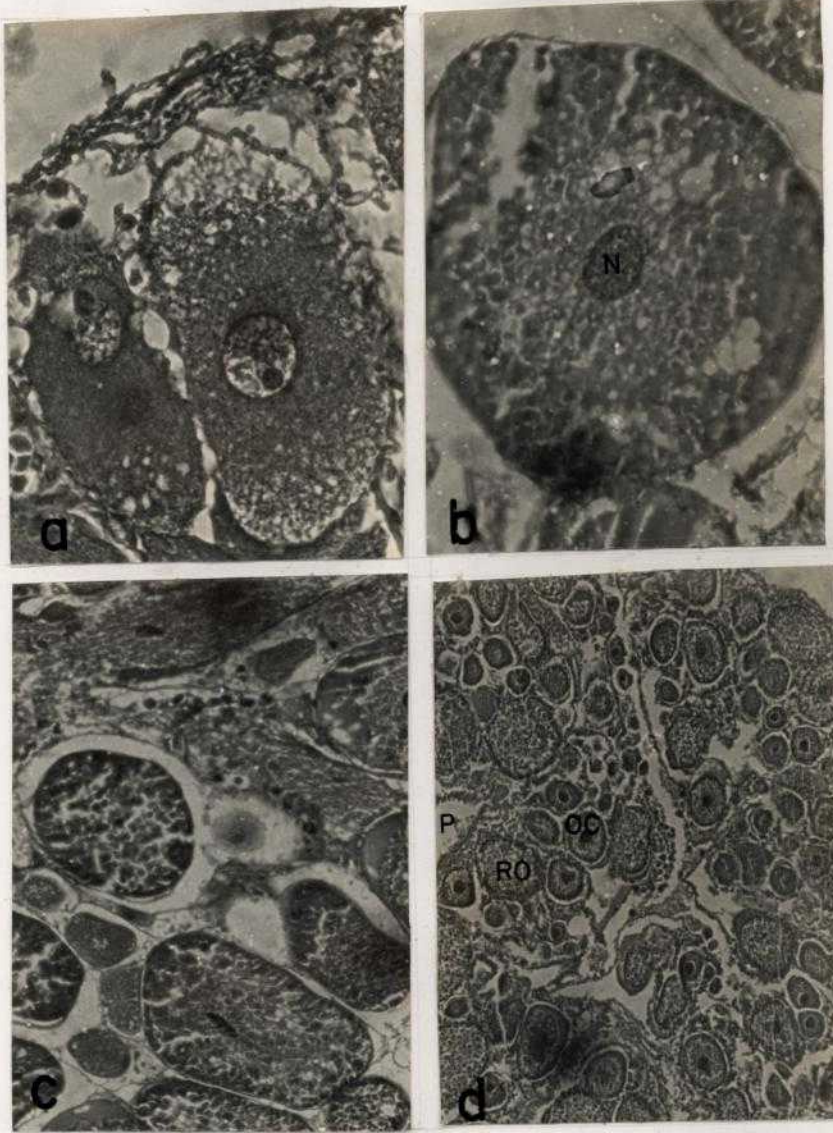


PLATE 11

Photomicrographs of ovary of C. (G.) smithii in ripe and spent stages.

- a. Transverse section of ovary showing oocytes undergoing early vitellogenesis (X400)
- b. Transverse section of ovary showing oocytes with nucleus (N) and diffused nucleolus (X400).
- c. Transverse section of ripe ovary nuclear material completely dispersed (X100)
- d. Transverse section of spent ovary. Developing oocytes (OC) and phagocytic cells (P) around unspawned ova undergoing resorption (RO) can be seen. (X100)

The vacuoles fuse with each other and ultimately form large unstainable yolk vesicles. Yolk globules also appear at this stage. The nucleolus looks diffused and stains homogeneous with hematoxylin (Plate 11b). The oocytes undergo further growth and attain a size of 374 μm when the ooplasm becomes completely flooded with yolk granules and the nuclear material gets dispersed in the cytoplasm (Plate 11c).

Maturity stages:

The 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 and 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 divisible into 5 maturity stages, namely, immature (stage 0), early maturing (stage 1), late maturing (stage 2), ripe (stage 3) and spent (stage 4). Table 1 shows details of the morphological changes taking place in different maturity stages of the ovary.

Immature (stage 0):

Ovary is thin, tubular, translucent and extremely difficult to locate macroscopically. It is usually less than 2 mm in thickness and without pronounced lobation. Ova are small, size ranging between 25 and 45 μm with a mean of 30 μm and difficult to isolate from surrounding tissues even after treatment in Gilson's fluid.

TABLE 1. Colour, Size, Gonadosomatic index (GSI) and ova diameter in different maturity stages of the ovary of Charybdis (Goniohellenus) smithii. Mean values of GSI and ova diameter are given in parenthesis.

Maturity stages	No. of observations	Colour	Horn width range (mm)	Weight (gms)	GSI	Ova diameter (μ m)
Immature	12	Translucent	1.1-1.5	0.34 ± 0.04	0.92-1.38 (1.23)	25-45 (30)
Early maturing	12	Ivory to light yellow	2.0-3.5	0.62 ± 0.14	2.4-2.9 (2.62)	51-119 (70)
Late maturing	20	Yellow to yellowish orange	3.5-7.0	1.10 ± 0.43	3.26-5.1 (3.91)	85-357 (177)
Ripe	5	Dark orange	5.5-10.0	4.10 ± 0.34	6.0-8.3 (6.6)	102-374 (233)
Spent	15	Translucent	2.0-4.0	0.37 ± 0.03	2.6-3.5 (2.82)	34-340 (102)

Early maturing (stage 1):

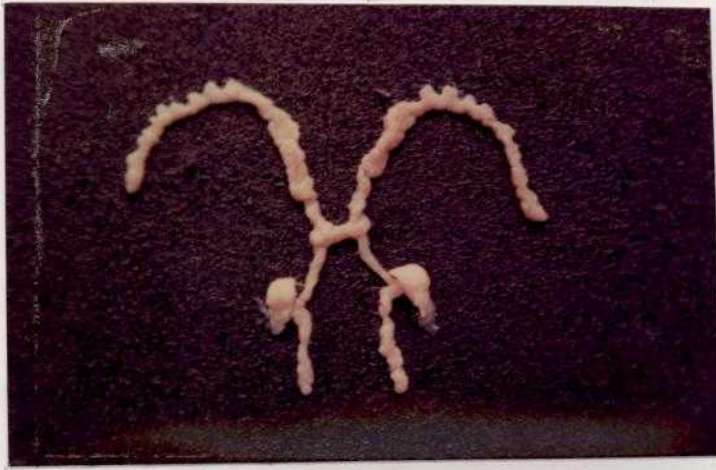
Ovary is easily visible macroscopically and ivory or light yellow in colour (Plate 12a). It occupies about one half the volume of hepatopancreas dorsally. At this stage ovary has a lumen and well developed germinal strand (Plate 10a). The ova diameter ranges from 51 to 119 μm with a mean diameter of 70 μm . This stage corresponds to the proliferative and previtellogenic phases.

Late maturing (stage 2):

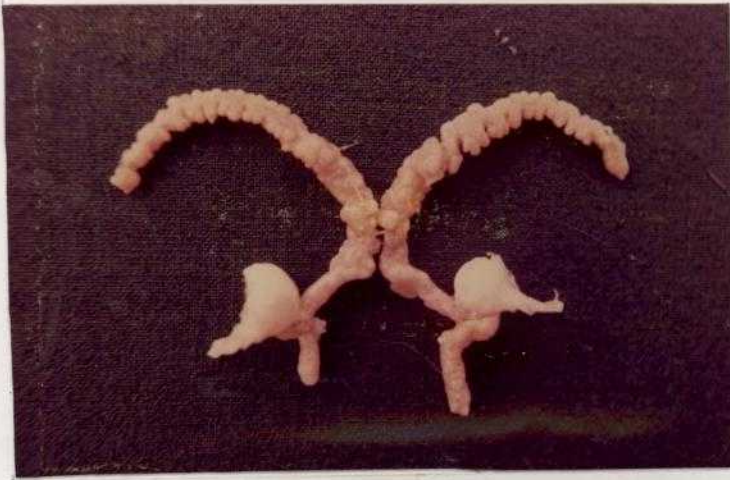
Volume of ovary is subequal to hepatopancreas in size. Ova are conspicuous when the ovary is viewed macroscopically. Colour of ovary varies from yellow to yellowish orange. Ova diameter ranges from 85 μm to 357 μm with a mean diameter of 177 μm .

Ripe (stage 3):

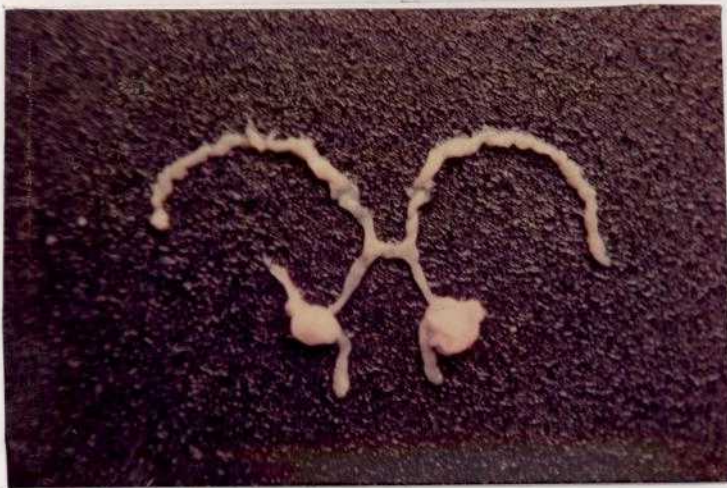
Ovary is the dominant visible organ obscuring hepatopancreas dorsally (Plate 12b). Colouration of ovary is dark orange. The enclosing fibrous connective tissue is highly stretched often to the point of bursting during dissection. Bulges caused by large ova can be clearly seen macroscopically. Ova measures between 102 and 374 μm in diameter, with a mean diameter of 253 μm . They carry large quantities of yolk granules and hence difficult to section (Plate 11b). Nuclei are no longer visible in the oocytes which have for most part of the ovary completed vitellogenesis.



a



b



c

PLATE 12

Ovary of C. (G.) smithii in different maturity stages.

a. Early maturing **b.** Ripe **c.** Spent

Spent (stage 4):

Ovaries appear flaccid, translucent and greatly reduced in size (Plate 12c). Unspawned ova may be visible through outer fibrous connective tissue. Seminal receptacles contains sperm. The ovary is less compact at this stage than in mature or ripe stages as the interstices spaces are filled with connective tissue. Germ strand is well defined, oogonia and developing oocytes radiating outwards from this region (Plate 11d). The greater part of the ovary consists of fibrous connective tissue and haemocoel spaces containing blood cells and phagocytes (Plate 11d). Mature unspawned ova undergoing resorption are often present and surrounded by phagocytes. The ova diameter ranges from 34 to 340 μm .

The percentage distribution of the various developmental stages of the germ cells in the ovary during maturity stages 1-4 has been studied based on count of cells in the histological sections (Fig. 3). In stage 1 the oogonial cells formed the largest group accounting for about 72% and the remaining part was formed of previtellogenic cells. In stage 2 of the ovary, the number of oogonial cells was considerably reduced (23%) while the previtellogenic cells formed 60% and vitellogenic cells 17%. In the 3rd stage as much as 71% was constituted by vitellogenic cells and the rest 19% by previtellogenic cells and 10% by oogonial cells. In the 4th stage the oogonial cells again dominated forming nearly 80% while the unspawned vitellogenic cells and previtellogenic cells accounted for about 19% and 1% respectively.

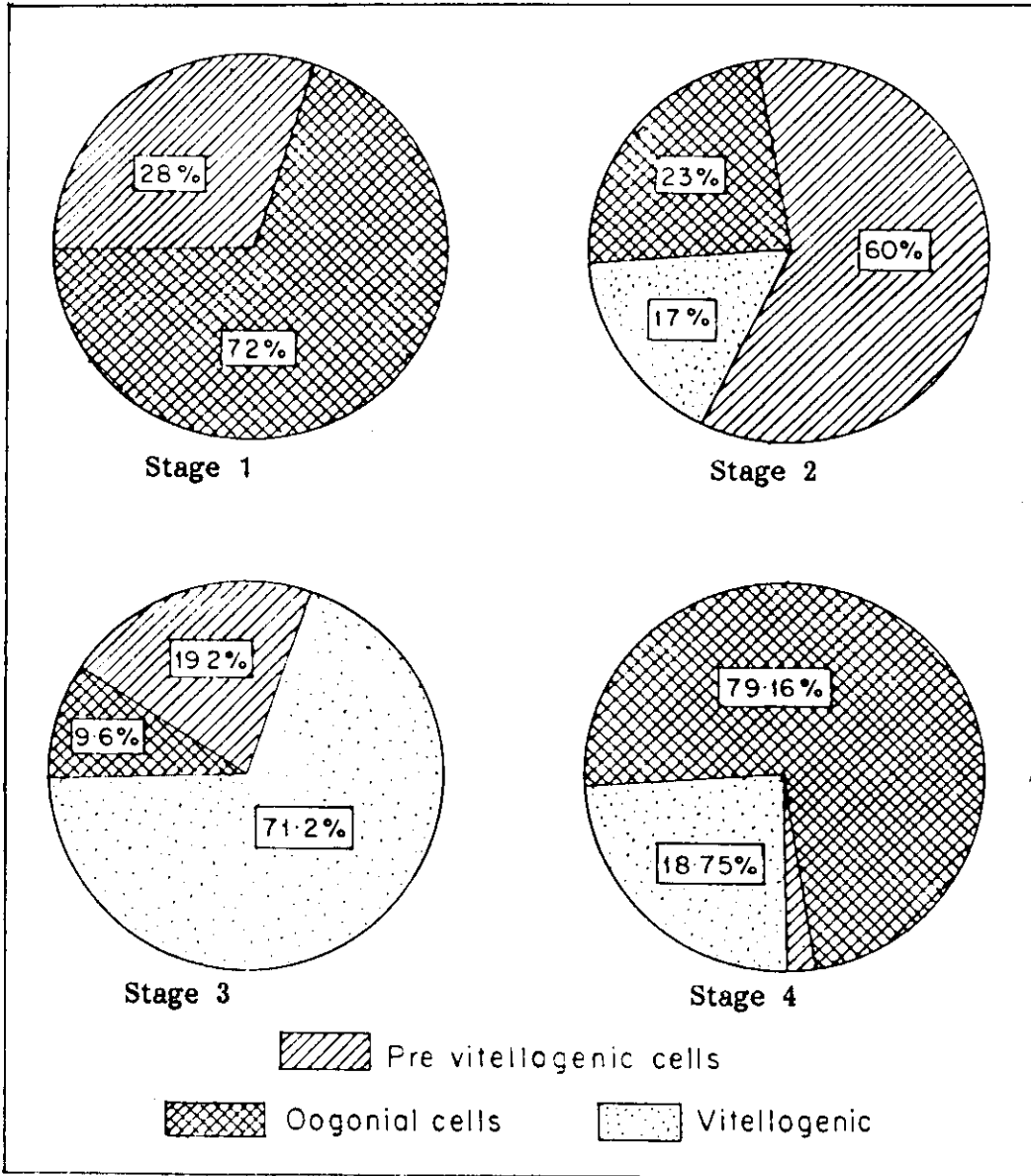


FIGURE 3. Percentage distribution of different gametogenic cells in the ovary in relation to reproductive phases.

Gonadosomatic index (GSI):

The mean Gonadosomatic index was found to be 1.23 in immature crabs which showed a gradual increase to 3.91 in late maturing. The highest GSI value of 6.6 was observed in stage 3 (ripe) followed by a steep decline in the spent stage (stage 4) with a mean value of 2.82 (Table 1).

Minimum size of maturity:

The smallest berried female encountered during the present-study measured 45 mm cw. From an analysis of incidence of ovigerous females at every 1 mm interval among 322 females over a size range of 40 mm -62 mm cw, the size at first maturity at 50% level was determined to be 48.7 mm (Fig. 4). From histological evidence all crabs larger than 47 mm cw examined had spermatophores in the vas deferens.

Breeding:

In female crabs the shape of vulva provides a reliable indication as to whether the animal has mated or not (Haefner, 1977; Melville-Smith, 1987c). During the present study, two types of vulvae could be noticed among subadult and adult crabs. In type 1, the vulva has the form of a closed slit (Plate 13a). The animal with this type of vulva is considered as non-mated or virgins. The ovaries at this stages are transparent and not clearly visible. In tye 2, the vulvae are fully opened holes (Plate 13b). All crabs with this type of vulvae have ovaries in various stages of maturation. The sermatheca of most of such animals are in enlarged condition. It is considered that the second type is the

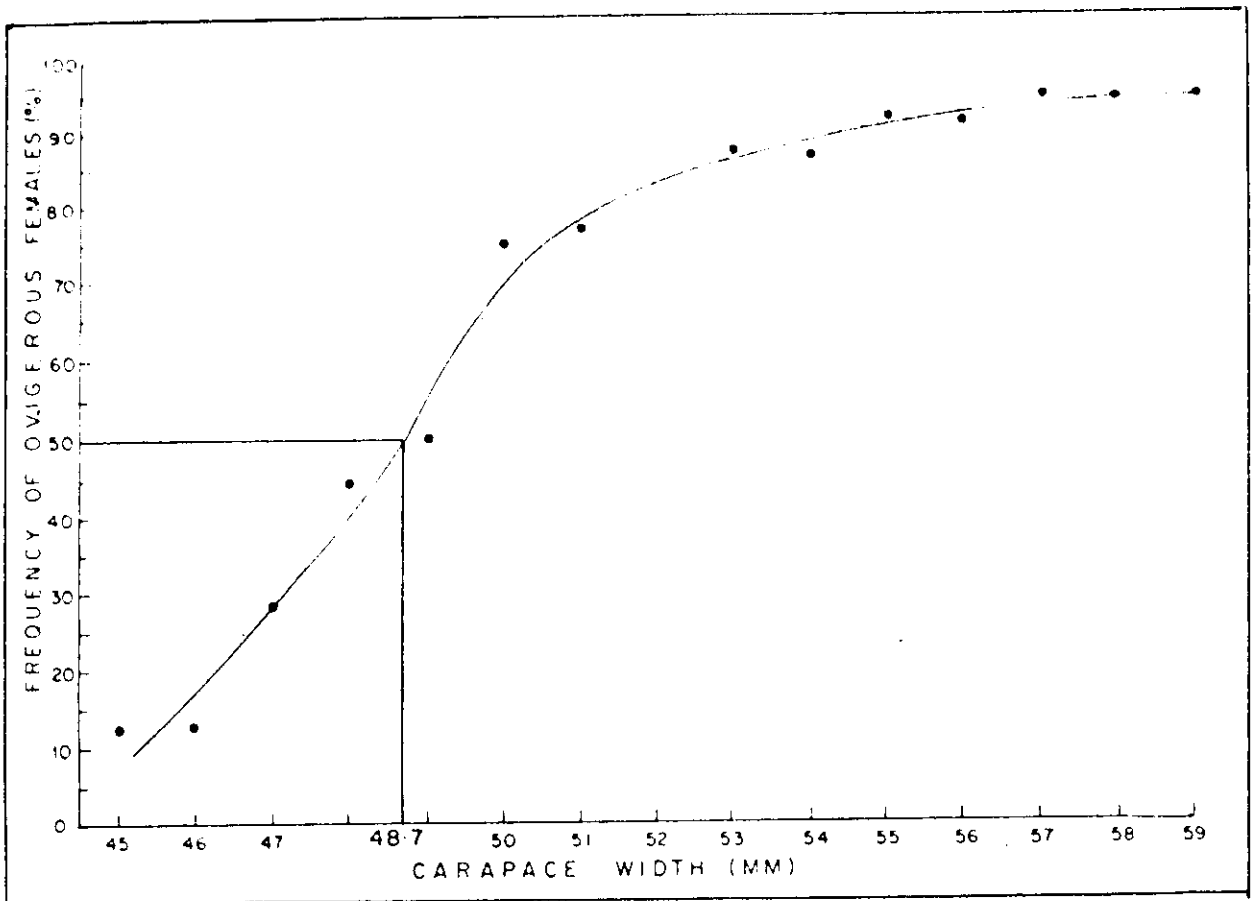
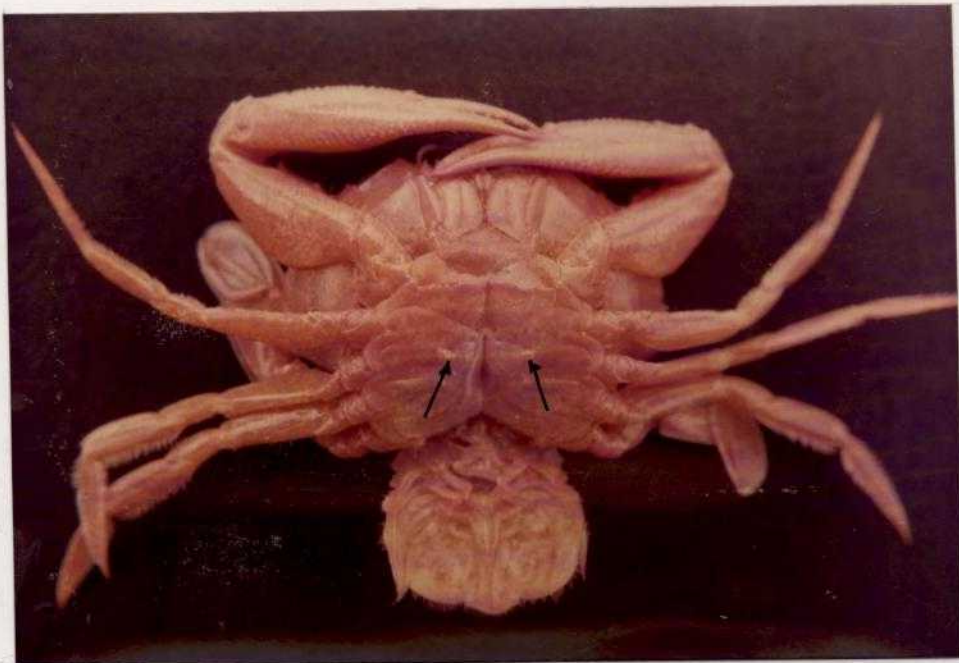


FIGURE 4. Eye fitted graph showing minimum size of oviposition at 50% level in C. (G.) smithii.



a



b

PLATE 13

- a.** Ventral view of thoracic sternite of non mated female crab showing closed vulvae.
- b.** Ventral view of thoracic sternite of mated female crab showing fully opened vulvae.

shape of mated vulvae which is comparable to the stage 3 of Chaceon maritae (Melville-Smith, 1987^c) and type 'f' of C. quinquedens (Haefner, 1977). None of the crabs obtained in the pelagic trawls had the second type of vulvae, thereby indicating that mating does not take place in the pelagic realm. It is also interesting to note that all the specimens examined from the bottom trawl catches had the second type of vulva which would clearly indicate that mating takes place actively at the bottom habitat.

A total of 197 female crabs in the size range 36-67 mm cw obtained from the pelagic trawl and 233 females in the size range 31-62 mm obtained from the bottom trawl catches were examined in detail for the incidence of ovarian changes and ovigerous condition. In the pelagic collections the ovaries of all specimens were found to be in the immature condition. Further, no crabs could be seen in ovigerous stage nor did they reveal any indication of egg carriage. The samples drawn from the bottom trawl operations, on the contrary, showed a high incidence of crabs in breeding condition. About 83% of crabs examined were in ovigerous state and the remaining had the ovaries in different stages of maturation.

The numerical data of ovigerous crabs from the southwest coast of India have been analysed separately for monsoon and nonmonsoon seasons in order to find the possibility of any seasonal variation in breeding activity. The size wise distribution of ovigerous females in relation to that of nonovigerous females for monsoon and nonmonsoon season is depicted in Fig. 5. It is found that during the nonmonsoon season about 78% of crabs were ovigerous and most of the nonovigerous crabs showed ovary in advanced state of development. The maximum frequency of

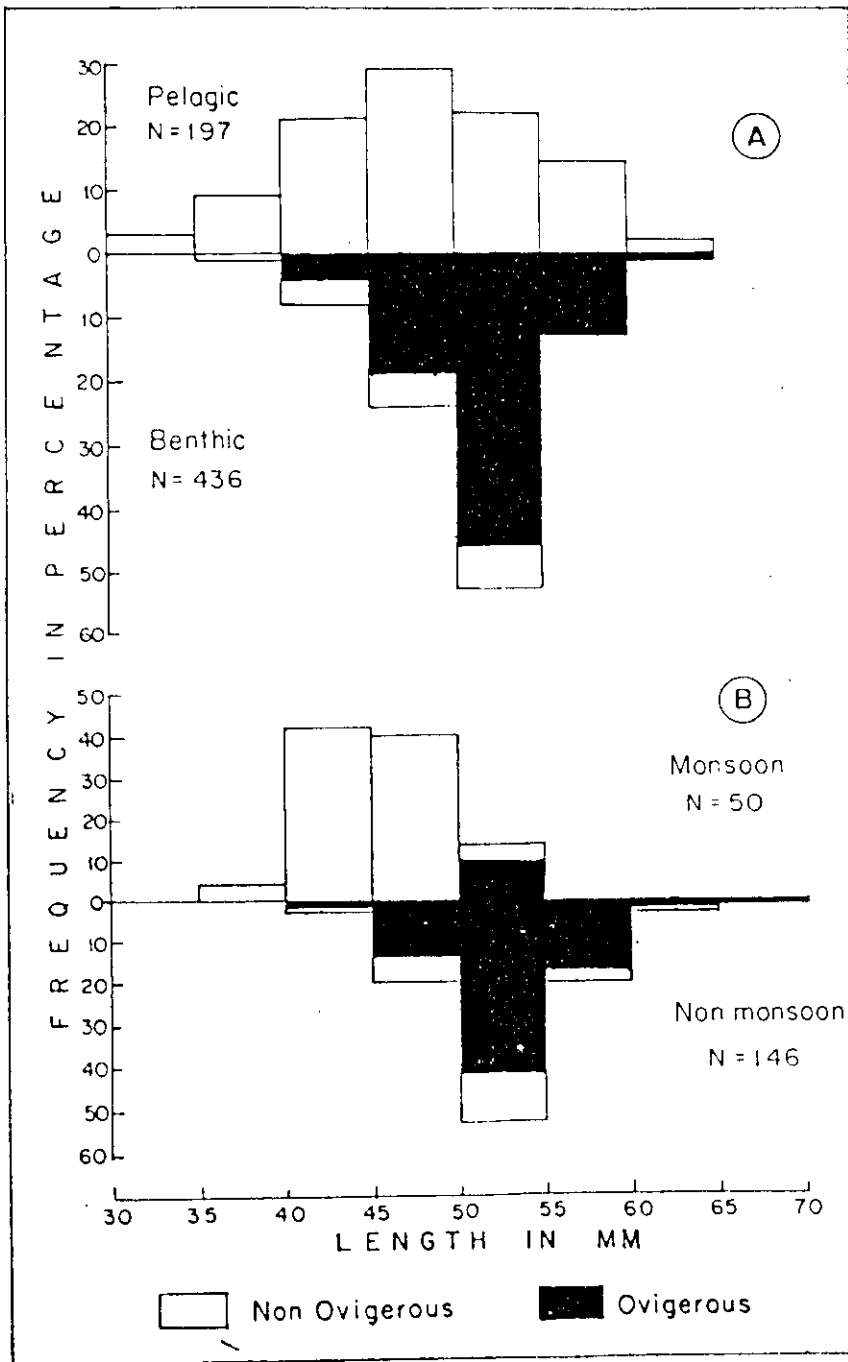


FIGURE 5. Relative abundance of ovigerous and non ovigerous females of *C. (G.) smithii* in the pelagic and benthic habitats (A) by size and seasons (B).

ovigerous crabs was observed during January-February along this coast. During monsoon season, out of 50 crabs examined hardly 15% were in berried condition thereby indicating relatively low breeding activities during this period. In the southeast coast about 90% of crabs collected during March 1988 were berried.

Egg carriage and embryonic development:

After extrusion of eggs during oviposition, the ova get attached to the ovigerous setae present on the endopod of the pleopods in female. The fertilized eggs undergo a series of developmental stages involving colour change, increase in size and change in shape due to embryonic growth. The successive changes taking place in the eggs during the ovigerous period have been studied by microscopic examination of eggs present in the berry of 30 crabs and the summary of observation is given in Table 2. It has been observed that all the eggs in a berry were in the same stage, of development suggesting that there is a synchrony between the developing eggs in the same animal. The following 3 different stages of berry/egg development could be noticed.

Stage 1 (Plate 14a):

This is the freshly acquired berry which is reddish orange in colour. The colour of egg mass resembles that of the ripe ovary ready for spawning. Eggs are spherical with a diameter of 233-340 μm ($X = 300 \mu\text{m}$) and are surrounded by two membranes, an inner and outer membranes. Both these membranes are transparent. The yolk is visible as yellow granules and dividing the surface into large polygonal areas.

TABLE 2. Colour of berry and shape & sizes of eggs in different stages of embryonic development.

Stages of Development	No. of Specimen examined	Colour of berry	Shape of eggs	Size of eggs in μ m	
				Range	Mean
Stage I	15	Reddish orange	Spherical	233-340	300
Stage II	10	Light yellow	Spherical	310-425	340
Stage III	5	Deep brown to Black	Elipitical	415-595	476

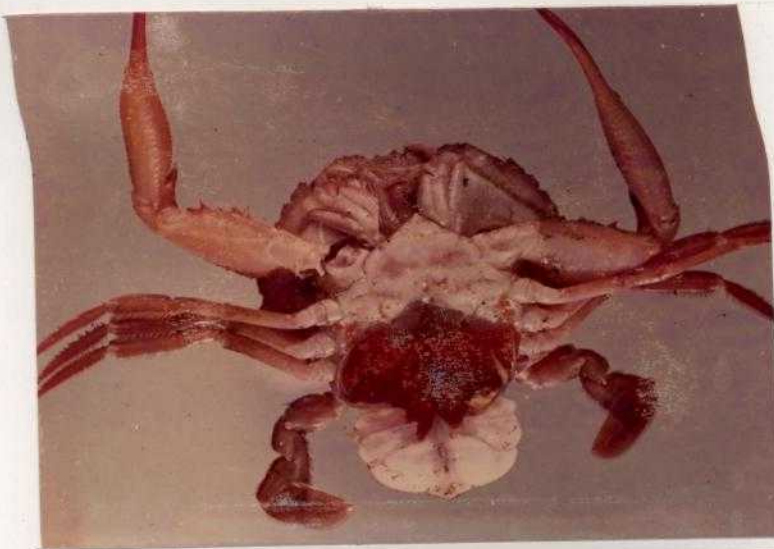
Stage 2 (Plate 14b):

Colour of berry is light yellow. The egg maintains its spherical shape but has grown to a larger size ranging between 30 and 425 μm ($X = 340 \mu\text{m}$). The developing embryo is faintly visible through microscope. Pigmentation of eye is discernible in some cases.

Stage 3 (Plate 14c):

The berry has changed to deep brown to black. Eggs are elliptical in shape with the length varying between 415 and 595 μm ($X = 476 \mu\text{m}$). Eyes of the embryo are clearly visible to naked eye. The embryo occupies most part of the egg capsule with little or no yolk present in it. The abdomen is curved inwards in such a way that the telson covers the rostral end of the head.

The ovaries of egg bearing females on dissection showed various phases of maturation. The development of ovary was found to be almost completed when the berry was in the third stage of embryonic development. This would suggest that ovarian maturation is a continuous process after attainment of maturity. After one batch of incubating eggs are hatched out, the ovary is ready for next spawning. It is also evident from this observation that the breeding of the species taken place more than once in its life time. The available data however do not permit to draw any conclusion as to the total numbers of spawning performed by this species during its life time.



a



b



c

PLATE 14

Egg mass of ovigerous females in different stages of embryonic development.

a. Stage 1.

b. Stage 2.

c. Stage 3.

Fecundity:

The fecundity was examined from 26 specimens measuring 48 mm to 51 mm cw. The number of eggs carried by an ovigerous individual varied from 1343 to 42,209 the average number being 16,168.

FOOD AND FEEDING HABITS

Study of the nutritional requirements and feeding behaviour have great relevance to the understanding of many biological processes. The qualitative and quantitative data of stomach contents provide basic information on food preferences, hunting habit, migratory behaviour and inter-relationships between species or prey-predator relationship. Food is also an important factor influencing abundance, growth and survival of animal in its different habitats. Food and feeding habits of aquatic organisms are normally studied by analysing the stomach contents. Unlike in finfishes where stomach content analysis is relatively easier due to the fact that the ingested food is often available in recognizable form, the stomach contents of crustaceans are rarely found in easily identifiable form due to the action of gastric mill. This difficulty coupled with the fact that the food at the time of capture itself is being crushed and disfigured by the action of chelipeds and the mouthparts could have been a reason for comparatively smaller efforts in the study of food and feeding habits of brachyuran crabs.

Information on the food and feeding habits of crabs from Indian coast is limited to the workers on a few commercial species such as Neptunus

(= Portunus) pelagicus (Chopra, 1939; George and Nayak, 1961; Patel et al., 1979), N. sanguinolentus (Chopra, 1939; George, 1949; Menon, 1952) and Scylla serrata (Joel and Sanjeevaraj, 1986; Prasad et al., 1988). Except for some passing remarks on the food of Charybdis (species not specified) by George and Nayak (1961) from Mangalore coast there is no work on this aspect in any commercially important species of the genus. Available information indicate that brachyuran crabs are mainly carnivores, preying mobile as well as sedentary animals. They are known to feed a wide variety of benthic organisms including bivalve and gastropod molluscs, brachyurans and anomurans, polychaetes, foraminiferans and fishes. Variations in food habit are also noted for the different life stages with instances of selective feeding in certain species. It is also reported that the diets of tropical and subtropical portunid crabs are relatively uniform because of regular availability of prey species while the diets of temperate species change markedly as a result of lower diversity and seasonal changes in the availability of prey species (Choy, 1986).

During the present investigation, the food and feeding habit of the juvenile, subadult and adult stages of C. (G.) smithii has been studied based on stomach content analysis of 283 specimens. Correlation coefficient of 0.90 for juveniles, 0.94 for subadults and 0.93 for adults showed that the percentage frequency of occurrence of each categorized food item was strongly related to the percentage volume of that item in the foregut. Since it was difficult to identify the food item upto species level, each food item was categorized upto the broad taxonomic group. The different types of food remains recognized under each group are given in Table 3.

TABLE 3. Summary of food categories recorded from the gastric mill of C. (G.) smithii.

Food type	Types of fragments found in gastric mill
Foraminifera	entire shell

MOLLUSCA	
gastropods	opercula, radula, rarely entire shell
bivalves	hynge structure, crushed pieces of shell fragments.
cephalopods	cuttle bone

CRUSTACEA	
amphipods	exoskeleton fragments including appendages
euphausiids	parts of body, external gills etc.
crabs/shrimps	fragments of exoskeleton including carapace and leg fragments, gills, eyestalk, gastric mill ossicles, mouth parts including maxillipeds maxillule and mandible.

PISCES	
teleosts	scales, bones, fin rays, lens of eyeball, otoliths etc.

Juveniles:

The stomachs of 108 juvenile crabs in the size range 11-30 mm cw were examined. Of these 98% contained food in varying degrees of fullness. Among those stomachs which contained food, about 80% were full and the rest half full. Shrimp crab and foraminiferans formed the common food item (Fig. 6A). Though foraminifera appeared to be the most frequently occurring prey, decapod crustaceans represented by crabs (C. (G.) smithii) and pelagic shrimps (Sergestes spp.) showed the highest contribution in terms of volume (Fig. 6B). Other items occasionally met with in the stomach included small bivalves, euphausiids, hyperiid amphipods and brachyuran zoea.

Subadults:

Of 79 subadult crab in the size range 30-40 mm cw analysed, 32 contained food thereby showing active feeding of these sizes. In those crabs with food in the stomach as much as 69% had stomach in full condition. Teleost fish and decapod crustaceans, other than shrimps, formed the most important components. Both these items were recorded in 63% of stomach and together constitute about 65% of total volume of the diet (Fig. 7B). Several of the foreguts examined were found to be fully packed with teleost fish remains. The fish items appeared to be those of myctophids which are known to coexist with this crab particularly in the pelagic realm. Shrimp occurred in about 25% of stomachs, but its contribution in terms of volume was rather low (2%) (Fig. 7A, 7B). Euphausiids and Foraminiferans occurred in 19% of stomach examined

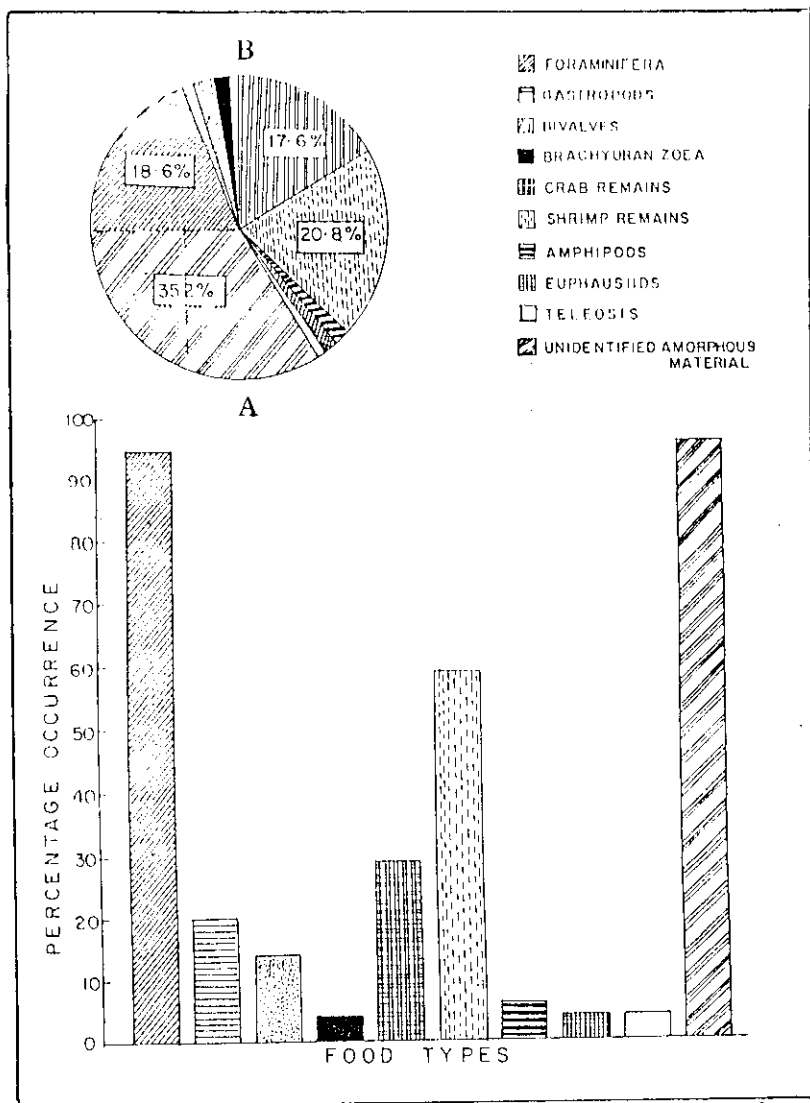


FIGURE 6. A. Percentage frequency of occurrence of dietary composition for juveniles.

B. Estimated percentage contribution of the different types to the total volume of the observed juvenile crab diet.

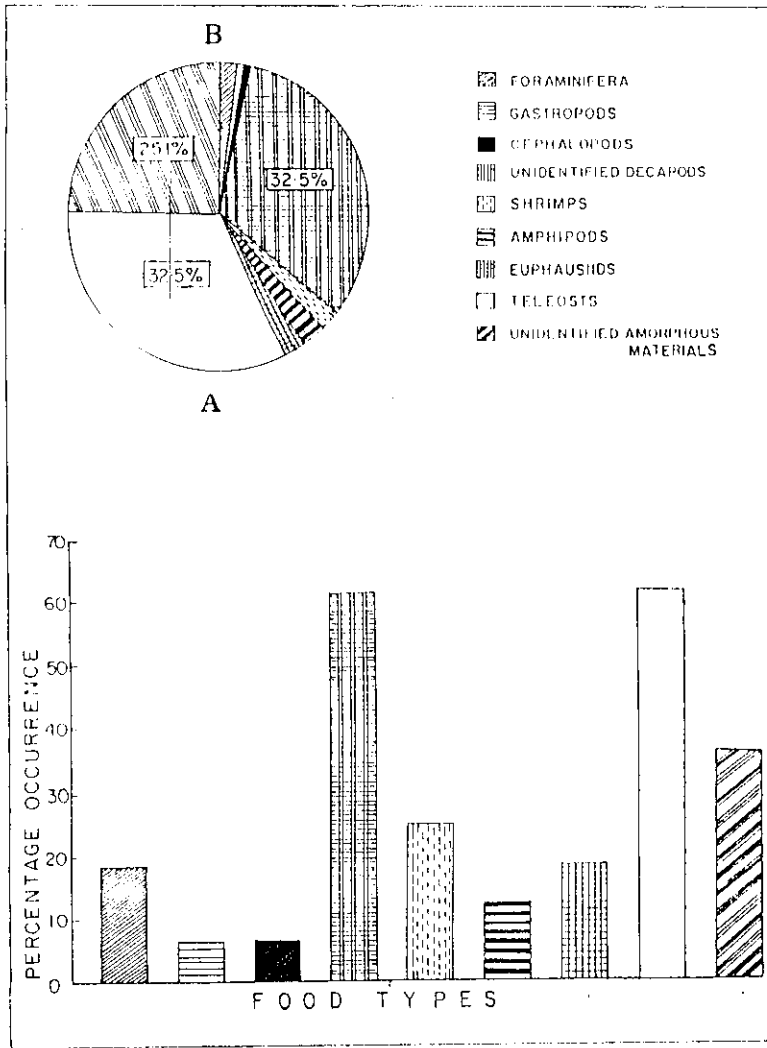


FIGURE 7. A. Percentage frequency of occurrence of dietary composition for subadults..

B. Estimated percentage contribution of the different types to the total volume of the observed subadult crab diet.

contributing 2% and 3% respectively by volume (Fig. 7A, 7B). Among the other minor items recorded, the occasional occurrence of juveniles of the oceanic squid Symplectoteuthis oualaniensis is noteworthy. This squid is reported to be one of the common nektonic items found in the offshore waters of the Indian coast (Nair, et al., 1990).

Adults :

A total of 96 adult crabs taken in the bottom trawl were analysed. Of this 77 were females and the rest males. Among females, 98% were in ovigerous state. Among the total number of crabs examined only 40% showed presence of food in the foregut thereby indicating relatively lesser feeding intensity than in the earlier life stages. Crustaceans, gastropod molluscs and teleost fishes formed the most dominant food items in the order of their importance (Fig. 8B). Among crustaceans, crabs were found to be a regular item and they were met within 78% of the stomach. Contribution of crab by volume was about 42%. In some specimens fragments of the same species could also be distinguished in smaller quantities. Crab was followed by shrimp (pandalids) in importance. They occurred in 39% of stomach and constituted 7% of the total volume of the foregut content. Gastropods (Luritella pteropod and others) occurred in 29% of the stomach forming 7% by volume (Fig. 8A, 8B). Teleost fish occurred less frequently (11%) and formed about 5% by volume. The rhizopods contributed only very insignificantly in the adult crabs against their abundance in the diet of juveniles.

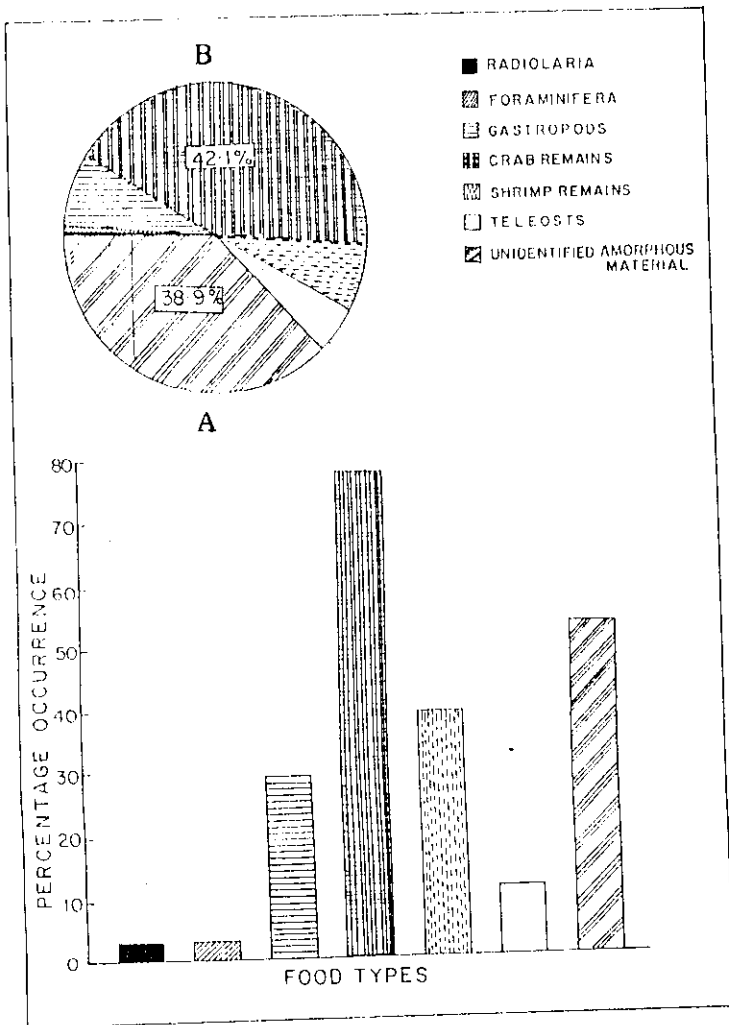


FIGURE 8. A. Percentage frequency of occurrence of dietary composition for adults..

B. Estimated percentage contribution of the different types to the total volume of the observed adult crab diet.

TABLE 4. Relative abundance of food items (% by volume) of juvenile C. (G.) smithii

Food items	Percentage in total food	
	Male	Female
Foraminifera	18.07	19.17
Gastropods	0.90	0.20
Bivalves	2.05	2.45
Brachyuran zoea	1.60	-
Crab remains	18.10	17.10
Shrimp remains	21.3	20.20
Amphipods	1.15	1.25
Euphausiids	1.15	1.25
Teleost	0.4	0.5
Unidentified amorphous material	35.28	34.92

TABLE 5. Relative abundance of food items (% by volume) of subadult C. (G.) smithii

Food item	Percentage in total food	
	Male	Female
Forminifera	1.06	1.92
Gastropods	0.40	0.20
Cephalopods	0.20	0.40
Unidentified decapods	32.80	31.90
Shrimps	01.47	01.95
Amphipods	02.28	03.08
Euphausiids	02.01	02.90
Teleost	32.90	32.10
Unidentified amorphous material	26.88	25.55

TABLE 6. Relative abundance of food items (% by volume) of adult C. (G.) smithii

Food items	Percentage in total food	
	Male	Female
Radiolarians	0.04	0.03
Foraminiferans	0.16	0.12
Gastropods	7.93	7.06
Crab remains	43.06	42.18
Shrimp remains	6.10	7.20
Teleost	5.36	4.16
Unidentified amorphous material	37.35	39.25

Variation in food habits between sexes:

The qualitative and quantitative data of foregut content of crabs were analysed separately for males and females of the different life stages in order to find out if there is any variation in the feeding intensities and the food preferences between the two sexes and the results are summarized in Tables 4, 5 and 6. The analysis indicates no significant variation either in feeding intensities or in the type of food consumed by the different sexes during the different stages of growth.

PROXIMATE COMPOSITION

A knowledge of the proximate composition of any edible organism is an important prerequisite to assess its nutritive value in order to take up commercial utilization of the same. Proximate composition in fresh condition and after processing has been studied in brachyuran crabs such as Carcinus maenas (Health, 1970), Portunus pelagicus (Badawi, 1971; Pillay and Nair, 1973; Radhakrishnan, 1979) Chionoecetes opilio (Addison and Ackman, 1972) Scylla serrata (Chinnamma George, 1973; Radhakrishnan, 1979) Uca annulipes (Pillay and Nair, 1973) P. sanguinolentus (Radhakrishnan, 1979). Podophthalmus vigil (Radhakrishnan and Natarajan, 1979), Thalamita crenata (Mercy Thomas, 1985) and the anomuran crab Paralithodes camtschatica (Seagran, 1958). Information on proximate composition of nonconventional deep-water resources of Indian waters is limited to finfishes (Gopakumar et al., 1983; Imamkhasim et al., 1987; Lekshmi Nair et al., 1988, 1990).

TABLE 7. Protein, carbohydrate, lipid, water and meat contents in different size groups of C. (G.) smithii (Standard deviation of mean is given in parenthesis)

Carapace width (mm)	Meat content (%)	Proximate composition (% of dry wet)			
		Protein	Carbohydrate	Lipid	Water
41-45	12.23 (0.68)	62.12 (1.63)	2.50 (1.09)	6.22 (0.85)	89.60 (3.25)
46-50	16.51 (0.82)	61.98 (0.82)	2.65 (1.01)	6.31 (1.35)	87.41 (1.55)
51-55	14.48 (0.46)	71.10 (2.04)	2.88 (1.55)	7.59 (0.69)	86.05 (1.47)
56-60	18.58 (0.85)	59.81 (2.12)	2.41 (1.25)	6.21 (0.47)	85.60 (1.38)
61-65	14.51 (1.22)	60.19 (1.38)	3.38 (1.38)	8.20 (1.10)	86.40 (0.81)
Mean	15.26 (2.14)	63.04 (4.13)	2.76 (0.35)	6.91 (0.83)	87.02 (1.42)

During the present investigation an attempt has been made to determine the proximate composition of C. (G.) smithii based on study of male crabs of intermoult stages in the size range 40-65 mm cw. Protein, carbohydrate, lipid and water content of the meat in various size groups analysed are summarized in Table 7.

The meat content of the body varied between 12.23 and 18.58% with a mean 15.26% (S.D = 2.14). The maximum meat content was observed in the size group 56-60 mm cw (18.58%) and minimum in the size group 41-45 mm (12.23%). The protein content varied between 59.81 and 71.10% with a mean value of 63.04 (S.D = 4.13). Maximum protein value was recorded in the size group 51-55 mm cw and minimum in 56-60 mm cw. The carbohydrate values varied from 2.41 to 3.38% (Mean = 2.76; S.D. = 0.35). Maximum carbohydrate was observed in 61-65 mm size group and minimum in 56-60 mm size group. The lipid value ranged between 6.21 and 8.20% with a mean of 6.91 (S.D = 0.83). The maximum lipid value was noticed in the largest size group 61-65 mm cw and minimum in 56-60 mm size group. Water content fluctuated between 86.05 and 89.60 (Mean = 87.02; S.D = 1.42).

DISCUSSION

Pelagic phase and swarming behaviour

It is a well established fact that the brachyuran crabs, in general, are bottom dwelling animals in their adulthood as implied by very term the Reptantia ('crawlers') for the group comprising of crabs and lobsters. Pelagic existence in advanced stage of life (juveniles, subadults, adults) is not a common feature in the life history of these animals. Instances of pelagic existence beyond megalopa stage have, however been reported in certain species of grapsid and portunid crab from the different parts of the world. Among coastal crabs pelagic occurrence of adults in large numbers has been reported in Varuna litterata particularly in the vicinities of river mouth and occasionally inside the estuarine environment (Barnard, 1950; Sankarankutty and Rangarajan, 1962; Sakai, 1976; Moto, 1980). During the pelagic phase, the species is found to drift along with floating objects (Sankarankutty and Rangarajan, 1962; Sakai, 1976; Moto, 1980). Kemp (1915) reported the occurrence of swarms of megalopa of the species at regular interval of the mouth of Ganges in the Bay of Bengal. Among portunid crabs pelagic occurrence of adult stages is reported in Polybius henslowi in eastern Atlantic (Clark, 1909; Blass, 1955; Bourdon, 1965; Della Croce, 1961; Allen, 1968) and Portunus affinis and Euphylax dovii in the eastern tropical Pacific (Faxon, 1893; Garth, 1946; Jerde, 1967). In the case of P. henslowi the bottom living specimens were recorded from the shelf waters upto 200 m depth in the eastern Atlantic coast. The species has been frequently observed in large numbers at the surface of the sea at considerable distance from the coast (Clark, 1909; Blass,

1955; Della Croce, 1961; Bourdon, 1965). Allen (1968) reports that in the coast of Spain both males and females of the species occurred in dense concentration in the surface waters of the sea 15 miles offshore where the depth was 1740 m.

Portunus affinis and Euphylax doyii are reported to exhibit large scale swarming in the surface waters as far about 200-400 miles from the shore (Juhl, 1955; Alverson, 1963; Garth and Stephenson, 1966; Jerde, 1967). Faxon (1893) noted that the specimens of P. affinis taken at the surface were small and much darker than those that came up in bottom trawl but they showed no structural differences. Jerde (1967) concluded that the pelagic stock of the species could have developed from larvae that drifted out to sea and subsequently developed into young and adult crabs.

Pelagic existence during the postmetamorphic phase has also been reported among galatheid crabs such as Munida gregaria and Pleuroncodes planipes, the former in the south Atlantic and south Pacific oceans and the latter in the Gulf of California and between Costa Rica and Mexico (Lagerburg, 1906; Matthews, 1932; Rayner, 1935; Longhurst, 1967; Gulland, 1971). Pelagic population of M. gregaria has been observed in large numbers either close to the land, over the continental shelf or over oceanic depths at some hundreds of miles from the land. The pelagic specimens were morphologically distinct from the benthic individuals. The important distinguishing characters being a highly flattened, foliaceous 3rd maxilliped with filtering device. Besides, the exoskeleton of the crab is also found to be lighter and less spinous than the benthic individuals (Matthews,

1932; Rayner, 1935; Williams, 1973, 1980). Animals with benthic characters were considered to be permanent members of the benthos, a typical life style for adult galatheids (Williams, 1980). It is also reported that the pelagic individuals are comparatively smaller in size than benthic crabs. From the laboratory observations on live animals Williams (1980) concluded that morphological characters adapted for pelagic existence gradually changes as the animal grows and takes the form found in benthic individuals as they settle at the bottom. P. planipes is represented by both the benthic and pelagic phase (Longhurst, 1967; Gulland, 1971). According to Boyd (1967) the pelagic and benthic phases are morphologically identical and based on size frequency studies he suggested that there could be an alternation between the two habitats. The author further concluded that the species could be either benthic or pelagic and that there was diurnal exchange between the two habitat.

During the present study it is observed that C. (G.) smithii has a distinct pelagic habitat noticed in all the life stages of the species including juveniles, subadults and adults. These different life stages also exhibit swarming tendencies during their pelagic phases. The absence of specimens of the crab less than 31 mm cw in the bottom collection clearly indicate that the settlement to the bottom takes place at that particular size which is the advanced juvenile stage of the species. Morphological observation of samples taken from the different habitats have not shown any indication of changes either with change in size or change of habitat. In this respect the species agrees with other brachyuran species

like P. affinis in which no morphological changes are reported along with change of habitat from pelagic to benthic or vice versa. Large surface swarms of C. (G.) smithii have also been reported by many workers from different parts of Indian Ocean (Sankarankutty and Rangarajan, 1962; Della Croce and Holthuis, 1965; Silas, 1969; Stephenson, 1972; Daniel and Chakrapani, 1984).

Anatomy of reproductive system

The anatomy of male and female reproductive system of C. (G.) smithii conforms to the general pattern in brachyuran crabs where, both the systems are 'H' shaped (Cronin, 1947; Estampador, 1949; George, 1963; Ryan 1967b, 1967c; Vasisht and Relan, 1971; Haefner, 1977; Joshi and Khanna, 1982; Melville-Smith, 1987; Wenner et al., 1987). In adult male, the internal organ consist of paired testes which are medially inter connected and paired vasa deferentia, which are differentiated into 3 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 vas deferens. The presence of a distinct vas efferens has been observed in certain other portunid crabs as a very small tube which is embedded in the mass of anterior vas deferens which is not macroscopically distinguishable (Cronin, 1947; Nishioka, 1959; George 1963). According to Ryan (1967c) this vas efferens is merely a specialized part of the proximal end of the AVD.

The paired ovaries are elongated, medially inter connected and lobulated in mature condition and occupy almost the same position as the testes in males. At the mid-lateral border each ovary is connected with the spermatheca which in turn communicate with the exterior by vagina, thus in general closely agreeing with the structure observed by Pearson (1909) in Cancer pagurus, Cronin (1942) and Johnson (1980) in Callinectes sapidus, Estampador (1949) in Scylla serrata George (1963) and Ryan (1967b) in Portunus sanguinolentus, Haefner (1977) in Chaceon (= Geryon) quinquedens Melville-Smith (1987^c) in C. maritae and Hirsch (1988^a) in C. fenneri. In variation from other species a recognizable oviduct has not been observed in this species between ovary and spermatheca. The presence of a short oviduct has however been reported in P. sanguinolentus (George, 1963; Ryan, 1967b). George (1963) reports that the oviduct, covered by gonadial tissue, runs for a short distance along the anterior innerside of the spermatheca and opens into it at about the middle portion. Pearson (1909) observed in Cancer pagurus that the two posterior prolongations of the ovary are connected together at the posterior end. A similar condition has also been reported by Estampador (1949) in species of genus Scylla in mature condition. In the present species, however, the posterior extremities of the ovaries remain separate permanently. 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 C. (G.) smithii, 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 prolongation on one side remained to be either shorter or longer than on the other side.

The histological structure of male and female reproductive organs conforms to the general pattern observed in brachyuran crabs by earlier workers (Cronin, 1942, 1947; Estampador, 1949; George, 1963; Ryan, 1967b, 1967c; Haefner, 1977; Joshi and Khanna, 1982; Melville-Smith, 1987c; Wenner, 1987). In the case of male P. sanguinolentus, Ryan (1967c) observed that subdivision of testicular lobe was only an occasional feature, and whenever noticed, it was only incomplete. Joshi and Khanna (1982) could not find any lobation in the testes of the freshwater crab Potamon koolooense. The present species showed incomplete lobation and each of the incomplete lobes is divided into many seminiferous lobules or tubules. There is a distinct seminiferous duct and all the seminiferous lobules have access to the same either directly or through other lobules. In P. koolooense Joshi and Khanna (1982) could not come across any distinct seminiferous duct, the seminiferous tubules directly opening into the vas deferens. The seminiferous duct in some cases has been reported to be branched as noticed by Cronin (1947) and Nishioka (1959) in C. sapidus. In the present species, no indication of branching of seminiferous duct was observed as in the case of P. sanguinolentus (Ryan, 1967c). Though many portions of seminiferous duct could be seen in a section, it could be due to the looping of whole testis as suggested by Ryan (1967c).

In the marine shrimp, Penaeus setiferus, King (1948) described three layers in the wall of the ovary, a thin layer of pavement epithelium, an inner layer of germinal epithelium and a relatively thick layer of connective tissue in between. In P. sanguinolentus, Ryan (1967b) described two layers of connective tissue for the thin wall of the ovary. Johnson (1980) observed a thin capsule of fibrous connective tissue on the wall

of the ovary of C. *sapidus*. The present study also indicates the presence of a thin capsule of fibrous connective tissue on the ovarian wall of C. (G.) *smithii*. Though the crustacean ovary does not possess any strictly compartmentalized germarium and vitellarium as in insects, a germinal zone on germinal epithelium is distinguished during ovarian development (Adiyodi and Subramoniam, 1983). Wide variations are also noticed in the placement of the germinal zone. The germinal zone may be either peripheral, as in P. *setiferus* (King, 1948) or central as in Carcinus *maenas* (Laulier and Demeusy, 1974). In P. *pelagicus*, the germinal zone is in the form of central shaft of germinal tissue (Dhas et al., 1980). Ryan (1967b) observed a central lumen bordering with germinal epithelium in the ovary of P. *sanguinolentus*. During the present study the germinal zone is found to be in the centre of the ovary. According to Adiyodi and Subramoniam (1983), aggregation of primordial cells in the centre of ovary may be advantageous for the easy displacement of primary oocytes to the growth zone in later stages.

In many species of brachyurans, fresh mating of female crabs is indicated externally by the presence of a hardened mass of spermatozoa together with associated secretions protruding from the vulvae, which is termed as the sperm plug (Hartnoll, 1969). No such 'sperm plug' was encountered during the present investigation as also reported in the deep-sea red crab C. *quinquedens* by Haefner (1977) and Elner et al. (1987).

Gametogenesis

Structural and ultrastructural studies of spermatogenesis on crustacean species of different taxonomic groups (King, 1948; Genthe, 1969; Malek and Bawab, 1974a, 1974b; Aiken and Waddy, 1980; Johnson, 1980; Durfort et al., 1985; Garcia Valero, 1988) have led to the finding that the process is basically similar in all 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 occur at the same stage of differentiation. According to Johnson (1980), mitosis of primary spermatocytes and meiosis of secondary spermatocytes are roughly synchronized so that almost all germ cells in a tubule are in the same stage of development, in agreement with the present results.

As in other crustaceans, the process of oogenesis in C. (G.) smithii too was completed after passing through two major developmental phases. The first was proliferative phase in which primary oogonial cells multiplied to form secondary oogonial cells and this in turn transformed into primary oocytes. The second was the vegetative phase, the first part of which (previtellogenic) involved accumulation of large amount of ooplasm in which yolk formation has not started; and the later part (vitellogenic) involved successive growth of the oocyte with repeated accumulation of yolk material in the cytoplasm. Similar observations have been made by Cronin (1942), Ryan (1967b) and Johnson (1980) in shallow water crabs.

Spermatophore

Following spermiogenesis, the spermatophores move down into the vas deferens in crustaceans (Hinsch, 1988a). The vas deferens functions as a site of sperm maturation, encapsulation of sperm into spermatophores, production of seminal fluids and storage (Langreth, 1969, Hinsch and McKnight, 1988). Though the process of spermatogenesis is basically similar in all decapod crustaceans (King, 1948; Genthe, 1969; Malek and Bawab, 1974a, 1974b; Alken and 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 and Subramoniam, 1984). Decapod crustaceans, which carry out external mating and fertilization phenomenon, develop greater complexity in the formation of spermatophores to protect the sperm mass as effectively as possible (Demestre and Fortuno, 1992). In brachyuran crabs with 'internal fertilization' the simplest type of spermatophore is found (Subramoniam, 1991). Uma and Subramoniam (1984) report a non-pedunculate vesicular spermatophore for brachyuran crabs. In the Hawaiian red crab Ranina ranina, spermatophores are lacking and hence spermatozoa are transported in the seminal plasma (Ryan, 1984). In C. (G.) smithii a non-pedunculate vesicular spermatophore was observed as also reported in Scylla serrata by Uma and Subramoniam (1984). It is also noteworthy that the proximal part of AVD is made up of cuboidal epithelial cells and the distal part made up of columnar epithelial cells. Finding similar pattern in S. serrata Uma and Subramoniam

(1984) suggested that histological variations between the two regions of AVD are associated with the production of different secretory substances for the formation of spermatophore.

Maturity stages

There is little consistency among different workers who have studied the maturation of ovaries in brachyuran crabs as to the number of maturity stages recognized. Haefner (1976, 1977) recorded 6 stages in the rock crab Cancer irroratus and 5 stages in C. quinquegens. 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. Erdman and Blake (1988a) classified the developmental stages as six in the golden crab, C. fenneri. In the present species 5 maturity stages are recognized including spent stage.

Only very few workers have described any well defined maturity stages in male crabs. Haefner (1976), using the small variations in opacity and size of testes, has described 6 maturity stages for males of C. irroratus. In the present species, however, no distinct developmental stages were discernible for the testes externally.

Breeding:

Although adult crabs of C. (G). Smithii are represented in large quantities in the pelagic as well as bottom habitat none of them showed

any indication of breeding in the former habitat. Examination of the reproductive organs of animals above the estimated minimum size of maturity showed that absolutely no maturation process is taking place in those animals during the pelagic phase. Similarly the condition of vulvae of females during this phase of life have not thrown any proof of mating taking place during the period of pelagic life. All these suggest that there is little possibility of any breeding activity for the species during the period of its pelagic existence.

The gonadal maturation, mating and other aspects of breeding were observed only among crabs obtained in the bottom trawl collections. It is seen that among the samples examined from bottom trawl catches, vast majority were in advanced stages of maturation and 53 to 98% of female crabs were in ovigerous condition. Among ovigerous females, almost all showed ovaries in different stages of maturation and this has been noticed in all the size ranges beyond the minimum size of maturity. From this it would appear that the crab breeds actively at the bottom and each animal is likely to breed many times in its life time.

Della Croce and Holthuis (1965) noticed the absence of ovigerous crabs of C. (G). smithii in their dip net collection from the surface waters of Indian ocean. Silas (1969) came across berried females with carapace width ranging 46 to 52 mm in the bottom trawl collections. Studying the distribution of the offshore crab P. affinis, Jerde (1967) noted the absence of ovigerous crabs in the pelagic habitat. Ovigerous females of the species, according to this author, occurred only at the bottom

in the coastal waters. From a detailed study of the distribution of spawning population of P. affinis in the Pacific ocean, Jerde (1967) concluded that the pelagic stock of the species found in the oceanic waters were not part of reproductive population and that they might have developed from the larvae that drifted out to sea and subsequently develop into young crabs. In another deep-sea crab, P. henslow, Allen (1968) opined that surface aggregation of the species could be related to mating behaviour. Although he could not find any ovigerous crabs during the pelagic phase, all the crabs analysed by him were in advanced stage of maturation. Among the galatheid crabs M. gregaria and P. planipes Young (1925), Boyd (1967) and Williams (1980) have encountered ovigerous females in the pelagic samples. Williams (1980), however, is of the view that the occurrence of berried M. gregaria in the pelagic realm is a rare phenomenon.

It has been demonstrated by Stephenson (1934) that the species occurring in the tropical waters may exhibit several types of breeding cycle i.e. continuous breeding around the year, discontinuous breeding in relation to lunar phases during greater or shorter period in an year, two spawning periods and lastly one single breeding season. A number of littoral and sublittoral crabs of the south west coast of India are reported to breed for an extended period or throughout the year. P. pelagicus breed for about 9 months from August to April, with maximum breeding activity between December and January (Pillay and Nair, 1968). On the east coast of India this species is reported to breed continuously throughout the year (Rahman, 1967). Chandran (1968) reports a biannual breeding for C. variegata on the same coast. According to Sastri (1975) and Melville-Smith (1987c) seasonal reproductive cycles are usually triggered by environ-

mental changes such as day length and temperature. The deep-sea by virtue of its unchanging environmental conditions, could be regarded as season less (Brunn, 1957, Menzies, 1965; Menzies et al., 1973) and consequently none of the environmental stimuli might operate to cause seasonal changes in breeding. Rokop (1974, 1977) has examined the reproductive patterns of a variety of deep-sea benthic invertebrates and has concluded that most of the time reproduction in this environment is year round. Melville-Smith (1987c) reports a continuous reproductive pattern for the deep-sea crab C. maritae on the southwest African coast. In the eastern coast of Mexico Hinsch (1988b), however, observed a seasonal reproductive pattern for the related deep-sea crab C. fenneri. During the present study, ovigerous crabs could be recorded in most of the months from the south west coast of India. The data anyhow also indicate a peak breeding activity during the non-monsoon period. Studying the breeding pattern of the deep-sea pandalids which coexist with C. (G.) smithii in Indian waters, Suseelan (1984) reports a peak breeding activity during winter season when there is a slight increase in water temperature at the bottom.

The fecundity estimated for this crab by Silas (1969) varied between 11,363 and 29154 with a mean value of 21,956. However, the present results indicate a wide variation in fecundity which ranged from 1343 to 42,209 with a mean value of 16,165. The size of eggs found in the berry was found to be comparatively larger in this species, the maximum diameter recorded being 595 μ m as compared to the size reported for related species occurring in the coastal waters of India (George, 1949; Prasad and Tampi, 1953; Naidu, 1955). In the case of C. (G.) feriatus

Padayatti (1990) recorded the maximum size of a 0.43 mm diameter. Several authors have also reported larger yolky eggs for the deep-sea brachyuran crabs (Haefner, 1978; Hines 1982, 1988; Hinsch, 1988). According to Hines (1988b) the larger egg size for the deep-sea brachyurans is to provide nutritional flexibility to their larvae when compared to the smaller eggs of species inhabiting the neritic regions of the sea where these larvae get a more predictable source of food than in the deep-oceanic region.

During the development of brachyuran eggs, marked changes in the colour of berry have been reported by many authors, Prasad and Tampi 1953; Haefner, 1978; Erdman and Blake, 1988^a. According to Dupprez and McLachlan (1984) the colour variations are due to biochemical changes and embryological development. Variations in the colour of egg mass have also been noticed between species (Haefner, 1978; Erdman and Blake, 1988^a). In the deep-sea crab C. fenneri the colour of berry immediately after oviposition has been reported to be light purple or burgundy which gradually turns dark purple and then purple brown prior to hatching of the eggs (Erdman and Blake, 1988^a). The eggs of C. quinquedens are normally red orange which change to brown purple and then black as development advances (Haefner, 1978). Among coastal crabs of south east coast of India, Prasad and Tampi (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. More recently Padayatti (1990) reported the colour of egg mass of ovigerous C. (C.) feriatius to be orange red in colour in the initial stage, which gradually turns to yellowish brown, brown and then to black at the time

of hatching. In the present species also the egg mass is found to be more or less in same colour as in C. (C.) feriatus at all stages of embryonic development.

Food and Feeding

During the pelagic existence, as revealed from the data of juvenile and subadult crabs, C. (G.) smithii feeds more actively than during its benthic existence. It is interesting to note that among the juvenile crabs whose stomachs were examined as many as 98% contained food and many of them were in gorged condition. Among the subadult crabs which also occurred in the pelagic habitat nearly 70% of stomachs examined were with food, whereas the percentage of crabs with food in the stomach was considerably low (40%) in the case of adults obtained from the bottom. It would thus appear that the feeding intensity is comparatively low among the adult crabs found at the bottom.

In the case of tanner crab, Chionoecetes bairdi juveniles fed more intensively than adult crabs (Jewett and Feder, 1983). Among King crab Paralithodes camatschatica similar observations have been made by several authors (Logvinovich, 1945; Cunningham 1969; Jewett and Feder, 1982). Studying the food and feeding activity of C. bairdi Jewett and Feder (1983) concluded that "small crabs might be expected to feed more intensively than larger crabs, since molting frequency among smaller crabs is greater requiring a greater energy demand".

The food preference of C. (G.) smithii conforms to the general pattern of food habits observed in brachyuran crabs. In general, the

species is a carnivore feeding on a wide variety of food items that are encountered in its natural surroundings occupied at different phases of life. The most common food items consumed include decapod crustaceans and fishes as in the case of most other portunid crabs (Ropes, 1968; Caine, 1974; Warner, 1977; Elner, 1981; Haefner, 1985b; Joel and Sanjeevaraj, 1986). Qualitative study of food of the different life stages however reveals notable variations in the types of food predominantly eaten by the crab at different stages of growth. For instance, it is seen that the most preferred food item in the juvenile stage are pelagic shrimps, crabs and pelagic foraminiferans whereas in the subadults and adult crab the same are teleost fishes (myctophids) and brachyuran crabs respectively. The high percentage of pelagic shrimps and myctophids in the dietary of the juvenile and subadult crabs found in the pelagic environment may be due to the abundance of such organisms in that habitat. The existence of dense concentration of pelagic shrimps and myctophids in the Deep Scattering Layers of the southwest coast of India has been pointed out by some authors (Suseelan and Nair, 1990; Mini Raman and James, 1990). Studying the food and feeding habit of the lobster Homarus americanus, Ennis (1973) also arrived at the same conclusion that the preponderance of prey species in the stomach reflects the relative abundance of the same in the habitat. The ability of younger stages to prey upon relatively fast moving planktonic organisms like pelagic shrimps and myctophids is noteworthy. According to Joel and Sanjeevaraj (1986) the better efficiency of juvenile crabs to capture more active preys could be due to the slim and sharp toothed chela with relatively high proportion of fast contractile muscles. Warner (1977) is also of view that the preying ability is relatively more among juvenile crabs than the adults.

A strong cannibalistic tendency of C. (G.) smithii is clearly evident from the incidence of occurrence of the same species in the stomach of juveniles as well as adult stages. In the stomach of some of the juvenile crabs obtained in the IKMT samples, fragments of this species accounted for a major portion of the food eaten. In the case of adult crabs however, this species in the stomach was relatively less although brachyuran remains formed one of the major items of food consumed at the bottom. From this, it may be inferred that cannibalistic tendency of C. (G.) smithii is relatively more pronounced in the juvenile stages which is exclusively spend in pelagic realm than in adult crabs. Cannibalism is reported to be very common feature among brachyuran crabs both in mature and laboratory conditions (Benedict, 1940; Cargo and Cronin, 1951; Darnell, 1958; Yasuda, 1967; Powels, 1968; Feder and Jewett, 1977; Paul et al. 1979; Elner, 1981; Paul, 1981; Jewett and Feder, 1983; Wear and Haddon, 1987; Joel and Sanjeevaraj, 1986). Jewett and Feder (1983) reports a predominance of juveniles of the same species among the crustacean food of the tanner crab C. bairdi. According to Paul (1981) cannibalistic behaviour in Callinectes arcuatus is more pronounced in areas where crab density is maximum. In Indian waters, cannibalism is more common in the mud crab, S. serrata and S. tranquebarica (Joel and Sanjeevaraj, 1986).

Proximate composition

Brown (1986) described the meat recovery rate of commercial portunids and found that the average recovery rates in P. pelagicus and S. serrata were 39% and 29% respectively. Sumpton (1990) reported a

meat recovery rate of 35% for C. natator. The percentage of meat content of T. crenata, a portunid species found along the southeast coast of India, varied between 16.4% and 26.3% (Mercy Thomas, 1985). In the present species the percentage of meat ranged between 12.23% and 18.5%. The comparatively smaller size of the species could be attributed to the low meat content. Chinnamma George and James (1971) observed a linear relationship between meat weight and body length in S. serrata.

Percentage of protein in the meat of T. crenata ranged between 64.9 and 75.2 (Mercy Thomas, 1985). Badawi (1971) reported an average protein value of 73.5% in dryweight for P. pelagicus. Studying the nutritive value of P. vigil Radhakrishnan (1979) reported a variation of protein content between 57.7% and 76.6%. During the present study protein content of meat has been found to vary between 59.81% and 71.10% and dry weight. The carbohydrate content of the meat in C. (G.) smithii (2.41-3.38) is within the range (1.4-9.8%) reported for the allied species T. crenata (Mercy Thomas, 1985). In P. vigil, however, Radhakrishnan (1979) recorded a lower percentage of 1.2-2.1. The lipid content in the present species is comparatively low, the value ranging between 6-8% as against higher values reported in T. crenata (5.4-15.6%) by Mercy Thomas (1985) and in P. vigil (16.8-31.9%) by Radhakrishnan (1979). In P. pelagicus however Badawi (1971) recorded a much lower value of 4.78% from Egyptian waters.

SECTION 3

DISTRIBUTION, ABUNDANCE AND POPULATION CHARACTERISTICS

It has been established in the previous chapter that the species occupies two habitats - the benthic and pelagic habitats - in its life history. In order to understand the pattern of distribution and population characteristics of the species in these two ecological regimes, the collections taken by the Isaacs-Kidd Midwater Trawl (IKMT), pelagic trawl and bottom trawls during the cruises of FORV Sagar Sampada have been studied separately and the results are discussed in this chapter. The IKMT used during the cruises had 2.5 m length and 4 m vertical opening with a mesh size of 1.5 mm (stretched) at the cod-end. The net sampled the planktonic organisms of the Deep Scattering Layers (DSL) which occupied the upper strata of ocean upto a maximum depth of 600 m from the surface (Suseelan and Nair, 1990). The DSL was single layered or multi layered with varying intensities and characteristic pattern (Mathew and Natarajan, 1990; Menon and Prabhadevi, 1990). The principal layers are found generally in the depth range 200-600 m especially during day time. The net was operated at the appropriate depth of DSL recorded by echosounders at a frequency of 38 khz and 120 khz. Usually the samples were collected from the principal layer of each station and the net was operated for 30 minutes during each haul horizontally along the DSL at a towing speed of 3 knots/hour. Of the total number of 433 IKMT operations, 261 were taken on the west coast, 128 on the east coast and 44 around Andaman-Nicobar Islands. The distribution of hauls taken by this gear in each of the half degree square is shown in Fig. 9.

The pelagic trawl used by FORV Sagar Sampada had a maximum total length of 100 m, head rope length of 46.4 m and foot rope length of 26 m with a uniform mesh size of 40 mm (stretched) at cod-end. The net operated upto a maximum depth of 400 m from the surface and during each operation it was trawled for 30-45 minutes at a towing speed of 3.5-4.5 knots. Of the total No. of 334 pelagic trawling operations, 165 were taken on the west coast, 85 on the east coast and 84 around the Andaman-Nicobar islands. The trawling was conducted between latitudes 05°00' and 22°00'N in the Arabian Sea and latitudes 05°00' to 21°00'N in the Bay of Bengal. The distribution of hauls taken by this gear in each of the half degree square is shown in Fig. 11.

The bottom trawling operations were undertaken using mainly the High Speed Demersal trawls (HSDT 1, 2 & 3) developed by the Central Institute of Fisheries Technology, Cochin (Panicker, 1990). These nets are basically two seam or four seam type of demersal trawl of 44.5-46.5 m total length, 23.2-28.0 m head rope length and 26 m foot rope length. The mesh size at cod-end was uniformly 40 mm (stretched) and the net was operated at a trawling speed ranging 3.5-4.5 knots. The duration of bottom trawling varied between 30 minutes and 1 hour. The bottom trawling was conducted between 30 and 777 m depth on the continental shelf and upper continental slope. Most of the trawling operations however, were carried out between 50 and 450 m depth. Out of 445 hauls examined during the present study, 243 hauls were taken on the west coast, 178 on the east coast and 254 in Andaman-Nicobar Islands. Fig.13 shows the distribution of bottom trawling operations.

SPATIAL DISTRIBUTION AND ABUNDANCE

Pelagic realm

The distribution of C. (G) smithii in the pelagic realm was studied based on its occurrence and numerical abundance in the IKMT collection as well as the pelagic trawl collections. Out of the 433 samples of IKMT examined from different regions of Indian coast, the crab was represented in 108 samples in highly varying numbers ranging between 1-862 per haul (Fig. 10). The crabs formed approximately 0.3% in the total DSL population in terms of number, the maximum percentage being 81.3 recorded off Colachel, (near Cape Comorin)(Fig. 10).

In the Eastern Arabian Sea, where 88 hauls proved to be positive in terms of presence of these crabs out of 261 hauls taken, the species has been recorded through out the west coast of India between Cape Comorin in the south and Dwaraka in the north (08°15'N 21°30'N). A few hauls north of Dwaraka did not yield any specimen of the species. In general, the crab was sparsely distributed in the oceanic waters except for a few large collections taken near the Lakshadweep (Fig.10), where its number per haul recorded was less than 10 in most of the positive hauls. Dense concentration was recorded mostly in the neritic and contiguous waters (Fig. 10). The minimum depth of the station from where the species has been encountered was 48 m at Lat. 14°00'N and 74°10'E. Table 8 gives details of the samples containing more than 10 crab/haul. In the North West coast, the area between Marma Goa and Bombay recorded maximum catches and so also off Veraval. The maximum catch/haul

DISTRIBUTION OF MIDWATER TRAWL OPERATIONS

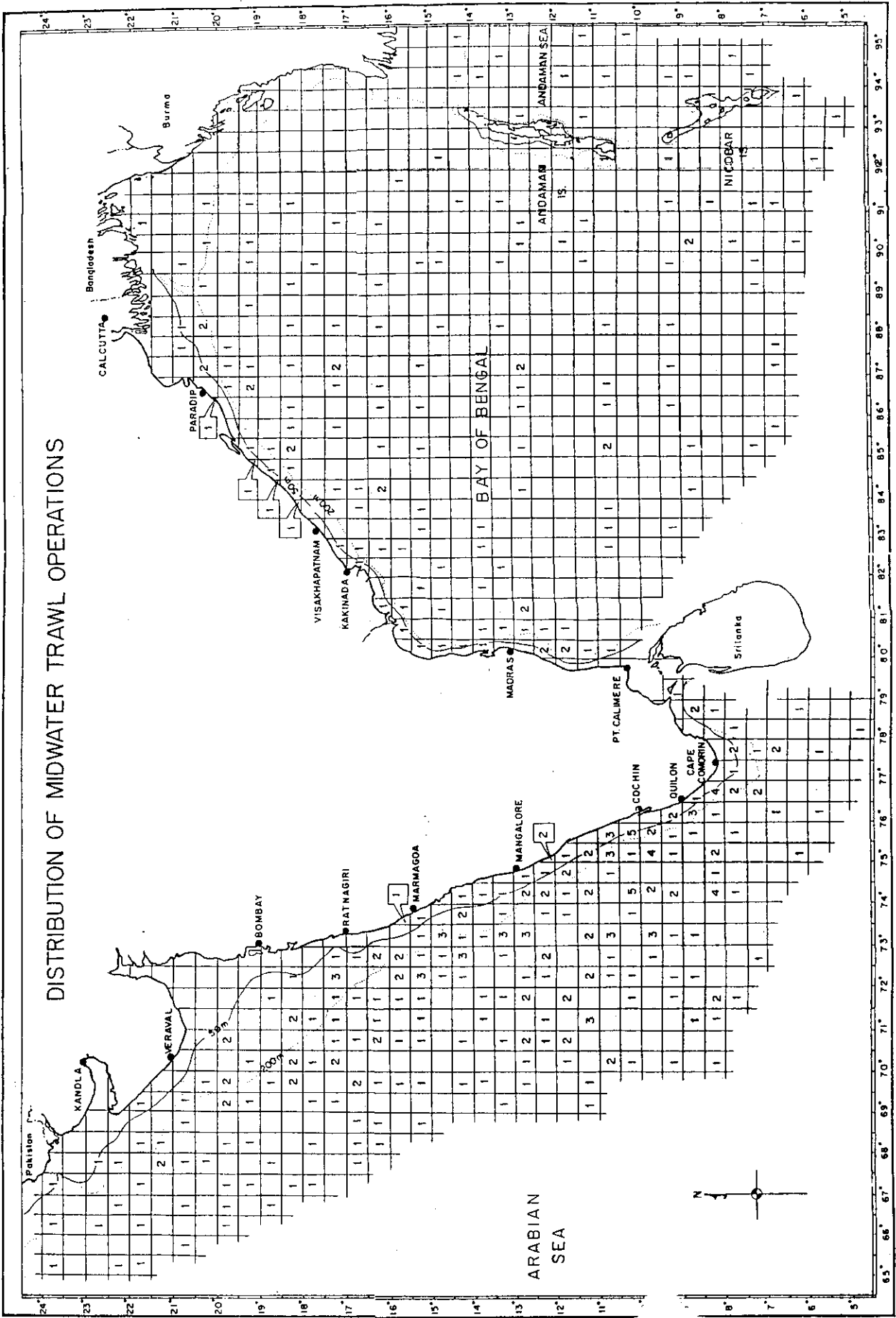


FIGURE 9

DISTRIBUTION AND ABUNDANCE OF
CHARYBDIS (GONIOHELLENUS) SMITHII
 BASED ON MIDWATER TRAWL COLLECTIONS

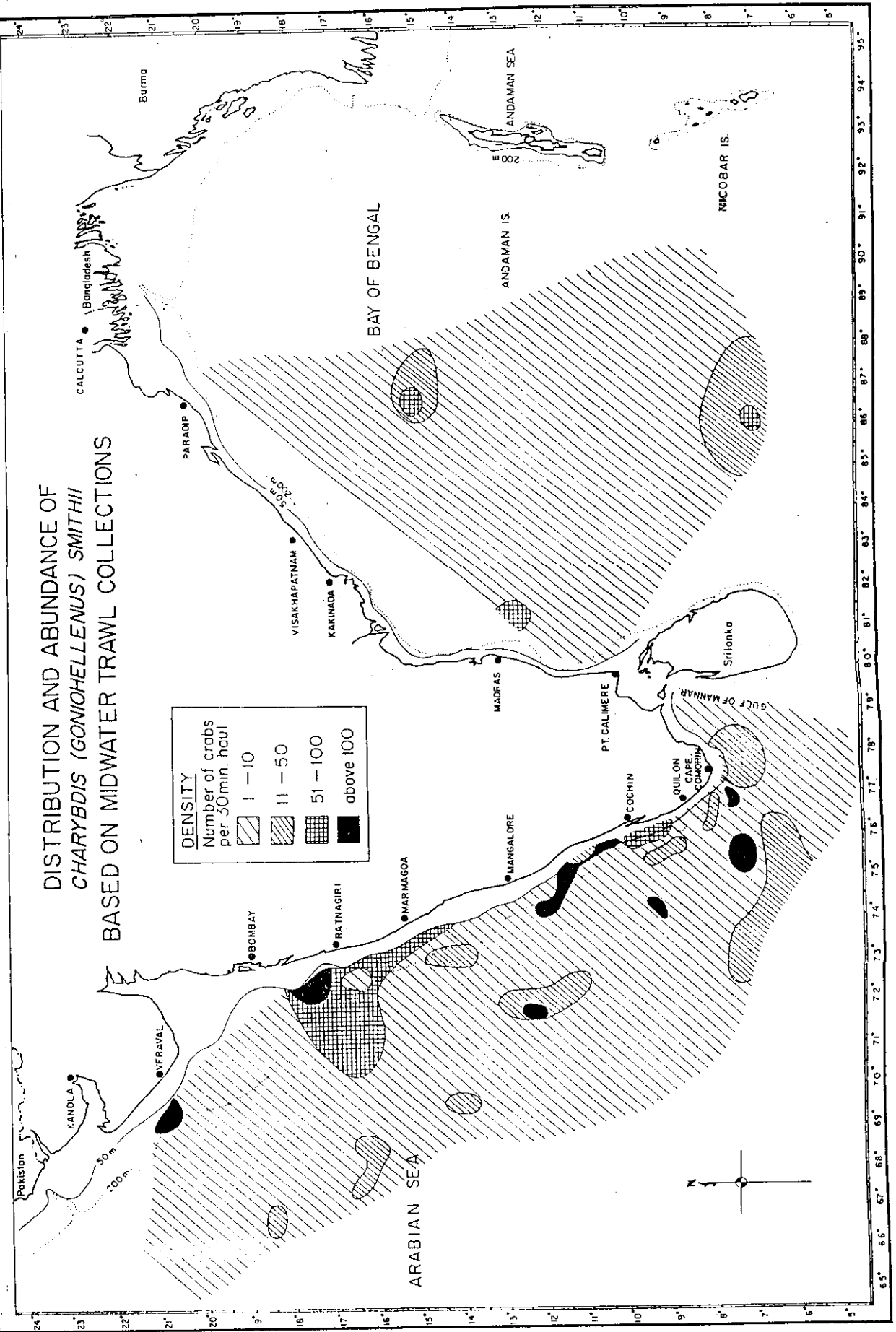


FIGURE 10.

of 116 and 217 numbers were recorded off Ratnagiri and Veraval respectively. In the southwest region catches above 100 numbers/haul were recorded in relatively more number of stations, majority of the rich collections having been recorded off the Kerala Coast. The maximum number/haul amounted to 862 which was recorded southwest off Quilon (Fig. 10).

On the east coast, out of the 128 hauls taken, 20 hauls were positive with crabs numbering 1-60 per haul. It was found to be distributed almost throughout the area surveyed including the waters off Cape Comorin, Gulf of Mannar and the Central and Western region of the Bay of Bengal. The crabs were recorded generally from the oceanic waters of this coast (Fig. 10). On few occasions, however the species was taken in the coastal waters also upto a minimum depth of 42 m especially off Cape Comorin. Table 9 gives details of the samples containing more than 10 crabs per haul. It may be seen from the table that density of crab population sampled by IKMT was poor in the east coast when compared with collections recorded on the west coast. The maximum number of crabs recorded per haul amounted to only 60, which was taken off Madras. Area of fair abundance of crabs were extremely patchy and the same were recorded in the central and southern region of Bay of Bengal and off Madras where depth of station ranged about 3400-3800 m. On the middle and upper east coast, though a number of IKMT operations were carried out the crabs were taken from the neritic and nearby oceanic waters.

The IKMT(44) sampling carried out in the Andaman Nicobar regions did not yield any positive hauls for this crab.

TABLE 8. Catch details of C. (G.) smithii in the IKMT collections yielding more than 10 crabs/haul on the west coast.

Sl. No.	Date of Operation	Position		Depth of Station (m)	No. of crabs
		Latitude (N)	Longitude (E)		
1	03.08.1985	06°46'	75°58'	1875	11
2	15.04.1985	07°24'	75°50'	1821	24
3	16.04.1985	07°30'	75°30'	2765	862
4	17.04.1985	07°31'	76°47'	1670	76
5	25.06.1986	08°58'	75°46'	320	22
6	28.06.1986	09°29'	75°58'	163	52
7	27.03.1985	09°29'	74°15'	2671	172
8	28.06.1986	10°00'	75°47'	260	72
9	02.07.1986	10°27'	75°55'	228	172
10	10.08.1985	11°00'	72°01'	1645	37
11	12.08.1985	11°02'	75°19'	165	16
12	01.07.1986	11°03'	75°77'	260	23
13	01.07.1986	11°28'	75°02'	262	59
14	13.09.1985	11°59'	71°30'	1724	172
15	13.01.1986	12°00'	74°00'	1572	148
16	14.02.1985	12°50'	71°58'	1646	11
17	23.08.1985	13°59'	69°33'	4109	37
18	08.12.1985	14°00'	74°10'	48	26
19	25.08.1985	14°59'	73°00'	230	37
20	18.07.1986	15°30'	73°31'	150	89
21	24.08.1985	16°00'	68°20'	3870	13
22	19.12.1985	16°00'	72°40'	504	96
23	12.08.1985	16°30'	73°30'	115	58
24	11.10.1985	17°30'	72°30'	96	116
25	18.12.1985	21°00'	69°22'	174	217

In the pelagic trawl, the crab was caught in comparatively greater numbers than in the IKMT operations. Out of 334 pelagic trawl hauls (Fig. 11) examined 72 hauls proved to be positive with the crabs in varying numbers ranging from 2 to 54,306 per hour of trawling.

In the eastern Arabian Sea where 48 hauls proved to be positive out of the 165 hauls taken, the species occurred throughout the coast between south off Cape Comorin and Sourashtra coast (05°00'N-21°00'N) (Fig. 12). The crab was fairly abundant in the pelagic trawl hauls almost throughout the coast. The catch details of hauls yielding more than 100 crabs/hour of trawling on this coast are given in Table 10. The density of the crab population was comparatively low in the north western region, where fairly abundant population was recorded only off Veraval in the oceanic waters. In the southwest coast, on the contrary, the pelagic trawl recorded several rich collections of the crab in the neritic and contiguous oceanic waters off Travancore coast and Cape Comorin. The minimum depth at which the crab was caught in the pelagic trawl from this coast was 83 m off Quilon where a single haul taken on 24th July 1985 yielded an unusually heavy catch of 54,306 crabs for half hour of trawling. A similar dense concentration of crabs yielding more than 500 crabs/haul was also recorded in the oceanic waters west of Lakshadweep islands. In addition to these productive grounds, fairly rich shoals were also noticed around Lakshadweep islands and in the oceanic waters of Cape Comorin.

DISTRIBUTION OF PELAGIC TRAWL OPERATIONS

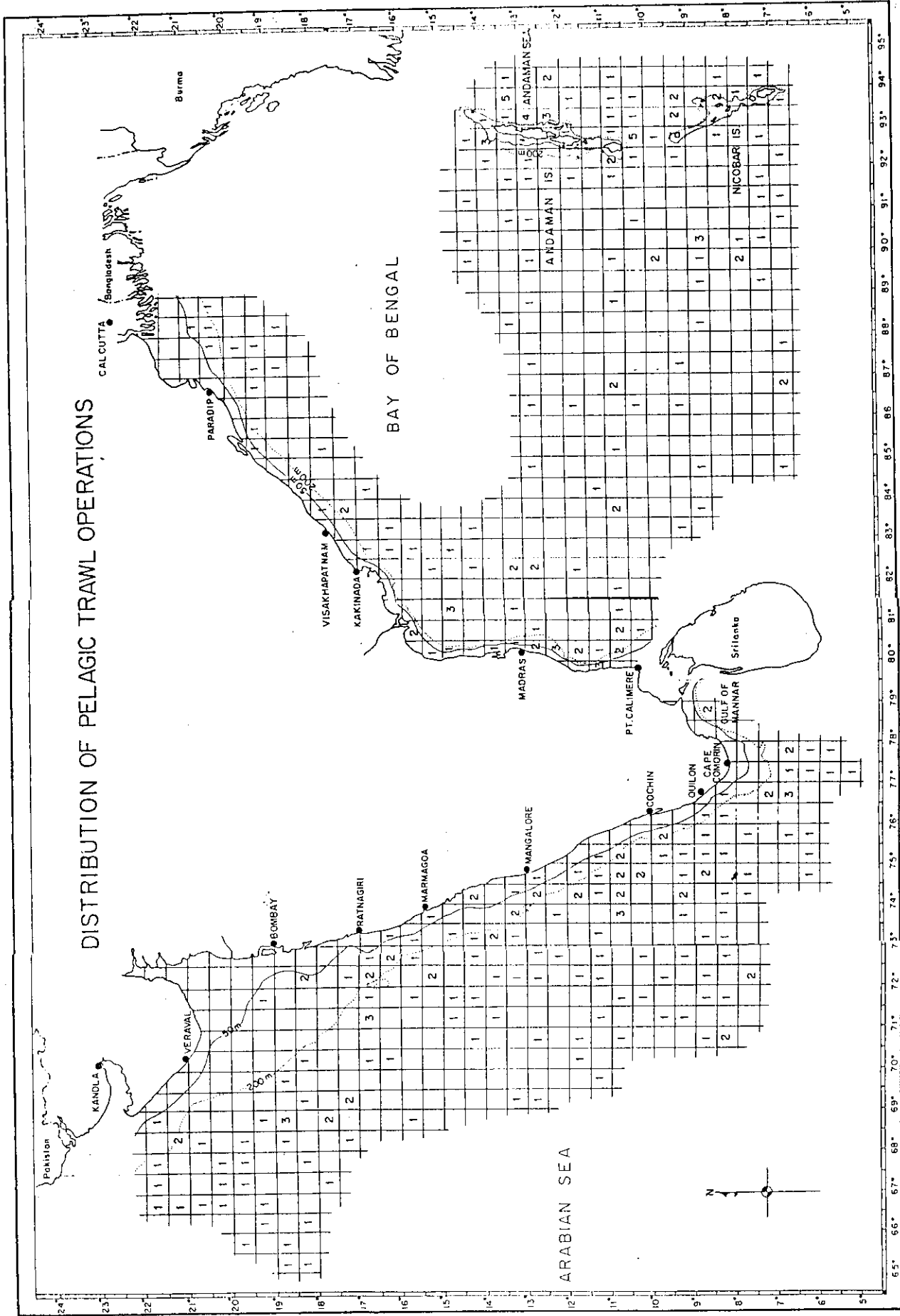


FIGURE 11.

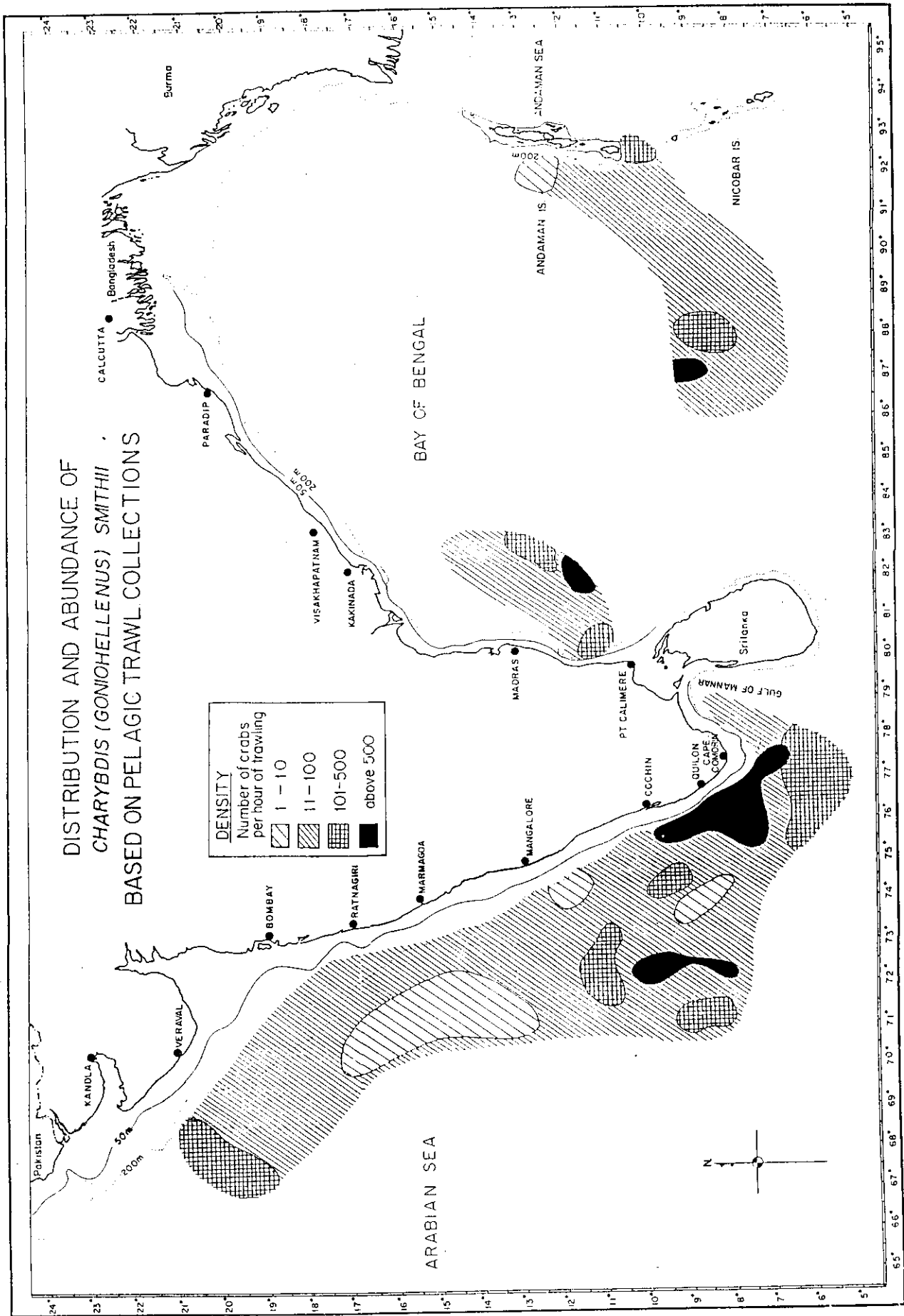


FIGURE 12.

TABLE 9. Catch details of *C. (G.) smithii* in the IKMT collections yielding more than 10 crabs/haul on the east coast.

Sl. No.	Date of Operation	Position		Depth of station (m)	No. of crabs
		Latitude (N)	Longitude (E)		
1	10.06.1986	06°55'	87°00'	3756	14
2	11.06.1986	06°55'	86°00'	3826	56
3	11.06.1986	07°00'	85°00'	3815	43
4	21.07.1985	07°30'	07°51'	121	16
5	21.07.1985	07°51'	77°56'	42	16
6	21.07.1985	07°52'	78°12'	697	16
7	10.06.1986	12°30'	81°10'	3403	60
8	08.05.1986	15°00'	87°24'	2865	22

On the east coast the species was caught in the pelagic tawl only from the Gulf of Mannar and the adjoining oceanic waters upto Latitude $05^{\circ}00'N$, in the South East coast region between point Calimere and Machalipatnam, and east of Srilanka between Latitudes $06^{\circ}00'-09^{\circ}30'N$ and long $86^{\circ}00' - 88^{\circ}00'E$ in the southern Bay of Bengal. Table 11 shows details of productive hauls in this region. The maximum number of (520 nos) of crabs/hour of trawling was recorded in the oceanic waters between Point-Calimere and Madras at a bottom depth of about 3500 m at lat. $11^{\circ}30'N$ and Long. $82^{\circ}00'E$ in December 1986. A similar rich haul was also recorded from the southern central region of Bay of Bengal at lat. $09^{\circ}00'N$ and long. $87^{\circ}05'E$ (515 nos) where bottom had depth of about 3540 m. In most of the other areas of the east coast where pelagic trawling has been attempted, there was no catch of the crab what so ever.

In the Andaman-Nicobar region, from where as many as 44 hauls were taken on the western side of the islands and 40 hauls in the Andaman sea, the crab was represented only in 4 hauls taken from the Bay of Bengal area. There was absolutely no crab in the collection taken from the Andaman sea. The crab population showed a distribution in continuation with the stock recorded in the central southern region of Bay of Bengal.

In order to understand the vertical distribution pattern of the crab in the pelagic realm the crab catch data has been compiled depth

TABLE 10. Catch details of C. (G.) smithii in the pelagic trawl collections yielding more than 100 crabs/haul on the west coast.

Sl. No.	Date of operation	Position		Depth of station (m)	Total No. of crabs
		Latitude (N)	Longitude (E)		
1	02.08.1985	05°10'	77°27'	2767	302
2	01.08.1985	05°58'	77°25'	2391	290
3	03.08.1985	06°02'	75°04'	2754	302
4	22.08.1986	06°30'	77°01'	1660	498
5	03.08.1985	06°47'	76°97'	1858	252
6	22.07.1985	06°59'	77°30'	889	693
7	22.07.1985	07°15'	77°05'	195	1764
8	22.06.1986	07°20'	76°42'	1650	1701
9	21.08.1986	07°30'	75°30'	2410	932
10	07.08.1985	08°03'	72°10'	2396	781
11	04.01.1986	08°04'	71°00'	4158	214
12	24.07.1985	08°30'	76°25'	83	54306
13	04.01.1986	09°00'	71°00'	3699	158
14	08.01.1986	10°00'	72°04'	2120	176
15	10.08.1985	10°03'	71°38'	2837	449
16	08.01.1986	10°57'	72°00'	1663	391
17	05.10.1986	19°00'	66°00'	3197	189

TABLE 11. Catch details of *C. (G.) smithii* in the pelagic trawl collections yielding more than 100 crabs/haul on the east coast.

Sl. No.	Date of operation	Position		Depth of station (m)	Total No. of crabs
		Latitude (N)	Longitude (E)		
1	22.08.1986	06°30'	78°00'	2983	126
2	07.06.1986	09°00'	87°05'	3537	515
3	21.12.1986	11°00'	80°10'	75	126
4	18.12.1986	11°30'	82°00'	3463	520
5	21.12.1986	11°26'	79°59'	532	126
6	19.12.1986	12°36'	82°31'	3370	189

wise between 0 and 400 m covered by pelagic trawl at 50 m depth intervals (Table 12). The analysis has shown that the crab occupies all the depth strata of this pelagic zone, the abundance of crab, however, did not indicate any significant pattern. Barring a heavy catch of crabs amounting to over 54,000 number/haul recorded for an exceptionally high catch rate at 0-50 m depth, there is no consistency in abundance of the crab in different depth strata.

Benthic realm

Bottom trawling operations carried out on the continental shelf and upper continental slope between 30 to 777 m depth indicated a wide distribution of the species at the bottom along the Indian coast. Details of productive areas are shown in Table 13. Out of 445 bottom trawl hauls examined, 42 hauls yielded crabs in varying degrees of abundance. On the west coast the crab was represented in 37 hauls out of ~~243~~ hauls taken between Cape Comorin and Kutch. The species was found to be distributed in the offshore waters between Cape Comorin and Bombay occupying upto 356 m. In the northwest region it was sparsely distributed and recorded between 88 to 93 m bottom depth. The southwest coast region has been found to be densely populated (Fig. 14) with this species with maximum catch rates of nearly 1.8 tonnes/hour. Dense concentrations were recorded between Mangalore and Ponnani in the North and Cochin and Cape Comorin in the south. As many as 7 hauls yielded more than 100 kg/hour along this coast. The maximum (1100-1740 kg) having been recorded off Alleppey. The species has been recorded along this coast at depth between 88 to 356 m.

TABLE 12. Depthwise distribution of catch rates of C. (G.) smithii in pelagic trawl operations.

Depth range (m)	Total No. of crabs in positive hauls	Average catch/ hour
0- 50	58006	2552
51-100	207	23
101-150	1072	214
151-200	388	97
201-250	315	158
251-300	1606	352
301-350	441	110
351-400	1901	950

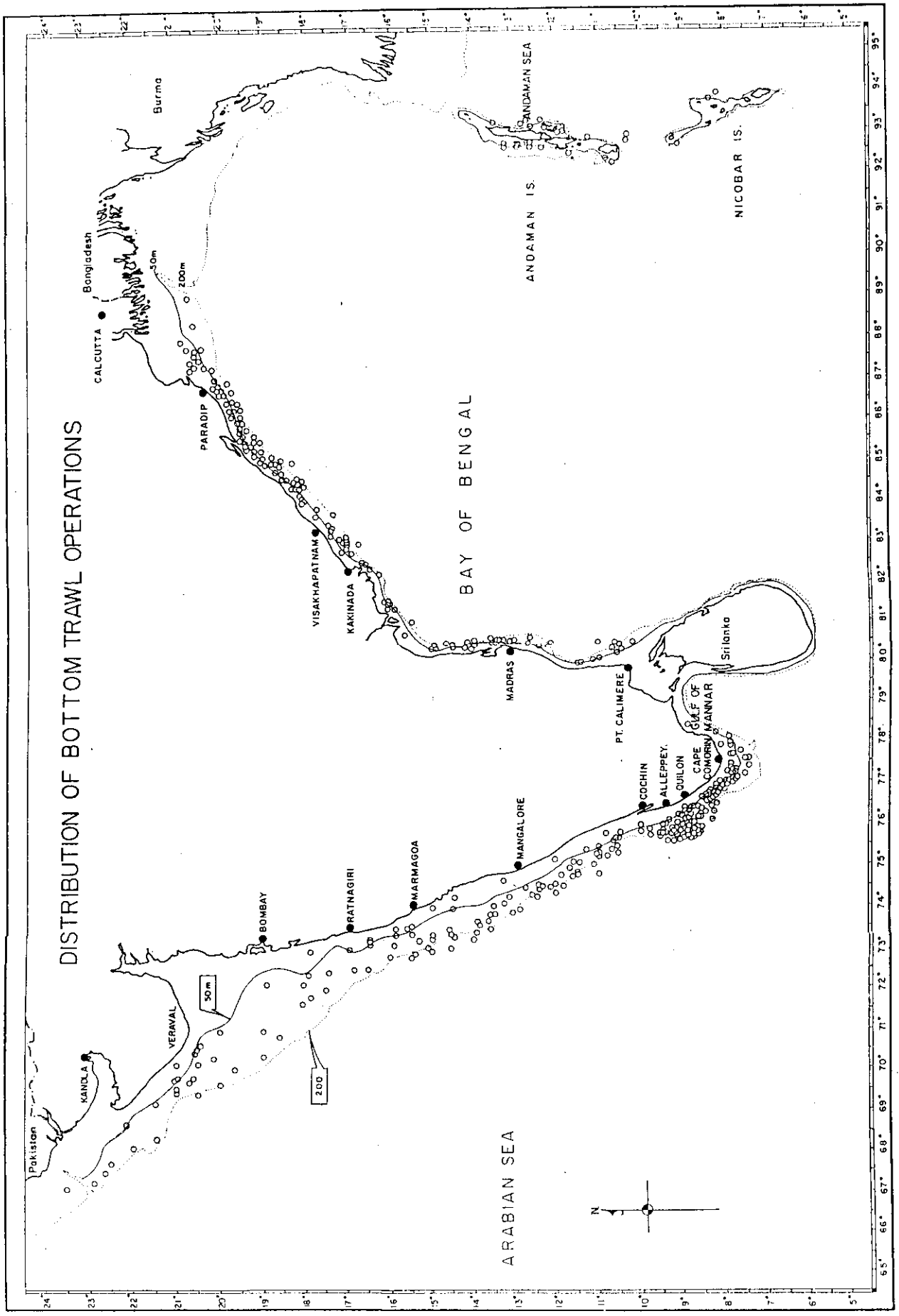


FIGURE 13.

DISTRIBUTION AND ABUNDANCE OF
CHARYBDIS (GONIOHELLENUS) SMITHII
 BASED ON BOTTOM TRAWL COLLECTIONS

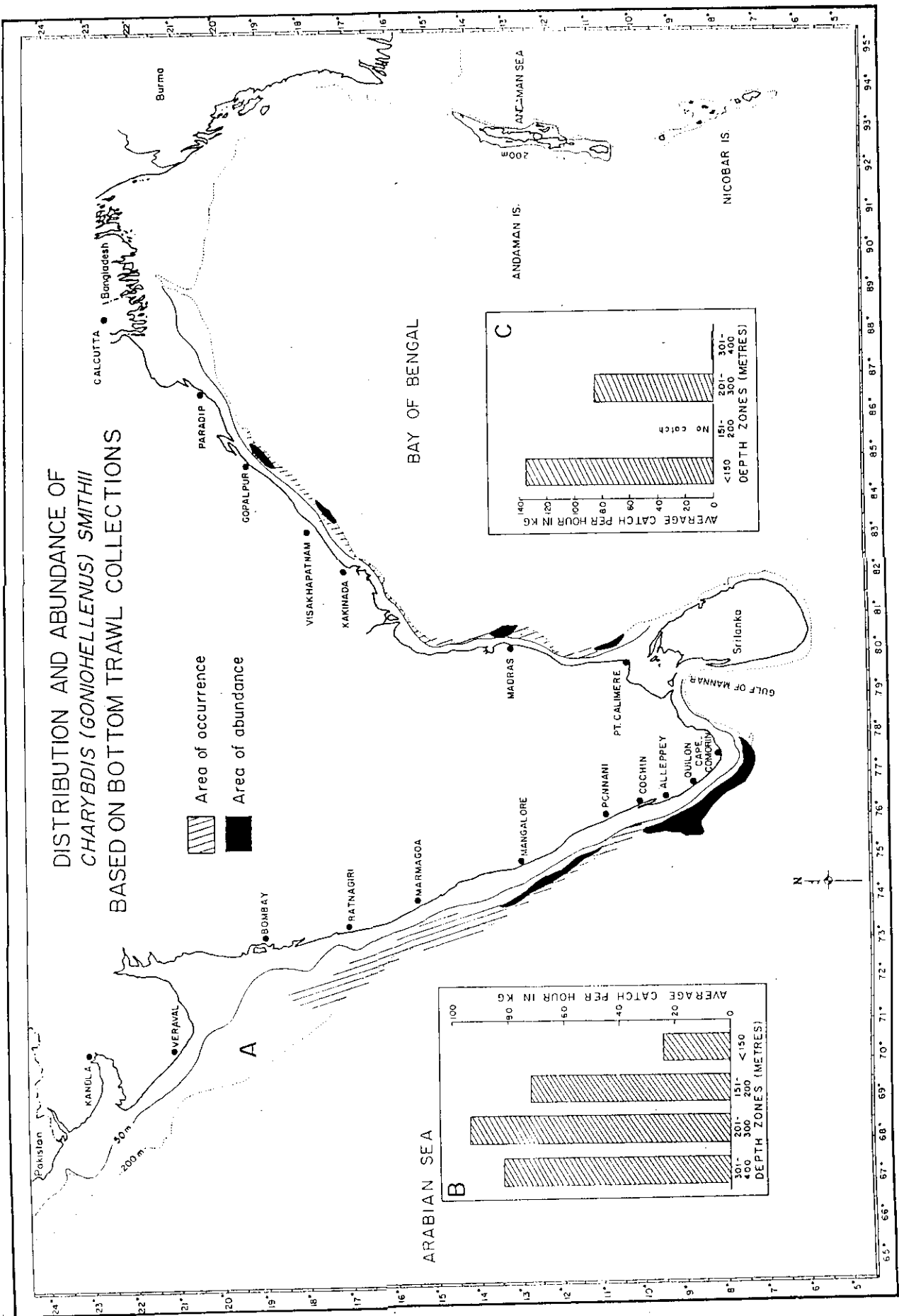


FIGURE 14.

TABLE 13. Catch details of *C. (G.) smithii* in the bottom trawl collections yielding more than 10 kg. of crabs/hour of trawling.

Sl. No.	Date	Position		Depth (m)	Catch/hr (Kg)
		Latitude (N)	Longitude (E)		
WEST COAST					
1	25.08.1986	07°30'	77°30'	88	114
2	14.12.1991	08°19'	76°28'	245	26
3	02.01.1988	08°20'	76°00'	235	75
4	10.12.1987	08°21'	76°40'	170	100
5	02.01.1988	08°38'	76°11'	273	33
6	12.12.1991	08°56'	75°48'	335	15
7	10.12.1991	08°58'	75°58'	190	18
8	19.11.1991	09°02'	75°56'	185	185
9	06.01.1988	09°04'	75°40'	260	24
10	06.01.1988	09°04'	75°44'	299	44
11	06.01.1988	09°08'	75°40'	344	74
12	19.11.1991	09°02'	75°56'	185	480
13	12.12.1991	09°15'	75°53'	225	1100
14	08.01.1988	09°18'	75°55'	239	79
15	09.01.1988	09°19'	75°52'	326	1740
16	16.12.1991	09°48'	75°36'	195	57
17	29.11.1991	11°11'	75°58'	170	43
18	28.11.1991	11°44'	74°35'	185	51
19	27.11.1991	12°17'	74°24'	175	170
20	26.11.1991	12°30'	74°12'	185	109
EAST COAST					
1	21.06.1988	10°40'	80°10'	113	12
2	25.03.1988	13°23'	80°27'	60	500
3	29.05.1988	17°27'	83°33'	203	85
4	24.01.1987	18°51'	85°01'	71	10

On the east coast, out of the 178 trawl hauls taken 5 hauls proved to be positive. In the Gulf of Mannar though a few trawling operations have been attempted the crab was not recorded. The distribution of the crab along the east coast extended between Point Calimere and Gopalpur. In general the catch was comparatively poor along this coast. fairly dense concentrations being observed to be highly localized. Two notable catches were recorded on this coast, one off Madras at 60 m depth (500 kg/hour) and other Visakhapatnam at 203 m depth (85 kg/hr.)

The Andaman-Nicobar water did not yield any positive haul for this species although as many as 24 bottom trawling operations were conducted around the islands.

BATHYMETRIC DISTRIBUTION AND ABUNDANCE

C. (G.) smithii is recorded during the present study from a depth of 60 m to 356 m on the continental shelf and upper continental slope. Though occupying almost through out this depth range in both the coasts of India the depth of high concentration varied considerably in the west and east coast. In order to study the variation in the density of crabs by depth the date of the positive hauls have been compiled depth wise in 4 depth zones namely, zone 1: less than 150 m, Zone 2: 151-200 m, Zone 3: 201-300 m and Zone 4 : 301-400 m depths. The relative abundance of crab in the different depth zones have been studied on the basis of average catch/hour in kg calculated for the total number of positive hauls taken in each of the depth zones from the west and east coasts separately.

On the west coast the species was recorded from 88 m to 356 m depth. The average catch in the depth zones less than 150 m worked out to 24 kg/hour for a total number of 37 positive hauls. The catch rate increased considerably in deeper depth zones (Fig. 14 B), with average catch/hour ranging from 72 kg to 95 kg. The maximum catch rate of 94 kg/hour was recorded in the depth zones 201-300 m. In still deeper waters, however, the catch rate was found to decline (82 kg/hour).

Most of the positive hauls with catches of 100 kg and above per hour of trawling were recorded along the southwest coast of India in depth more than 151m(Table 13). Out of total number of 37 hauls taken from this coast the depth zone less than 150 m recorded one haul with 114 kg/hour of trawling (88 m) off Cape Comorin, depth zone 151-200 m had 4 hauls with catches ranging from 100-480 kg/hour of trawling and in depth zone 201-300 m one haul with a catch of 1100 kg/hour and depth zone 301-400 m one haul with the highest catch of 1740 kg/hour off Quilon.

On the east coast the species was recorded from 60-306 m depth. The average catch in the depth zone less than 150 m worked out to 135 kg/hour (Fig. 14B) for a total no. of 4 positive hauls involving 4 hours of fishing. This was the maximum of the catch rates recorded in the individual depth zone on this coast. This was due to a single rich haul at 60 m depth off Madras, with the record catch of 500 kg/hour of trawling (Table 13). Though as many as 7 bottom trawling operations were conducted in the depth zone 151-200 m extending a total effort of 7 hours, there was no catch of this species. In the deeper depth zones however the

crab was again recorded with a catch of 85 kg/hour in a single haul taken off Visakhapatnam (203 m) and 1 kg/hour in depth zone 300-400 m.

SEASONAL DISTRIBUTION AND ABUNDANCE

As the trawling operations of the different gears undertaken by the FORV Sagar Sampada were of exploratory nature, continuous time series data on the occurrence of the crab was not available for all the regions covered in the study. However an attempt has been made to utilize the available data in order to understand the seasonal pattern of distribution of the crab in the two different habitats, (viz. pelagic and benthic) occupied by them during the life history. For this purpose catches of positive hauls of the individual months of different years were pooled and average catches per haul worked out gearwise for the west and east coast separately.

Pelagic habitat:

In Eastern Arabian Sea the crab was recorded through out the year except in May in which month no pelagic/midwater trawling was attempted. The monthly abundance of crab against the total number of hauls taken and the total number of positive hauls recorded for this species in the IKMT is shown in figure 15A. The average number of crab per haul ranged from 2 in February to 80 in July. Relatively higher abundance of the crab was also recorded in April (71 nos/haul) and December to January (50-51 Nos/haul). The average catch recorded was considerably low in the months of February, June, August and October (2-14 nos/haul). The monthly trend in abundance thus indicated no definite

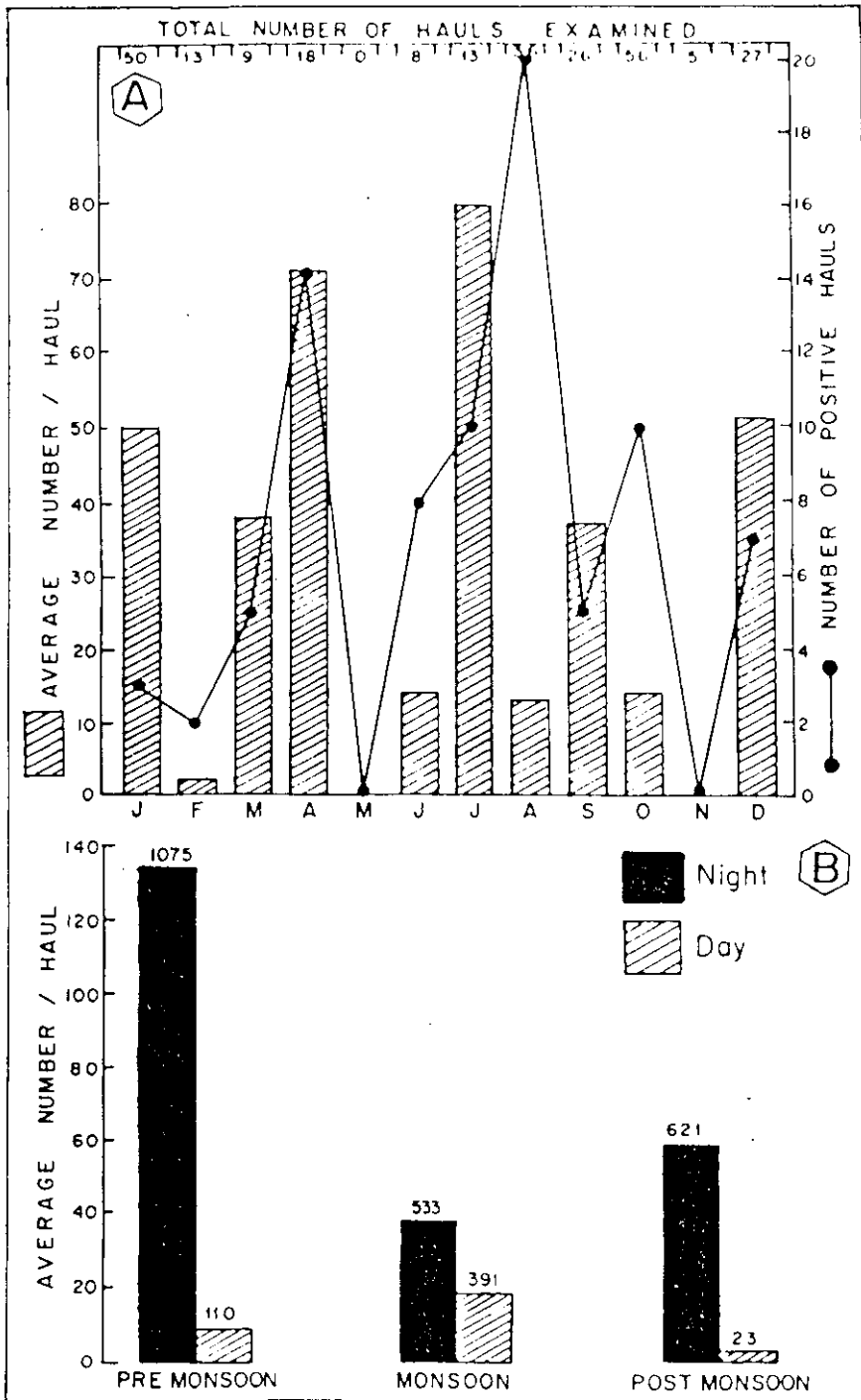


FIGURE 15. Monthly (A) and Day & Night variations (B) in the abundance of C. (G.) smithii in the IKMT hauls.

pattern. Although pelagic trawling was conducted almost throughout the year (except in April and May (Table 14), the crab was encountered in this net only during January, June, July, August, October and December in highly varying numbers. The monthly average number/hour of trawling was least in December (28) and the highest in July (14,198). Very high catch rate amounting to nearly 10,000 crabs/hour of trawling was also recorded in June and the next highest catch rate amounting to over 300 numbers/hour was recorded in August. The percentage of positive hauls was also maximum during the 3 monsoon months (June, July and August (51-92%) which would indicate that the monsoon season is most productive for this crab in the pelagic realm on the west coast. In the other months of the occurrence of crab (January and October) the average catch rate worked out to 138 and 110 numbers/hour respectively with low percentage of positive hauls.

On the east coast the crab was taken in the IKMT hauls during February, April, May, June and July with average monthly catches ranging from 10 (February) to 139 (June). Though this net was operated during March, August, September months the crab was not encountered in the collections. Pelagic trawling operation was attempted along this coast throughout the year except in October and November. However the presence of C. (G.) smithii was noticed only during June, July, August and December (Table 14) with relatively low catch rates ranging between 32 and 156 numbers/hour in June and December respectively. In the Andaman-Nicobar region the pelagic trawling operations conducted during the month of April, June, August, September, October and November yielded positive

TABLE 14. Monthwise particulars of pelagic trawling operations, positive hauls and catch rates of C. (G.) smithii.

Months	Total No. of hauls examined	No. of positive hauls	Average No./hour of trawling
WEST COAST			
January	22	19	138
February	5	-	-
March	24	-	-
April	-	-	-
May	-	-	-
June	3	2	9801
July	6	4	14198
August	15	14	301
September	20	-	-
October	22	2	110
November	8	-	-
December	40	7	28
EAST COAST			
January	19	-	-
February	2	-	-
March	9	-	-
April	4	-	-
May	3	-	-
June	20	7	32
July	5	1	33
August	8	5	69
September	4	-	-
October	-	-	-
November	-	-	-
December	11	7	156

hauls for this crab only in June and August when the frequency of positive hauls was only 3 out of 12 (25%) taken in the former and 1 out of 9 hauls (11.1%) taken in later month. An average catch rate of 126 number/hour was recorded in June and 54 numbers in the single positive haul recorded in August.

Benthic habitat

Bottom trawling operations carried out along the west coast of India numbering 16 in January to 44 in July yielded catch of C. (G.) smithii in as many as 37 hauls. There was no trawling operation between March and May. While the frequency of occurrence of crab in the bottom trawl was as high as 35 to 50 percent during the postmonsoon period of November to January, it was extremely low during the rest of the months (Table 15). The average catch rate was also found to be maximum during the period November-January (78-271 kg/hour), the maximum having been recorded in January, during the rest of the year when crab was recorded in the trawl catch (July-October) abundance was generally poor except during August when the single positive haul recorded, out of 18 operations conducted, yielded an abundant catch of 114 kg/hour. On the east coast though bottom trawling was conducted throughout the year, the crab was represented only during the first half of the year when the frequency of positive hauls are very low. The maximum catch rate of 500 kg/hour was recorded in the month of March. In May also the catch rate was fairly high (85 kg/hr) in the single positive haul recorded. In the remaining months the catch rate varied between 2 and 12 kg/hour.

TABLE 15. Monthwise particulars of bottom trawling operations, positive hauls and catch rates of C. (G.) smithii

Months	Total No. of hauls examined	No. of positive hauls	Average catch/hour (Kg)
WEST COAST			
January	16	8	271
February	20	-	-
March	-	-	-
April	-	-	-
May	-	-	-
June	29	-	-
July	44	1	1
August	18	1	114
September	26	5	1
October	28	1	1
November	28	10	78
December	34	11	119
EAST COAST			
January	21	1	10
February	28	1	2
March	6	1	500
April	9	-	-
May	8	1	85
June	13	1	12
July	1	-	-
August	9	-	-
September	20	-	-
October	28	-	-
November	17	-	-
December	18	-	-

DAY AND NIGHT VARIATIONS IN ABUNDANCE

Changes in abundance of crabs in the pelagic collections during day and night could throw light on the nature of vertical migration of these crustaceans as the DSL is characterized by cyclic changes in position in the upper columnar region of the sea with the change of day and night (Menon and Prabhadevi, 1990). According to Mathew and Natarajan (1990) the Deep Scattering Layers ascend to surface on epipelagic realm during night and descend to deeper waters during day. In order to understand the variations, if any, in the abundance of crab during day and night, the catches of IKMT and pelagic trawl taken in the Eastern Arabian Sea were analysed separately for day and night. As the bottom trawl operations were conducted mostly during day time, no meaningful analysis could be attempted for catch comparison between day and night for this gear.

The catches of positive hauls yielding more than 10 crabs/haul by the pelagic nets during day and night are shown in Tables 16 and 17. It can be seen that in IKMT hauls, the crab abundance during night was occasionally very high, but such large collections were rather sporadic. Crabs numbering more than 100/haul was recorded in 6 hauls during night, with the highest catch of 862 crabs off Cape Comorin. In the day series of hauls, wide fluctuations in abundance of crab was not observed as in the night series of hauls. The maximum number per haul recorded during day time was only 72. The average number of crabs per haul worked out from pooled data of all the positive hauls of IKMT separately for the night and day operations seasonwise (Fig. 15B) indicates that in all the seasons of the year the abundance of crab in the DSL is considerably higher during night than during day time.

TABLE 16. Comparative catch details of *C. (G.) smithii* for day and night series of IKMT hauls yielding more than 10 crabs/haul in the eastern Arabian Sea.

Sl. No.	Day hauls				Night hauls			
	Month & Year	Position		Total No. of crabs	Month & Year	Position		Total No. of crabs
		Lat. (N)	Long. (E)			Lat. (N)	Long. (E)	
1	Mar. '85	09°30'	75°32'	68	Mar. '85	09°29'	74°15'	162
2	Jul. '85	07°30'	76°38'	13	Apr. '85	07°24'	72°50'	24
3	Jul. '85	08°00'	76°50'	17	Apr. '85	07°30'	75°30'	862
4	Aug. '85	11°01'	72°01'	10	Apr. '85	07°31'	76°47'	76
5	Aug. '85	14°00'	60°34'	59	Aug. '85	06°46'	75°58'	11
6	Aug. '85	14°59'	73°00'	37	Aug. '85	16°30'	73°30'	58
7	Aug. '85	08°00'	75°38'	22	Aug. '85	13°59'	69°33'	37
8	Aug. '85	11°02'	75°19'	16	Aug. '85	14°59'	73°00'	37
9	Aug. '85	16°00'	68°31'	13	Sep. '85	11°59'	71°30'	172
10	Jun. '86	10°00'	75°47'	72	Sep. '85	12°50'	71°58'	11
11	Jul. '86	11°28'	75°02'	59	Dec. '85	14°00'	73°00'	26
12	-	-	-	-	Dec. '85	21°00'	69°22'	217
13	-	-	-	-	Dec. '85	16°00'	72°40'	96
14	-	-	-	-	Jan. '86	12°00'	74°00'	148
15	-	-	-	-	Jan. '86	08°58'	75°46'	22
16	-	-	-	-	Jun. '86	09°29'	75°50'	52
17	-	-	-	-	Jun. '86	10°30'	75°17'	10
18	-	-	-	-	July '86	11°03'	75°77'	23
19	-	-	-	-	July '86	10°27'	75°55'	172
20	-	-	-	-	July '86	14°30'	73°56'	54
21	-	-	-	-	July '86	15°30'	73°30'	89

TABLE 17. Comparative catch details of C. (G.) smithii for day and night series of pelagic trawl hauls yielding more than 10 crabs/haul in the eastern Arabian Sea.

Sl. No.	Day hauls				Night hauls			
	Month & Year	Position		Total No. of crabs	Month & Year	Position		Total No. of crabs
		Lat. (N)	Long (E)			Lat (N)	Long. (E)	
1.	Jul. '85	06°59'	77°30'	693	Aug. '85	05°58'	77°25'	290
2	Jul. '85	07°15'	77°05'	1764	Aug. '85	06°47'	76°97'	252
3	Jul. '85	08°30'	76°25'	54306	Aug. '85	08°02'	72°10'	781
4	Aug. '85	05°10'	77°27'	302	Aug. '85	11°08'	71°00'	101
5	Aug. '85	06°02'	76°97'	252	Aug. '85	10°58'	73°06'	88
6	Aug. '85	10°03'	71°38'	441	Aug. '85	10°51'	74°46'	42
7	Aug. '85	08°56'	74°56'	11	Dec. '85	07°27'N	76°41'	76
8	Jan. '86	08°04'	71°00'	214	Jan. '86	12°00'	71°00'	19
9	Jan. '86	09°00'	71°00'	158	Jan. '86	10°00'	72°04'	176
10	Jan. '86	10°00'	71°00'	44	Jan. '86	12°03'	72°58'	74
11	Jan. '86	13°00'	71°00'	63	Jan. '86	14°01'	72°35'	25
12	Jan. '86	10°57'	72°00'	391	Jan. '86	08°54'	72°00'	20
13	Jan. '86	10°02'	73°00'	57	Aug. '86	09°32'	75°31'	958
14	Jan. '86	11°00'	73°00'	32	Aug. '86	09°28'	74°30'	19
15	Jan. '86	10°54'	74°00'	13	Aug. '86	07°30'	75°30'	932
16	Jan. '86	08°00'	71°58'	19	Aug. '86	06°39'	77°01'	498
17	Jan. '86	08°00'	75°00'	19	-	-	-	-
18	Jun. '86	07°20'	76°42'	1701	-	-	-	-
19	Oct. '86	19°00'	66°00'	189	-	-	-	-

In the pelagic trawl operation, the day series of hauls showed more or less similar levels of crab abundance as in the night series of hauls, except for three hauls taken during day, in which exceptionally high catches of crabs numbering nearly 2000 to 55,000/haul were recorded between Quilon and Cape Comorin during the southwest monsoon period.

SIZE FREQUENCY DISTRIBUTION

The size frequency distribution of C. (G.) smithii has been studied based on a total number of 1750 crabs collected from the catches of different types of gear operated by Sagar Sampada. The overall size frequency distribution worked out by pooling the data of individual samples is depicted for male and female separately gearwise in Figure 16. The size of species represented in the samples ranged from 11 to 72 mm cw for male and 11 to 69 mm cw for female. Males thus showed slightly larger size than the females in the population.

IKMT

The IKMT samples contained all the life stages of crabs, including the zoea, megalopa, juvenile, subadult and adult. The first two stages however have not been considered for the present study. Examination of a total of 439 number of males and 353 number of females caught by this gear has shown a size range 11 to 63 mm cw for male and 11 to 60 mm cw for females (Fig. 16A). Juvenile crabs measuring 11 to 20 mm formed the major component of the IKMT samples in both sexes. For the total number of samples, this size group accounted

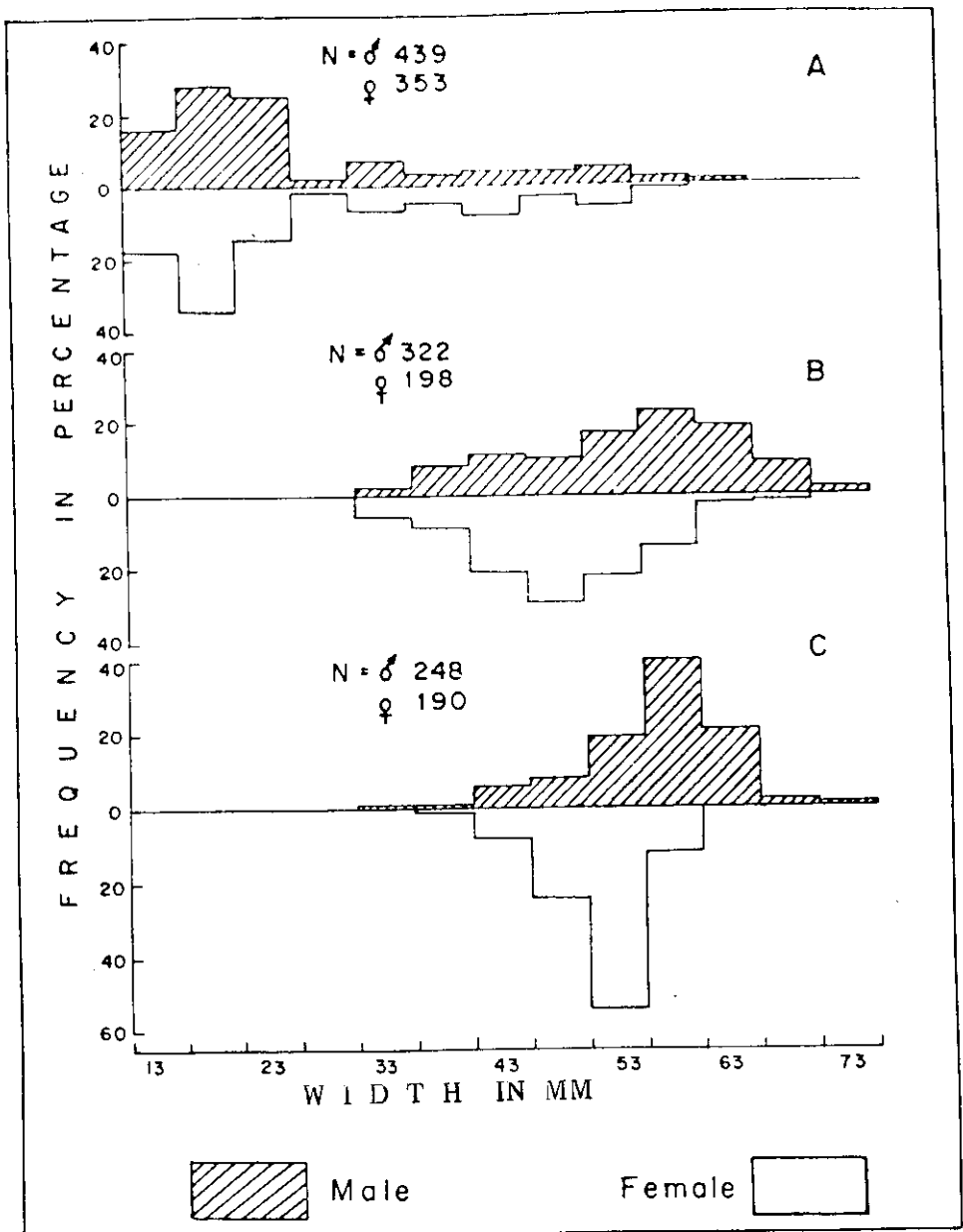


FIGURE 16. Overall size frequency distribution of *C. (G.) smithii*, sexwise, in the collections of different types of experimental nets. A. IKMT; B. Pelagic trawl; C. Bottom trawl.

for about 70%. Crabs larger than this size group, which represented subadults and adults were generally scarce. However individuals in the size range 34-54 mm cw were more frequently met with in both sexes especially when the catch were low in this gear. The size frequency distribution of individual samples taken from some of the rich collections of the IKMT is shown in Fig. 17 A-H. It can be seen that in all these samples the range of size represented was narrow in both sexes. These samples were predominantly constituted by juveniles ranging from 12 to 20 mm cw with more or less identical size distribution for both sexes. The size frequency histogram showed more or less unimodal pattern with modes falling between 13.5 to 19.5 mm carapace width for males and females. Examination of modal distribution of individual samples showed no consistency in the dominance of any particular size group over space and time within this narrow size range of juveniles.

Pelagic trawl

The size frequency distribution of pelagic trawl collections comprising of a total of 322 male and 198 female crabs (Fig. 16B) showed a size range of 31 to 72 mm cw for males and 31 to 69 mm cw for females. The crab population sampled by this net is thus seen to be constituted by subadults and adults in both sexes. In the over all size frequency distribution (Fig. 16B) nearly 60% was constituted by size group ranging 51-65 mm cw in males and 85% by size group ranging 41-60 mm cw in females. In majority of the individual samples examined the range of size of crabs was rather narrow in both sexes. The size frequency distribution of 11 selected samples collected on different occasions from

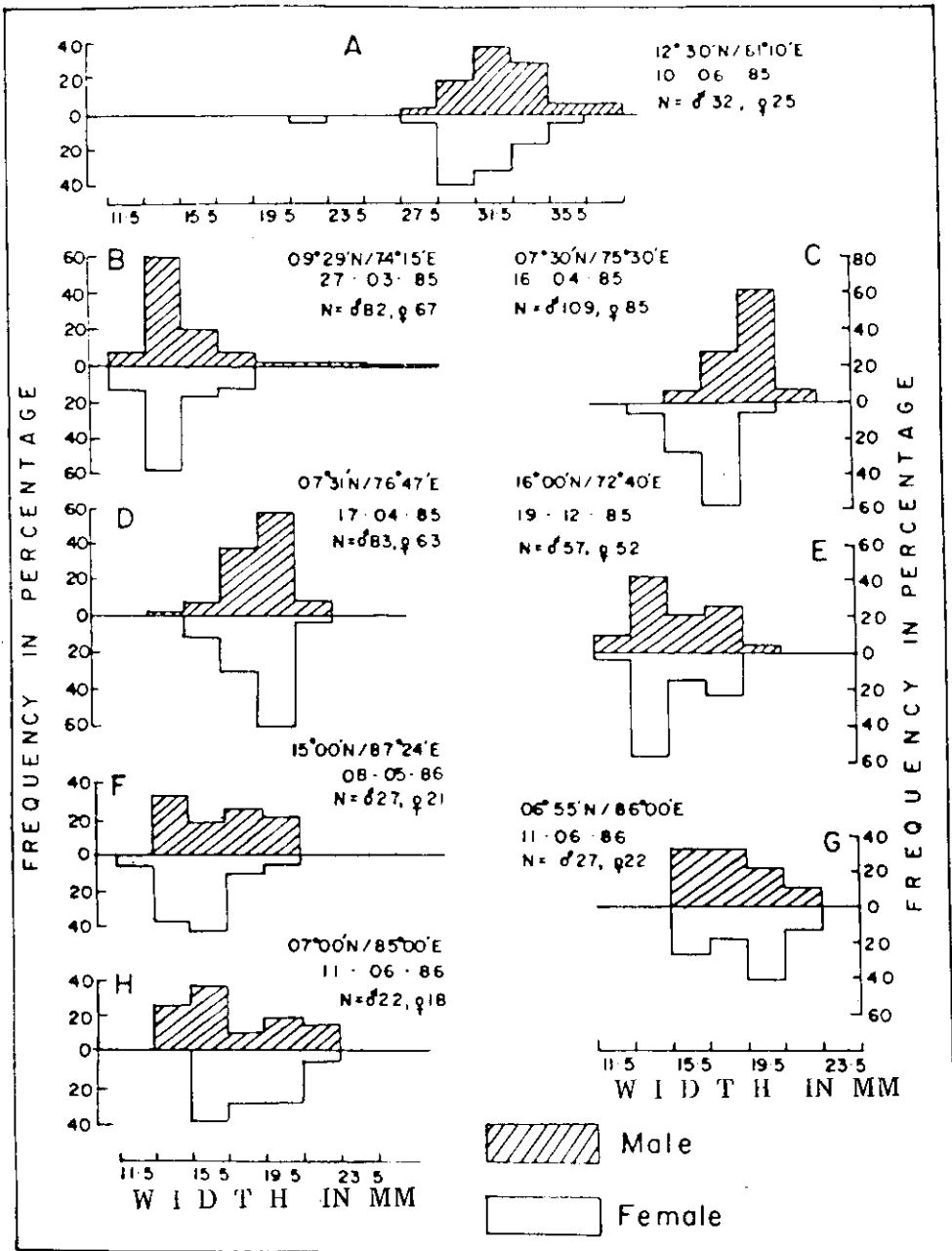


FIGURE 17. Sex wise size frequency distribution of *C. (G.) smithii* in the catches of selected IKMT hauls.

different parts of study area by this net (Fig. 18 A-K) showed that there is no consistency in the distribution of modal sizes over space and time. The size frequency was in most cases unimodal in both sexes. In the southwest coast out of six size frequencies illustrated, two showed mode at 61-65 mm cw two at 41-45 mm cw and one each at 41-45 mm cw in males. In the case of females two of the size frequencies indicated mode at 56-60 mm, two at 46-50 mm one at 51-55 mm and one at 41-45 mm cw. On the east coast out of 5 size frequency histograms two showed mode at 56-60 mm one each at 51-55, 55-60 and 66-70 mm cw in males while in females two mode at 46-50 mm and one each at 41-55 mm, 51-55 mm and 56-60 mm cw.

Bottom trawl

A total number of 438 crabs including 248 males 190 females were analysed for the size frequency distribution. It is observed that the size range of crab was more or less same as in the pelagic trawl collections which varied from 31-72 mm cw in male and 36-69 mm cw in females (Fig. 16 c). In the pooled data over 83% was constituted by size group 51 to 65 mm in males and 76% by the size group 46 to 60 mm cw in females. The advanced juveniles ranging in size from 31 to 40 mm in both the sexes were extremely rare in bottom trawl collections as compared with those in pelagic trawl collections. Subadults above 40 mm cw and the adult crabs formed almost the entire catch of most of the samples examined. The size frequency distribution of 8 selected samples collected on different occasions (Fig. 19A-H) of which 7 were collected from the southwest coast and one from south east coast (off Madras) showed that

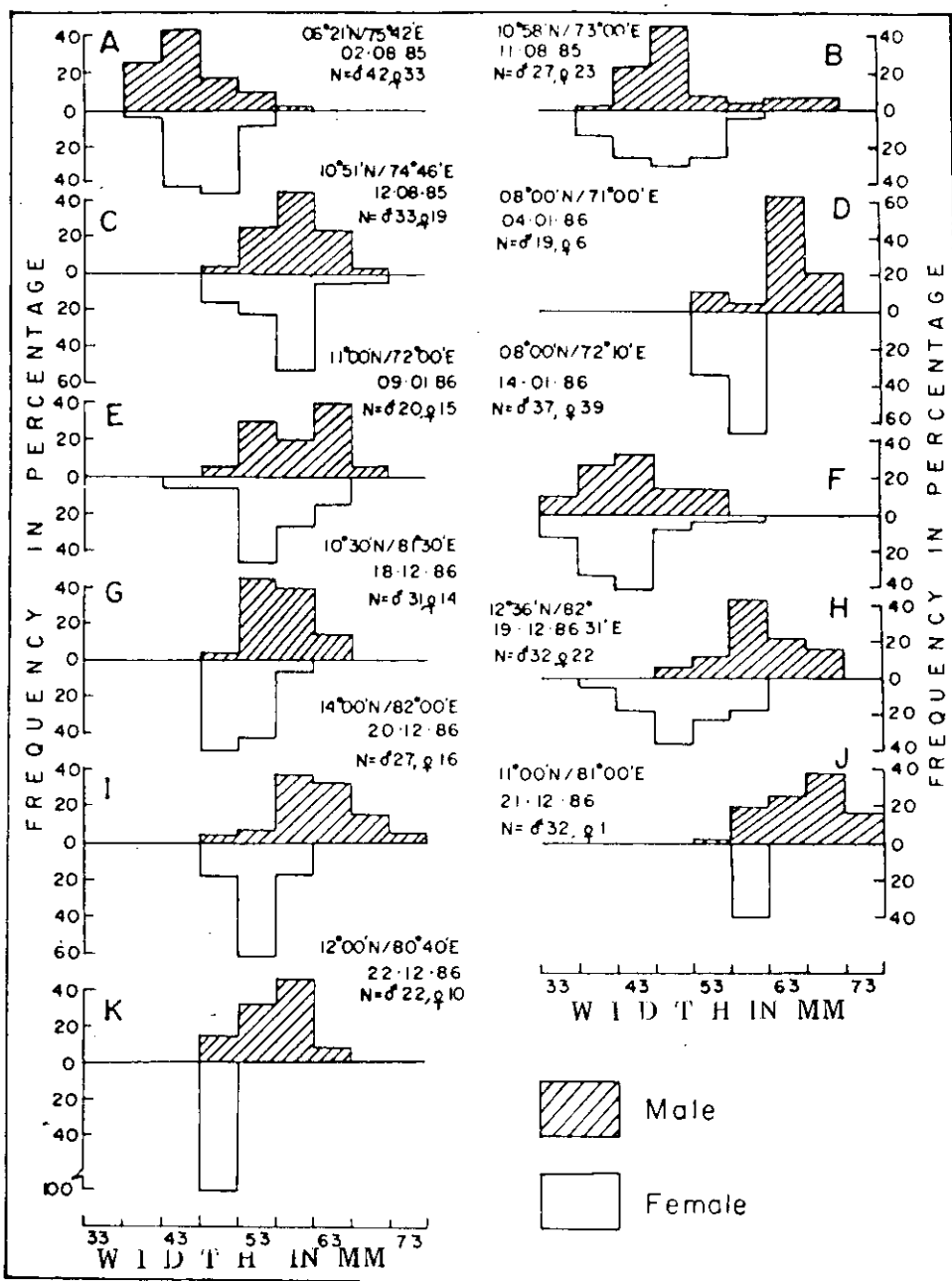


FIGURE 18. Sex wise size frequency distribution of *C. (G.) smithii* in the catches of selected pelagic trawl hauls.

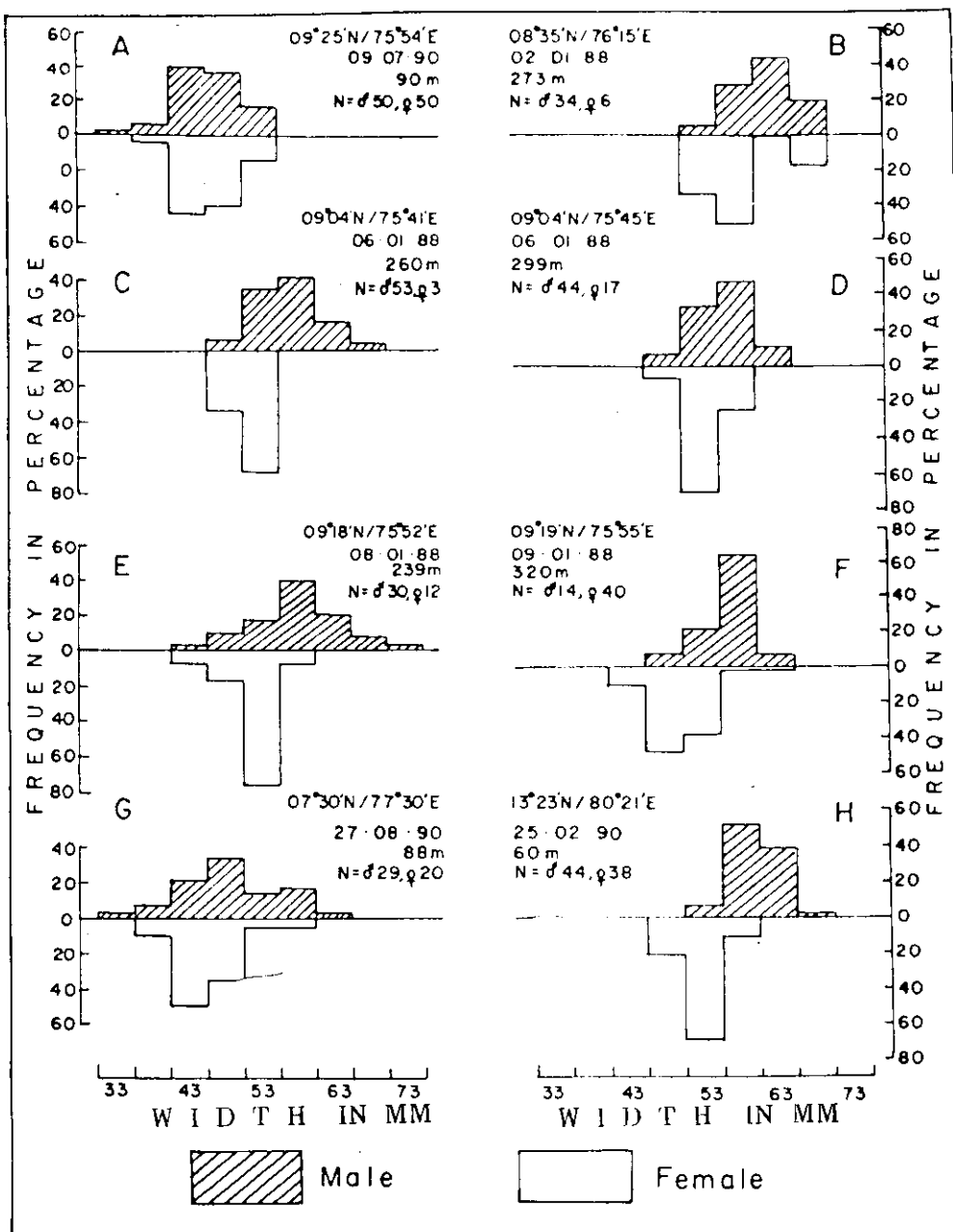


FIGURE 19. Sex wise size frequency distribution of *C. (G.) smithii* in the catches of selected bottom trawl hauls.

range in crab size was of narrow limit and the samples were more or less of uniform size with majority belonging to the size group 41-65mm cw in males 41-60 mm cw in females. In the southwest coast out of 7 size frequencies illustrated four showed mode at 56-60 mm cw, one at 46-50 mm and one at 41-45 mm cw in males. In the case of females three size frequencies indicated mode at 51-55 mm, two at 41-45, one at 46-50 mm and one at 56-60 mm cw. Size frequency distribution from the east coast showed a modal size at 56-60 mm cw in males and 51-55 mm cw in females.

The mean size of male and female crabs have been estimated for the eight samples used in Fig. 19A-H and the same are presented in Table 18. The mean size varied from 45.5 to 69.2 mm in male and 39.8 to 58.0 mm in female. In the south west coast of India, it is observed that the mean sizes were above 56.2 mm and 50.0 mm for male and female respectively during the nonmonsoon period (January) while the same were considerably low (< 48.8 mm in male and < 45.0 mm in female) during the southwest monsoon period (July and August). As the low mean values were recorded from comparatively shallower waters during the southwest monsoon, the smaller size obtained could be attributed to the variation in depth as well. The mean size recorded for the sample from the east coast was fairly high although the depth of collection was the minimum (60 m) and it was obtained during the summer month (February).

DISTRIBUTION OF SEX RATIO

The proportion between male and female crab in the catches of IKMT, pelagic tawl, bottom trawl operated in the Indian EEZ and contiguous

TABLE 18. Mean size distribution of C. (G.) smithii in bottom trawl samples.

Sl. No.	Date	Position		Depth (m)	Sample size(N)		Mean size (mm)	
		Lat (N)	Long (E)		Male	Female	Male	Female
WEST COAST								
1	02.01.1988	08°35'	76°15'	273	34	58	61.9	58.0
2	06.01.1988	09°04'	75°41'	260	53	03	56.9	51.0
3	06.01.1988	09°04'	75°45'	299	44	17	56.2	55.8
4	08.01.1988	09°18'	75°55'	239	30	12	69.2	51.8
5	09.01.1988	09°19'	75°55'	320	14	40	66.0	50.0
6	09.07.1990	09°25'	75°54'	90	50	50	45.5	39.8
7	27.08.1991	07°30'	77°30'	88	29	20	48.6	45.0
EAST COAST								
1	25.02.1990	13°23'	18°27'	60	14	38	59.8	52.4

waters has been studied from a total of 1804 crabs taken at random on different occasions. Details of the major samples used for the study and sex ratio calculated for individual samples are shown in Table 19-21 for each of the gear separately.

In the IKMT out of 792 crabs examined males formed 53% and females 47% thus showing a slight preponderance of males with an overall sex ratio of 1.2:1. The percentage of males in individual samples ranged from 52-57 (Table 19). The sex disparity however was not statistically significant in this gear.

In the pelagic trawl out of 520 crabs examined males formed 62% and females 38% indicating an overall sex ratio of 1.6:1. In all the samples percentage of male was higher than that of females, the values calculated for individual samples ranging from 54 to 97% (Table 20). Out of 11 samples studied, samples showed that variation in sex ratio was statistically significant.

In the bottom trawl, a total number of 492 crabs examined showed a male : female ratio of 2.1:1 there by indicating a dominance of male in this gear also. In all the individual samples examined, except one taken at Lat. $09^{\circ} 19' N$ long. $75^{\circ}55'E$ (320 m) during January 1988 in which the females dominated to the extend 74%, the males out numbered females by 54 to 100% (Table 21). The single sample examined from the east coast at lat. $13^{\circ}55'N$, long. $82^{\circ}23'E$ (60 m) showed an exclusive population constituted by males. Out of 9 samples subjected to chi square test, 6 showed that variation in sex ratio was statistically significant.

TABLE 19. Distribution of sex ratios of *C. (G.) smithii* in IKMT collections.

Sl. No.	Date	Position		Depth (m)	Sample size (N)	No. of males (%)	No. of females (%)
		Latitude (N)	Longitude (E)				
1	27.03.1985	09°29'	74°15'	3815	149	82 (55)	67 (45)
2	16.04.1985	07°30'	75°30'	2765	194	109 (56)	85 (44)
3	17.04.1985	07°31'	76°47'	1670	146	83 (57)	63 (43)
4	10.06.1985	12°30'	81°10'	3403	57	32 (56)	25 (44)
5	19.12.1985	16°00'	72°40'	504	109	57 (52)	52 (48)
6	08.05.1986	15°00'	87°24'	2937	48	27 (56)	21 (44)
7	11.06.1986	06°55'	86°00'	3815	49	27 (55)	22 (45)
8	11.06.1986	07°00'	85°00'	385	40	22 (55)	18 (45)

TABLE 20. Distribution of sex ratios of C. (G.) smithii in pelagic trawl collections.

Sl. No.	Date	Position		Depth (m)	Sample size (N)	No. of Males (%)	No. of Females (%)
		Latitude (N)	Longitude (E)				
1.	02.08.1985	06°02.7'	75°04.2'	2391	75	42 (56)	33 (44)
2.	11.08.1985	10°58'	73°00'	2141	50	27 (54)	23 (46)
3.	12.08.1985	10°51'	74°46'	2141	52	33 (63)	19* (37)
4.	04.01.1986	08°00'	71°00'	4158	25	19 (76)	06* (24)
5.	19.01.1986	11°00'	72°00'	1870	35	20 (57)	15 (43)
6.	14.01.1986	08°00'	72°10'	3094	76	37 (49)	39 (51)
7.	18.12.1986	10°30'	81°30'	1050	45	31 (69)	14* (31)
8.	19.12.1986	12°36'	82°31'	3423	54	32 (59)	22 (41)
9.	20.12.1986	14°00'	82°00'	3320	43	27 (63)	16* (37)
10.	21.12.1986	11°00'	80°10'	75	33	32 (97)	01* (03)
11.	22.12.1986	12°00'	80°40'	2643	32	22 (69)	10* (31)

* Significant at 0.01% level.

TABLE 21. Distribution of sex ratios of *C. (G.) Smithii* in bottom trawl collections.

Sl. No.	Date	Position		Depth (m)	Sample size (N)	No. of males (%)	No. of females (%)
		Latitude (N)	Longitude (E)				
1	22.03.1986	12°41'	80°27'	86	56	31 (55)	25 (45)
2	23.03.1986	13°55'	80°23'	60	52	52 (100)	0* (-)
3	02.01.1988	08°35'	76°15'	273	40	34 (85)	06* (15)
4	06.01.1988	09°04'	75°41'	260	56	53 (95)	03* (05)
5	06.01.1988	09°04'	75°45'	299	61	44 (72)	17* (28)
6	08.01.1988	09°18'	75°55'	239	42	30 (71)	12* (29)
7	09.01.1988	09°19'	75°55'	320	54	14 (26)	40* (74)
8	27.08.1988	07°30'	77°30'	88	49	29 (59)	20 (41)
9	25.02.1990	13°23'	80°21'	60	82	44 (54)	38 (46)

* Significant at 0.01 % level

In order to understand the variation in sex ratio by size groups, the size frequency data have been analysed sex wise and sex ratio worked for each of the size classes separately for pelagic and benthic region (Table 22). In most of the size groups the males outnumbered females, the degree of disparity was maximum in the higher size groups beyond 51-55 mm cw in the pelagic as well as bottom population. The females outnumbered males in the size group 41-45 and 46-50 mm cw by 2-11% in the pelagic region and in the size groups 41-45 mm to 51-55 mm cw by 17%-22% in the benthic region. The smallest size group 11-15 mm cw showed a sex ratio of nearly 1:1.

LENGTH-WEIGHT RELATIONSHIP

The relationship between carapace width and weight of the crab was studied from 87 males over a size range of 48-72 mm and 97 females over a size range of 45-69 mm.

The regression equation (linear) for each of the sexes was found to be as follows.

$$\begin{aligned} \text{Male} &= \log w = -8.673 + 2.967 \log L. \\ &\quad (r = 0.985). \end{aligned}$$

$$\begin{aligned} \text{Female} &= \log w = -10.677 + 3.515 \log L. \\ &\quad (r = 0.946) \end{aligned}$$

or in the exponential form

$$\text{Male } w = 0.00017114 L^{2.967}$$

$$\text{Female } w = 0.00002307 L^{3.515}$$

TABLE 22. Sizewise sex ratios (%) of C. (G.) smithii in the pelagic and bottom collections.

Size Group (mm)	Pelagic region			Benthic region		
	Sample size (N)	Percentage		Sample size (N)	Percentage	
		Male	Female		Male	Female
11-15	327	49	51	-	-	-
16-20	367	61	39	-	-	-
21-25	33	70	30	-	-	-
26-30	18	64	36	-	-	-
31-35	46	61	39	1	100	0
36-40	43	58	42	4	50	50
41-45	102	48	52	21	33	67
46-50	109	39	61	71	28	72
51-55	102	55	45	156	32	68
56-60	105	72	28	115	87	13
61-65	64	95	05	55	98	02
66-70	30	96	04	13	92	08
71-75	6	100	0	2	100	0

BREEDING POPULATION

It has been noticed in the previous chapter that the female crab attains maturity at 50% level when it is 48.7 mm cw. In order to study the abundance of breeding population in the two different ecological region viz. pelagic and benthic realms, the relevant data were analysed separately. From the pelagic region examination of a total of 591 female crabs in the size range 11 to 69 mm cw collected from the IKMT and pelagic trawl catches showed absolutely no crabs in maturity or berried condition. The ovaries of all the animals on dissection were found to be in immature stage. Out of 591 females studied as many as 78 crabs were above the minimum size of maturity at 50% level (48.7 mm cw) which did not show sign of maturity externally or internally. The condition of vulva of these crabs on closer examination have proved to be virgin (Plate 13).

Breeding population was observed only at the bottom. Out of a total of 438 crabs studied from the bottom trawl collections 190 were females. Among these females 83% were found to be ovigerous with eggs in different stages of development. The size of ovigerous crabs ranged from 45-60 mm cw and the maximum number of ovigerous animals belonged to the size group 51-55 cw. During this ovigerous stage, examination of the ovary indicated rematuration as mentioned elsewhere thereby indicating continuous ovarian development. Examining the samples collected on different occasions from the southwest coast it is found that the maximum percentage of ovigerous crabs (50-90%) were recorded from the relatively deeper waters beyond the 100 m line. Two samples taken within 100 m line however showed very low percentage of berried crabs

(15%). The non-berried crabs of these samples showed ovaries in early/late maturing stages. In the case of crabs studied from higher depths beyond 100 m lines majority of the non-ovigerous crabs showed ovaries in late maturing or ripe stage. The sample collected from the east coast at 60 m depth off Madras contained 93% of crabs in ovigerous condition.

D I S C U S S I O N

From the available information on the distribution of C. (G.) smithii in Indian ocean it may be seen that it is a widely distributed species in the region occupying the neritic as well as oceanic provinces of the pelagic realm and the outer continental shelf and upper continental slope (Stephenson, 1967, 1972; Silas, 1969; Suseelan et al., 1990; Sulochanan et al., 1991). From the seas around India Silas (1969) and Sulochanan et al. (1991) have indicated the occurrence of this species in sizeable quantities upto Lat. 16°00'N along the west coast and upto Lat. 19°00'N along the east coast with maximum concentration off Kerala, Karnataka and Tamil Nadu coasts. The present study of Sagar Sampada material indicates that this crab enjoys a wider distribution in Indian waters extending from Cape Comorin to Dwaraka on the west coast and almost throughout the east coast from Cape Comorin to Paradip. In the bottom the species is encountered at depths between 88 and 356 m on the west coast and between 60 and 306 m on the east coast. It is found to occupy the upper column of the ocean upto about 600 m (lower limit of pelagic sampling) over the entire Eastern Arabian Sea and most areas of the Bay of Bengal including Andaman waters. The areas of abundance of

the species at the bottom or in the pelagic realm varied considerably in different regions of the Arabian sea and Bay of Bengal.

Abundance at bottom

Though the crab was encountered through out the west coast in bottom trawl operations, dense concentrations were observed only in the southwest coast between Mangalore and Cape Comorin. Even in this region, the catch per haul varied considerably in different areas sampled. The maximum catch amounting to 1100-1740 kg/hour was recorded in two hauls taken off Alleppey. Analysis of catch in relation to depth indicates maximum concentration of the resource in 151-200 m Mangalore-Ponnani area and 201-300 m in Cape Comorin - Cochin area including the "Quilon bank" mentioned by Menon (1968). During the exploratory surveys conducted by R/V. Varuna, Silas (1969) recorded maximum concentration of the species between Lat. 11°00' and 13°00'N (Ponnani-Mangalore area) particularly in the depth zone (101-179 m) from where a maximum catch of 3500 kg of crab was recorded in a single haul at 142 m depth. The exploratory surveys of the Fishery Survey of India (Sulochanan, et al., 1991) showed maximum concentration of the crab at Lat. 11°00'-12°00'N (Ponnani-Cannanore area) and Lat. 09°00'-10°00'N (Quilon-Cochin area) at 101-200 m depthzone. The maximum catch recorded during these surveys amounted to 1240 kg/hour and it was recorded from the southern area.

The limited trawling operations conducted by Sagar Sampada in the Gulf of Mannar area did not prove any positive hauls. Sulochanan

et al. (1991), however, recorded an average catch rate of 46.59 kg/hr in this area for the FSI vessels.

Along the eastcoast, though a wide coverage of bottom sampling has been made by Sagar Sampada indicating the occurrence of C. (G.) smithii throughout the coast, the areas of large concentration of the crab were highly localized and restricted to certain pockets off Pt. Calimere Madras, Visakhapatnam and Gopalpur. Catch rates recorded in these productive grounds were also comparatively less than in the westcoast except off Madras, where a large haul of 500 kg of crab was taken at a very shallow depth of 60 m. The Fishery Survey of India has also indicated a poor standing stock for the crab along this coast, indicating a lesser resource of this crab along the east coast.

The foregoing analysis of the distribution pattern of the species on the shelf edge and upper continental slope would reveal that crab occupies an area characterized by low temperature and low dissolved oxygen for the bottom waters. According to Silas (1969) the outer continental shelf waters of the southwest coast of India beyond 100 m depth has a temperature ranging 15.5-23.0°C, salinity ranging 35.0-35.8 ppt and dissolved oxygen ranging 0.5-3.0 ml/L. On the upper continental slope upto 400 m depth the temperature ranged 9.0-18°C, salinity 35.0-35.2 ppt and dissolved oxygen 0.5-1.0 ml /L. From this it would appear that the temperature and dissolved oxygen at bottom changes drastically with the increasing depth while the salinity remains uniformly high.

Variations in the distribution and abundance of deep-sea crab have also been reported from other parts of world. The Geryonid crab Chaceon

(=Geryon) quinquedens is an important deep-sea crab contributing to commercial fishery in the western region of North and South Atlantic (Wigley et al., 1975). This species, known to occupy a wide range of depths between 40 and 2,155 m (Rathbun, 1937), is mainly an inhabitant of the bathyal zone (Wigley et al., 1975). In the Northwest Atlantic it is found in low concentration in relatively shallow waters, most commonly at intermediate depth (320-412 m) and sparsely in still deeper waters between Maryland and Eastern Georges Bank. (Wigley et al., 1975). Schroeder (1955, 1959) indicated that this crab is abundant at depths ranging between 275 and 750 m along the coast of Novascotia to Virginia. The related species C. fenneri enjoys a bathymetric distribution between 300 and 810 m in the same region of Atlantic ocean. Maximum abundance of this species is found between 450 and 550 m (Wenner et al., 1987). C. maritae, another deep-water crab found along the West African coast, has a bathymetric distribution extending from 350 and 1000 m depth but a commercial fishery exists for the species mainly at a depth of 600-700 m (Beyers and Wilke, 1980, Melville-Smith, 1985).

Many authors have attempted to correlate the variations in geographic and bathymetric abundance of the red crab C. quinquedens. Schroeder (1959) reported that temperature is not the single factor determining the geographic and bathymetric variations in distribution of the red crab population. Wigley et al. (1975) also arrived at the same conclusion. Though these authors could observe a definite trend of highest densities of the crab at a particular range of temperature (5°C-8°C) they could not correlate its abundance with water temperature, as substantially lower

densities of the crab were also observed in both warmer and colder temperature conditions. As the crab tolerated a temperature range of 3.1-12.7°C prevailing in a wide range of bottom depths and the eurythermic tolerance combined with natural upslope migration from deep colder water to shallower warmer water with increase in size and age, these authors suggested that the direct effect of water temperature on crab distribution was subordinate to other environmental and biotic influence.

While discussing the variation in depth distribution of C. fenneri, Wenner et al. (1987) tried to correlate the crab abundance with bottom sediment type and found that the golden crabs were abundant wherever the substrate contained a mixture of silt-clay and foraminiferan shells. Melville-Smith (1985) could not find any obvious reasons for the difference in the densities of C. maritae along the Southwest African coast. This author concluded that the depth-related difference in distribution might be due to fishing pressure as well as biological or hydrographical factors or due to combined effect of all these.

The bathymetric variations in the abundance of C. (G.) smithii along the southwest coast of India is examined in relation to temperature and substratum conditions of the trawling grounds. Studying the environmental characteristics of the deep-sea trawling grounds of this coast, Suseelan (1984) indicated that the outer continental shelf between 100 and 200 m depth had a temperature range of about 14 to 22°C with no recognizable variation between the southern and northern areas of about 10.5°C-16°C, the upper continental slope (200-450 m depth) also showed

little variation in this parameter between the southern and northern areas studied. Mass occurrence of this crab at rather shallower depth (60 m) on the Southeast coast of India during the present study reveals its tolerance of wide range of temperature conditions. From this it can be inferred that the crab abundance cannot be correlated with the bottom temperature alone. The bottom condition was found to be an important variable factor in the different trawling grounds of the Southwest coast. A perusal of available information (John and Kurian, 1959; Silas, 1969) would show that distinct variations occur in the nature of bottom conditions of the different areas of the coast. The outer continental shelf north of Cochin is reported to be of fine mud and sand while the same depth region of most of the southern areas are rocky. The bottom condition of the upper continental slope is generally soft due to fine grey mud composed of foraminiferan shells especially off Quilon and Alleppey. The abundance of crab thus appears to have a close relationship with the soft muddy substratum prevailing in the outer continental shelf north of Cochin and the upper continental slope south of Cochin. This observation is in agreement with that of Wenner et al. (1987) who noticed that the abundance of the Golden crab C. fenneri was closely related to a substratum characterized by a mixture of silt - clay and foraminiferan shell.

Abundance in pelagic region

Examination of several samples of IKMT and pelagic trawl catches of FORV Sagar Sampada during the present study has shown that C. (G.) smithii is a common occupant of the pelagic realm of the entire EEZ

and contiguous waters of the Indian ocean. The extensive distribution of the species in the ocean is also apparent from the widespread collections of the species from several localities of the east African coast, western Arabian Sea and in the Bay of Bengal reported by previous workers (Macleay 1838; Milne Edwards, 1861; Leene and Buitendijk, 1949; Sankarankutty and Rangarajan, 1962; Della Croce and Holthuis, 1965; Stephenson and Rees, 1967b; Silas, 1969; Mohammed and Suseelan, 1973; Daniel and Chakrapani, 1984; Sulochanan et al., 1991; Zamorv et al., 1991). The crabs in the pelagic region are found to be abundantly represented by younger as well as adult stages throughout the region. The present data has also indicated that the swarms of the crab including juvenile stages appeared rather suddenly at certain stations but did not continue to occur there in the same magnitude for long period, thereby indicating sporadic nature of swarming, Daniel and Chakrapani (1984) reported dense occurrence of zoea, megalopa and instar stages of the species in the Northwest Arabian sea and inshore waters of Madras coast from plankton and Neuston collections. The present study has revealed that the juvenile stages of this crab are important component of the pelagic communities occupying the Deep Scattering Layers of both the Arabian Sea and the Bay of Bengal. In the Arabian Sea, the areas of dense concentration are more in the neritic province on the northwest coast and in the neritic as well as oceanic waters on the southwest coast. In the latter region, the water around Lakshadweep Islands are densely occupied by these stages. In the Bay of Bengal, young crabs are sparsely distributed in the DSL, the maximum being observed in the vicinity of Madras. The occurrence of maximum numbers of young crabs off Madras is in support of the findings

of Daniel and Chakrapani (1984) who reported the same stages in appreciable numbers in the inshore waters of this coast.

Data on pelagic trawls operations also showed existence of a rich population of this crab represented by adults and subadults. As in the case of smaller crabs observed in the Deep Scattering Layers, advanced life stages of this species also enjoy a wide distribution in the study area, occurring both in the eastern Arabian sea as well as the Bay of Bengal. In the eastern Arabian sea, it has a continuous distribution extending throughout the west coast of India. Most of the population is found to occupy the oceanic waters. As observed in the case of juvenile crabs, the larger crab population sampled by the pelagic trawl also showed maximum density in the southwest coast and around the Lakshadweep islands. In the Bay of Bengal their distribution is found to be patchy and comparatively less abundant than in the Arabian Sea. The oceanic waters off Madras again proved to be inhabited by a rich population of this species. In the Andaman waters swarms of this species are observed for the first time. Though no serious effort has been made to study the quantitative distribution of crab population by any earlier workers in the eastern Arabian sea a few had made mention of the swarms and solitary occurrence of the crab in the surface and subsurface waters of the region (Sankarankutty and Rangarajan, 1962; Silas 1969; Daniel and Chakrapani, 1984). Most of these authors have also indicated that the pelagic occurrence of the crab is quite irregular as they appeared in large swarms suddenly and also

disappeared in quick succession from the pelagic habitat. The motivation for this peculiar nature in the pelagic distribution of the crab population is not fully understood.

Diverse opinions have been expressed regarding the changes in the pelagic distribution of the crab in the western Indian Ocean. Zamorov et al., (1991) report a seasonal migration of the crab from shelf waters to the pelagic realm when they are fed by yellow fin tuna. According to them, the crabs rise from the continental and islandshelves of the western tropical Indian ocean, travelling upto 100 miles offshore when the south west monsoon changes to the northeast one. The peak of migration is reached in September–November. The crabs, according to these authors as well as others (Losse, 1969; Daniel and Chakrapani, 1984; Zamorov et al., 1991) actively feed, grow and likely spawn during this period of pelagic existence. The present observations clearly indicate that in the case of this species the spawning does not take place in the pelagic realm. It is also believed by these authors that the larvae are probably transported by western currents to the shelf areas where they can settle. The crabs remain in the pelagic habitat until March, although their abundance apparently decrease from January. The present data however does not support the above conclusion with regard to the peak period of abundance of the crab in the offshore waters along this coast. A perusal of Table 10 would indicate that the maximum density of adult and subadult crabs obtained in the pelagic trawl was recorded during the southwest monsoon period with peak in June–July. Though relatively more number of pelagic trawling operations were conducted during the northeast monsoon period

between September and December, the crab abundance was considerably low.

A comparison of the quantitative distribution of juvenile crabs in the DSL with that of subadults and adults in the pelagic realm of eastern Arabian Sea (Figs. 10, 12) would reveal that the juvenile stages of crabs are more concentrated in the neritic province than in the oceanic province. On the contrary, the subadult and adult population is relatively more abundant in the offshore/oceanic region (Table 10 Figs. 10,12). This would suggest a possible drifting of crabs from the shelf waters to oceanic areas as the crabs grow to subadults and adults. Zamorov et al. (1991) reported an opposite pattern of drifting in which the larvae get shifted to shelf waters presumably from the oceanic region through western currents. This may probably be on the assumption that the reproduction and larval development are taking place in the oceanic waters for which supporting evidences are lacking in the present study.

Though brachyuran crabs, as a rule, are bottom dwelling animals in their adulthood, instances of pelagic existances of the adults and subadults have been reported in few species such as Varuna litterata (Fabricius) Polybius henslowi (Leach), Portunus affinis (Faxon) and Euphylax dovii Stimpson. V. litterata, a member of family grapsidae, is known to drift along with floating objects in the coastal waters of India (Sankarankutty and Rangarajan 1962). Among the swimming crabs of family Portunidae, P. affinis and E. dovii are reported to exhibit large scale swarming in the surface waters of eastern tropical pacific (Faxon, 1893; Garth, 1946; Jerde, 1967) and P. henslowi in the eastern Atlantic (Clark, 1909;

Blass, 1955; Bourdon, 1965; Della Croce, 1961; Allen, 1968). The distributional range of P. affinis and E. dovii in the eastern tropical Pacific surface waters extends as far as about 200 miles from the shore for the former and 400 miles for the latter species (Jerde, 1967). Young P. affinis were found to occur more than 100 miles offshore. Jerde (1967) reports that P. affinis occurred commonly in offshore waters from Cape Corrientes, Mexico to the Gulf of Panama. In cooler years when surface temperature were lower this species was encountered in the stomach of Skipjack tuna apparently indicating a direct relationship for the abundance of the species with low temperature condition of the oceanic surface waters.

Available information on the surface temperature off the southwest coast of India (Rao et al., 1973) indicates that the southwest monsoon period is characterized by the lowest temperature regime (25.3°C). The abundance of adult and subadult population of C. (G.) smithii in the pelagic realm appears to have a positive relationship with the lower temperature.

Pelagic existence during the postmetamorphic phase has also been reported among galatheid crabs such as Munida gregaria and Pleuroncodes planipes. M. gregaria is restricted to the South Atlantic and South Pacific oceans in the southern hemisphere (Lagerburg, 1906; Matthews, 1932; Rayner, 1935) Benthic individuals of this species have been reported to occur in abundance in 25-115 m depth off East Falkland islands and New Zealand (Thomson, 1898). Pelagic population of the species has been observed in large numbers either close to the land, over the continental shelf or over oceanic depths at some hundreds of miles from the land

in the South Pacific waters (Matthews, 1932; Longhurst, 1967).

Pelagic crab is morphologically distinct from the benthic individuals, the important distinguishing characters being a highly flattened, foliaceous 3rd maxilliped with filtering device. Besides, the exoskeleton of the crab is also found to be lighter and less spinous than the benthic individuals. (Matthews, 1932; Rayner, 1935; Williams, 1973, 1980). Animals with benthic characters were considered to be permanent members of the benthos, a typical life style for adult galatheids (Williams, 1980). It is also reported that the pelagic individuals are comparatively smaller in size than the benthic crabs.

Stray instances of the occurrence of larger crabs in ovigerous state have also been recorded for this species (Matthews, 1932; Williams, 1980). P. planipes is represented by both the benthic and pelagic phases in the Gulf of California (Longhurst, 1967) and between Costarica and Mexico on the outershelf and upper continental slope (Gulland, 1971). According to Boyd (1967), the pelagic and benthic phases are morphologically identical, the length frequency distribution of the benthic animals overlapping with that of the pelagic stocks, and based on this point he suggested that there could be an alternation of individuals between the two habitats. The author (Boyd, 1967) concluded that this species could be either benthic or pelagic and that there was diurnal exchange between the two habitats. According to Longhurst (1967) the larval forms of P. planipes are flushed out of Baja California centres of spawning into oceanic areas through offshore drift. The present study of C. (G.)

smithii indicates from the abundance of benthic breeding population restricted to the outer shelf and upper continental slope and the relatively greater concentration of juvenile stages in the neritic province on the west coast of India, that the early pelagic life stages of the species may get drifted from the nearshore waters to the oceanic areas as observed by Jerde (1967) in the case of P. affinis and Longhurst (1967) in the case of P. planipes.

Day and Night Variation in abundance

Comparatively larger catches of epipelagic and mesopelagic organisms in the DSL during night time than during day time has been reported by several workers from different parts of the world (Tucker, 1951; Aron, 1962; King and Iverson, 1962; Percy and Laurs, 1966). Some of them attributed this to visual avoidance of gear during day time. Studying the DSL population of the euphausiids during the Fishery Oceanographic cruises of FORV Sagar Sampada Mathew and Natarajan (1990) also noticed a remarkable increase of euphausiids during night time. The present study has shown that all the life stages of C. (G.) smithii including juveniles subadults and adults (Tables 16, 17) occur in the pelagic realm in appreciable numbers during night as well as day time. The subadults and adult crabs shared large swarming during day time also as evident from their heavy catches in the pelagic trawl between Quilon and Cape Comorin during the Southwest monsoon period (Table 17). This observation is in contrast to the findings of earlier workers (Della Croce and Holthuis, 1965, Silas, 1969; Daniel and Chakrapani 1984) who report that this species perform large-scale swarming in the surface and subsurface waters after sunset

and before sunrise.

Size distribution

A wide range of size of the crab varying between 11 and 72 mm cw has been noticed during the present study. According to the available information maximum size so far recorded for the species is 65 mm (Della Croce and Holthuis, 1965). The pattern of size distribution observed in the different nets during the surveys of Sagar Sampada brings out the fact that the DSL population is predominantly constituted by juveniles in the size range 11-20 mm cw. It is also noteworthy that in most of the rich collections of the IKMT, variation in size range was of very narrow limit and most of the rich collections were identical with regard to the size composition. Among juveniles of this size range, there is apparently no variation between the two sexes. Occurrence of juvenile crabs in the pelagic realm does not appear to be a common feature in brachyuran crabs and information on similar behaviour in other species of brachyura is extremely limited. Rice and Hartnoll (1983) reported few juvenile stages of the majid crab Dorhynchus thomsoni from the pelagic collections taken from oceanic waters of North Atlantic. These authors also quoted the observations of Hartnoll (1971) who came across pelagic occurrence of juveniles of some of the Pinnotherid species.

Daniel and Chakrapani (1984) doubtfully identified first instar stage of the species from the North Western Arabian Sea in appreciable numbers from the plankton and neuston collections. The rich collections of advanced

instar stages during the present cruises of Sagar Sampada would suggest that pelagic phase for juveniles is a common feature in the life history of C. (G.) smithii. Size frequency distribution of pelagic trawl samples shows that subadult and adult population with sizes ranging between 31 and 72 mm cw also have a life in pelagic realm at least partly, if not for the entire population of the species. The dominant size group for males is 51-65 mm cw while for females it is 41-60 mm cw. The absence of crabs smaller than 31 mm size may be due to the larger cod-end mesh size of pelagic trawl operated during the present survey.

The size frequency distribution of bottom trawl samples depicts a pattern dominated by adult-crabs larger than 40 mm cw. The subadult crabs smaller than this size were extremely rare (Fig. 19). It is also interesting to note that juvenile stages which were abundantly represented in the IKMT collection proved to be totally absent in bottom trawls the minimum size recorded being 31 mm cw. Studying the deep-water crustaceans taken during the resource surveys of Sagar Sampada along the Kerala coast Suseelan, et al. (1990) recorded a size range of 42-72 mm cw for this species in bottom trawl during the 40th cruise when the cod-end mesh size of the net used was 22 mm, which is closer to the mesh size of the IKMT. It was also observed quite often that the bottom trawl collections of Sagar Sampada included other crab species measuring more or less the same size (or some times smaller size) as the juvenile C. (G.) smithii caught in the IKMT. All these observations point to the fact that juvenile crabs of C. (G.) smithii below 20 mm cw may not have a benthic life as in the case of most of the species of Brachyura.

Comparatively large size are recorded for males than females and this is in confirmation with the general pattern in most of the portunid crabs. Silas (1969) also recorded a greater size for males than females for this species. Significant difference in size between male and female have also been observed in C. opilio (Katoh et al., 1956; Pereyra, 1966; Haefner, 1978; Sheeba, 1988; Padayatti, 1990; Wenner et al., 1987). According to Katoh et al. (1956) the disparity in size between the two sexes is caused by the variation in growth rates. They conjecture that the growth in female crabs ceases with the attainment of maturity while the males continues to moult, and grow even after attainment of maturity.

Sex ratio

Distribution of sex ratio by size groups of C. (G.) smithii clearly indicates that males were more numerous than females in most of the size groups except in the very early juvenile stage of 11-15 mm cw in which the male-female ratio remained almost equal and the size around which the animals attains maturity (41-55 mm cw) in which the females dominated at various levels. The sex ratio beyond 51-55 mm size was increasingly in favour of males in all the successive size groups, reaching the level of 100% in the largest size group of 71-75 mm. 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). Wenner (1972) opined that sex ratio in most of the marine crustacea is a function of size and that an appreciable deviation from 1:1 ratio may be widespread among these organisms. The same author has also indicated five possible factors affecting changes in sex ratio namely (1) growth rate

(2) longevity factor (3) sex reversal (4) differential mortality and (5) differential migration. In the present case it would appear that a 1:1 ratio between the sexes is noticed in the early stages of the life of the crab and there is deviation subsequently either in favour of males or females on account of one or more of the above factors. Since the different sexes are distinguishable at all the advanced size groups with well developed sexual characteristics internally as well as externally the possibilities of sex reversal may be ruled out. The present data is not adequate to attribute the sex disparities to differential mortality or differential growth rate. Longevity factor and differential migration can be taken as possible contributing factors for the differential distribution of the sexes noticed in this crab. A perusal of table 22 would indicate that the male crabs are likely to have a longer lifespan than the females as the larger size groups are represented mostly by this sex. It is quite possible that female mortality may be relatively more after reaching the reproductive age. Studying the population characteristics of deep sea pandalid prawn, Pandalus borealis Allen (1959) observed a high mortality rate for females during the spawning period. He estimated that 50% of the 18 months old prawn (Youngest-spawners) die at the time of egg laying. Dablstrom (1970) observed in the related species of P. jordani that the female mortality is high during or shortly after ovigerous period and consequently a steady decline in the number of female in the population of California coast. Drastic reduction in the number of female crab of C. (G.) smithii in the largest size group could also be caused by similar eventualities associated with breeding as the other pandalid prawns and the crabs have more or less similar reproductive

behaviour. Since, the data on hand reveals that most of the crabs above 50-55 mm cw taken at bottom are in breeding (ovigerous) stage and perhaps the animals may not survive for long period, incidence of mortality may be more for this population due to the less oxygenated cold water environment as compare to the more oxygenated and warmer coastal waters. Examination of sex distribution in the IKMT catches indicate that sexes are almost equally distributed in their juvenile phase. However in the pelagic as well as bottom trawl collections, considerable disparities have been observed in the sex distribution in some of the hauls which could be attributed to differential migration of adults and subadults. A scrutiny of sex distribution in selected samples of bottom trawl catch shown in Table 21 would reveal that in all the samples except one, the male dominated over females by 14-100%. In the case of a single sample taken at the deepest station with a bottom depth of 320 m, the females dominated the catch forming as much as 74% over the male population. Though a conclusive inference cannot be drawn from the single case it may be a pointer to the fact that females are relatively more abundant than males in the population with increase in depth, however more sampling is necessary to establish this fact. Silas (1969) pointed out that sexual segregation atleast during some season is suspected in this species as often only males or females appear in the trawl catch.

Distribution of Breeding population

Incidence of occurrence of crabs in the breeding phase in the pelagic and benthic catches of various gears operated by FORV Sagar

Sampada indicates that the pelagic population is entirely constituted by nonbreeding individuals which have not shown any indication of gonadal maturation, egg carriage or mating. Though many of the crabs of both sexes caught by pelagic trawl were close to the maximum sizes, the gonads remained only in the immature condition. The crabs in the various maturity stages and in ovigerous state were recorded only in the bottom trawl which would indicate that breeding of the species takes place actively at the bottom. It is interesting to note that among the female crabs recorded in the bottom trawl catches 83% were ovigerous and that the maximum breeding activity is noticed in relatively deeper waters beyond the 100 m line on the west coast. In the east coast it is observed that intensive breeding is also taking place in shallow waters. According to Della Croce and Holthuis (1965) this crab occupies extensive areas of the Western Indian Ocean where all the female crabs observed in the upper layers of the ocean were nonovigerous. Daniel and Chakrapani (1984) however suggest the possibility of breeding of the species in the pelagic phase of its life based on collection of larvae from the surface. Pelagic swarming and factors responsible for such behavioural pattern in brachyuran and anomuran crabs have been the subject of detailed investigations in some parts of the world in the recent past. The results of the present observation show that this peculiar behaviour of the strictly bottom dwelling crustaceans coming up to the pelagic realm is not connected with the reproductive cycle.

Studying the pelagic phase of portunid crab P. affinis in the eastern tropical Pacific, Jerde (1967) observed that none of the pelagic female

of the species was ovigerous. From this, the author expressed the doubt about the pelagic population of the species not having a period of benthic existence. In the light of this observation he concluded "it is possible that the pelagic P. affinis found far at sea over deep water are not part of the reproductive population. They may have developed from larvae that drifted out into sea and subsequently developed into young crabs where conditions are favourable". P. henslowi, another example of portunid showing swarming behaviour in the eastern Atlantic, is frequently met with in very large numbers at the surface of the sea in the oceanic region (Clark, 1909; Blass, 1955; Bourdon, 1965; Della Croce, 1961; Allen, 1968; where the shoals are reported to consist predominantly of adult male. But in contrast to the earlier species, this species appear to breed in the surface waters of the oceans since, the gonads of some crabs showed signs of advanced maturity in both sexes. Many of the females were found with sperm plug and rarely ovigerous females were also recorded during the pelagic phase. Based on this the authors inferred that mating may be the reason for their aggregation.

In galatheid crabs, M. gregaria and P. planipes breeding is reported to taking place mostly at the bottom of continental shelf. But the occurrence of maturing/ovigerous females have been reported in the pelagic phase also, leading to the conclusion that breeding of the species may take place in pelagic realms (Young, 1925). In the case of M. gregaria the studies of Williams (1980) based on data for over 10 years in the southern New Zealand waters have shown that the pelagic occurrence of the species in one year during the winter season was rather unusual in that some of the females were found for the first time to be berried,

pointing to the possibility of breeding of the species taking place in the pelagic phase also. However, during the present study of C. (G.) smithii there was absolutely no indication of maturing of gonads or mating during pelagic phase.

S U M M A R Y

S U M M A R Y

1. The thesis embodies the results of a detailed study of the taxonomy, biology, distribution and population characteristics of Charybdis (Goniohellenus) smithii in the Indian EEZ and contiguous waters based on material obtained from the fishery - Oceanographic surveys of FORV Sagar Sampada during 1985-1991.
2. Examination of several male and female specimens obtained from different regions of Indian coast has enabled to establish the identity of the species in Indian waters. The taxonomic features of the species studied for different life stages including juveniles, subadults and adults have shown little variation in the major distinguishing characters at different stages of growth. The species has also been recognized from a rarely occurring allied species C. (G.) omanesis not so far reported from Indian waters. The important diagnostic features of these two co-existing species are compared and discussed.
3. C. (G.) smithii is observed to occupy both pelagic and bottom habitats. While the pelagic phase is passed by all life stages including juveniles, subadults and adults, the benthic phase is passed by only subadult and adult crabs. The settlement of crab at bottom appears to take place in advanced juvenile stage of about 31 mm cw. All the life stages represented at bottom and in the pelagic environment exhibit swarming tendency.
4. The gross morphology anatomy and histology of the male and female reproductive systems have been described. The reproductive systems conforms to the general pattern in portunid crabs. Male reproductive system consists of paired tests, vasa deferentia, ejaculatory ducts

and external penes. The mature testis has the appearance of white convoluted tube which is sandwiched between the hypodermis of carapace and hepatopancreas. The vas deferens is differentiated into a coiled anterior vas deferens (AVD), a massive median vasdeferens (MVD) and a narrow posterior vas deferens (PVD).

5. The testis is incompletely divided into lobes, each lobe consisting of a group of seminiferous lobules. All the seminiferous lobules have access to seminiferous ducts. Spermatogenesis is initiated from the peripheral germinal zone of testis and it involves a progressive reduction of cytoplasm and condensation of chromatin in the developing cells.
6. Female reproductive system consists of paired ovaries, spermatheca and vagina. The 'H' shaped ovary is devoid of an interconnection at the posterior extremities and almost completely fills the body cavity in mature stage. Histologically the ovary shows a medially placed germinal zone consisting of oogonia and younger oocytes during early phase of maturation. These germinal cells get displaced towards the peripheral region of ovary as development progresses.
7. Oogenesis involves three broader phases 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 primary oocyte undergo rapid growth and attain a diameter of about $85\mu\text{m}$. In

vitellogenic phase the oocytes undergo further growth attaining a diameter of 374 μ m when the ooplasm become fully flooded with yolk granules. In mature ova nuclear material get completely dispersed in the cytoplasm.

8. Ovarian maturation is accompanied by distinct colour changes and increase in volume of ovary. Based on colour and size of ovary and changes in GSI five maturity stages were recognized, namely immature, early maturing, late maturing, ripe and spent. The different maturity stages are described.
9. The size at first maturity at 50% level for females is found to be 48.7 mm cw. The smallest berried female encountered during the study however measured 45 mm cw.
10. Though the adult crabs occupy both pelagic and bottom habitats breeding is found to take place only at the bottom. From the condition of the ovary in ovigerous crabs it is also inferred that the crab breeds more than once in ^{its} life time.
11. The species appears to breed throughout the year with peak breeding activities during non monsoon period on the southwest coast.
12. In ovigerous crabs the fertilized eggs undergo a series of developmental stages involving change of shape and colour and increase in size. The newly acquired berry is reddish orange in colour which changes to light yellow and finally to deep brown or black.

The total number of eggs in a berry ranged from 1343 to 42,209 with a mean number of 16,168.

13. Food and feeding habits of different life stages of the crab have been studied based on stomach content analysis of 283 specimens. During the pelagic existence juvenile and subadult crabs feed more actively than the benthic adult crabs. The food consists of a wide variety of invertebrates and myctophid fishes. The most highly preferred food items are pelagic shrimps, crabs and foraminiferans for juveniles, myctophids and decapod crustaceans other than shrimps for subadults and crabs for adults.
14. A pronounced cannibalistic tendency has been observed in the crab particularly among juveniles.
15. The proximate composition of crab meat has been studied for adult males. The protein content of meat varied from 59.8 to 71.1% dry weight, lipid content from 6 to 8% and carbohydrate content from 1.4 to 9.8%. The meat recovery rate worked out 12.23 to 18.5% of bodyweight and the water content of meat ranged from 86.05 to 89.60%.
16. A detailed study of the spatial distribution and abundance of the species in the pelagic and bottom habitats in the Indian EEZ and contiguous waters upto 05°00'N has been attempted based on the results of 433 Isaacs-Kidd Midwater trawl operations, 334 pelagic

trawl operations ^{and} 445 bottom trawl operations conducted by FORV Sagar Sampada. A detailed study of the catches of 108 IKMT operations, 72 pelagic trawl operations ^{and} 42 bottom trawl operations conducted by FORV Sagar Sampada has been attempted and the distribution and abundance of the crab mapped out for the regions upto 05°00'N.

17. The species enjoys a wide distribution in Indian waters extending from Cape Comorin to Dwaraka on the west coast and almost throughout east coast from Cape Comorin to Paradweep. The bathymetric distribution extends from 88 to 356 m on the west coast and 60 to 306 m on the east coast. The crab is found to occupy the upper column of the ocean upto about 600 m (the lower limit of IKMT coverage) over the entire eastern Arabian Sea and most areas of the Bay of Bengal including Andaman Waters.
18. The benthic population is found in maximum concentration along the southwest coast between Mangalore and Cape Comorin, with the highest catch rates of 1100-1740 kg/hour of trawling recorded off Alleppey. The depth zones 151-200 m off Mangalore to Ponnani coast and 201-300 m off Cape Comorin to Cochin coast proved to be most productive for the species.
19. In the pelagic region, the crab is represented almost throughout the study area. Its maximum concentration is observed to be in the neritic region on the northwest coast and neritic as well

as oceanic region including Lakshadweep in the southwest coast. In the case of adult and subadult crabs occupying the pelagic environment, occurrence of swarms, which was sporadic in nature appears to have a positive correlation with cooler surface temperature of water, particularly during monsoon period.

20. Day and night variation in abundance of the crab in the pelagic environment is described. While adult and subadult crabs do not exhibit any marked variation in their abundance between day and night hours, the juvenile population in the DSL is found to be relatively more abundant during night than during day time.
21. The population characteristics such as size frequency distribution, sex ratio and breeding stock are described. The size of the crab in all the three gears studied range between 11 and 72 mm cw. The predominant size group noticed are 11-20 mm cw for IKMT, 41-65 mm cw for pelagic trawl and 46-65 mm cw for bottom trawl catches. Males are slightly larger than females.
22. Though all the life stages are represented in the pelagic environment, juveniles below 31 mm cw are not encountered at the bottom.
23. Distribution of sex ratios shows almost equal proportion of both sexes in the juvenile population while in most of the advanced size groups, preponderance of male over female is noticed in the pelagic as well as bottom habitats.
24. The crab population occupying the pelagic realm are found to be exclusively in non-breeding phase while breeding stock is observed only at the bottom.

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A P P E N D I X

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1. Preliminary observations on the distribution and abundance of the swarming crab Charybdis (Goniohellenus) smithii Macleay in the Deep Scattering Layers along the west coast of India

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PRELIMINARY OBSERVATIONS ON THE DISTRIBUTION AND ABUNDANCE OF THE SWARMING CRAB *CHARYBDIS (GONIOHELLENUS) SMITHII* MACLEAY IN THE DEEP SCATTERING LAYERS ALONG THE WEST COAST OF INDIA

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ABSTRACT

Results of a preliminary study of the distribution and abundance of the swarming crab *Charybdis (Goniohellenus) smithii* Macleay in the Deep Scattering Layers on the west coast of India are presented based on the analysis of 244 IKMT samples collected by FORV *Sagar Sampada* during February, 1985 to January, 1986. The swarming crab is found to exist throughout the west coast of India as against its known distributional limit in the north upto Bhatkal in Karnataka coast. Maximum density was observed along the southwest coast. The DSL population included all life stages of the crab such as zoea, megalopa, juvenile, subadult and adult, of which juveniles in the size range 12-20 mm carapace width dominated.

INTRODUCTION

The swarming crab *Charybdis (Goniohellenus) smithii* Macleay is an endemic species to the Indian Ocean where it has been reported from the Arabian Sea and off Southeast Africa as *Charybdis smithii* Macleay and *Charybdis (G.) edwardsi* Leene and Buitendijk (Della Croce and Holthuis, 1965; Sankarankutty and Rangarajan, 1962; Silas, 1969; Mohamed and Suseelan, 1973). Recently it has also been encountered in the Bay of Bengal during the fishery-oceanographic cruises of FORV *Sagar Sampada*. The correct systematic position of the species was ascertained only recently in an exhaustive revision of the portunid crabs by Stephenson (1972).

In Indian waters *Charybdis (G.) smithii* is considered to be a potentially important deep sea crab occupying the outer shelf and upper continental slope regions. It is often found swimming in large numbers in the oceanic waters. Considering the commercial prospects of this species, a detailed investigation on its biology and resource characteristics has been taken up recently based on the collections of FORV *Sagar Sampada*. In the present paper the results of a preliminary study of the distribution and abundance of this crab in the Deep Scattering Layers (DSL) off the west coast of India are given together with notes on the biology of the crab population occurring in the DSL. So far no study has been carried out on these aspects in any part of the world in general and in the Indian EEZ in particular.

MATERIAL AND METHODS

The material for the study was obtained from the Isaacs-Kidd Midwater Trawl (IKMT) collections taken by FORV *Sagar Sampada* during her fishery-oceanographic cruises from February, 1985 to January, 1986. The IKMT collections were taken in the Deep Scattering Layers which occupied depths upto about 600 meters from the surface. Each haul was of 30 minutes duration. A total of 244 IKMT samples were analysed for the crabs covering the entire west coast of India between Latitudes 07°00'N and 23°30'N and Longitudes 64°30'E and 77°00'E. The distribution of IKMT hauls in the study area is shown in Fig.1.

The crab population of each sample was completely sorted out and measurements of the carapace width (C.W.) were recorded sexwise to the nearest millimetre for all specimens except larval stages whose numerical abundance alone was recorded. A total of 1,542 specimens were measured comprising of both sexes. The measurements of carapace were grouped into 2 mm size classes sexwise for studying the size frequency distribution. Sexes were separated based on the shape of abdomen and the number of pleopods present in it.

OBSERVATIONS

Spatial distribution and abundance

Out of the 244 samples of mid water collection analysed from the entire west coast of India, 59 samples contained the swarming crab in varying

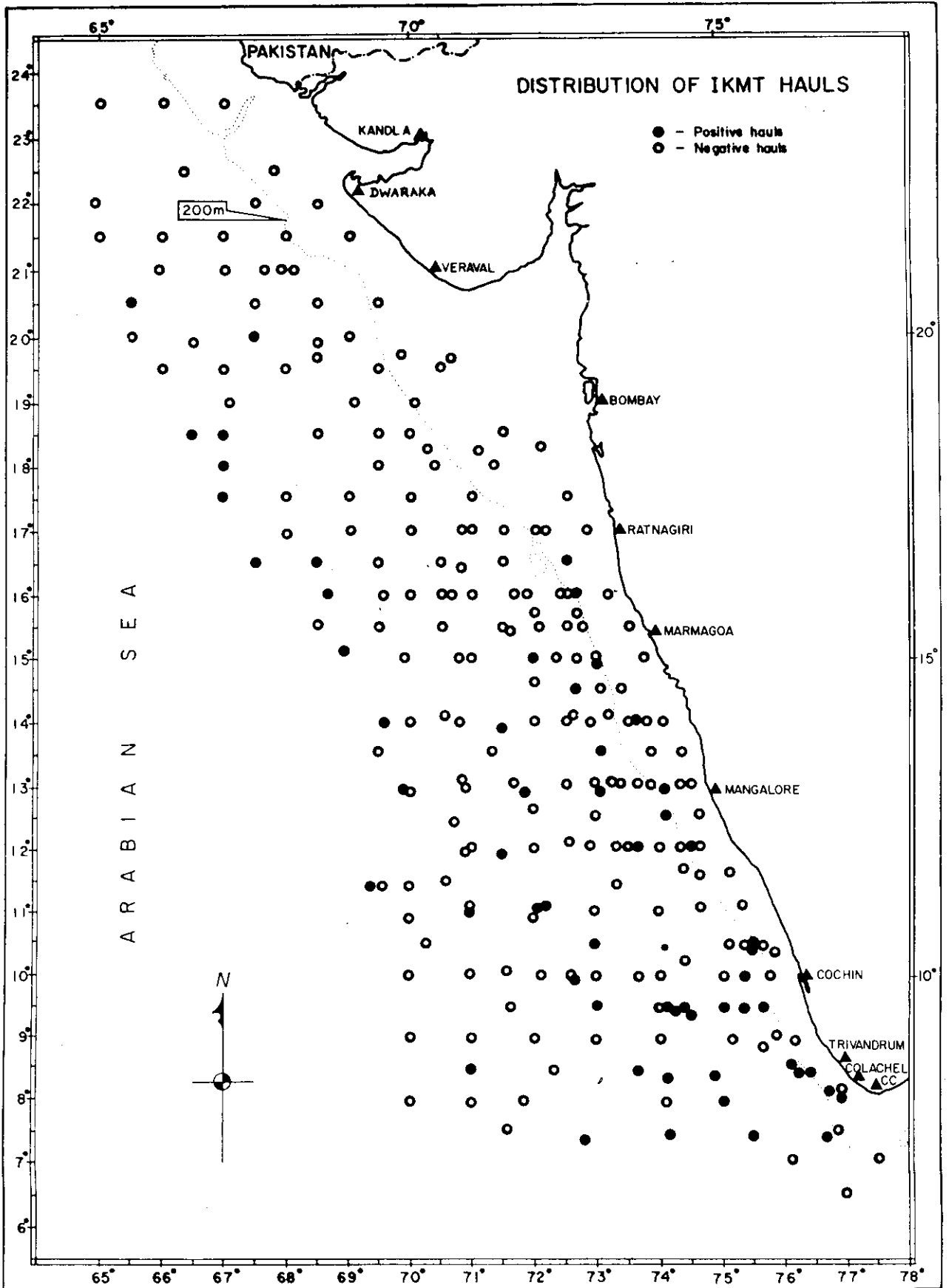


Fig. 1. Positions of IKMT hauls along the west coast of India.

numbers mixed with other pelagic groups. The species accounted for about 0.3% in the total DSL population in terms of number (Menon and Prabhadevi (1990), the maximum percentage being 81.3 recorded in the oceanic waters off Colachel on the southwest coast. The species is found to be occurring all along the west coast between Kanyakumari and Dwaraka (Fig. 2). In the positive hauls, the abundance of crab showed vast variations. Majority of these hauls yielded only stray specimens numbering less than 10 crabs per haul. Table 1 gives details of the samples containing more than 10 crabs per haul. In general, relatively more number of samples rich in crab population was recorded in the region between Ratnagiri and Mangalore, and Cochin and Kanyakumari, the maximum abundance having been observed off Trivandrum to Kanyakumari. Whenever rich catches were recorded, they were found to be sporadic and there was no consistency in the occurrence of crab in any particular region. The maximum number per haul amounted to 862 which was recorded off Colachel in the oceanic waters where the depth of the sea bottom was over 2,700 m.

Analysis of catch with reference to different depths of occurrence indicates that the species is distributed only in the outer continental shelf and in the oceanic waters. The minimum depth of the station from where the species has been encountered was 93 m at Lat. 18°30'N. The species showed its presence in varying densities within the shelf region upto about Ratnagiri, and beyond this it was encountered only in the oceanic waters far beyond the continental shelf.

Table 1. Catch details of *Charybdis (G.) smithii* in the IKMT collections yielding more than 10 crabs/haul

Sl. No.	Position		Depth at station (m)	Total number of crabs	Percentage in total biomass by number
	Lat. (N)	Long. (E)			
1.	08° 24'	72° 50'	1821	13	3.6
2.	07° 30'	75° 30'	2765	862	81.3
3.	07° 30'	76° 31'	1492	13	13.6
4.	07° 31'	76° 47'	1670	76	22.3
5.	08° 00'	76° 50'	99	17	21.2
6.	08° 30'	76° 12'	680	11	4.5
7.	09° 29'	74° 15'	2671	162	48.0
8.	11° 00'	72° 01'	1645	10	15.8
9.	14° 00'	66° 33'	4109	59	8.5
10.	14° 59'	73° 00'	229	37	14.8
11.	16° 00'	72° 40'	504	96	59.2
12.	16° 00'	68° 30'	3751	13	3.6

Seasonal distribution and abundance

The species was encountered in the samples throughout the year except during May and June when there was no IKMT collection. In order to study the seasonal variation in the abundance of crab in the DSL, the catch data have been pooled and averages taken for 3 seasons, namely, premonsoon (February-May), monsoon (June-September) and postmonsoon (October-January). It is found that the average number of crabs per haul varied significantly in different seasons of the year. The average catch rate per haul worked out to 64.79, 7.62 and 23.6 for premonsoon, monsoon and postmonsoon seasons respectively. The maximum number of crabs recorded in individual sample (862) was obtained during the premonsoon season (April).

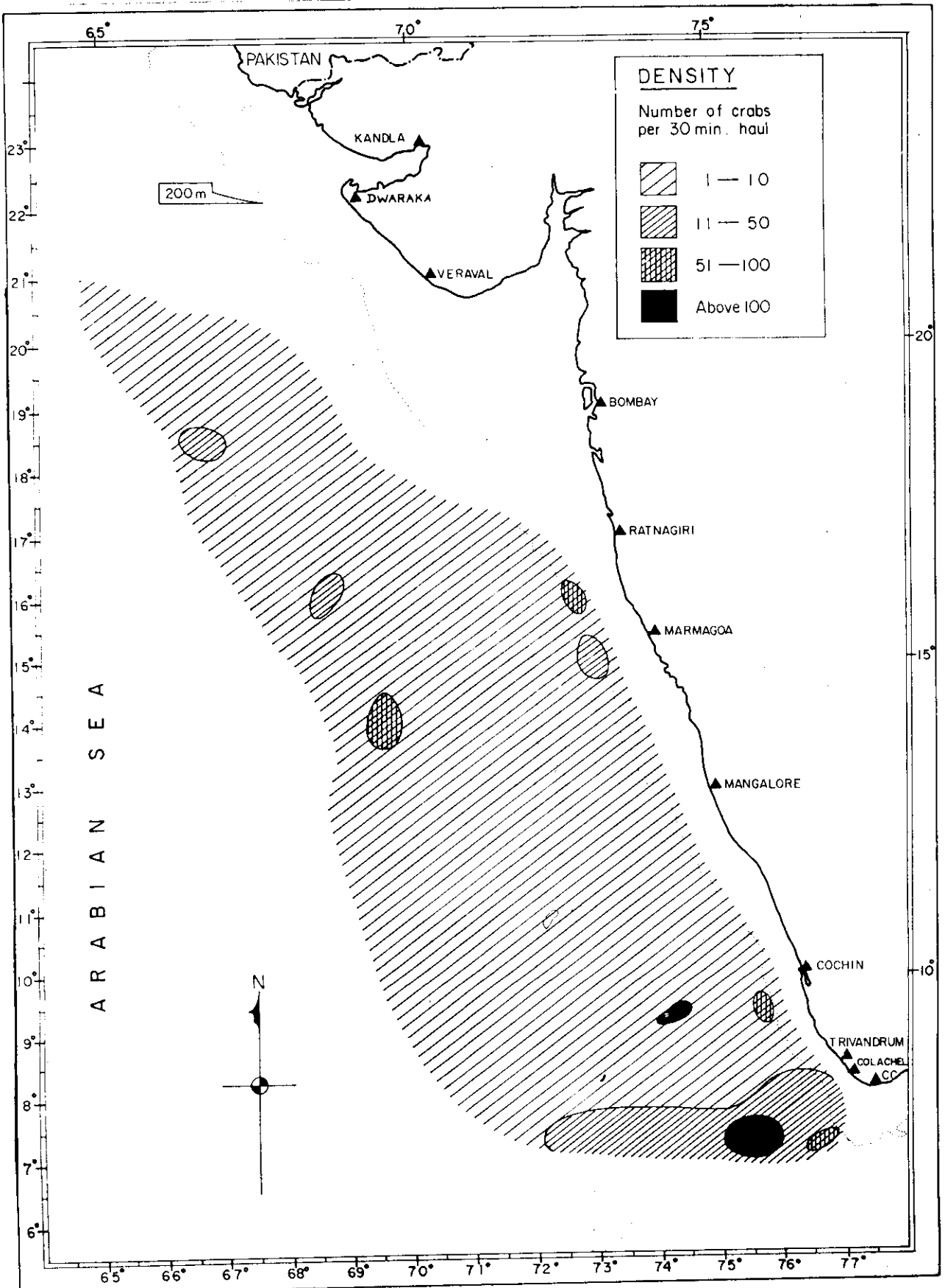
Diurnal variation in abundance

From the analysis of the data collected during day and night separately, it is seen that during night, crab abundance was very high occasionally, but such rich collections were rather sporadic. (Tables 2 & 3). In the day series of collection, however, wide fluctuations in the abundance of crab were not observed as in the night series of collection. The maximum number of crab per haul recorded during the day time was 68 as against 862 crabs in the night.

Biological observation

Size composition

The IKMT samples contained all the life stages of the swarming crab, viz. zoea, megalopa, juvenile, subadult and adult. The juveniles dominated in most of the samples examined. The size frequency data have been pooled together and plotted sexwise to study the general size composition of the species in the DSL (Fig. 3A). It is seen that there is not much variation in the size composition between the two sexes. The size range of the crab, after the megalopa stage, was from 12 to 64 mm C.W. for male and 12 to 60 mm C.W. for female. Juveniles measuring 12 to 20 mm C.W. formed the major component of the crab population for both sexes. In the advanced size groups, comprising of subadults and adults, individuals in the size range 34 to 54 mm C.W. were fairly common for both sexes. A study of size frequency distribution of some of the rich collections of the crab (Fig. 3 B-E) has shown that the richness of the crab samples was due to the abundance of juveniles in the size range 12 to 20 mm C.W.



388 Fig. 2. Distribution pattern and abundance of *C. (G.) smithii* in the Deep Scattering Layers on the west coast of India.

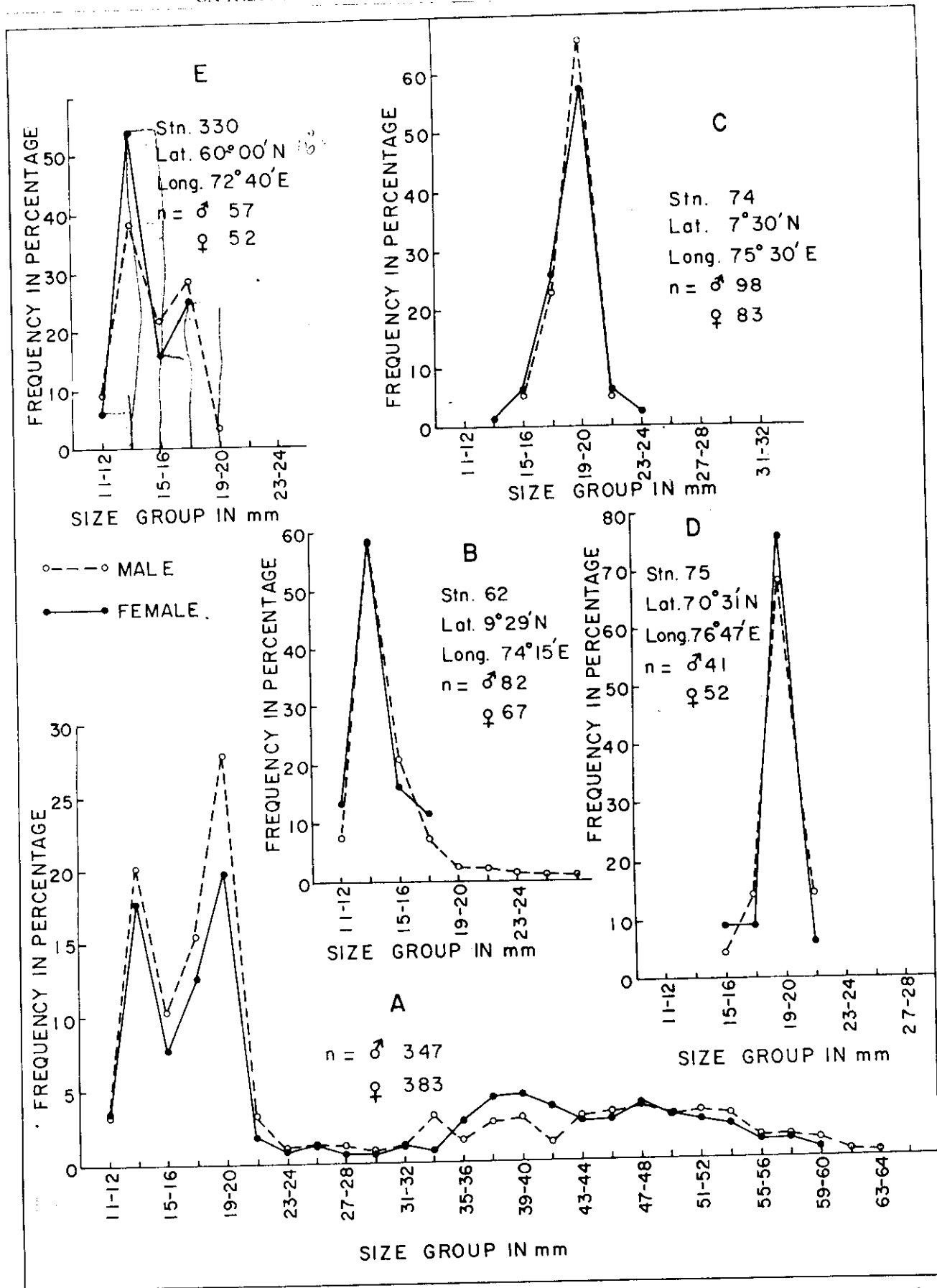


Fig. 3. Size distribution of *C. (G.) smithii*. A, pooled for all samples; B-E, individual samples rich in crab specimens.

TABLE 2. Catch details of *Charybdis (G.) smithii* in the day series of IKMT hauls arranged monthwise

Sl. No.	Month & year	Position		Total number of crabs
		Latitude E	Longitude E	
1.	Feb., 1985	11° 00'	71° 00'	1
2.	Mar., "	09° 30'	75° 32'	68
3.	" "	08° 21'	74° 54'	2
4.	" "	08° 30'	76° 12'	1
5.	Apr., "	07° 30'	74° 10'	9
6.	" "	09° 30'	73° 00'	1
7.	" "	08° 28'	74° 01'	1
8.	" "	09° 30'	75° 00'	3
9.	Jul., "	07° 30'	76° 38'	13
10.	" "	08° 00'	76° 50'	17
11.	" "	08° 14'	76° 38'	1
12.	" "	08° 30'	76° 26'	2
13.	" "	09° 30'	75° 24'	3
14.	" "	10° 00'	75° 25'	1
15.	Aug., "	11° 01'	72° 01'	10
16.	" "	12° 00'	74° 30'	3
17.	" "	12° 50'	69° 59'	4
18.	" "	14° 00'	60° 34'	59
19.	" "	14° 59'	73° 00'	37
20.	" "	15° 00'	72° 00'	4
21.	" "	16° 00'	68° 31'	13
22.	Sep., "	18° 00'	67° 00'	1
23.	" "	20° 00'	67° 30'	1
24.	Oct., "	17° 30'	67° 00'	1
25.	" "	14° 30'	72° 41'	1
26.	" "	13° 30'	73° 03'	1
27.	" "	16° 30'	67° 30'	2
28.	Jan., 1986	09° 00'	75° 00'	1

Sex ratio

In the total crab population, the percentage composition of male and female was 52 : 48, thereby showing a slight preponderance of males. In the larger size group comprising of subadults and adults, the overall sex ratio was 47 : 53.

REMARKS

Available information on the distribution pattern of the swarming crab along the west coast of India shows that the species occurs only in the south-west coast upto about Bhatkal in Karnataka coast (Silas, 1969). The present study reveals that the species enjoys a distribution throughout the west coast of India. Since the present investigation is only based on the IKMT samples taken from the pelagic realm, it is not certain whether at the bottom also the species occurs throughout the west coast of India. The fishery resource surveys carried out by the Polish vessel *M. T. Muraena* on the continental shelf and upper continental slope along the northwest

TABLE 3. Catch details of *Charybdis (G.) smithii* in the night series of IKMT hauls arranged monthwise

Sl. No.	Month & Year	Position		Total number of crabs
		Latitude (N)	Longitude (E)	
1.	Mar., 1985	11° 29'	69° 26'	1
2.	" "	10° 31'	75° 52'	8
3.	" "	09° 29'	74° 15'	162
4.	Apr., "	08° 30'	73° 38'	1
5.	" "	08° 30'	73° 00'	1
6.	" "	07° 24'	72° 50'	13
7.	" "	07° 30'	75° 30'	862
8.	" "	07° 31'	76° 47'	76
9.	" "	10° 29'	75° 30'	4
10.	" "	10° 30'	73° 00'	2
11.	" "	09° 30'	74° 07'	1
12.	" "	09° 30'	74° 20'	4
13.	Jul., "	08° 30'	76° 02'	2
14.	Aug., "	09° 51'	72° 40'	2
15.	" "	11° 02'	72° 02'	2
16.	" "	12° 50'	73° 01'	3
17.	" "	12° 00'	71° 30'	3
18.	" "	12° 50'	71° 00'	1
19.	" "	14° 00'	71° 30'	5
20.	" "	14° 00'	73° 31'	1
21.	" "	15° 01'	68° 58'	4
22.	" "	16° 00'	68° 31'	13
23.	Oct., "	20° 30'	65° 30'	2
24.	" "	20° 30'	65° 30'	3
25.	" "	18° 30'	66° 30'	2
26.	" "	18° 30'	67° 30'	3
27.	" "	16° 30'	72° 30'	1
28.	" "	12° 30'	74° 03'	1
29.	" "	16° 30'	68° 30'	2
30.	Nov., "	12° 00'	73° 42'	3
31.	Dec., 1985	16° 00'	72° 40'	96

coast of India in late seventies (Bapat *et al.*, 1982) have not indicated the presence of this species in the bottom trawl catches from any areas north of Karnataka. Examination of the trawl catch data of FORV *Sagar Sampada* also does not reveal the presence of this species in this region (Suseelan *et al.*, 1990). The poor abundance of *C. (G.) smithii* in the IKMT collections examined from this region during the present study could indicate less possibility of the existence of a rich benthic population of the species along the northwest coast.

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