ECOLOGY AND POPULATION DYNAMICS OF THE MANGROVE CLAM *POLYMESODA EROSA* (SOLANDER 1876) IN THE MANGROVE ECOSYSTEM

Thesis submitted for the degree of
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August 2007

CERTIFICATE

This is to certify that the thesis entitled ' **Ecology and Population Dynamics of the Mangrove Clam *Polymesoda erosa* (Solander, 1876) in the Mangrove Ecosystem'** submitted by Sandhya Clemente for the award of the degree of Doctor of Philosophy in Marine Science is based on original studies carried by her under my supervision.

The thesis or any part thereof has not been previously submitted for any degree or diploma in any Universities or Institutions.

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All the corrections suggested by the examiners have been incorporated

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DECLARATION

As required under the University Ordinance 0.19.8 (iv), I hereby declare that the present thesis entitled '**Ecology and Population Dynamics of the Mangrove Clam *Polymesoda erosa* (Solander, 1876) in the Mangrove Ecosystem'** is my original work carried out in the National Institute of Oceanography, Dona-Paula, Goa and the same has not been submitted in part or in full elsewhere for any other degree or diploma. To the best of my knowledge, the present research is the first comprehensive work of its kind from the area studied.

Sandhya Clemente

Sandhya Clemente

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- John M. Templeton

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CHAPTER 1

INTRODUCTION

Coastal areas are not simply geographic locations proximate to the world's oceans but are arrangements of complex, diverse and fragile ecosystems, unique in nature. These very features require special attention. Coastal ecosystems, such as mangroves, coral reefs, backwaters, estuaries, lagoons and seagrass beds, besides performing crucial coastal protection functions, provide rich spawning and breeding grounds for fish and other aquatic organisms. Another important dimension is the vital contribution that coastal ecosystems make sustaining livelihood, particularly of fishing communities. From both an economic and livelihood perspective, fisheries are one of the most important of the resources available in coastal areas. The rapid development of coastal areas, fuelled largely by macroeconomic policies supporting industrialization as well as by the pressure to generate foreign currency through the mass production of goods for global export markets, is, therefore, a matter of concern. Such unplanned and unsustainable development is generating huge profits for relatively few people at the expense of the many who are left with a degraded and polluted environment. The commercial rights of developers are overriding the communities' rights to livelihood.

A strategy for integrated coastal zone management, though not yet fully implemented everywhere, is the key for ensuring the survival and sustainable development of the coastal resources in the region. The successful management of marine resources requires a solid understanding of how ecosystems function. Incorporated in this understanding is knowledge of the distribution of habitats and of the species that inhabit them. The interaction of species with each other and their responses to the activities of man are of great importance for coastal resources management. It is difficult to conserve any particular resource in the absence of a comprehensive, integrated framework for policy, planning and management. Although coastal zone management programs are created to address broad resource systems, or ecosystems, they have to be based upon detailed knowledge of individual resource units. It could be said that the key to successful

coastal zone management strategy is information. To enhance resource development capabilities, each country should acquire and maintain an inventory of its coastal environments and resources. A management plan should include an assessment on the status of pollutants, both on the organism and ecosystem levels and a monitoring program set up.

1.1 The Mangrove Ecosystem

Mangrove forest is an assemblage of salt tolerant trees and shrubs, and is the dominant feature of coastal areas in tropical countries. They flourish in estuarine or brackish water environment. Low wave energy, low salinity condition, high tidal amplitude and gentle slopes promote development of mangroves. They are habitats of enclosed intertidal mud flats where wave action is greatly reduced and which receive an influx of freshwater. The mangrove ecosystem comprises an intertidal area having creeks, channels, mudflats, rock/coral reef flats, and estuaries etc, which provide varied habitats for a variety of animal and plant species.

Mangroves are the most productive ecosystems and considered as national wealth of maritime countries. The marine and brackish water zones between high and low tide level are the fond homes of a unique environment with a heterogeneous assemblage of biocoenosis acclimatized to life in a very inhospitable and un-predictable environment; mainly in the tropical inter-tidal zone spreading about 10 million ha. in 30 countries (Saravanan, 2005). Traditionally wetlands have been viewed as environments associated with disease, difficulty and danger, but ecologists realize that these are amazingly productive areas and just waiting to be tapped. The fauna include resident and migrant arboreal, terrestrial, aquatic and semi aquatic species. Mangroves serve as breeding, nursery and feeding grounds for a large number of terrestrial and aquatic organisms. It also provides protection from predation and refuge for juveniles of many species. Mangroves and estuaries are a migratory path for catadromous and anadromous fishes.

Mangrove wetlands are highly productive fringe ecosystems ranking second only to coral reefs in terms gross productivity and tertiary yields (Wafar et al., 1999). Also known as the mangals, they represents a highly specialized and complex ecosystem occurring in the sheltered coastal areas of tropics and subtropics, provide a complex, 3-dimensional habitat for organisms to live in. Organisms can inhabit the mangrove tree trunk, leaves, root surface, the mud surface and also burrow into the mud. The mud snail *Terebralia sulcata*, for example, inhabits both the mud surface and the mangrove tree trunk. Sessile organisms, including the oyster *Saccostrea cucullata* and barnacles *Euraphia withersi*, attach onto the mangrove tree trunks and root surfaces. Bivalves such as *Anomalocardia squamosa* and *Gafrarium pectinatum* burrow inside the mud. Crabs such as *Scylla* spp. and *Perisesarma bidens* burrow inside the mud but to feed they emerge from their burrows, and *Perisesarma* actually climb into the trees (Dudgeon, 2004).

The varieties of plants and animal life found in the ecosystem are closely interdependent. Due to the availability of quality food and shelter, this coastal habitat resulted in one of the most diverse and highly efficient ecosystem of the world. Because of the intertidal nature of the mangrove environment, there is an associated movement of fish and other animal species into and out of the mangroves, as well as their presence as larval forms. There is also seasonal movement of some animals, particularly birds, to and from the mangroves.

Mangroves accumulate large quantities of nutrients from ocean and land and the high macrophytic production generates much detritus, which is also a major source of organic carbon (energy). They provide a temporary habitat for organisms from marine and terrestrial systems and mangroves function as nursery ground for commercial species (Guerreiro et al., 1996) and provide nursery habitats for fish and shrimp that mature elsewhere each year. These "coastal greenbelts of protection" play a vital role in also reducing sedimentation and shoreline erosion, enhancing wild fisheries and providing marine life, medicines,

fruit, honey, lumber, fuel wood, tannins and aesthetic beauty. Mangrove - trees and shrubs that live in tropical tidal zones line 25% of the world's tropical coastlines. Plankton production in the tropics appears to be less seasonal compared to temperate waters and dominated by the nano- and pico-size fraction. It is therefore likely that most of this production is recycled in the water column rather than deposited on to the coastal seabed, as supported by the low amounts of the chlorophyll *a*, degraded pigments and in situ primary production (excluding sea grass beds and some semi enclosed coastal lagoons) measured in the most sub- tidal sediments in the tropics. Outwelling of leaves, bark, roots and other tree components derived from mangroves thus appears to be the main source of plant detritus for benthic food chains in most tropical coastal areas (Fleming et al., 1990).

Organisms living in this habitat are immersed during high tides, whilst they are, completely exposed during low tides. Mangroves, therefore, pose a very challenging environment. They will face difficulties in gaining strong anchorage in the soft substratum, obtaining enough oxygen from the anoxic mud and also need to tolerate fluctuating salinity and desiccation stress during low tides. Organisms living in this habitat have, therefore, adaptive features enabling them to survive in such a stressful environment.

Benthic community plays a crucial role in the mangrove ecosystem. Among the benthic communities the epibenthic species dominate the fauna. These organisms play an important role in the food web of mangrove ecosystems. One of the important diverse group found here is the Mollusca, which play an important role, in the mangrove area. The most successful species in the mangroves are those that can adapt to the salinity and temperature stresses that are characteristics of these environments (Ferraris et al., 1994). The composition of the molluscan assemblage can be used to assess the health of mangroves (Skilleter, 1996).

Among the molluscs, bivalves form an economically important group, which includes oysters, clams, mussels, scallops, ark shells, and cockles and forms regular fishery all over the world. Especially, mussels and clam resources offer greatest subsistent fishery to the coastal population. However, mangrove bivalves are probably the least well known, as there is little comprehensive information in the literature about them. Widespread interests in bivalve biology stems in large part from the fact that they form an important food resource for human consumption.

About 80-90% of the commercial seafood species that inhabit tropical oceans spend some part of their lives in coastal mangroves. Mangroves line 8% of the world's coastlines (Burke et al., 2000) and about 25% of tropical coastlines, covering a surface area of 181,000 km^2. Some 112 countries and territories have mangroves within their border. Globally, more than 50 species in 16 different families are considered mangroves. The Indus delta region contains the world's fifth-largest mangrove forest. India has approximately 700,000 ha of area covered by mangroves along the estuaries and major deltas. The Indian mangroves comprise approximately 59 species in 41 genera and 29 families. Of these, 34 species belonging to 25 genera and 21 families are present along west coast. There are about 25 mangrove species, which have restricted distribution along the east coast and are not found on the west coast. There are approximately 16 mangrove species reported from the Gujarat coast, while Maharashtra has about 20 species, Goa 14 species and Karnataka 10. There are hardly three to four species of mangrove, which are rarely found along the Kerala coast. The associated mangrove flora is quite common to both the coasts, with minor variations in distribution.

The most dominant mangrove species found along the east and west coast of India are listed below: *Rhizophora mucronata, R. apiculata, Bruguiera gymnorrhiza, B. parviflora, Sonneratia alba, S. caseolaris, Ceriops tagal, Heretiera littoralis,*

Xylocarpus granatum, X. molluscensis, Excoecaria agallocha, Lumnitzera racemosa, Avicennia officinalis, A. marina. Kandelia candel, Avicennia marina, Acanthus ilicifolius, Bruguiera gymnorrhiza and *Aegiceras corniculatum*, which are located near the seaward areas of the mangrove, and *Lumnitzera racemosa* and *Excoecaria agallocha*, which are commonly found near the landward side where there is more freshwater input. In the landward areas, there are also a variety of shrubs and trees, which are never immersed by the high tides, which can be described as mangrove associates. Common mangrove associates in India include *Hisbiscus tiliaceus*, *Clerodendron inerme* and *Pandanus* sp. There are eight species of mangroves like *Sonneratia caseolaris, Suaeda fruticosa, Urochondra setulosa* etc., which have been reported only from the west coast (www.indian-ocean.org). Some of the very important bivalves found in the mangroves are oysters like *Saccostrea, Crassostrea,* clams like *Villorita cyprinoides, Meretrix casta, M. meretrix, Kataleysia opima* etc.

1.2 Threat to biodiversity

Mangrove forests once covered three-quarters of the coastlines of tropical and sub-tropical countries, but only half of that area remains intact today. It is estimated that over 50% of the world's mangroves have been destroyed and they continue to decline at an alarming rate and over 50% of the original areas of mangroves in tropical countries have been lost. According to the recent estimates, India has lost at least 75% of its mangroves (Quarto, 2004).

Destruction of mangroves leaves coastal areas exposed to erosion, flooding and storm damage, alters natural drainage patterns, increases salt intrusion and removes critical habitats for many aquatic and terrestrial species, with serious implications for biodiversity, conservation and food security. Loss of mangrove forest results in increased sediment transport onto downstream coral reefs (Perera, 2006). Mangrove destruction can cause a decline of local fisheries that will actually exceed the gains from shrimp production, leading to a net protein loss.

Because of the loss of half the world's mangrove forests, the world's coastal fishers may have lost 4.7 million tons of fish per year (Perera, 2006).

Mangrove resources and biodiversity have traditionally been undervalued, putting its resources at a lower priority level. Unregulated use of resources, increased demand for the resources and rapidly expanding coastal development, makes mangrove resources at risk. Mostly all deleterious impacts on coastal biodiversity stem from ignorance and lack of understanding of the importance and how it gets affected. Primarily, uncaring attitude towards the nature, lack of basic insight towards importance and economic value of the existing resources are the main reasons that leads to many negative impacts on biodiversity and its conservation.

Basically, threat to the survival of the existing diverse flora and fauna of mangrove ecosystem originates from various facets. The lack of awareness among fishermen community and intensive development activities undergoing at the mouth of estuary, are the most prominent among them.

1.3 Man and Molluscs

Mollusca are the second largest phylum in the animal kingdom. They are essentially aquatic, mostly marine, few freshwater and some terrestrial. The marine molluscs are found in all conceivable environments from upper intertidal zone down to the abyssal depth of the ocean floor. Among the invertebrates, molluscs are one of the groups that have widespread commercial potential. It comprises of seven classes *viz*, Aplacophora, Polyplacophora, Monoplacophora, Gastropoda, Scaphopoda, Pelecypoda, Cephalopoda. Pelecypoda or Bivalvia. Molluscs are known to be highly palatable and nutritious food. They constitute a valuable fishery resource in various sectors of coastal areas. Apart from its food value, it is one of the main sources of lime. The exploitation of bivalves has been observed to be only as a subsistence occupation, but the growing demand for

protein food and multiple uses of the mollusc shell in lime-based chemical industries have created tremendous awareness of the benefits of exploiting and developing molluscan resources. Cephalopods, bivalves and gastropods are the principal groups of molluscs exploited from coastal, estuarine and backwater environments. The total annual production of molluscs is 1.4 lakh tons, which is 10% of total marine fish landing. The yearly landing of cephalopods, bivalves and gastropods are 43,000; 96, 300 and 1, 256 MT, respectively (James et al., 1989).

1.4 Bivalves

The Bivalvia is the second most speciose class and economically the most important in the phylum Mollusca. The Pelecypoda, Bivalva or Lamellibranchia (Latin for leaf-gill) (the only class with three names!!), known more commonly as just bivalves, because they have two separate halves to their shells. It includes oysters, clams, mussels, scallops, ark shells and cockles, which forms a regular fishery all over the world. Bivalves are distinctive within the Mollusca in that they are almost always completely enclosed within their shells. The shells are made of calcite or aragonite and are bilaterally symmetrical. They are laterally compressed, typically with shells divided in two halves, or valves, hinged together dorsally by an elastic, chitinous, external or internal ligament. The bivalve hinge bears sets of interlocking teeth that prevent the valves from sliding along each other as a result of external forces (e.g. predation), or improperly shut. The shell is kept shut by action of the paired adductor muscles. The adductor muscles counter the tension in the elastic ligament, which tends to keep the shell valves, spread apart. Most of the bivalve body is located dorsally in the shell. The mantle cavity in bivalves is located ventrally and laterally. Folds of the mantle margin form the exhalant and inhalant siphons. Most of the mantle cavity is occupied by the paired ctenidia, which in bivalves perform not only their original role as site of gas exchange, but also become the major food-gathering and food-sorting organs in

filter- feeders. The head in bivalves is reduced, probably as result of a sedentary or attached lifestyle.

Bivalves have lost the radula, eyes or tentacles as present in other molluscs, but some have acquired secondary tentacles and eyes along the mantle margin. The mouth is located well inside the animal, and a pair of fleshy labial palps helps direct the food particles toward the mouth after these particles have been collected and sorted by the ctenidia. Bivalves can be deposit-feeders (subclass Protobranchia), using their long, modified labial palps to collect food particles from the bottom surface. Protobranchs do not use their ctenidia as food-collecting organs. Most bivalves are filter-feeders (e.g. subclasses Pteriomophia and Heterodonta) and have well-developed ctenidia that display an elaborate sorting system of cilia-lined grooves and surfaces that select particles of the right size and density for feeding. In addition, the highly specialized carnivore bivalves in the order Septibranchia have their ctenidia modified as septa that help pump water in, sucking in small crustaceans and other small prey. Like gastropods, bivalves can live in a highly diverse gamut of habitat conditions: oysters permanently attach themselves to hard substrates, mussels and ark shells live temporarily attached by bundles of protein fibers called byssus, most clams burrow in sand or mud, and representatives of a number of different families can bore themselves for life into rock, wood, or other hard substrates.

Most bivalves are dioecious; i.e., males are separate from females. A few bivalve species are, however, hermaphroditic; e.g. the fresh water families, Unionidae and Sphaeriidae, and the marine families in the Anomalodesmata subclass. Several others, notably the common oyster, *Ostrea edulis,* begin life excreting male gametes, later shift to female gametes, and may, later still, revert again to excreting male gametes. Reproduction in bivalves is mostly through external fecundation and, like gastropods; bivalves display a wide range of modes of development, from species having planktotrophic, long-duration veliger stages to

those brooding their offspring in the mantle cavity (Avril, 2007). The bivalve mollusc is thought to have originated in the warm shallow euhaline coastal waters and gradually invaded estuaries and brackish systems, as well as all the reaches of the world ocean. Because the adult forms of majority of these animals are benthic or bottom dwelling, many different evolutionary adaptations to the benthic habitat have occurred. The most common life styles are: buried within burrows in unconsolidated soft sediments; attached by byssal threads to pebbles or more consolidated sediments, cemented to shells or rocks; and as semimobile members of the epibenthos. Today clams, mussels, oysters, and scallops exemplify these adaptations, respectively. In nature there are often gradients of sediments from muddy unconsolidated materials to high-energy environments, with bivalves zoned accordingly (Morton, 1988).

A variety of bivalve molluscs are prominent members of many diverse marine systems. These animals have reached their greatest abundances in shallow coastal waters and estuaries. They are largely influenced by the environmental changes such as rainfall, amount of freshwater discharge of rivers, tidal amplitude, temperature, changes in salinity and pH, and occurrence of obnoxious blooms of phytoplankton. Bivalves have broad temperature ranges. The shell size and thickness are related to the temperature. With decreasing temperature, the size and shell thickness decrease. This is due to calcium carbonate being unsaturated in cold waters. Bivalves are common in fully oxygenated waters. Opportunists can be found at deeper depths. They can tolerate broad salinity ranges but most are diverse in marine settings, though some are found in freshwater settings (Dame, 1996).

Bivalves have long played a role in feeding the world's population. Another area where they are important is for man's ornamentation and adornment throughout the ages. Pearls are very economically important as a jewelry item, and many bivalve shells are used in various decorative ways. Bivalves are highly

specialized not only in their shape, but in their physiology as well. A number of trace and heavy metals are present in very low concentration in marine environment but it is difficult to directly estimate these metals in the medium. Certain suitable sentinel organisms such as mussels, oysters, and clams show insidious tendencies to accumulate certain heavy metals. Hence, are widely used as bioindicator organisms in different parts of the world. The exploited bivalves comprise clams (70%), cockles (9.5%), mussels (3.6%), oysters (1.0%) and windowpane oysters (14.5%). Exploitation ranges from small-scale harvesting of natural stocks to intensive cultivation and technical manipulation of oysters for pearls (James et al., 1989).

Commercial exploitation of bivalves for food is dominated globally by epifaunal taxa such as ostreids, mytilids and pectinids; in addition a high diversity of infaunal species, many of which are of major local or regional importance, is exploited. Annual harvests of bivalves for human consumption represent about 5% by weight of the total world harvest of aquatic resources (Roberts, 1999). Decline in commercially important species, as a result of overexploitation and pollution, led to the global movements of bivalve culture and the development of aquaculture. The harvesting and cultivation of bivalves has environmental consequences, which must be overcome to ensure sustainable management of these valuable resources.

The world trade of bivalve meat has been estimated to be around 1.3 million MT and is making further strides, with an annual growth rate of about 10% percent per year. By species, the most important bivalves are oysters and clams with 4.7 million MT each, while scallops and mussels are less important at 2.0 and 1.8 million MT, respectively. It is seen that relatively few bivalves enter international trade, at least when compared to shrimp or salmon (Josupeit, 2006). Molluscs can contribute significantly to increase marine fish production in India. Production of marine bivalves in India is mainly through small-scale fisheries and its annual

estimate is about 10,000 tones chiefly from South West coast of India. Indian coastal and marine zones including the islands of Andaman and Nicobar and Lakshadweep abound in a wealth of nutritionally rich edible bivalves (Ninawe, 2005). Inspite of the availability of rich bivalve fauna, the country could not make any headway in the export of marine bivalves so far due to the non-availability of required technology. From the fact that India possesses vast resources in terms of natural water bodies and species diversity, it can be seen that India has a great potential to contribute to the global economy. It is important to adopt a rational exploitation strategy based on propogation of some of the edible bivalve species, most suited to local climatic conditions in captivity. For this, one of the basic requirements is clear understanding of the habitat ecology.

1.5 Need to study the lesser-known bivalves like *P. erosa*

1.5.1 Documentation and Conservation

The literature suggests that, the number of marine species known from the Indian seas could be of the order of 13,000 or higher (Ramakrishna and Venkataraman, 2002). However, the inventory is very detailed only in the case of commercially important groups of fishes or molluscs. In terms of spatial coverage, probably only two-thirds of the total marine habitat has been covered till today and the remote islands and other minor estuaries still virtually remain untouched. It is, therefore, likely that true inventory of coastal and marine biodiversity could be several times higher than what is known today. Probable estimates of species diversity have been variously arrived at, by extrapolation of known number of species from a section of the habitat to others. With microbes, such estimates are even less certain. In all probability, the number of species from all groups and all habitats of seas could be of the order of several million but we know only a fraction of that for certain (Venkataraman and Wafar, 2005). Even the most recent and most global inventory, the Ocean Bio-geographical Information System

(OBIS), has no more than 40,000 species listed. What is unknown of the diversity, thus, far exceeds what is known. Equally important as knowledge of what lives in the seas, is a prediction of what would live there in the future. This is especially true of regions where rapid loss of habitats and decline in water quality could be drastically altering the species diversity. Accelerated loss of coastal and marine biodiversity components over the last few decades has been of great concern (Venkataraman and Alfred, 2002). Environmental changes, overexploitation and habitat loss are among the major causes of species loss that, according to certain estimates, is of the order of a species per day (Kannaiyan, 2005). It is not known what fraction of this loss is from marine environment, a situation owing to a lack of systematic coverage of all faunal and floral classes with the prominence placed often on economically important groups, or on habitats of deep-sea where one out of two species collected could be new to science. This scenario addresses, therefore, the need to know in depth the marine biodiversity of India and study the constraints to its sustainability.

1.5.2 Food Security

More than two billion people subsist on diets that lack essential vitamins and minerals required for normal growth and development. World population is projected to reach 8.3 billion by 2025. Thus, the fundamental challenge ahead is to produce and equitably distribute an adequate food supply for the growing population. Total global food production now stands at around five billion metric tones annually. This needs to be increased through various food security measures through adoption of high yielding varieties and use of various new biotechnologies to prevent hunger and malnutrition in the human welfare.

Fisheries sector provides an overall 17% of the world's animal protein intake to which the Asian countries contribute around 26%. The world per capita fish consumption is about 12 kg per year, 8 kg for developing countries and 25 kg for

developed countries. The per capita fish consumption for India is even less than 8 kg per year (Ninawe, 2005). There is a need to exploit the food from sea as a security against under nutrition and malnutrition as sea has ample scope for continuous supply of protein rich food for socioeconomic upliftment.

1.6 The clam resources of India

In India, the development of molluscan fisheries is very important especially in Goa, where almost 90% of population relishes seafood. During southwest monsoon when fishing in the open sea is suspended due to inclement weather, the clams, oysters and mussels substitute the marine fishes. Clams in particular lend themselves well to myriad of habitats and broad environmental ranges. Generally, they are more abundant along the west coast than the east coast of India (Alagarswamy and Meiyappan, 1988). In Goa, four species (*Meretrix casta, Paphia malabarica, Villorita cyprinoids, Katelysia opima*) of clams are commercially exploited. In addition to these several other species of clams are also consumed by the local people but are not commercially exploited – *Mactra* sp., *Sunetta scripta, Meretrix meretrix, Donax scortum, Placuna placenta, Solen kempi, Anadara rhombea* and *Polymesoda erosa* (Ingole, 2004).

P. erosa is one of the largest in size among the non-commercial species and is found throughout the year in mangroves along the west coast of India. The systematic position of *P. erosa* in the taxonomic classification is as follows:
Phylum: Mollusca
Class: Bivalvia or Pelecypoda
Order: Heterodonta
Genus: *Polymesoda*
Species: *erosa*

They are indiscriminately harvested for human consumption, particularly during the monsoon season. Recent studies suggest that due to overexploitation and other anthropogenic changes, abundance of commercially exploited clam resources especially those in the backwaters and estuaries have been reduced considerably (Anon, 2002). Mining activities, sand extraction and industrial pollution are the main reasons affecting the clam resource (Ingole et al., 2006). The exploitation of seed clam (juvenile size) before attaining maturity and destruction of habitat are some of the most important factor adversely affecting the clam fishery. Therefore, there is an urgent need for conservation of clam population along the coastal area. Popularizing and commercializing of the non-commercial species could be other way of increasing the clam population.

1.7 *P. erosa* – hope for the future

Diverse representatives of Corbiculoidea are distributed throughout the tropics (Morton, 1988). There are 147 species of *Polymesoda* found around the world (Severeyn et al., 1996). The occurrence of *Polymesoda* in Gulf of Mexico mangroves was given by Morton (1984) whereas; its presence in the Indo-Pacific region was given by Prashad as early as 1932. However though it occurs in India and is available throughout the west coast and *P. bengalensis* in the east coast (Ingole et al., 1994), there are no records of it being exploited commercially. It was first reported from the Chorao Island (Mandovi River) along the west coast of India by Ingole et al. (1994). This species is also reported from the other mangrove areas of Goa, Karnataka, and Maharashtra (Ingole et al., 2002). Although *P. erosa* is distributed along the central west coast of India; it is discretely exploited, for human consumption in Goa. Kraeuter (1976) discussed the ecological significance of *Polymesoda* to the ecosystem in which it inhabits. Recently, Haynes et al. (2001) described the use of *P. erosa* as a potential indicator organism. According to the available information, this clam species has

preference to the mangrove habitat (Ingole et al., 2002) and is mostly found in the *Avicennia* zone of the mangroves (Meehan, 1982).

Despite their economic importance and food potential mangrove clams have received very little attention (Ingole et al, 2002). Information on the world–wide distribution and abundance of some *Polymesoda* species are available (Pamatmat, 1979; Duobinis-Garya and Hackney, 1982; Hackney, 1985; Severeyn et al., 1996). The growth rate, longevity, size at first maturity, spawning period, recruitment, genetic variation, biotic and abiotic environmental factors influencing the growth and breeding aspects of few species of *Polymesoda* is given by Ruiz et al. (1998). Literature shows that different species of mangrove clam forms a cheap source of protein in the diet of many tropical islanders (Johannes and Hviding, 2000; Muller, 2003). However, literature specific to *P. erosa* in particular is very limited around the world. Except for the casual observations of Macnae (1968) and Berry (1972), very less scientific work has been done on this species. A study on the biology and functional morphology of *P. erosa* from Southeast Asian mangroves was reported by Morton (1976). Later Morton and Chan (1990) studied the salinity tolerance of *P. erosa* along with four bivalve species from Hong Kong mangroves. Recently, Gimmin et al. (2004) studied the relationship of shell dimensions and shell volume to live weight of *P. erosa* from Australian mangroves. In India, studies on *P. erosa* are limited to its occurrence (Ingole et al., 1994) and some aspects of the population characteristic of *P. erosa* from Chorao mangroves (Ingole et al., 2002). Inspite of the fact that *P. erosa* is recognized as commercially, ecologically and pharmacologically important marine bivalve species, very little is known about its ecology, population dynamics and resource potential and comprehensive information on *P. erosa* is not available in the literature.

Further, the suitability of the mangrove clam for human consumption has not been investigated. However, knowledge of the stock size, fishing season, exploitable

resource and food value are essential for commercialization of any species. More importantly, however, such a study will put future studies of this bivalve on sounder footing, especially since it is used as food, but is threatened by the wide scale destruction of its habitat. Mangroves are under severe stress due to reclamation and urbanization and as a result many of the valuable resources including *P. erosa* are at a risk of demise primarily due to habitat destruction.

In view of this, a research investigation dealing with the distribution, ecology and population dynamics of the mangrove clam *P. erosa* was initiated at the National Institute of Oceanography, Dona Paula, Goa.

1.8 Aims and objectives

The output of research on bivalves during the last century is copius, but when one looks at it objectively, the imbalance between temperate and tropical waters is strikingly evident. Most of the results, hypotheses and models are from the temperate waters, whereas, the greatest diversity and biological productivity are from tropical ecosystems. There is clearly a need to enhance our understanding of the bivalve ecology of tropical ecosytems and this is especially important with respect to mangroves as these are one of the most poorly understood ecosystems till date.

Although a fair amount is known about the diversity in bivalve mollusc species through space and time, bivalve diversity of the mangroves is only known for a few commercially important species, and the role of bivalves in biodiversity and ecosystem functioning is relatively unknown. Further, even in the tropics itself, in contrast to the large number of studies of bivalves inhabiting sandy and rocky coastal zones, ecological investigations of the bivalves from tropical mangrove environment are relatively few. In mangrove ecosystems, the varieties of plants and animal life forms found are closely interdependent and the habitat for different fauna is partitioned between the unvegetated low tide region, the mid

tide region and the high tide region towards the landward side. The faunal processes in each of these regions and their interrelationships contribute to the functioning of the mangrove ecosystem.

Studying/quantifying the fauna of a mangrove ecosystem becomes essential for the assessment of the productivity of these highly specialized and productive ecosystems. Hence, an understanding of the faunal ecology will be of immense application in rational use and management of the resources from mangroves. It may be noted that earlier studies on mangrove bivalves from Indian coast are mainly on the occurrence and distribution of those species, which are found in the low tide and the mid tide towards the seaward region. However, there are various species of bivalves found abundantly in the interior mangrove forests. The mangrove clam *Polymesoda erosa* forms a major part in the diet of many tropical islanders and has a potential for commercial harvest in India as it is abundant along the central west coast and is consumed by the local people of Goa.

The mangrove clam has been studied from the Southeast Asian and Australian mangroves with virtually no information from Indian coast. However, these studies do not consider its population dynamics or its nutritional aspects. Also, the specific habitat selection of this clam in the high intertidal region is not studied. Besides, these studies lack comparison- the above studies are from entirely different geographical region wherein the whole ecosystem processes will be different compare to the Indian coasts. In assessing the potential for commercial harvest of *P. erosa* it is essential to better understand the ecology as well as its population dynamics before attempting to develop a sustainable management plan. The lack of information about current distribution and abundance of the mangrove clam *Polymesoda* means that it is difficult to predict what level of harvest can be considered sustainable.

The present study focuses on the ecological aspects and population dynamics of *P. erosa* with its implication as a resource for food and aims at understanding the spatial and temporal variations in the clam abundance with respect to physical and biological parameters. It addresses the following issues, which were formulated as the broad objectives of the study.

1.8.1 OBJECTIVES

- Survey of the mangrove areas along the Central West coast (between Kumta and Ratnagiri) for the distribution of *P. erosa*
- Morphometric studies of *P. erosa*
- Understanding *P. erosa* and its environment
- Reproductive biology of *P. erosa*
- Recruitment of *P. erosa*
- Seasonal variability in biochemical and calorific contents in *P. erosa*

1.9 Significance of the study

The information, gathered in the present study with what is already available, will help in understanding and modeling the ecological and physiological processes of *P. erosa* in the mangrove ecosystem. This would, in turn, help in evolving better management policies of the clam as well as the mangroves.

This work considers studies understanding ecology and biology of *P. erosa* along the central west coast of India. It is aimed at collecting information on the distribution, morphometry, reproduction, biochemical composition and the adaptation of *P. erosa* to varying environmental condition. Specific topics included are life cycle and settlement strategies, factors affecting recruitment and growth.

CHAPTER 2

STUDY AREA & SAMPLING

2.1 Description of study sites (for distribution and abundance)

Though there exists reports on the occurrence of *P. erosa* along the Indian coasts and that they are more abundant along the west coast, this data was not collected and assessed adequately. To meet the objectives of the present study, a number of sites along the Central West coast of India from Ratnagiri to Kumta were chosen and surveyed for the distribution of *P. erosa* (Fig 2.1). Chorao island, Goa was selected as a site for comprehensive ecobiological study.

At each site, six sampling stations over a tidal elevation gradient were selected for carrying out the investigations. These stations represented the non-vegetated low tide region, vegetated mid tide region and the interior mangrove forest in the high tide region (vegetated refers to the presence of mangroves at the sampling site). The description of each study sites is as follows:

2.1.1 Shirgoa and Kalbadevi mangroves at Ratnagiri

Ratnagiri (16°15'00" - 17°05'00"N Lat. and 73°15'30" - 73°22'30"E Long.) is located on the west coast of India, bound by Arabian Sea. The predominant soils are laterite. The Ranpur jetty and Bhagwati Bandar ports are the important minor ports. In north, the mangroves are present along the Shirgao creek and south along the Kurla creek (http://iomenvis.nic.in/Maharashtra%20Home.htm).

Shirgao

The Shirgao creek is fringed with healthy patches of mangroves. Altogether, 7 true mangrove and 3 associated species are reported from this area. In some areas, the social forestry department had planted *Sonneratia alba* and *Rhizophora mucronata* resulting in the dominance of these species. Other species are *Kandelia kandel*, *Avicennia officinalis* .The average density

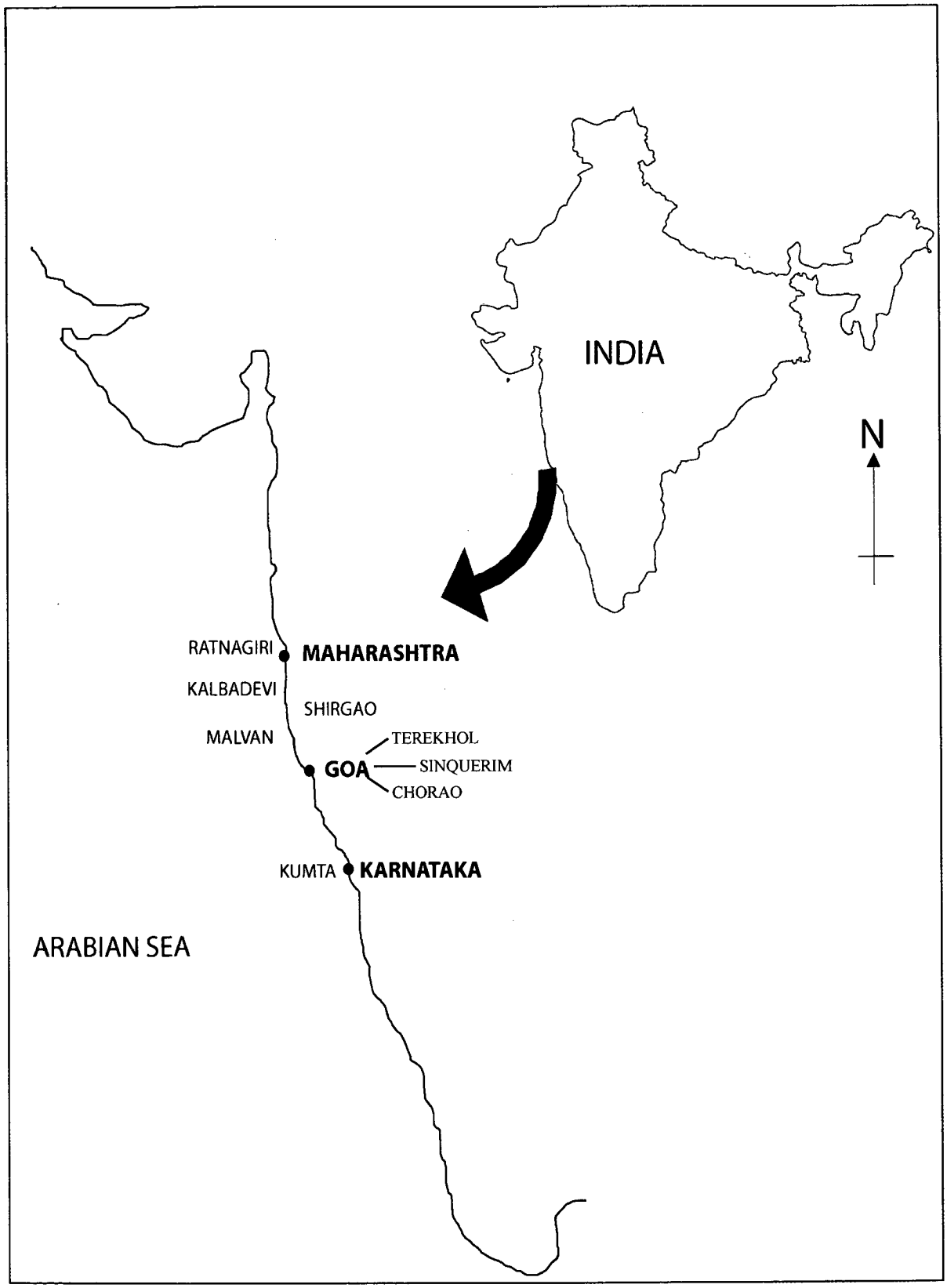


Fig. 2.1: Map showing the sampling locations for the distribution and abundance of *P. erosa*

observed was 20-23 plants per $10m^2$ quadrant. This is also one of the rich fishing areas.

Kalbadevi

Kalbadevi (16^0 59' 10"N and 73^0 16' 25" E) estuary is 7 km north of Ratnagiri town. It is situated at the base of hills, receives freshwater influx in monsoon. Western side of creek is open seashore. The substratum is less sand and more mud interior near the hillside region and less mud with more sand in the seaward region and rocky along the interior region.

Mangrove belt is spread over 7 km towards eastern hillside region, which gets exposed during the low tide. In the interior of mangrove belt, the tide-water is arrested by constructing many small bunds for aquaculture. Total 12 species of mangroves belonging to 6 different families and 7 genera are found in this area. These are *Sonneratia alba, S. apetala, S. caseolaris, Rhizophora mucronata, R. apiculata, Ceriops tagal, Avicennia marina, A. alba, A. officinalis, Lumnitzera racemosa, Acanthus ilicifolius and Aegicerous corniculatum.* Among these, the *Sonneratia alba* species is dominant followed by *R. mucronata, Acanthus ilicifolius, Sonneratia caseolaris, S. apetala, A. marina, A. alba, A. officinalis, R. apiculata* and *L. racemosa.*

2.1.2 Kolamb creek, Malvan

Malvan is located approximately 35 km from the Mumbai – Goa, National highway No. 17. The average atmospheric temperature ranges from 16.5°C – 33.1°C with minimum and maximum values during January and May respectively. Most of the rainfall occurs during June - October. The coast mainly consists of granites and gneisses and in a few gneissic interruptions the rocks are covered by laterite. Malvan coasts extend from 16° 00' 00' N to 16° 05' 00 N Lat and 75° 25' 00' E to 75° 30' 00' E Long. The average atmospheric temperature

ranges from 16.5° to 33.1°C with minimum and maximum values in January and May, respectively. The climate of Malvan is typical of monsoon, cool and dry seasons with low intensity of north-eastern winds from the land (November to February) and hot dry season from March to May followed by rainy season (June to September) (Subramanian and Sampath, 2001).

The coast is marked by islands, rocky promonatories, sandy beaches and mud flats – mangroves in the environments of Kalavali and Kolamb creek. Kolamb rivers flank the Malvan coast in the north. Eighteen species of mangroves and associated species are found in Kolamb creek. The dominant mangrove species along the Kolamb creek are *Avicennia* sp., *Rhizophora* sp., *Sonneratia* sp. *Ceriops* sp., *Lumnitzera* sp., *Aegiceras* sp., *Exocoeria* sp. Associated species like *Derris heterophylla* abound on the mangroves towards the upstream region.

2.1.3 Terekhol and Sinquerim mangoves in Goa

Terekhol

Terekhol is in the northernmost tip of Goa. The entire coastal stretch is protected by continuous 5 - 6 m high sand dunes with dune vegetation. In this stretch, two major creeks, which open into the Arabian sea are lined with mangroves with a luxuriant swamp a little inland, all of which are found behind sand dunes. The mangroves at Terekhol were dominated by *Avicennia officinalis and Sonneratia alba* followed by *Rhizophora mucronata, Acanthus illicifolius* and *Ceriops tagal.*

Sinquerim

The soil shows predominantly a mixture of lateritic rock and clay. The dominant mangrove species are *Rhizophora, Sonneratia.* The *Avicennia* dominated zone is

reclaimed for building houses and as such very few *Avicennia* species are found. The mangrove associate *Derris heterophyla* is common towards the landward region of the mangrove zone.

2.1.4 Alvenondi-Alvekodi Island, Kumta

Located at 14°28' N lat. 74°23' E long.; 4 km from Kumta town, Alvedandi-Alvekodi creek runs from coast for about 4 to 5 kms. The soil is lateritic, acidic and reddish brown in colour. The mean annual precipitation is 3200 mm, occurring mainly from May to November. The total mangrove area is 358.3 ha with minor forest of 103.0 ha. The common mangrove species observed at Alvenondi-Alvekodi Island are *Avicennia alba and A. officinalis*, *Sonnertia* sp., *Rhizophora* sp., *Acanthus ilicifolius, Sesuvium* sp. (Ramachandra et al., 2000).

2.2 Choice for selecting Chorao as site for comprehensive study

As mentioned earlier, even though there exists reports on the occurrence of *P. erosa* along the Indian coasts and that they are more abundant along the west coast are available, this data was not collected and assessed adequately. Sites chosen for studies are likely to be selected based on the type and need of study and other reasons such as accessibility. The Chorao island was chosen as it supports a large population of mud clams, enabling the observation of several clams to occur simultaneously. It was also known from the literature, that large populations of *P. erosa* are found in these mangroves (Ingole et al., 1994; 2002). The distance from the working laboratory (NIO, Dona Paula) to the island is also shortest compare to any other mangrove areas in Goa, making it most convenient to transfer the live clams after collection in the shortest time possible, which is a basic requirement when studies dealing with the physiological aspects are considered.

2.3 Description of Chorao Island

2.3.1 Location

Goa is located on the western coast of Indian peninsula between the latitudes 15°48'00" North to 14°53'54" North and longitudes 74° 20'13" East to 73° 40'33" East. It is separated from Maharashtra by the Terekhol river in the north, Karnataka in the South, the Western Ghats in the east, and Arabian Sea in the west. The coastal strip of Goa is highly indented with sea cliffs, notches and promontories alternating with rivers and estuaries. Goa has a moderate temperature showing negligible variations in different seasons. May is the hottest month while January and February are the coldest. There is a prevalence of tropical weather rest of the year. Southwest monsoon brings rain between June and September. July is the month that receives maximum rainfall while February gets least amount of rain. The average temperature varies between 25°C - 30°C .The average rainfall is approximately 325 cms, the average daily hours of sunshine is nine to ten hours in summer and three to five hours during the monsoon.

Of Goa's total land area of 3,70,000 ha, the mangrove area is 500 ha, having declined sharply from a recorded 20,000 ha in 1987 distributed all along seven estuaries including Cumbarjua canal. The mangrove flora consists of 15 species of 10 genera belonging to 7 families. The dominant mangroves are *Rhizophora mucronata*, *Sonneratia alba* and *Avicennia officinalis*. Major mangroves in Goa are recorded from Mandovi - Cumbarjua - Zuari complex (Kumar, 2000).

2.3.2 The Mandovi river

Among the seven rivers, Mandovi is one of the major rivers of Goa and is important for the economy of the state. It flows through the mining areas and is

heavily used to transport iron and manganese ores to the Marmagao harbor. The Mandovi, also called the Madei river at its head, rises in the main Sahyadris in the dense forest of Karnataka. The river has the large drainage basin and has length of 81 km. The watercourse is dotted with several islands. The course is accompanied by remarkable changes in the landscape and drainage. There are typical features of a drowned topography with the island of Divar standing prominently in mid-course with its northern counterpart, the Chorao island, not looking so prominent as island because it is on the right bank of the Mandovi and encircled by the small but complex network of the Mapusa drainage.

The estuary is about 5 m deep on an average. Its cross-sectional area decreases from mouth to head, and tides occur up to a distance of about 50 km (Shetye et al., 1995). The increase in elevation of the estuarine channels prevents tides from propagating beyond this distance. At the upstream end, the estuary receives freshwater from rivers originating from the mountain ranges in the Western Ghat. The Mandovi river extends about 75 km before meeting the Arabian Sea. The width at the mouth is ~ 3.2 km and narrows down to less than 0.25 km upstream. The estuary has an annual cycle of variations in its hydrographic features leading to three distinct periods: monsoon (June-September), post-monsoon (October-January) and pre-monsoon (February-May). With the onset of monsoon, the addition of freshwater increases considerably, resulting in stratification varying between 1 and 2 m. The runoff in the estuary is highly seasonal, just as is the precipitation. The runoff peaks during the most active phase of the Indian summer monsoon, decreases rapidly after withdrawal of the monsoon and remains negligible from about January till the onset of the next monsoon which generally occurs during late May or early June. This estuary become seawater dominated during March-May and with the onset of the monsoon, the salinity becomes very low. In the estuary, freshwater influx through riverine runoff is high during the monsoon months, with discharges of 175 $m^{-3}s^{-1}$ (Unnikrishnan et al., 1997).

During the non-monsoon period, the input of fresh water is negligible and is regulated by the semidiurnal tides.

2.3.3 Tides and currents in the Mandovi estuary

It has been classified as a tide dominated tropical coastal plain estuary and geomorphologically identified as drowned river valley estuary (Murty et al., 1976). The tide in the estuary are mixed, semi-diurnal nature with a maximum amplitude of 2.3 m. the amplitude of this tides remain unchanged over a distance of about 40 km from the mouth and then decays rapidly upstream over the next 10 km (Shetye et al., 1995). The flow in the estuarine channels is primarily tidal after withdrawal of the monsoon, and continues to be so until onset of the next monsoon. It is homogeneously mixed, except in the monsoon season when the rivers become stratified forming a salt wedge. The residence time of the water in the Mandovi estuary is 5–6 d during the monsoon season and about 50 d during in the nonmonsoon seasons (October–May). Water current velocity in the estuary during flood tide is higher and currents are directed towards the left side of the river. Water remains well mixed from February to May when fresh water runoff is less (Murthy et al., 1976).

2.3.4 Chorao island

Chorao Island lies in the backwaters of Mandovi estuary, with extensive mangroves towards the western low-lying tip (Fig. 2.2). It is located between 15°25' - 15°30'N Lat and 73°45'E - 73° 59' E Long. This island is a basically rocky projection of basalt but the land surface has been peripherally extended by heavy siltation upto the present edge of the river water. The whole area has mangrove vegetation of 14 different species and is covered by a network of criss-cross water channels having tidal variations. Earlier the backwater area of this island was protected by the bunds of laterite stones, and was used for paddy cultivation and fish farming. Gradually, the mangroves have grown over about

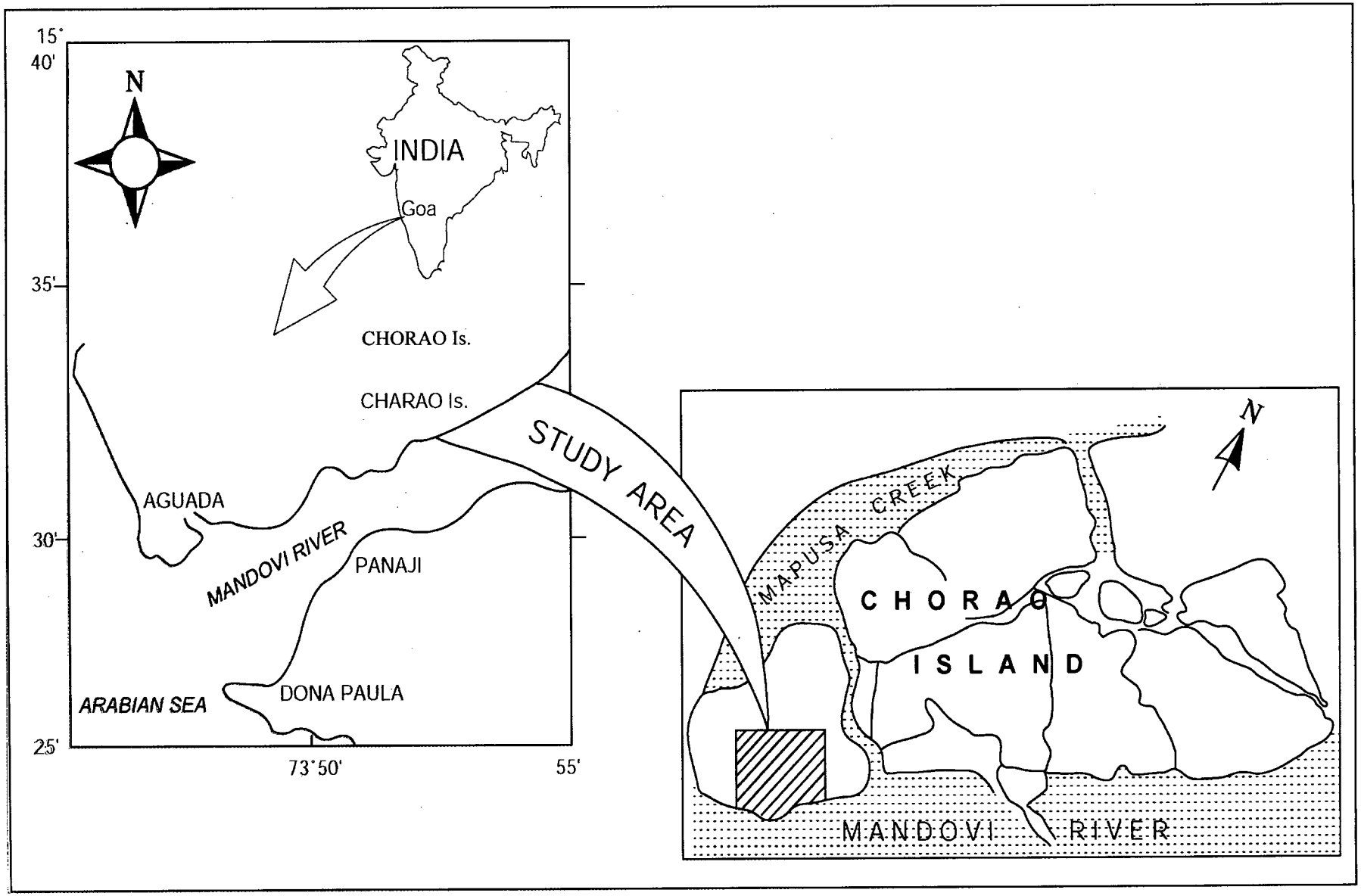


Fig 2.2: Map of Chorao island showing the sampling site for *P. erosa*

250 ha area, making the land useless for agriculture. Mangrove flora of this island is represented by 12 genera and 15 species. The dominant plants are *Rhizophora* sp., *Avicennia* sp. *Sonneratia* sp. and *Excoecaria* sp. The faunal elements commonly seen are many varieties of fishes, prawns, crabs and oysters. Brackishwater crocodiles and otters have also been observed. The avifauna of this mangrove forest is very rich and consists of resident as well as migratory birds. Taking into consideration, luxuriant flora and fauna of this mangrove island, it was acquired by the Government and declared as a bird sanctuary (Plate 2.1), giving it full protection from poaching and deforestation (Untawale, 1986).

2.3.5 Climatological Features

Data on climatological parameters such as rainfall, humidity, and air temperature during the sampling period of the present study were obtained from the field station of the Indian Meterological Department, Goa. Based on the southwest monsoon, the climatic pattern is divided into three seasons viz. pre-monsoon (February to May), monsoon (June-September) and post-monsoon (October-January) seasons.

Air temperature

The monthly mean air temperature with the, minimum and maximum values is shown in (Table 2.1). Average temperature varied seasonally and ranged from 25.6 to 30.4°C. Minimum temperatures were recorded in the post-monsoon season (26.6±0.05°C) and maximum in the pre-monsoon season (27.5± 2.0°C).

Humidity

The average humidity for the year 2004-2005 was higher in the morning than in the evenings. Annually the values ranged from 60 to 90% and maximum humidity

Table 2.1: Data on the climatological features (a) Temperature (b) Humidity and (c) Rainfall for the sampling collection date with monthly average

Date	Temp^{0}C			Relative humidity in %		Rainfall in mm
2004-2005	Max	Min	Mean	0830 hrs	1730 hrs	
July 23rd	30.5	24.7	27.6	85	82	4.7
Avg. July	29.8	24	26.9	93	87	17.1
Aug. 8th	29.5	23.7	23.7	87	79	37.4
Avg.Aug.	29.7	23.9	26.8	91	84	*
Sept. 24th	30.6	23.2	26.9	96	78	13.8
Avg. Sept	30.3	23.1	26.9	92	83	*
Oct.16th	31.9	24	27.9	89	63	0
Avg. Oct.	33	23.7	28.4	82	72	*
Nov.22nd	35.4	21	28.2	63	63	0
Avg.Nov	33.9	22.5	28.3	75	63	*
Jan 19th	29.9	18	23.9	89	52	0
Avg. Jan	31.8	19.7	25.8	84	60	0
Feb. 21st	29	18	23.5	83	57	0
Avg. Feb.	32	20.1	26.1	83	62	0
Mar 21st	32.5	25	28.7	90	71	0
Avg. Mar.	32.2	20.1	26.1	83.8	62	0
April 21st	33.9	20.2	27	60	66	0
Avg. April	33.5	24.9	27.1	78	69	*
May 25th	34.3	27.2	30.7	73	71	0
Avg. May	34.2	26	4	69	0	
June	29.4	23.7	25.4	88	83	4.6
Avg. June	29.3	25.5	27.6	90	87	19
July 23rd	30	24.2	26.5	87	84	4.2
Avg. July	29.1	23.8	25.6	89	85	17.4

* Indian Meteorology Department, Goa

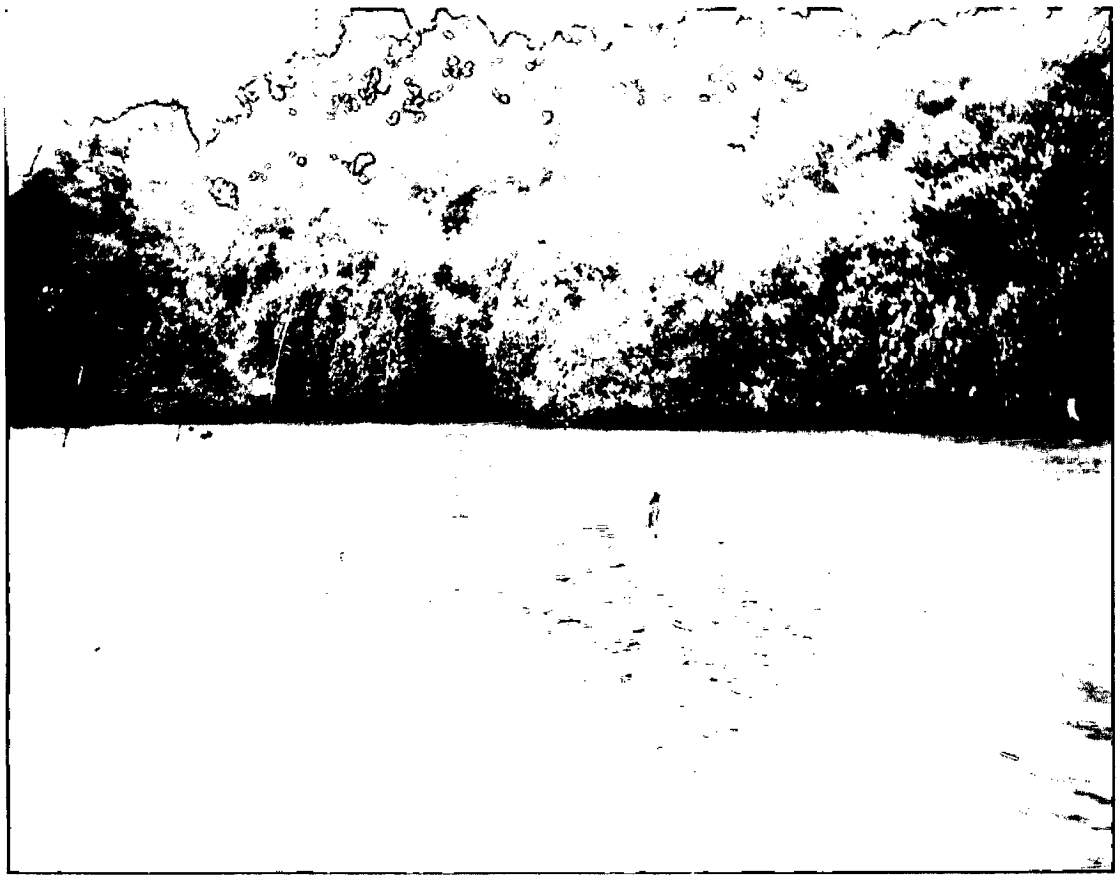


Plate 2.1: View of Chorao island (study site) from river side

was observed in the monsoon season (88.3±1.4%), with minimum values in the pre-monsoon season (71.9± 2.0 %; Table 2.1).

Rainfall

The seasonal variations showed high rainfall in the monsoon months. The post- and pre-monsoon constitute the dry season, with low rainfall (Table 2.1). In the monsoon season, the maximum average rainfall was recorded during August sampling (37.4 mm) and minimum during July (4.7 mm and 4.2 mm during 2004 and 2005, respectively).

2.4 Sampling

2.4.1 Sampling protocol

The sampling began in July 2003 and at monthly intervals from the month of July 2004 and continued till July 2005. Sampling could not be conducted in the month of December 2004 due to inclement weather that coincided with the world famous disastrous tsunami during that time. Sampling for abundance and distribution was done seasonally and for the comprehensive study, sampling at Chorao was done monthly. At each sampling period, the samples were obtained during low tide.

2.4.2 Sampling Design

For distribution studies, clams were recorded within 9 to 12 quadrants of $1m^2$ from a plot of approx. 500-1500 m^2 from all sites. At Chorao island, three transects approximately 500 m long and 20-40 m apart were established on a gradient of tidal elevation covering the low- tide, mid- tide and high- tide level designated as LT, MT and HT (Plate 2.2 and 2.3). Three replicates were randomly

Plate 2.2: Exposed low tide region at Chorao island with the *Rhizophora* dominated mid-tide in the background

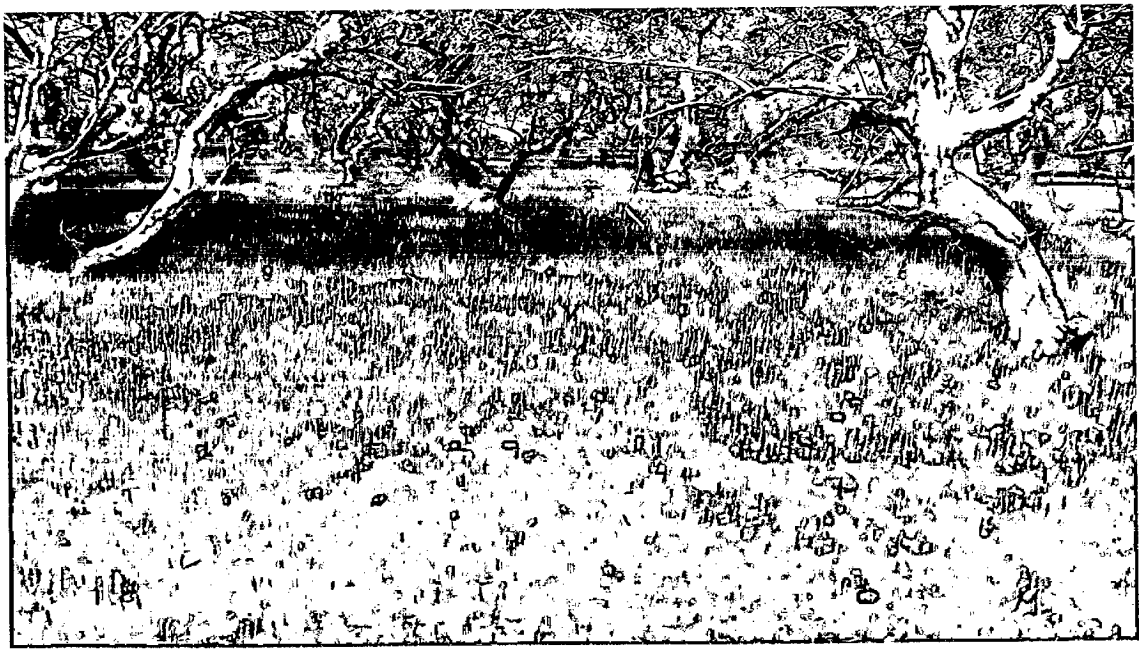


Plate 2.3: The high tide region inside the *Avicennia* forest in the study area at Chorao island

selected within each transect in the direction from upstream to the downstream side of the estuary and the individual replicates were separated by at least 15 m.

The three sites in each transect were assigned the following three treatments:

1. Collection of settling stages of the mud clams (from cages)
2. Collection of juveniles (0.25 m^2)
3. Environmental parameters (sediment and water)

2.4.3 Sampling for clam population

The adult clams were collected randomly by hand-picking (Plate 2.4) and live specimens were transported in plastic crates to the laboratory. On each sampling occasion, minimum of 30 specimens of various size groups were collected. Juvenile clams were collected by taking the upper 5cm layer of sediment from a marked area of 0.25m^2 (Plate 2.5). To collect the settling stages of the clams, metallic cages were set up and material retained on the cage was collected (Plate 2.6).

2.4.4 Sampling of environmental parameters (sediment and water)

Once each month, the samples were collected from each site along each transect monthly in close proximity to each other to minimize spatial variability and were considered as replicates. The parameters including temperature, pH, salinity, dissolved oxygen (DO), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^-) and chlorophyll *a* (chl *a*) from the interstitial water were analyzed.

The above enviromental parameters were also analyzed for the water samples collected from the adjacent estuarine water at three stations. Each station was at a distance of approximately 500 m. Due to shallow depth, only surface water

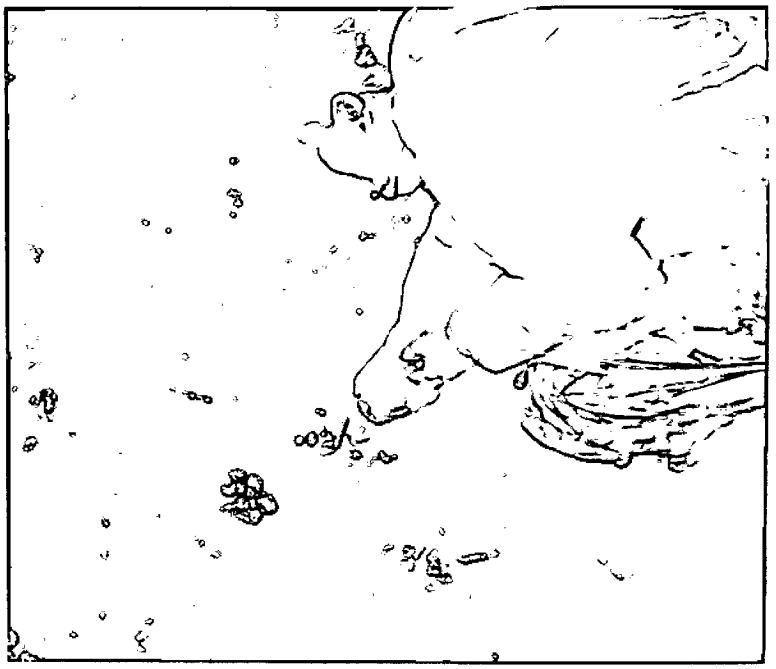


Plate 2.4a: Collection of adult clams in the field

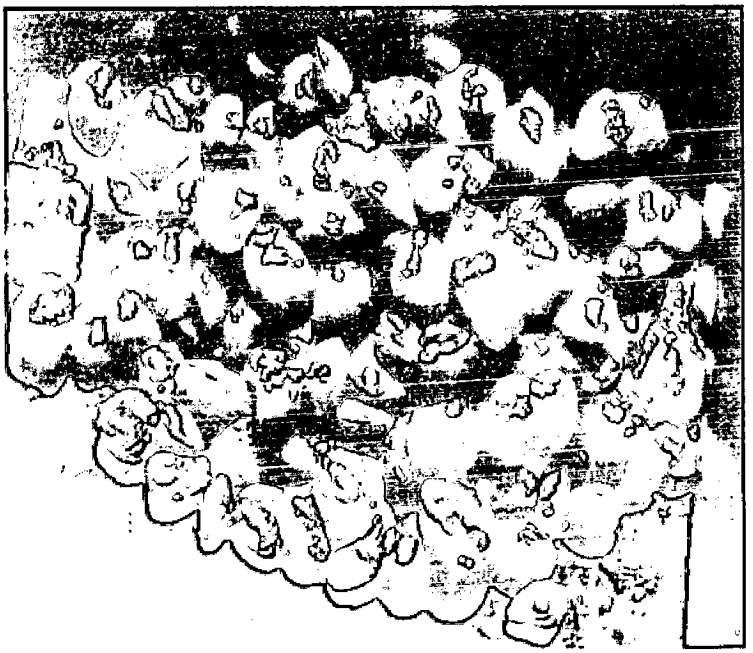


Plate 2.4b: Plastic crate with *P. erosa*

Plate 2.5: Sediment collection and sieving for juveniles

Plate 2.6: Cages in the field experiment to study *P. erosa* settlement

samples were collected at all the stations. Samples were collected from fixed points in duplicates. About 250 ml of water was collected for each parameter except for chl *a* wherein 500 ml was collected. After collection, the samples were transported immediately in iceboxes to the laboratory. Samples meant for dissolved oxygen (DO) were fixed immediately with Winkler reagents in the field itself and later analyzed in the laboratory. Samples for the measurements of nitrite, nitrate and phosphate were kept at freezing temperatures and were analyzed within 6-12 hours of collection. pH was analyzed in the field with a hand held pH meter (Lab India pH meter) and salinity measurements were done in the laboratory using Autosal Salinometer. The samples for chl *a* were filtered onto GF/C filter pad, and the filter with the particulate matter was extracted immediately in 90% acetone for flourometric measurements of chlorophyll pigments.

Sediment samples could be obtained regularly only from the LT and MT stations and samples for the analysis of nutrients and DO could not be obtained during January and April at HT, as the sediments were very dry with little or no water in the interstitial spaces. The pore water for DO, salinity and nutrients was collected after digging the sediment and allowing water to get accumulated in this space. The measurements of nitrite, nitrate and phosphate were done spectrophotometrically. For sediment chl *a*, samples were collected from the surface sediments and were transferred in autoclavable vials covered with foil. In the laboratory, 90 % acetone was added to the samples and the chlorophyll extract was used for flourometric measurements. After measurements, the sediment residue was dried in an oven and its weight was later obtained with an electronic balance (precision 0.001g).

CHAPTER 3

MORPHOMETRY OF *P. EROSA*

3.1 Introduction

Growth is one of the most used measures of an organism's vitality in a given environment. In bivalves, the size is directly related to its age, and this cumulative increase in biomass with respect to time is termed "absolute growth" while the percentage increase in biomass per unit time is "relative growth" (Seed, 1976). As growth represents changes in bivalve size, it is most often measured as shell length, weight, and volume. There may be complications in just measuring single shell parameters, as shell growth may be different from soft body growth due to environmental factors or variations in the reproductive cycle of the bivalve. It is the soft body that carries out the living processes of the animal, not the shell. Thus, allometric relationships are often developed between shell parameters and body weight in order to non-destructively estimate soft body biomass on living bivalves (Dame, 1972). Shell growth is a function of calcium availability in water and, therefore, the amount of water pump across the bivalve tissues, the pH of the internal system, the intermediary metabolism of the animal, and the environmental temperature that controls the rates of most of these processes. Although, shell size is related to soft body tissue mass, it is not a direct measure of body size, because some of the controlling factors are different.

Growth is the three-dimensional process with all dimensions changing over time. The allometric principles of animal morphology have long been recognized, since the concept of allometry was first postulated by Huxley and Tessier (1936). Allometry is the study of the relationship between two measurable variables, or in most general sense, allometry is the study of size and its consequences (Reiss, 1989). Bivalve shell growth and shape are influenced by abiotic (exogenous/environmental) and biotic (endogenous/physiological) factors. A variety of environmental factors are known to influence the shell morphology and relative proportions of many bivalve species, such as latitude (Beukema and Meeha, 1985), depth (Claxton et al., 1998), currents (Fuiman et al., 1999), water

turbulence (Hinch and Bailey, 1988), wave exposure, type of bottom and type of sediment (Claxton et al., 1998) Burrowing behaviour, ability and efficiency also affect the relative growth of the bivalve species (Seed, 1980). Studying growth and establishing allometric relationships are useful information for managing resources and understanding environmental changes. The growth of bivalves is mostly estimated by measuring the shell dimensions or the volume of the animal and also by measuring the shell rings (Deval, 2001).

Despite the existence of studies concerning morphometric aspects of bivalve populations from the Indian coast (Parulekar et al., 1986), currently no information on morphometry of *P. erosa* is available. Worldwide, some morphological aspects of this species are reported by Morton (1976) from Hong Kong mangroves and Gimmin et al. (2004) from the Australian mangroves. Dimensional studies in lamellibranchs reveal that animals coming from different localities have differences in their dimensional ratios. Knowledge of the sex ratio, size at first maturity of a species determines the number and size of individuals that must be held for conditioning and spawning which is very essential for developing aquaculture practises. At present, the *P. erosa* population is subject to a low level of artisanal fishery for local consumption only. Therefore, data on yearly catches are not available. Any future commercial exploitaion will need adequate stock management which necessiates the knowledge of the population dynamics that is based on the morphology of the animal. Hence, the present study was undertaken on the morphological aspects of *P. erosa*.

3.2 Materials and Methods

The clams were collected from the mangrove habitats along the central west coast of India between Kumta and Ratnagiri in different seasons. In addition, monthly collection of *P. erosa* population at Chorao island was done by hand picking

randomly from the high tide region (HT). Clams were immediately transported to the laboratory, where they were analysed for the different morphometric parameters. Although, the collection of small size group (<30 mm) of clam is difficult and time consuming, attempts were made to collect the smallest size clams quantitatively. For this purpose, a marked area of 0.25 m^2 was sampled by excavating only top 5 cm sediment layer. All the material was sieved on a 300μm mesh sieve and preserved in 5% formalin Rose – Bengal solution. However, due to a wider range of clam size, regular samples do not represent the quantitative data for all size groups within the population. Most of the individuals collected however, represent the mean size groups with majority being the matured specimens (as indicated by their mature gonads).

Following the field collection, the bivalves were kept in running water overnight to allow any sediment to be cleared from the mantle cavity and gut. Then, the intact clams were washed, blotted dry and then left for a short- time (10-15 minutes) in air to allow the shell surface to dry before being measured and weighed. The morphometric variables recorded were total length, width and height, total weight of the whole specimen and wet and dry weight of the soft parts. The measurements were done as total length (TL) (maximum distance on the anterior-posterior axis), height (maximum distance on the dorsal-ventral axis, across the shell middle axis), and width (maximum distance on the lateral axis, between both valves of the closed shell). All variables were measured to the nearest 0.01 mm with a vernier caliper. Total weights (TW) to the nearest 0.01 g were determined after drying the shell with paper towels. Sex is determined based on the colour of the gonads. The gonad is black in females and creamy white in males. The wet tissues were blotted and their weights were measured to the nearest 0.01 g with a Mettler PB602-S electronic balance. The dry weights were recorded after drying the tissue in the oven at 60°C to a constant weight for 72 hours. The volume of mantle fluid was measured after draining the fluid in a beaker.

3.2.1 Growth measurements

Following a particular cohort by measuring size frequency distribution through time is a common technique among population ecologists. In this method, a given year class is followed, and the change in the average size of the mode is equivalent to average growth. The ultimate length or the asymptotic length ($L\infty$) attained by *P.erosa* was determined by the Ford Walford plot (Ford, 1933; Walford, 1946). The size frequency distribution was calculated for 10 mm length intervals.

3.2.2 Size at first maturity

To estimate the theoretical size at first maturity, data on TL and TW was subjected for correlation analysis and on the basis of break in a regression line discerned by inspection of a scattergram of LT/TW data (Ingole et al., 1998).

3.2.3 Sex ratio

The ratio of males to females was determined from microscopic examination of the gonadal smear. Clams were deemed sexually mature if gametes were present. A chi-square goodness of fit test was used to test the hypothesis that there was an equal representation of male and female mud clams in the population.

3.2.4 Morphometric relationship

The estimation of the morphometric relationships between the shell dimensions (length, width and height) and total weight, soft tissue wet weight and soft tissue dry weight were independently evaluated using log transformation of the equation (Ricker, 1973):

$$Y=aX^b$$

$$LogY= Log\ a + b\ LogX$$

Where, Y is total weight (g), or soft tissue weight (wet or dry weight) in grams, and X is one of the dimensions (length, width or height) in millimeters, ***a*** is the intercept (initial growth coefficient); ***b*** is the slope (relative growth rate of variables). The length to total weight relationship was evaluated separately for males and females as well as for clams collected during the different seasons. So also the allometric relationship between clams collected from different locations were separately estimated. The parameters ***a*** and ***b*** of the morphometric relationships were estimated by linear regression analysis (least squares method), and the association degree between variables was calculated by the determination coefficient (r^2). Additionally, the 95% confidence limits of *b* and the significance level of r^2 were also estimated. An F- test was applied to test whether the slopes of the regression lines were significantly different from zero. The difference in the mean size between different sites as well as males and females was tested using an analysis of variance (ANOVA). Differences between regression lines of males and females, and of seasons were tested using the two-tailed Student's t-test and ANOVA (Fowler et al., 2000). Routine regression and ANOVA was done using the Statistica version 5.5 (Statsoft, 1999).

3.3 Results

3.3.1 Structural Morphology

3.3.1.1 The Shell

The mangrove clam, *P. erosa* possesses a massive shell and is infaunal, inhabiting the landward fringe in the thick mangrove forest (Plate 3.1). The shell of *P. erosa* is large, thick, and dark in colour externally and white internally (Plate 3.2). The largest specimen found in Chorao Island, measured 102 mm in length, 98 mm in width and 54 mm in height. The clam's shell is plump and globular, the valves

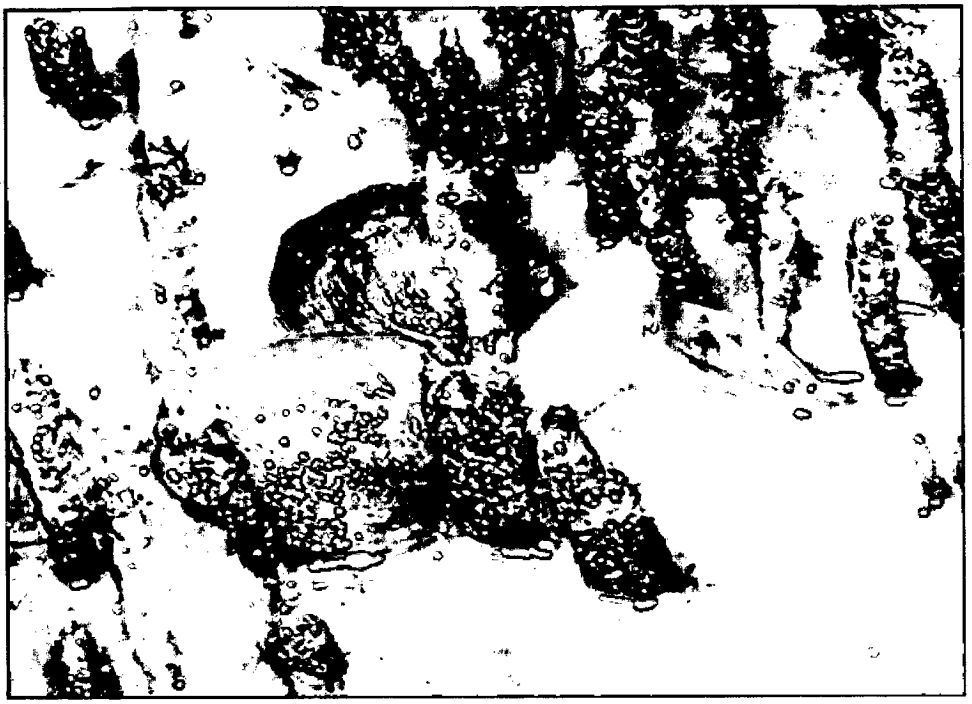


Plate 3.1: Mangrove clam *P. erosa* in *Avicennia* roots

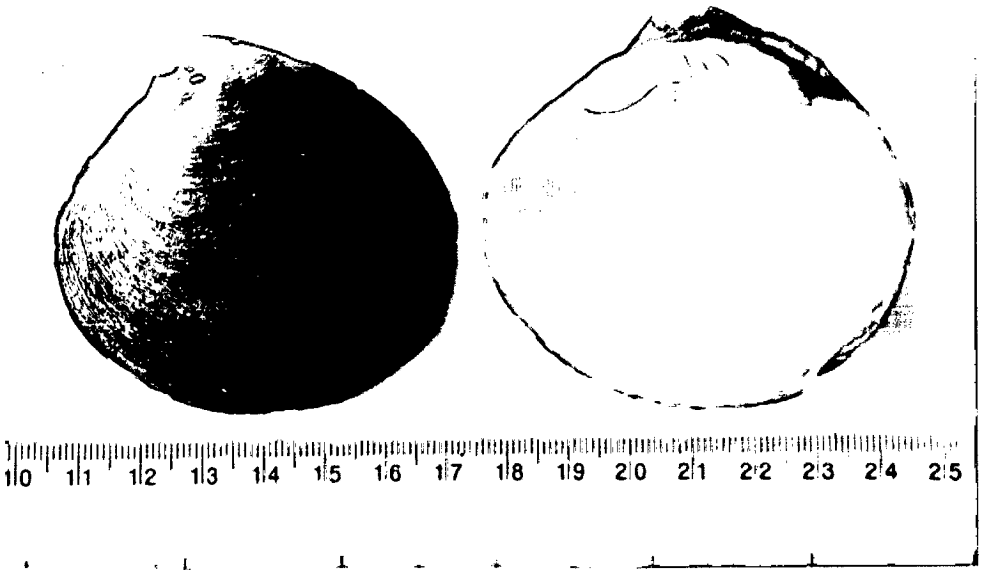


Plate 3.2: Shell valves of *P. erosa* (external and internal view)

being thick and heavy. Majority of the clams have their umbonal beaks heavily corroded (Plate 3.3) while living. The shell is aragonitic. According to Taylor and Brand (1975), the shell of all corbiculids is similar in composition. Smaller, younger clams possess a more rounded shell. The shell is equivalve with left and right valves being symmetrical and has similar weights (Fig. 3.1a). The shell valve margins meet through the entire length, except for a small gap mid-posteriorly. In the left valve, there are three cardinal teeth and two lateral teeth, one anterior and one posterior. In the right valve, there are three cardinals and two anterior and a single posterior tooth (Fig. 3.1b and 3.1c). The hinge teeth are stout, which, lock the shell tightly when the valves are united. The shell possesses a pallial line but there is no pallial sinus. The umbones are prominent and are near the anterior end. Most of the variability in form is apparently related to the differences in the height of the umbones. The shell interior is white. Young shells are dark green, but the colour disappears with age and older individuals are stained black.

3.3.1.2 The Siphons

The siphons of *P. erosa* (both inhalant and exhalant) are very short (Plate 3.4). The inhalant siphon bears a crown of 20-30 tentacles. Surrounding the tentacles is an outer circlet of small papillae at the base of the siphon. The exhalant siphon is somewhat conical and much smaller than the former on. This siphon does not possess the tentacular crown but is surrounded by the papillae, which run as two parallel rows, one on each mantle lobe. The papillae progressively shorten and soon terminate. The siphons and the mantle margins are deeply pigmented in *P. erosa* and hence, it is difficult to observe the siphons in fully open form. The siphons rarely open out fully except when immersed in water and are held between the borders of the valve.

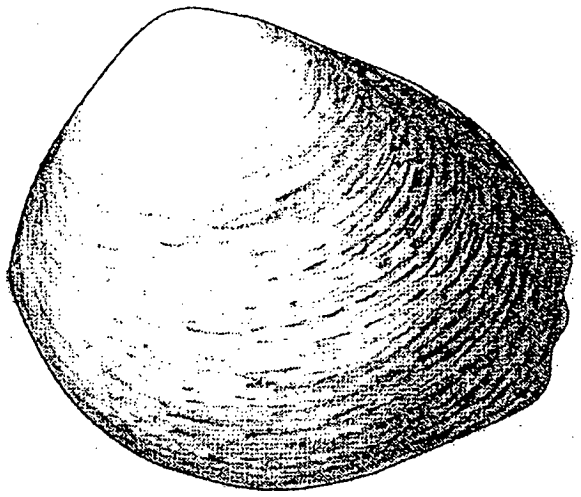


Fig. 3.1a; *P. erosa*, Shell valve (External view)

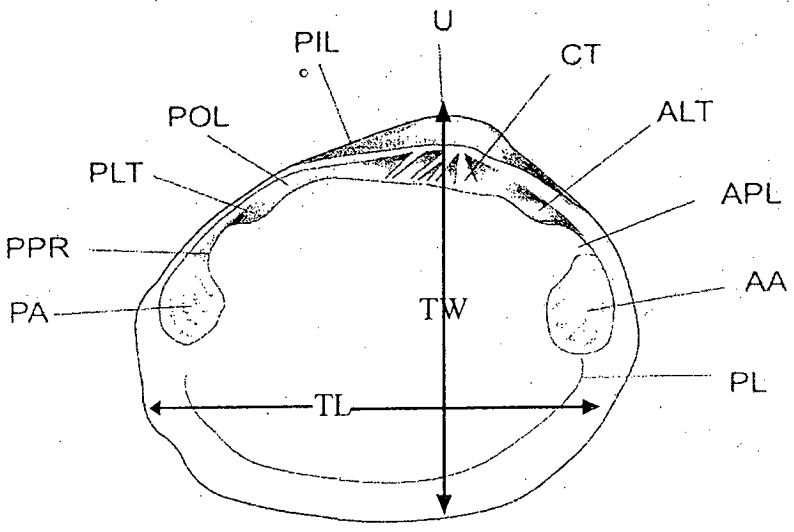


Fig. 3.1b: *P. erosa*, interior view of the left shell valve

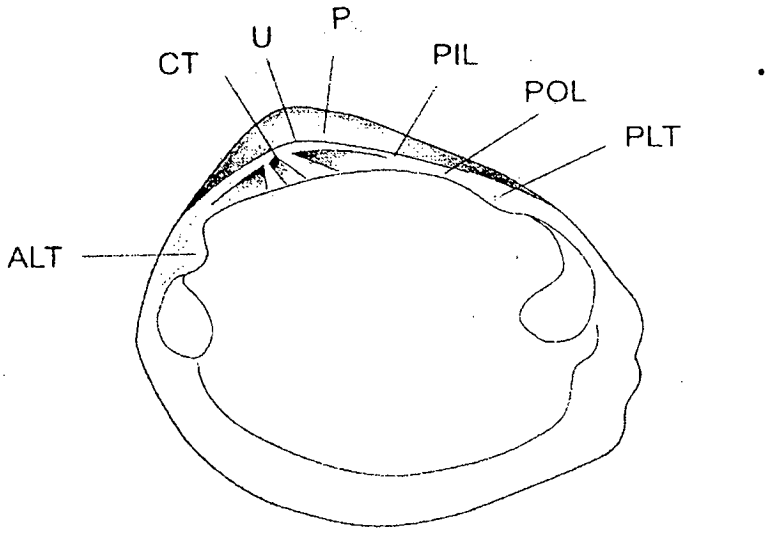


Fig. 3.1c: *P. erosa*, interior view of the right shell valve

Fig 3.1b. Interior view of left shell valve

PA Posterior adductor muscle (or scar)

PPR Posterior pedal retractor muscle (or scar)

PLT Posterior lateral tooth

POL Posterior outer ligament layer

PIL Posterior inner ligament layer

U Umbo

CT Cardinal tooth

ALT Anterior lateral tooth

APR Anterior pedal retractor muscle or scar

AA Anterior adductor muscle (or scar)

PL Pallial line

Fig 3.1c. The hinge plate of right shell valve

ALT Anterior lateral tooth

P Periostracum

E Eroded region of shell

CT Cardinal tooth

U Umbo

AIL Anterior inner ligament layer

PIL Posterior inner ligament layer

POL Posterior outer ligament layer

PLT Posterior lateral tooth

Plate 3.3: *P. erosa* with heavily corroded umbo

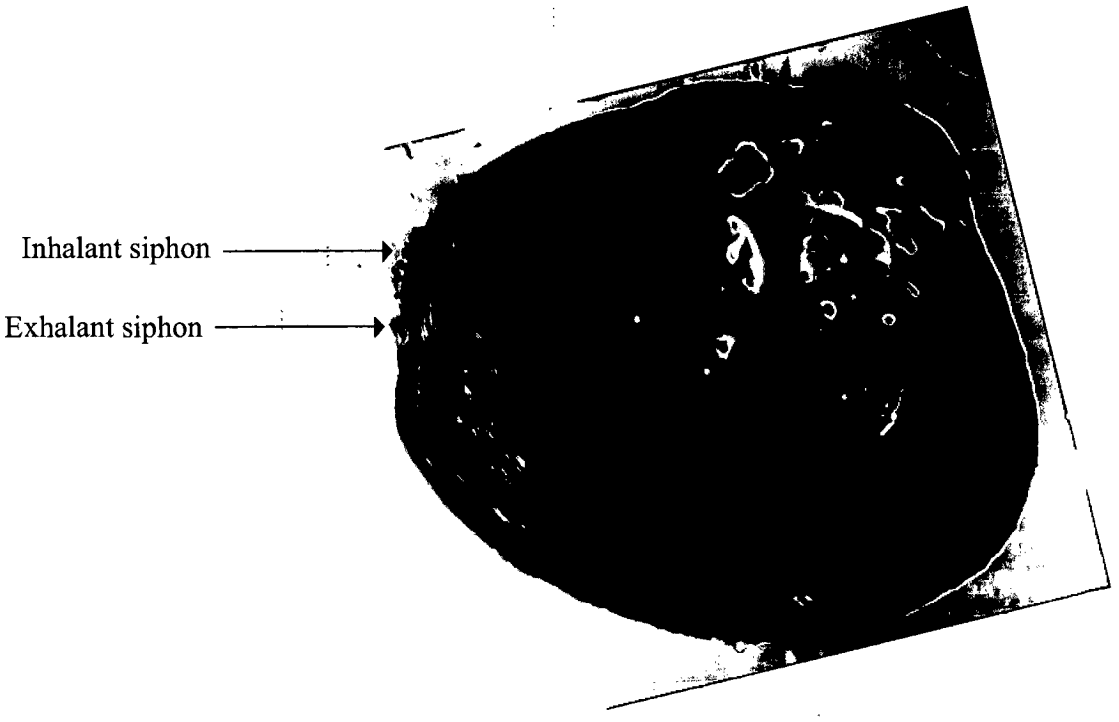


Plate 3.4: *P. erosa* with extended inhalant and exhalant siphon

3.3.1.3 The pedal gape

The pedal gape (Plate 3.5) extends ventrally from the inhalant siphon to the anterior adductor muscle. Through the gape the large creamish white muscular foot can protrude. When they are not covered by water, the shell valves gape slightly, and when the animal is removed from the burrow, they close tightly together. When they close (usually happen, if disturbed), a jet of water is often ejected from the pedal gape.

3.4 Size variation of *P. erosa* along the west coast of India

The size of *P. erosa* in the present study, varied from 1.5 to 102 mm and the adults are usually not >102 mm, with majority of clams between 70 to 80 mm (Plate 3.6). The frequency of clams observed in the different size classes recorded is summarized in figure 3.2. Statistically significant differences in the size classes recorded from different locations during the study were observed ($F=4.564$, $df=55$, $p=0.000942$) and at all sites, clams represented the mean size classes except for Kalbadevi and Terekhol where only smaller and medium size classes were found. Location-wise details of morphometric measurement of *P. erosa* population are given in table 3.1. Maximum total weight, volume of mantle fluid, wet and dry weight was observed in the clams with the maximum total length (largest) and the lowest values for the above mentioned parameters were observed in the clams with minimum total length (smallest). However, this trend was not consistent with all the different size classes since some specimens with large sizes did not always show maximum total weight, wet weight and dry weight.

3.5 Population Structure

The size of *P. erosa* ranged from 1.5 to 102 mm. There was no significant difference in the mean size of the monthly samples ($F=1.988$, $df=25$, $p>0.05$; Table 3.2), as well as the different size classes recorded for one year did not show

Table 3.1: Location-wise details of morphometric measurements (range) of *P. erosa* population collected during the present study

Location	Length (mm)	Total weight (g)	Wet weight (g)	Dry weight (g)
Malvan	31.7-72.1	11.05- 190.16	1.16-15.63	0.18-2.35
Kumta	37-92.9	9.4-197.8	1.84-43.4	1.09-8.02
Sinquerim	56.48-94.72	60.95-265.73	9.14-29.13	1.32-5.22
Shirgao	56.4 – 81.9	51.4 -151.4	6.02 – 21.73	0.95- 4.56
Terekhol	42.5-60.3	21.12-49.3	3.03-10.59	0.58-2.02
Chorao	33.74-102.2	13.4 –205	1.08-45.2	0.89-8.54.
Kalbadevi (Single clam)	59.8	48.63	4.76	0.67

Table 3.2: Results of ANOVA between months on (a) mean length and (b) size classes of *P.erosa* at Chorao island

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
(a) Mean length					
Month	88.03	1	88.026	1.988	0.1713
Residual	1062.45	24	44.269		
(b) Size class					
Month	23.18	12	1.932	0.010	1
Residual	25912.83	130	199.329		

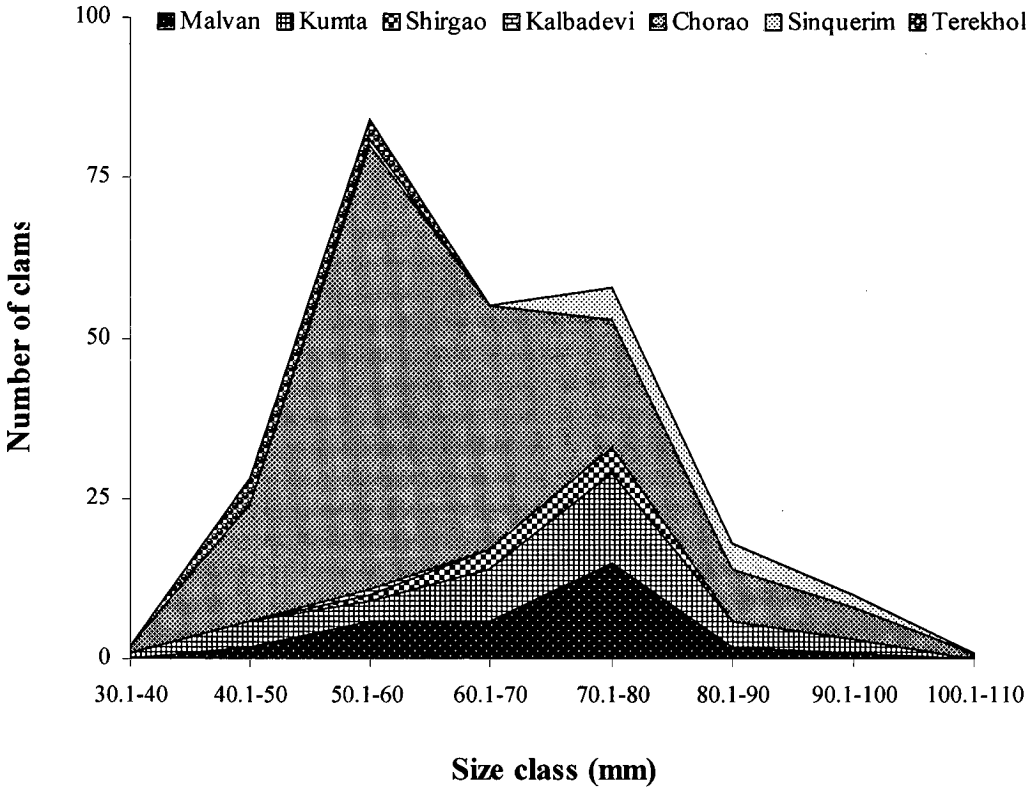


Fig 3.2: Size-wise distribution of adult *P. erosa* in the mangroves along the central west coast of India

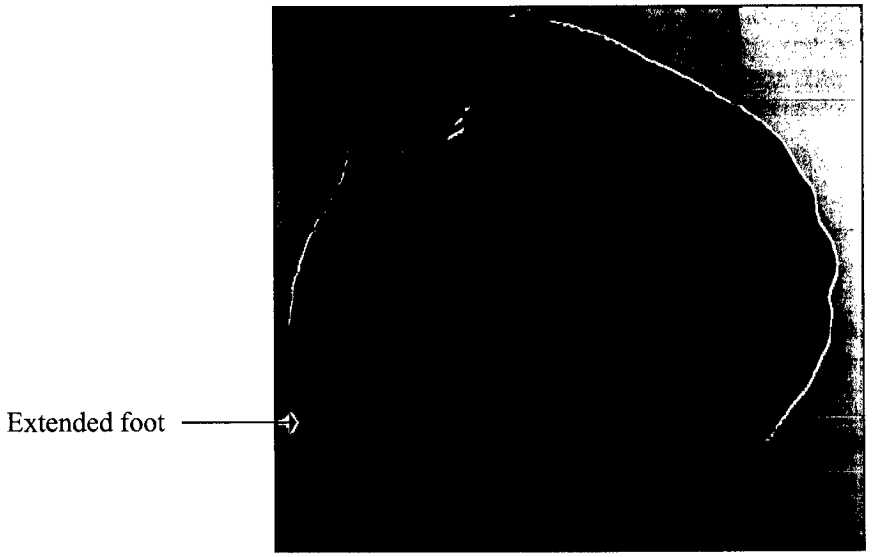


Plate 3.5: *P. erosa* with foot extended through pedal gape

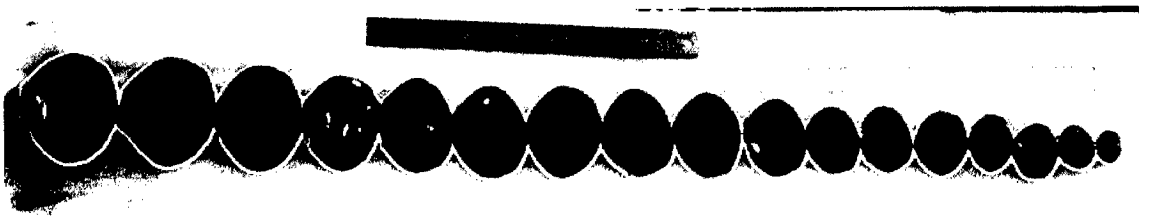


Plate 3.6: Size variation in adult *P. erosa*

a significant variation in different months (F=0.0096, df=142, p>0.05; Table 3.2). The sex of all adult clams could be determined based on gonadal state. Sexes are separate in *P. erosa* with no incidence of hermaphroditism at Chorao island, although reported only in a single specimen from the Hong Kong mangroves (Morton, 1985). The gonads were not developed in the small specimens (<30mm). The indication of few sperms in males and developing ova in females were within the size class of 30.1-40 mm shell length. Sexually ripe clams were found in all sizes above 35 mm. In a year class, males are always smaller than female. Sexes are identifiable at TL of > 35 mm (Fig. 3.3). The smallest sized clam with identifiable sex, a male specimen recorded in this study was 35.3 mm shell length. Thus, sex differentiation takes place at the size of 30.1-35 mm and sexual maturation could occured around 40 mm sizes when the clams are ~5 months old. If the individuals of the first year class begin their life as benthic recruitee in around July, they can grow upto 40.1-50 mm in December (Fig 3.4). The TL of the clams ranged from 3.83 mm to 102 mm for females and from 3.6 mm to 9.4 mm for males. Mean TL for males and females was 65.8±6.5 SD mm and 69.5±6.8 SD mm, respectively (Fig. 3.5). No significant difference was found in the mean TL of males and females (F=1.988, p=0.171, df=25). The largest was a female with 102 mm TL, observed in March 2005. Most of the individuals were in size classes larger than 40.1 – 50 mm and the most dominant size class was 70.1-80 mm (Fig. 3.6). Eventhough, females outnumbered males in most of the months (Fig 3.7), the overall sex ratio for male to female, was not significantly different from the theoretical 1:1 ratio (χ^2=2.1, df=1, p=0.1743).

The data on sex ratio in relation to length presented in figure 3.8 showed that, both male and female clams at Chorao mangroves were most abundant in the 60.1-70 mm shell-length class, however, males were dominant in the smaller length groups and females dominated in the larger length groups. In females, the length group 70.1 – 80 mm was the most dominant whereas the dominant size group for male was 50.1–60 mm. The 100.1-110mm size group was represented

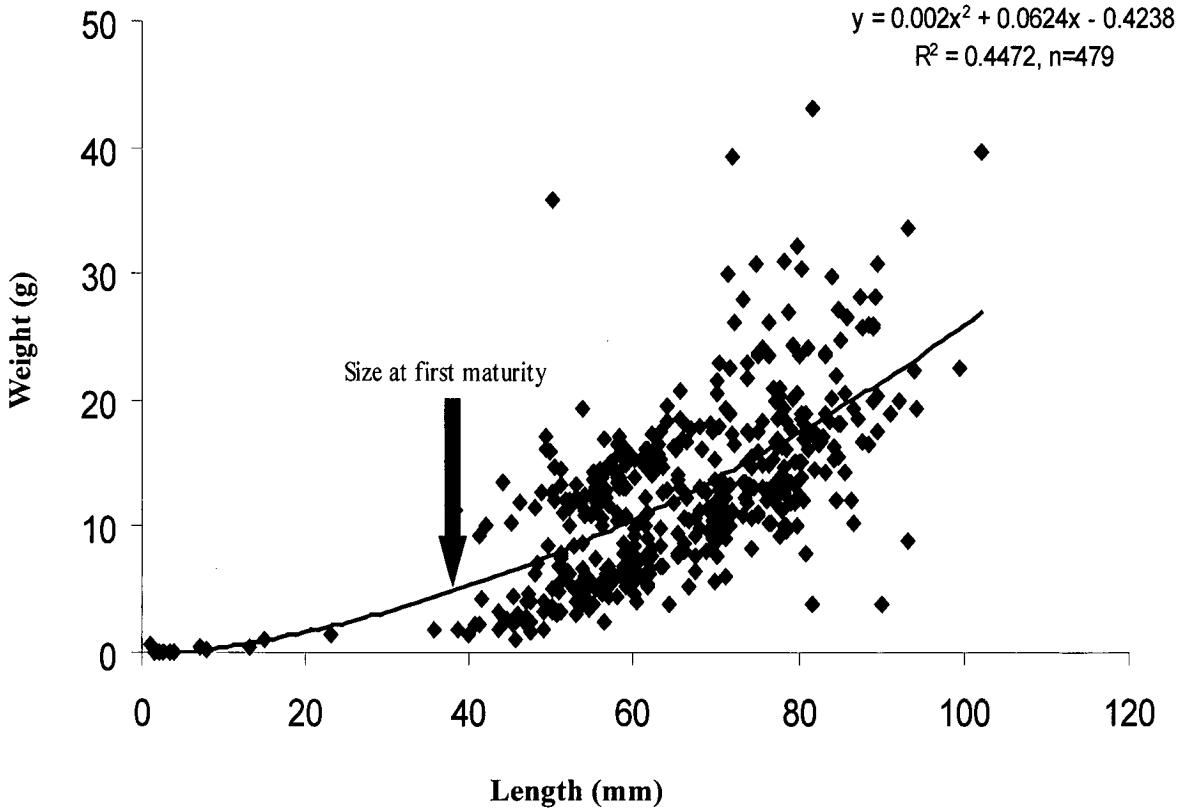


Fig. 3.3: Regression of soft tissue weight of *P. erosa* on shell length

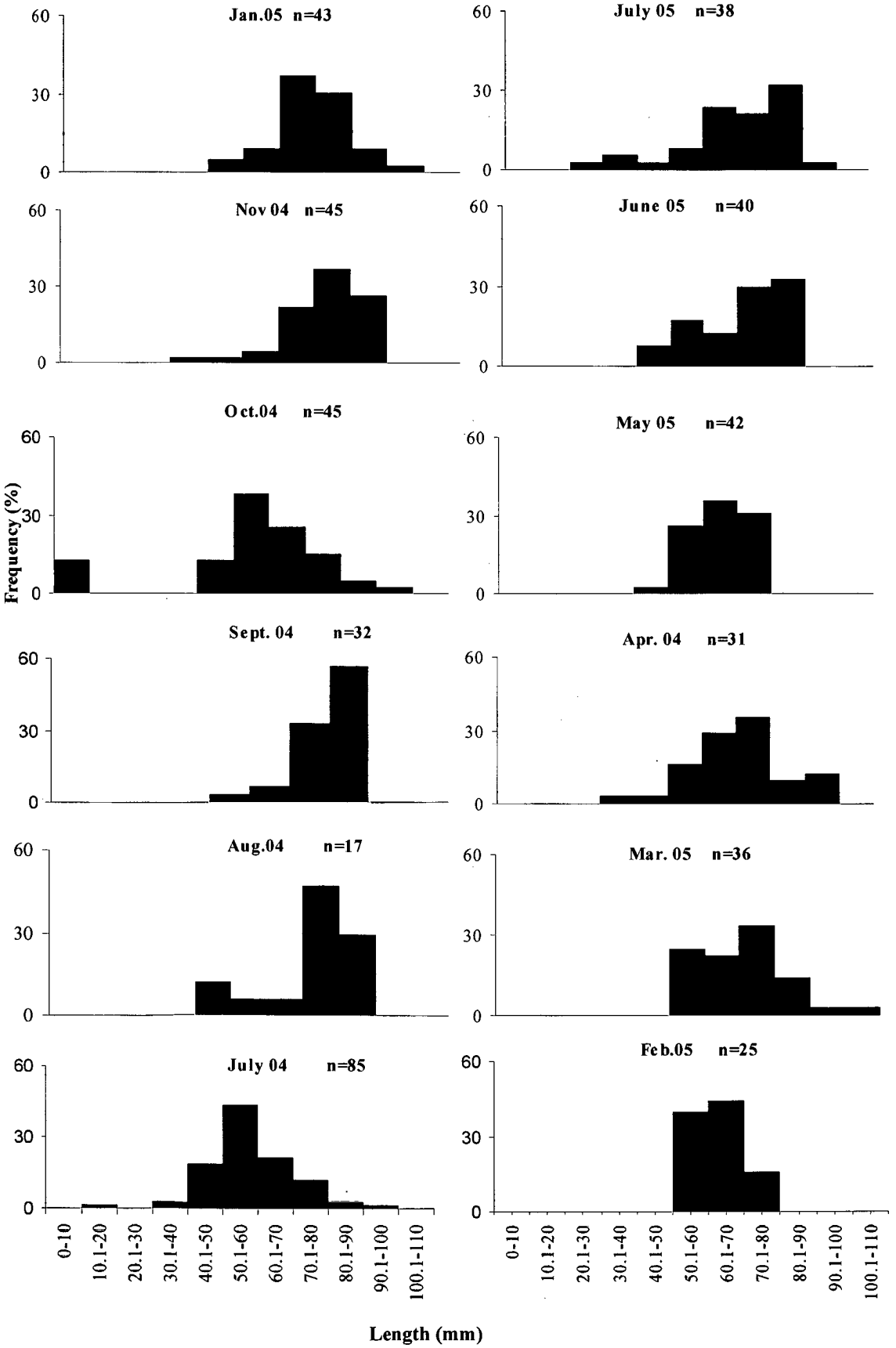


Fig 3.4: Size frequency distribution of *P. erosa* in different months at Chorao island, Goa

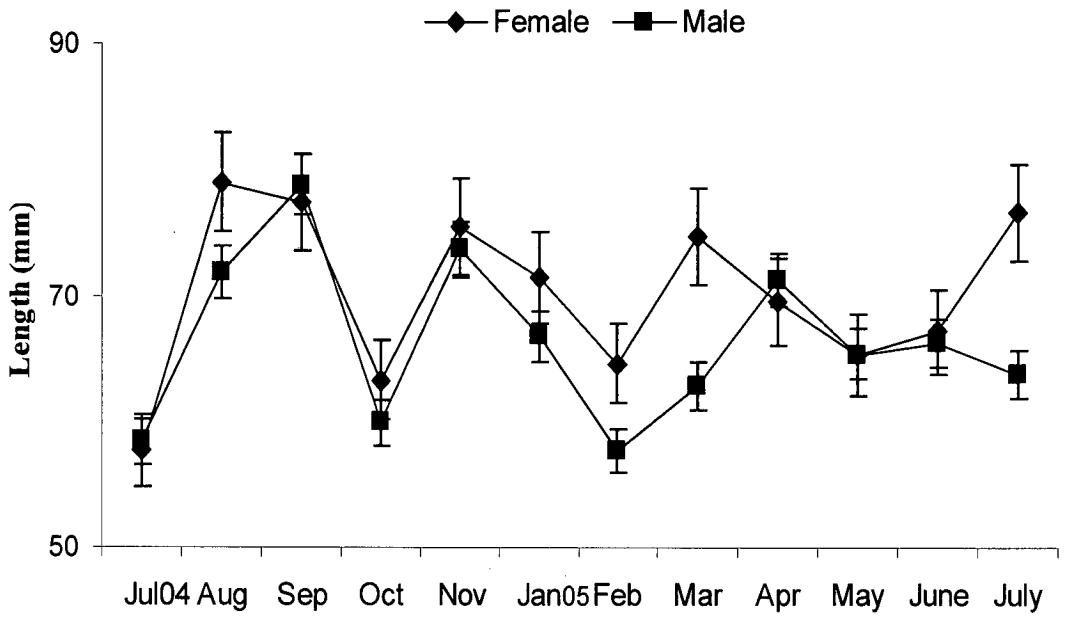


Fig 3.5: Mean length of males and females of *P.erosa* in different months

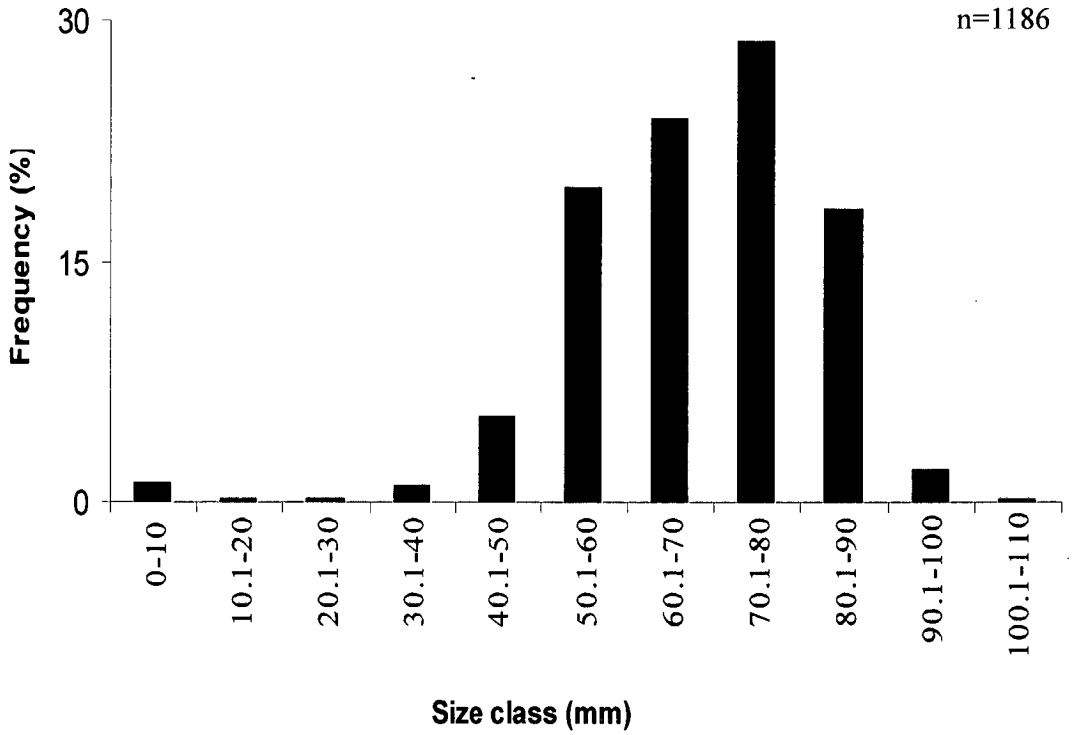


Fig 3.6: Percentage of *P. erosa* observed in different size classes at Chorao Island

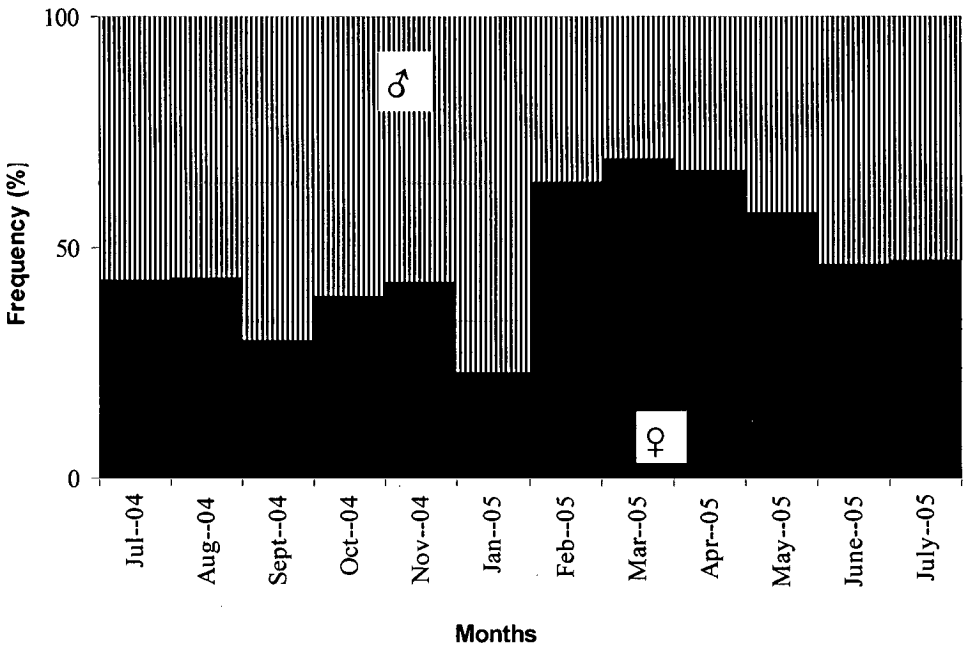


Fig 3.7: Percentage of male and female *P. erosa* in different months

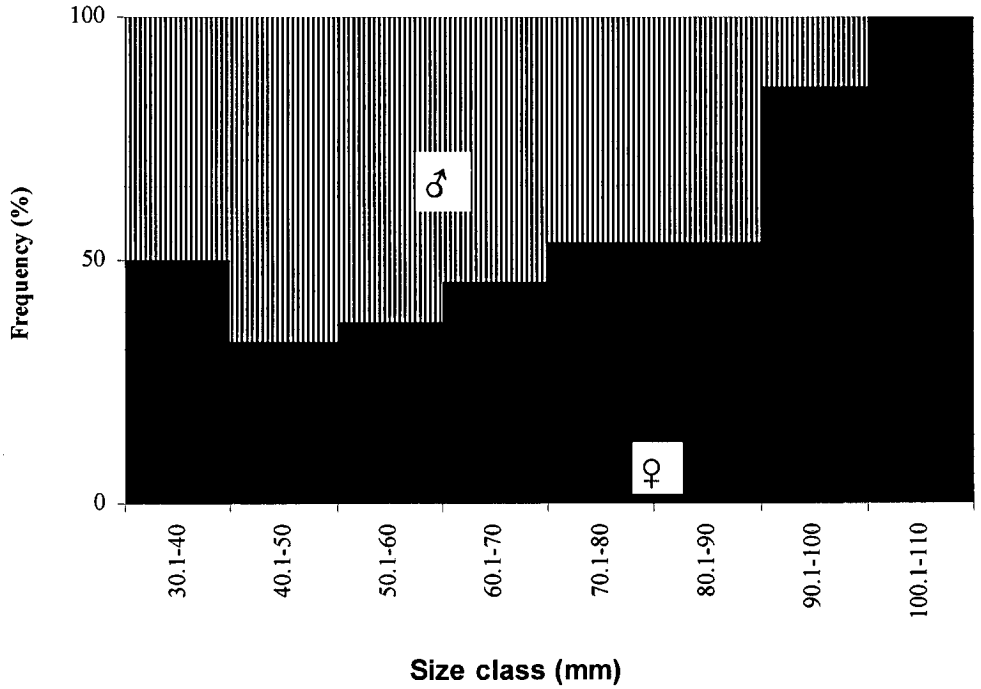


Fig 3.8: Percentage of male and female *P. erosa* in different length groups

only by females. However, at all length intervals, the numbers of males and females are not significantly different ((χ^2=14.78, df=7, p>0.05). Thus, the null hypothesis of independence between sex and length can be accepted for *P.erosa.* Seasonal variations in the sex ratio were apparent for females from February to July and for males from August to January. The sex ratio for *P. erosa* did not show significant variation over 12 months of study period (χ^2=32.67, df=11, p>0.05). However, Chi-square test on monthly ratio revealed that the sex ratio bias for male was significant only in January (χ^2= 7.41, df=1, p=0.0063) and for females in March and April (χ^2=6.277, df=1 p=0.0123; χ^2=4.05, df=1, p=0.0442, respectively). At the Chorao island, *P. erosa* is therefore a gonochoristic bivalve.

3.6 Growth

The length frequency distribution showed that, there was an appreciable modal shift in length of cohorts with time (Fig 3.4). The small newly recruited clams appeared during July to October 2004 at Chorao mangrove mudflat. An analysis of size frequency distribution shows that, the mode at 50.1-60 mm in July 2004 progressively moves to 60.1-70 mm in August, indicating an increase of 10 mm. In March, this mode is shifted to 100.1-110 mm (Fig. 3.4) showing a monthly growth rate of about 4 mm. However, this mode is not traceable after March. In July 2004, a mode appears at 0-10 mm and this is traceable through November – December, 2004 upto January 2005 reaching a size of 60.1-70 mm, thus attaining an average monthly increase of 10 mm during the first year of recruitment. In February 2005, the mode at 60.1-70 mm does not change, but then moves to 70.1-80 mm in March 2005 (Fig. 3.4), indicating a monthly increase of 5 mm. In April 2005, the mode at 70.1-80 mm does not change and only in July 2005 was shifted to 80.1-90 mm (Fig. 3.4), thus showing a monthly growth of 3.3 mm. This indicates that, during the first year, the growth rate is faster, but as clams attains maturation, growth rate decreases. The clam can grow upto 100 mm in approximately 4 years. The asymptotic or the ultimate length that can be attained

by *P. erosa* in Chorao mangrove mudflat, was estimated as L∞=120 mm (Fig 3.9).

3.7 Morphometric relationships

In all the allometric relationships of *P. erosa*, all the slopes of the regression lines are significantly different from zero. The estimated coefficients of the length-weight relationship and other statistical details are summarized in (Table 3.3). Shell length, shell width and shell height showed a strong correlation with total weight (Fig 3.10 to 3.12). At least 83 % of the variation in the latter is accounted for the variation in shell dimensions. Among the shell dimensions, shell length is the best estimator of total weight with r^2 of 95 %. However, when applied to soft tissue weights, the correlation of shell dimensions are not so strong (r^2 values of 46-47 %) and with dry tissue none of these shell variables is a good predictor (r^2 values of 21-27 %).

The differences in total weight of male and female during the different seasons were estimated using only the shell length since the length showed a comparatively stronger correlation than the width and height (Fig 3.13; Table 3.4). The slope for male's regression line is found to be significantly higher than the females ($t=2.9315$, $df=587$, $p<0.01$). The slopes are constantly higher during the monsoon season (Table 3.4), indicating more variability in total weight than that of the summer season. The slope of the female's regression line during post-monsoon season is significantly lower than for the monsoon season ($t=3.0637$, $df=139$, $p<0.001$; Fig. 3.14 and 3.15), while the slopes for the males do not differ significantly ($t= 1.2716$, $df=223$, $p>0.05$; Fig. 3.16 and 3.17). Combined data for both sexes showed a significantly different slope ($t=-2.7890$, $df=364$, $p< 0.001$), for clams collected during the summer season than the clams collected in the monsoon season (Fig 3.18 and 3.19). However, when contrasting the two sexes collected in the same season, the result is not significant (summer: $t=2.2845$,

Table 3.3: Morphometric relationship of shell dimensions with total weight and soft tissue weight of *P. erosa*

Relationship	n	a	b±SE	r^2	F*
Total weight (g)					
Length vs Total weight	**594**	-3.404	2.9373±0.0535	0.8357	3010.971
Width vs Total weight	594	-3.483	3.035 ± 0.558	0.8332	2958.9
Depth vs total weight	594	-2.162	2.591 ± 0.047	0.833	2953.77
Wet Soft tissue weight (g)					
Length vs wet weight	455	-2.899	2.172 ± 0.1075	0.4238	407.9
Width vs wet weight	455	-2.874	2.199 ± 0.1109	0.414	392.6
Depth vs wet weight	455	-1.936	1.889 ± 0.0948	0.4169	396.7
Dry soft tissue weight (g)					
Length vs dry weight	455	-2.131	1.946 ± 0.1674	0.247	211.3
Width vs dry weight	455	-2.74	1.758 ± 0.1320	0.213	103.1
Depth vs dry weight	455	-2.166	1.188 ± 0.1624	0.275	187.9

Table 3.4:Morphometric relationship of shell weight with total weight of female and male *P.erosa* during different seasons

Sex	Season	n	a	B±SE	r^2	F
Male	**Monsoon**	79	-3.868	3.200 ± 0.081	0.952	1557.7
Male	**Postmonsoon**	146	-3.5	2.979 ± 0.120	0.809	610.1
Male	**Premonsoon**	41	-2.816	2.629 ± 0.250	0.738	109.8
Female	**Monsoon**	52	-3.856	3.201 ± 0.102	0.951	977.4
Female	**Postmonsoon**	89	-2.668	2.531 ± 0.1569	0.744	253.1
Female	**Premonsoon**	70	-1.924	2.119 ± 0.2347	0.545	81.4
Male + Female	**Monsoon**	131	-3.861	3.199 ± 0.063	0.952	2541.9
Male+ Female	**Postmonsoon**	235	-3.2	2.817 ±0.096	0.785	852.7
Male + Female	**Premonsoon**	111	-2.111	2.226 ± 0.173	0.602	164.9

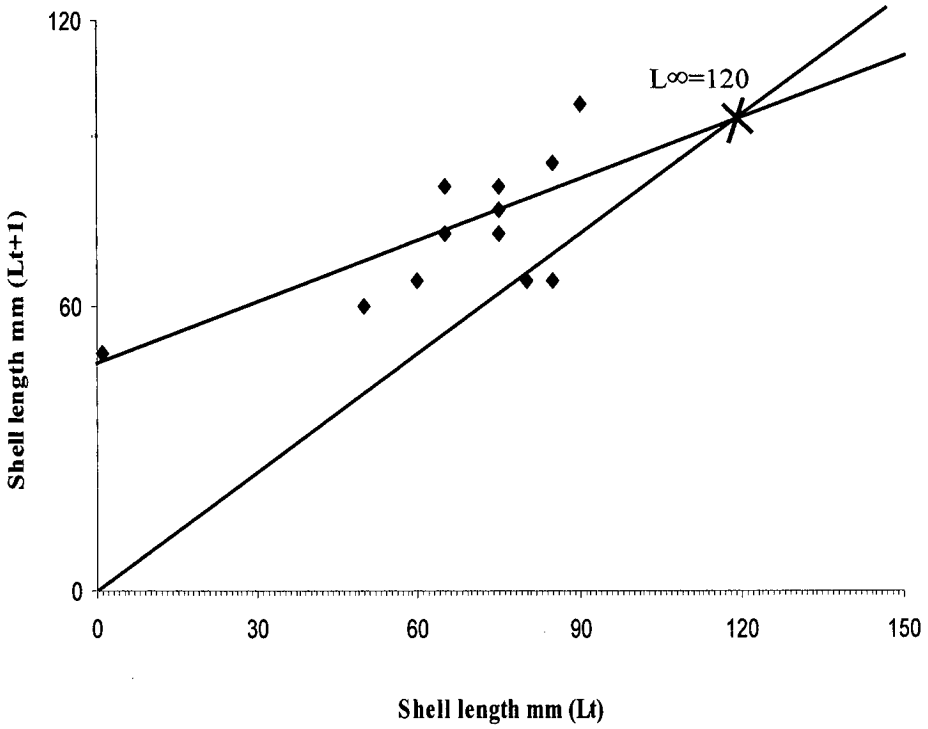


Fig 3.9: The asymptotic length of *P. erosa* estimated for Chorao Island population

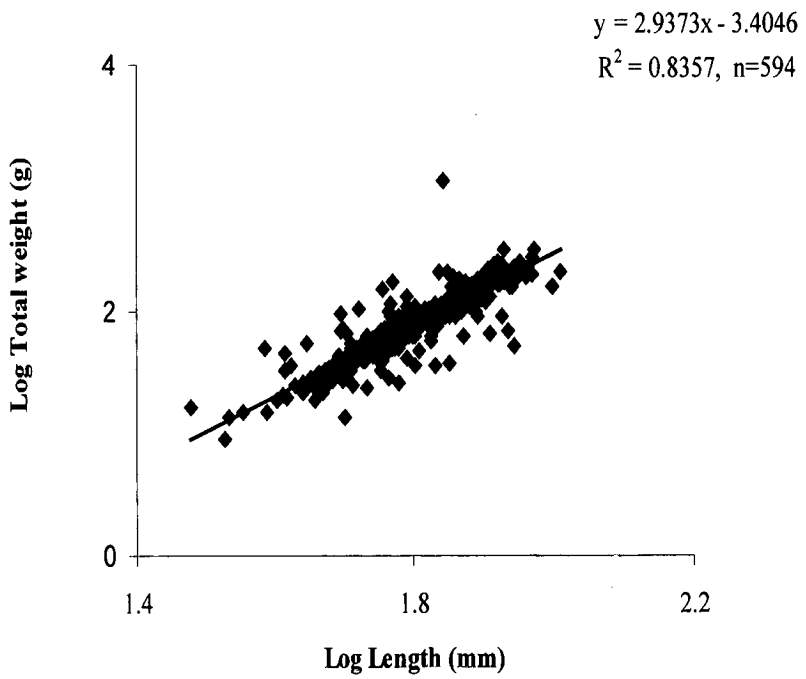


Fig 3.10: Shell length and total weight relationship of *P. erosa*

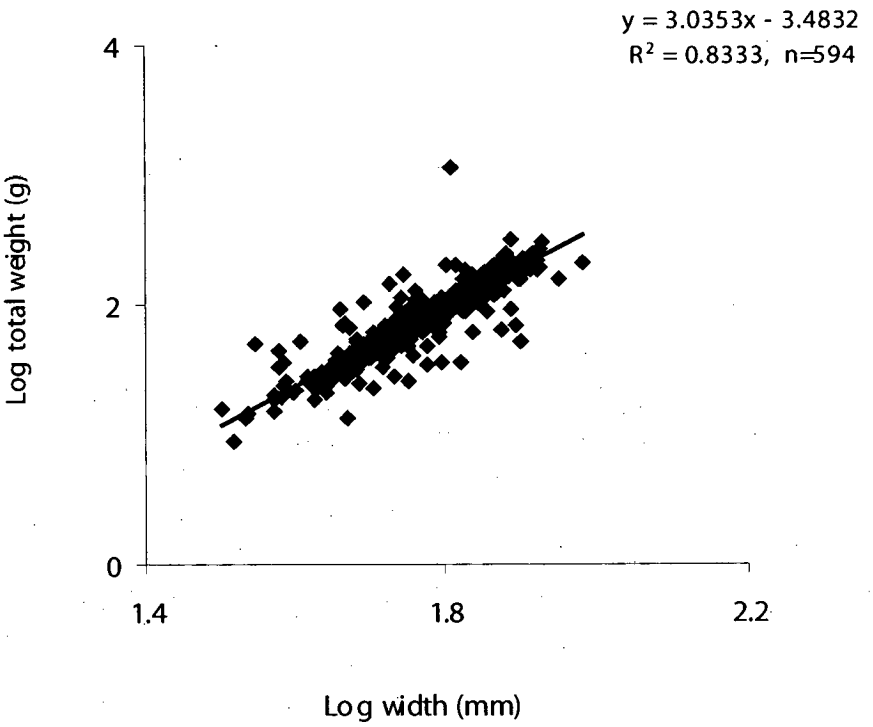


Fig 3.11: Width and total weight relationship of P. erosa

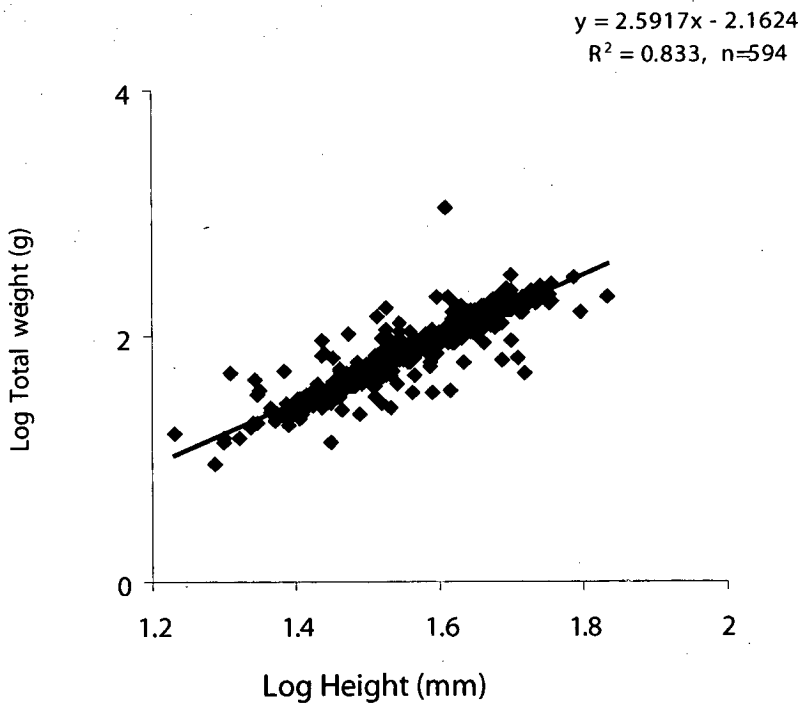


Fig 3.12 : Depth and total weight relationship of P. erosa

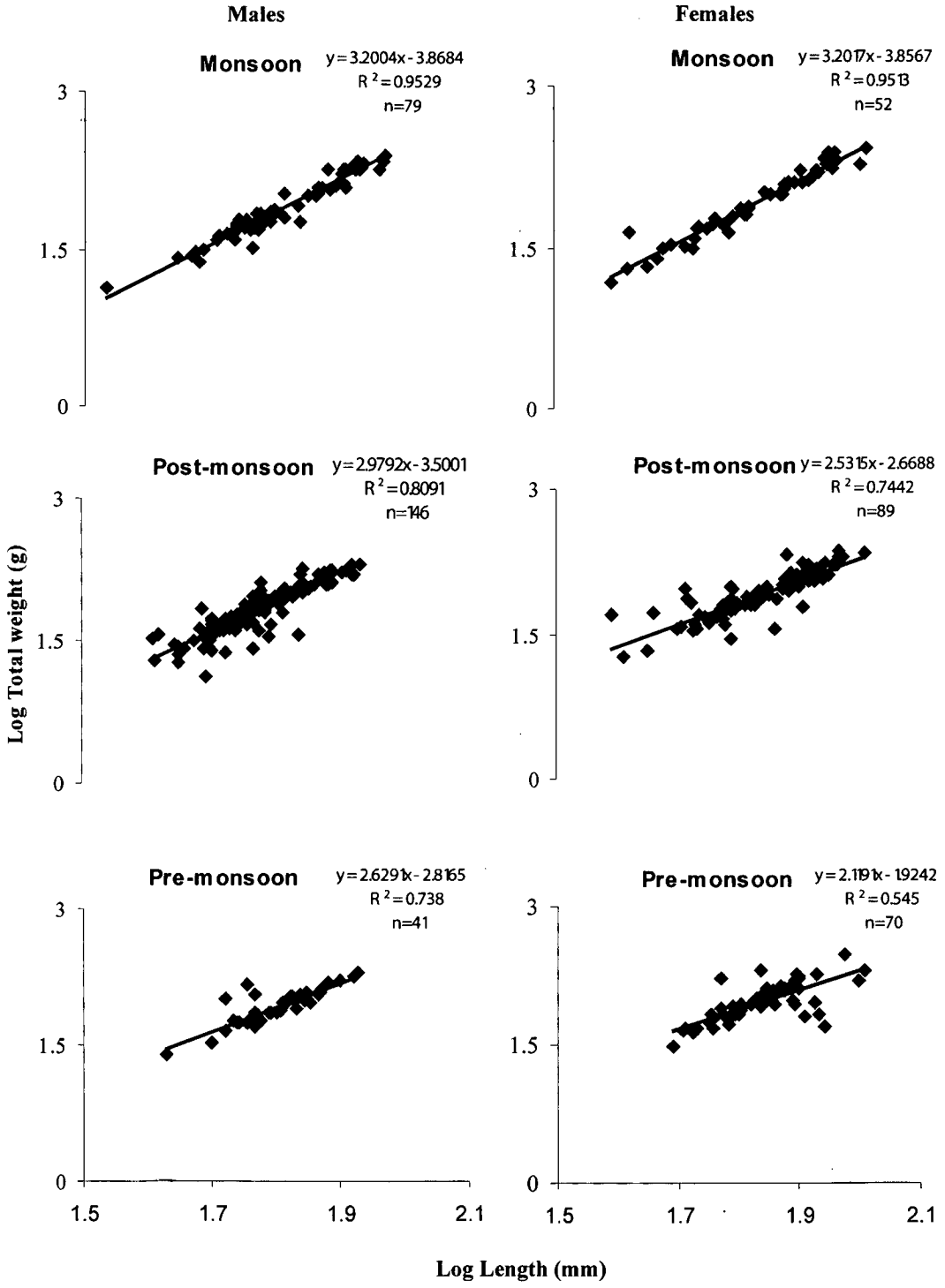


Fig 3.13: Relationship of shell length and total weight of males and females of *P. erosa* in different seasons

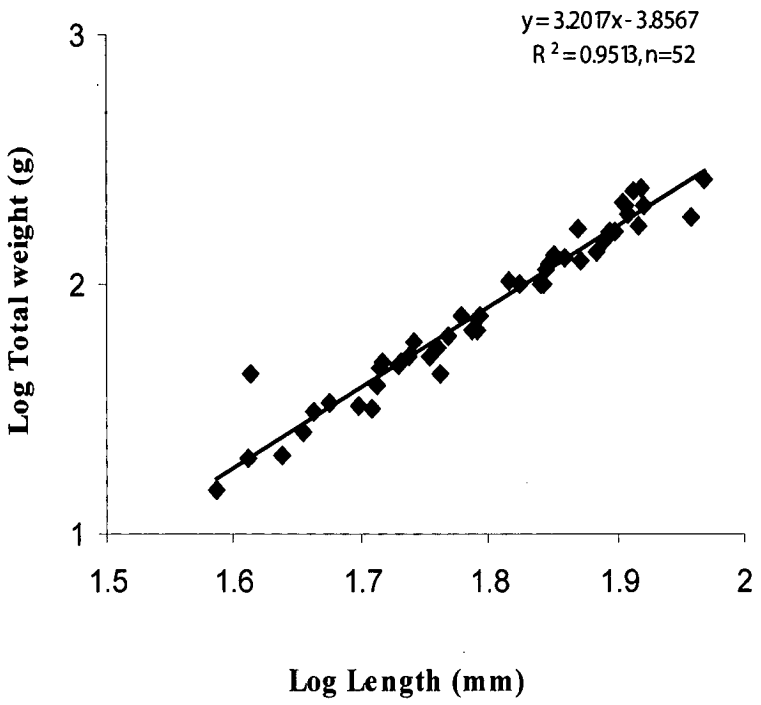


Fig. 3.14: Shell length and total weight relationship of female *P.erosa* during monsoon

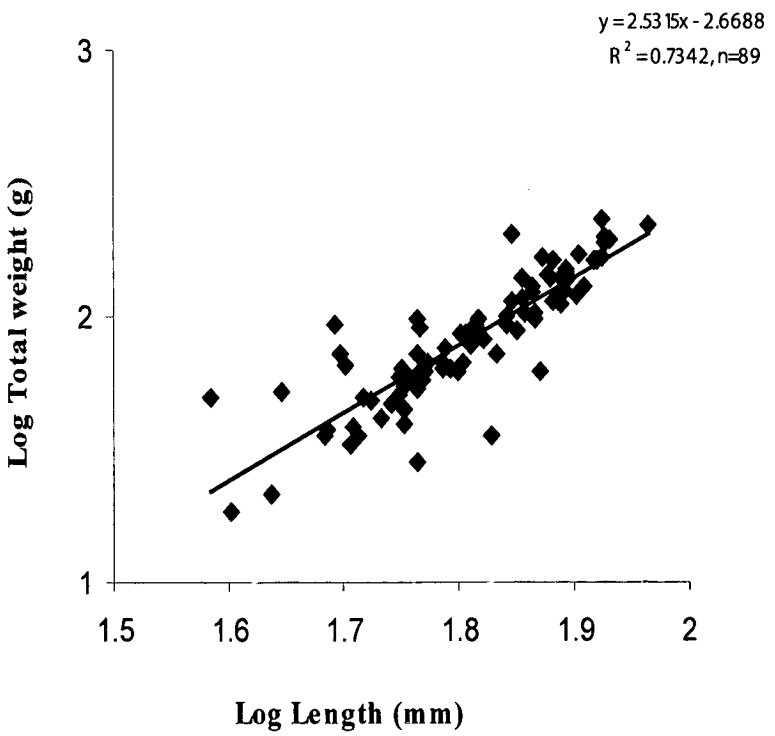


Fig. 3.15: Shell length and total weight relationship of female *P.erosa* during post- monsoon

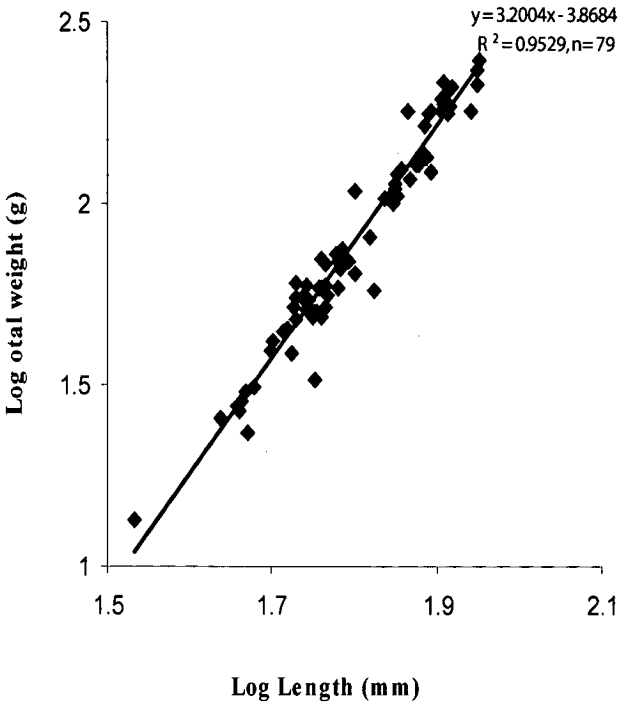


Fig. 3.16: Shell length and total weight relationship of male *P.erosa* during monsoon

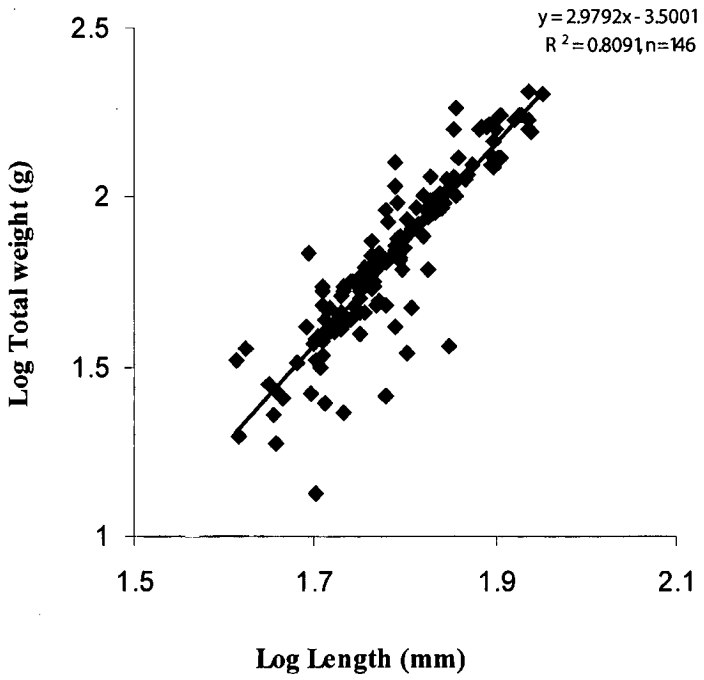


Fig. 3.17: Shell length and total weight relationship of male *P. erosa* during post-monsoon

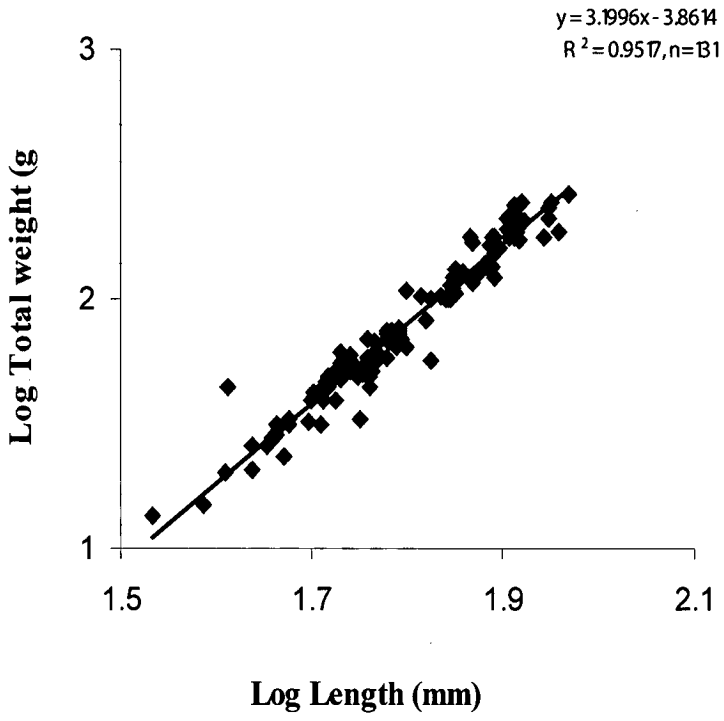


Fig. 3.18: Shell length and total weight relationship of male and female *P. erosa* during monsoon

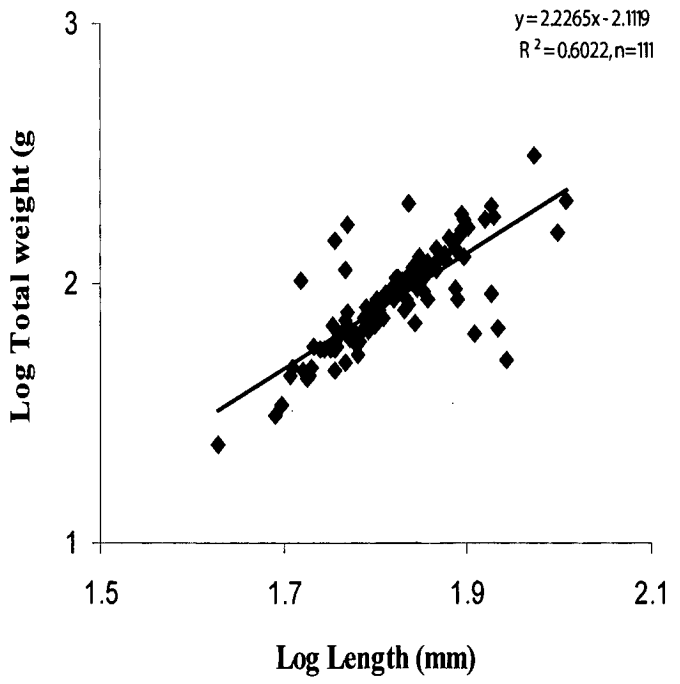


Fig. 3.19: Shell length and total weight relationship of male and female *P. erosa* during pre-monsoon

df=233, p>0.05, monsoon: t=0.0077, df=129, p>0.05). Furthermore, when the results of the length to total weight relationship between different locations were compared, it was seen that there exist no significant difference (F=2.25093, df= 34, p>0.05, n=35).

3.8 Discussion

3.8.1 Growth in Size

From the size frequency distribution it appears that the growth is very rapid in the initial phase i.e. in the size group of 0-10 mm to 50.1-60 mm. The rate is approx. 10 mm during first 5-6 months after recruitment. Thereafter, the growth rate decreases to a monthly average of only 3.3 mm (Fig. 3.4), mainly due to the maturing gonads. Most of the published information on the growth of bivalves suggests that, young bivalves grow quite rapidly in size, and the growth rate is decreased as the animal grows. This suggests the possibility of a decreased growth rate in the older individuals as an effect of size as well as age. It is seen from the figure 4 that, individuals of 0-10 mm size group recruited in July of 2004, attains a size of 40-50 mm in December 04 and grew to a size of 60 mm in the first six months, showing an average growth of 10 mm per month. During the next six months the clam grew by 20 mm with a monthly average growth of 3.3 mm and attained a length of 80-90 mm at the age of one year. It appears that, the growth from 60-80 mm is comparatively faster as it grows with an average rate of 5 mm per month. After this length, the clams grow at rates of 2.5 mm per month. Thus, it can be concluded that *P. erosa* grew at a very fast rate during its early life and the rate was considerably retarded in the later period of life (Fig. 3.4). The decreased growth observed from April to July could probably be due to the allocation of more energy in the gamete production than the shell growth because gametogenesis in *P. erosa* starts around 40 mm size

and attains its peak during 6-8 months of age around 50-70 mm shell length (Fig.3.3).

In the present study, the growth parameters of *P. erosa* could not be estimated, as the asymptotic length (L∞) was calculated based on the monthly data, which was biased towards the mean size and the smaller and larger sizes were poorly represented. Such problems arise due to the difficulty in sampling the smaller population which was done by handpicking and is very well explained by a statement of Ralph and Maxwell (1977): "according to Knight (1968) and Theisen (1973), very misleading values of L∞ are obtained by using data that does not cover the whole or most of a species growth".

3.8.2 Morphometric relationships

The results on the allometric relationship show a strong linearity between shell dimensions and total weight, with poor relationships between shell dimensions and the soft tissue. This indicates that the soft tissue of *P. erosa* does not change much although the clams grow steadily. The lack of a strong correlation between shell size and meat tissue for *P. erosa* is different from that reported for other bivalves but the ***b*** value for the length – weight relationships is within the range observed for other bivalves such as *Mytilus edulis* (Rodhouse et al., 1984), *Chamelea gallina* (Deval, 2001). Nevertheless, similar findings were observed in the study of allometric relationship in *P. erosa* from Australian mangroves (Gimmin et al., 2004), but the r^2 for the shell dimensions and wet weight of the soft tissue were very low compared to the values observed in the present study. These differences may be related to the particular ecological characteristics of the different areas. Further, some disagreements on the species morphometric relationships may be a consequence of distinct hydrological and sedimentological features between different geographical areas (Gaspar et al., 2002). The higher determination coefficients in shell dimensions and total weight relationship than

shell dimensions and soft tissue, reveals that growth in *P. erosa* in terms of total weight, is less variable than growth in soft tissue. Factors such as the reproductive state of the animal (Rueda and Urban, 1998) and physical as well as biological variables of the habitat (Thorarinsdottir and Johannesson, 1996) are known to affect the growth of bivalves and can change the allometry between the shell and flesh. It is seen that fully-grown shell of *P. erosa* make the clams heavier, either because of increased shell mass or a higher amount of water or mantle fluid inside the shell. The amount of mantle fluid could be related to the species survival strategies and may vary seasonally depending upon the reproductive state of *P. erosa*. The large thick shell constitutes excellent characteristics to inhabit the extremely adverse conditions of the mangroves. *P. erosa* is found in the high zones of the mangrove forest, which is emersed for long periods of time. The clams are potentially exposed to dessication and a wide range of salinities as well as starvation since these clams are filter feeders. To protect the body against adverse environmental conditions and predators, they need thick valves that can be closed tightly. The need for thicker and heavier shells than normal has been reported for bivalves inhabiting periodically dry zones (Seed, 1968).

The need for strong shells and a high capacity to live in adverse conditions might direct more energy to shell growth than the growth of the soft tissue. According to Currey (1998), investment in the shell, limits the growth of an individual. In addition, a low rate of flesh tissue growth is useful for survival of the animals exposed to prolonged emersion. During the periodic emersion, the clams need to maintain a sufficiently large volume of water inside the shell to create a watery environment for survival of the body tissue (Seed, 1968; Ansari et al., 1978). If the soft tissue continues to grow and occupy a large part of the space inside the shell, then there would not be enough water to support the metabolic needs of the increased tissue.

The higher slope values for the regression line in males than females probably indicate that males gained more weight with increase in length, indicating a better condition than females. The ***b*** values for the shell length and total weight relationship of the clams in the monsoon season (Fig. 3.18) were significantly different to those during the summer season (Fig. 3.19). This probably could be because the clams spawn during the monsoon season. Variation in the value of ***b*** to some extent is due to the proportion of shell mass. In conclusion, only shell dimensions are not good estimators for the biomass production of *P. erosa.* Nevertheless, the allometric relationship between shell length, shell width and shell height to total weight can be used to monitor the growth of this species in the natural population.

3.8.3 Size at first maturity:

The theoretical size at first maturity for *P. erosa* at Chorao mangroves as seen from figure 3.3, is in agreement with the observed size of smallest egg bearing female (40 mm). However, the mean size of egg bearing female may vary with time during the reproductive season, either due to the growth of females or due to the entry of newly maturing females. Moreover, the growth rate can significantly alter the size at first maturity (Ingole et al., 1998). Since the physical inspection did not show the presence of matured eggs in females below 40 mm TL, maturation in female *P. erosa* at Chorao occurs around ca.40 mm TL. However, males being smaller than females mature at smaller size, ~ 35 mm length.

3.8.4 Sex ratio

At Chorao island the male: female ratio in *P. erosa* conforms to 1:1 in all months barring few exceptions. According to Fisher (1930), in gonochoric species, selection acts on the sex ratio of the offspring in order to equalize the contribution of both sexes to the fitness of their parents, favouring at the population level an

overall sex ratio of 1:1. Although, prevalence of females is a general rule (Ponurovsky and Yakovlev, 1992), in the present study, the males prevailed in most of the months. The male domination reported here is in general agreement with previously reported sex ratios for different bivalve species (Amaro, 2005). Altough, there was no statitically significant difference in the male: female ratios throughout the entire shell length size distribution analyzed, males generally prevailed in the smaller size classes (Fig. 3.8). Several authors have also noted, males to dominate in small size classes with females often becoming more prevalent as size/age increases (e.g. *P. zelandica*, Gribben and Creese, 2003; Gribben et al., 2004). Males typically dominate protandric bivalve species in the first year (Alan et al., 2004) whereas older age classes are generally equal. The sex ratio of *P. erosa* at Chorao island were equal over the size range of collected clams. Although, females prevailed in the largest size class and males in the smallest size class recorded, there is insufficient data to conclude that the ratio is biased towards a particular sex. If females dominate larger size classes, then harvesting larger clams may specifically target females, seriously compromising the sustainability of local populations. Hence, to make a full assessment of the sexual development of *P. erosa*, mud clams will have to be collected over the entire size/age range for several populations.

CHAPTER 4

P. EROSA & ITS ENVIRONMENT

4.1 Introduction

The environment affects any natural growth process. It affects the physical, chemical and physiological characteristics of the organism. Each study site is a minor ecosystem in itself, and hence to study any organism, the study of the micro–environment is a must. The existence of an organism in a given environment implies that the organism has succeeded or survived in the presence of all the abiotic and biotic influences that impinge upon it. A major requirement in ecological studies is to understand the factors contributing to the structure and dynamics of biological communities through time and space. Shellfishes are integral components of the intertidal ecosystem. The interactions between established bivalve beds and other organisms and elements of the coastal ecosystem are numerous and complex. Environmental factors such as water temperature; salinity, food availability, substrate and predators determine the distribution, abundance and condition of different shellfish species. In similar but reverse fashion, shellfish exert a dramatic influence on the character and condition of the environment, providing three-dimensional structure and habitat for plant and animal life and playing particularly important roles in the uptake and recycling of energy and nutrients (Dennis-Perez, 2003). Organisms in the intertidal zone are subject to exposure as the tide drops and submergence as the tide rises. During exposure, inhabitants are faced with increased temperature variability and increased desiccation. During these periods, exposed bivalves retain precious moisture by remaining totally inactive (wherein their metabolic rate drops to zero, so they can last a long time without water), retaining fluid within their mantle cavity (Dame, 1996).

Temperature not only limits the spatial distribution of bivalves but is also a major controlling factor in many physiological rate processes, eg. feeding and growth, that plays important roles in many ecosystem level processes. The majority of marine bivalves live within a temperature range from near –3°C to +44°C

(Vernberg and Vernberg, 1972). Coastal and estuarine bivalves tend to be eurythermal and oceanic forms are typically stenothermal in tolerance. In many species, it is the tolerance of the mobile larval stage or reproductive period that is most sensitive to temperature.

Salinity may affect the structural and functional properties of animals through changes in (1) total osmotic concentration, (2) relative proportion of solutes, (3) coefficient of absorption and saturation of dissolved gases, (4) density and viscosity (Kinne, 1964). Although salt concentration is fairly constant, in the oceans at about 35 psu, in coastal and estuarine regions, salinity varies along a gradient from freshwater in landward areas to full marine. The interaction of the two factors, temperature and salinity, with various bivalve processes can describe the potential habitat of a given animal.

The pH of water is known to affect the physiology of mollusc. More mollusc species are found in harder waters than low calcium waters. However, though attempts had been made to relate molluscan distribution directly with pH, clearer correlations are found with calcium content or total alkalinity (Macan, 1950). One of the most important role pH plays in the bivalve functioning is of shell formation. Bivalves need to have a sufficiently alkaline pH of the extrapallial fluid to permit deposition of calcium carbonate (Wilbur, 1964). Studies have shown that pH indeed may have an effect on phytoplankton growth and that this effect drives species succession.

The ability to maintain a relatively normal uptake of oxygen is important for organisms that may encounter low oxygen availability (hypoxia) frequently in their environment. Bivalves are known to change their oxygen consumption under depleted DO conditions (Bayne, 1971). Most of these studies earlier revealed that, the capability for metabolic regulation varies among species, and also varies with

the environmental conditions, size, and physiological state of the animals (Shumway and Koehn, 1982).

Most mangrove forests appear to exchange substantial amounts of dissolved nutrients with adjacent marine ecosystems (Rivera-Monroy et al., 1995). Moreover, as suggested by Middleburg et al., (1996) mangroves are a sink for nutrients. Phytoplankton utilizes nitrate, nitrite, ammonium and urea for their growth. Phytoplankton abundance in estuaries is known to depend on factors such as light (Cloern, 1987), nutrients (Gallegos et al., 1997), stability of water (Paerl et al., 1998), turbidity (Cloern, 1987), river flow (Fisher et al., 1992) and temperature (Pennock and Sharp, 1994). Of all these factors, nutrient availability has frequently outweighed others (Hendzel et al., 1994).

Environmental factors play an important role in the biodiversity and ecological function of mangrove ecosystem. Studies conducted in the mangroves have described the abundance and distribution of benthic fauna in relation to environmental conditions (Ashton, 1999). The importance of the environmental characteristics for the development and survival of any organism is well documented. Several biotic and abiotic factors profoundly influence the biology of any aquatic animal. As a general rule, the distributional limit of the animal concerned to any particular ecosystem is determined by the degree of influence exerted by each of these factors, either independently or in combination with others. It is therefore, vital to study the ecology of any organism in relation to its environment.

Information on the environmental characteristics of *P. erosa*'s habitat is lacking except for some rudimentary information by Morton, (1976). Nevertheless, studies on some environmental parameters on few species of *Polymesoda* are available which can give some insight on how different environmental parameters affect *P. erosa*. More than two decades back, Pamatmat (1979) studied anaerobic

heat production in relation to temperature, body size and anoxia in *P. caroliniana*. Deaton (1982) studied on regulation and the activity of adenosine triphosphatase (ATP) activity in *P. caroliniana* along with some other freshwater bivalves. Hackney (1985), studied the effect of abnormally low temperature on *P. caroliniana*. Severeyn et al. (1996) studied in depth, the effect of environmental parameters on the growth of *P. solida*.

Suspension-feeding bivalves are important habitat modifiers that can facilitate surrounding communities by providing refuge from predation and changing boundary flows and through the production of organically enriched biodeposits (Norkko et al., 2005). Suspension feeding invertebrates such as barnacles and bivalves occupy a central position in the food webs of intertidal communities throughout the world (Blanchette et al., 2007). The apparent wide range of temperature and salinity tolerances of *P. erosa*, as evidenced by its natural range and preferred environment, make this species an attractive candidate for aquaculture. The clams in particular are a cheap source of protein and are consumed throughout the world as a delicacy. *P. erosa* is an important ecological component of mangrove communities and is an abundant member of the mangrove ecosystem (Morton, 1976; Meehan,1982). Given that these clams hold such importance as a food source, and as the local communities along the mangrove regions eat them, it has a high potential for commercial harvesting (Ingole et al., 2002). When a species is considered for commercial harvesting, the natural bed won't suffice which obviously necessitates the development of culture techniques. However, successful manipulation of animals in culture is predicated on an understanding of the physiological systems underlying optimal conditions. It is thus necessary to characterize the effects of the environmental parameters on the clams to optimise industrial development and farm practise.

Hence, to understand the clam *P. erosa* in its natural environment, the present study has been planned to investigate the environmental parameters, which were

monitored on a monthly basis to account for fluctuations in these parameters and relate them to the physiological conditions of the clams.

4.2 Materials and Methods

Clams were collected monthly from July 2004 July 2005 by randomly handpicking from a marked area of approximately 1500 m^2. After sampling, the clams were transported to the laboratory. The clams were grouped in different size classes of 10 mm interval. The intact bivalves were washed and blotted dry. The total length, width and height were measured. All measurements were made to the nearest 0.1 mm using Vernier callipers. Total weights to the nearest 0.01 g were determined after drying the shell with paper towels after blotting the excess fluid. The wet tissues were blotted and their weight was measured to the nearest 0.01 g. The dry weights of the tissues were recorded after drying the tissues in the oven to a constant weight for 72 hours. A total of 10 clams were studied for the gut content analysis. After collection, specimens were frozen to interrupt gut-content digestion. After dissection, the soft tissue was preserved in buffered 5% formaldehyde for 3 days and the gut was than separated from the other visceral organs and few drops of Lugol's were added. Wet weight of the gut was recorded and the contents were extracted and diluted up to a volume of 10 ml and homogenized. A subsample of 1 ml of the diluted gut content solution was analyzed using a Sedgwick-Rafter cell and the quantitative occurrence of phytoplankton cells in each gut was recorded.

Condition index is used to characterize the apparent "health" or in other words, the physiological activity of the animals (growth, reproduction, secretion, etc.) under given environmental conditions. Condition Index (CI) was determined according to Walne and Mann (1975):

$$CI = \frac{\text{Dry weight of meat (g)}}{\text{Dry weight of shell (g)}} \times 100$$

All the parameters including temperature, pH, salinity, chlorophyll *a* (chl *a*), dissolved oxygen (DO), nutrients (NO_2^-, NO_3^-, PO_4^-) of estuarine water and pore water was analyzed following standard procedure described by Strickland and Parsons (1972).

4.2.1 Temperature

Temperature of surface water and sediment was measured during each sampling with mercury Celcius thermometer (precision 0.1°C).

4.2.2 pH

pH of estuarine water as well as sediment pore water was recorded with a hand held pH meter.

4.2.3 Salinity

The electrical conductivity ratio of the water as well as interstitial water was measured in a Guildline "Autosal" model 8400A Salinometer (measurement range: 0.005–42 psu). The salinity of the samples was calculated using the equation for conversion of conductivity ratio to salinity (UNESCO, 1983).

4.2.4 Dissolved Oxygen (DO)

The classical Winkler's method was adopted for the determination of dissolved oxygen. The physically dissolved oxygen in a measured volume of water is chemically bound by a divalent manganese solution followed by a strong alkali to precipitate manganese as manganous hydroxide. Any dissolved oxygen rapidly oxidizes an equivalent amount of manganese to basic hydroxides of higher valence states. After the precipitate is well settled, the sample is acidified to a pH < 2.5. When the solution acidifies in the presence of iodide, the oxidized manganese again reverts to the divalent state. This reacts with the iodide ion,

which has been added to the water sample previously. The iodide is oxidized liberating free iodine; equivalent to the original dissolved oxygen content of water is liberated, which in the presence of excess iodine forms a complex. In the final step, iodine is titrated against a standard solution of thiosulphate using starch as indicator. The end point of titration is marked by the colour change from blue to colorless. The dissolved oxygen is calculated from the titrable number.

4.2.5 Nitrite-Nitrogen (NO_2^--N)

The method of Benschneider and Robinson (1952) was used for measuring nitrite. In this method, the dissolved nitrite reacts with sulphanilamide in an acid solution. The resulting diazo-compound then reacts with N-(1–naphthyl)– ethylenediamine to form a highly coloured azo-dye, the optical density of which is measured at 543 nm.

4.2.6 Nitrate-Nitrogen (NO_3^--N)

Nitrate was measured by the method of Wood et al. (1967). In this method, nitrate is reduced almost quantitatively to nitrite on passing the sample through amalgamated cadmium column and the resultant nitrite was determined as per the procedure for nitrite. The measured absorbance is due to initial nitrite in the sample and nitrite obtained after reduction of nitrate. Necessary correction was therefore made for any nitrite initially present in the sample.

4.2.7 Phosphate-Phosphorus (PO_4^--P)

Phosphate was estimated by the method proposed by Murphy and Riley (1962), which involved the reaction of phosphate and molybdate ions in acidic solution forming molybdophosphoric acid. For this, the samples were made to react with acidified molybdate reagent and then reduced using ascorbic acid. The absorbance of the resultant phosphomolybdate blue complex was measured at 885 nm.

4.2.8 Chlorophyll *a* (chl *a*)

The concentration of phytoplankton, a primary component of the food of the mangrove clams (Morton 1976), was estimated by quantifying the concentration of chl *a*. The pigments contained in phytoplankton include chlorophyll *a*, *b*, and *c* of which chl *a* is the most important. In the present study, chl *a* was determined flourometrically based on the technique described by Strickland and Parsons (1972).

For water sample, a known volume of water was filtered onto a GF/F glass fibre filter paper and for sediment samples an approximately 1 g of sediment was collected. Pigment was extracted from the filter/sediment in 90 % acetone. The extracts were used for the estimation of flouroscence using a Turner design flourometer. The flouroscence values were converted to chl *a* using appropriate calibration factor.

4.3 Effect of temperature, salinity and air exposure on *P. erosa*

The clams at Chorao island are found in the high tide region inside the *Avicennia* forest towards the landward region (Plate 2.3). This region gets inundated only during the flood spring tide, as a consequence these clams remain emersed for prolong periods of time. They also have to cope with the drastic changes in temperature and salinity during the daily tidal cycle. To get a closer view of how *P. erosa* must be coping with the extreme conditions of mangroves habitat, an experiment to study the effects of dessication and changing temperature, salinity (both these factors have a major influence on bivalves) was conducted in the laboratory.

Temperature tolerance in air by the clams was determined by placing 4 – 5 similar sized clams in damp sediment (collected from the study area) within 4 glass containers. The glass containers were kept in different temperatures: (1) placed

with direct sunlight, (2) placed with no access to sunlight (3) placed with moderate sunlight (i.e. shaded from the top) and (4) placed in the freezing temperature. They were examined regularly to determine condition and were considered dead, if the adductor muscles did not contract when the valves were levered apart.

Salinity tolerance was examined by placing 4 – 5 similar sized clams in an aerated tank containing water. Initially, freshwater was added to the clams which was then made up to a salinity of 18 psu followed by 30 psu. The effect of changing salinity was observed for about 2 hours. Similarly, effect of salinity was observed for 10 days in each salinity condition by keeping the clams in different tanks and was examined regularly. Death of clams, if any, was confirmed as described above.

Effect of air exposure was studied by keeping 4 – 5 clams in air without any sediment or water in room temperature as well as a warm place (with a lighted bulb) and a cooler place (a container with water wherein clams were kept in a dry plate). As described above, the clams were examined regularly to detect for mortality if any.

4.4 Data Analyses

All the environmental variables were checked for colinearity using the Pearson's product moment correlation coefficients. Pearson's correlation matrix was run to detect an effect of tested conditions on the clams. Principal Component Analysis (PCA) was conducted to see the degree of correlation of the different parameters among each other. The influence of all the physico-chemical parameters studied on the clams growth (meat dry wt.) was examined using a multiple regression model using SPSS 7.5.1 and correlations were performed using Statistica version 5.1 software. To ensure assumptions for normality and homogeneity, the Shapiro

Wilks and Levene's test was done (Sokal and Rohlf, 1995). Significance was concluded at $p < 0.05$.

4.5 Results

Environmental parameters studied at Chorao are summarized in Fig. 4.1 – 4. 8.

4.5.1 Temperature

The water temperature was highest in the month of April 2005 (32.6°C) and the lowest value was recorded in the month of July 2004 (24.7°C). The sediment temperature showed a significant difference ranging from 27.1°C (Sept.) to 34.2°C (Mar.) at LT, 23.1°C (Aug.) to 28.3°C (Mar.) at MT and 24.6°C (Sept.) to 30.3°C (Apr) at HT (Fig. 4.1). The seasonal variations in sediment as well as water temperature exhibited a gradual increase from the beginning of the post-monsoon months to reach a peak at the end of the pre-monsoon season. A decrease in the temperature during the monsoon season into the post-monsoon season was evident. There were no differences in temperature between the MT and HT area. However, the sediment temperature recorded at the LT region was comparatively higher than the MT and HT area (Fig. 4.1). This was obviously because of the vegetation in the MT and HT area, which shades these areas whereas LT region gets exposed to sunlight, as there is no vegetation.

4.5.2 pH

The pH of estuarine water was highest in June 2005 (8.4) and lowest in July 2005 (7.1). The pH of the pore water varied between 7.0 (Sept.) to 8.4 (Mar) at LT, 6.3 (Aug) to 7.6 (Jan) at MT and 6.5 (July) to 8.0 (Oct) at HT (Fig. 4.2). The pH of estuarine water did not show any seasonal fluctuation. The highest and lowest values observed in the monsoon season whereas, pore water pH baring the LT region, and were slightly higher in the warmer months than in the wet season.

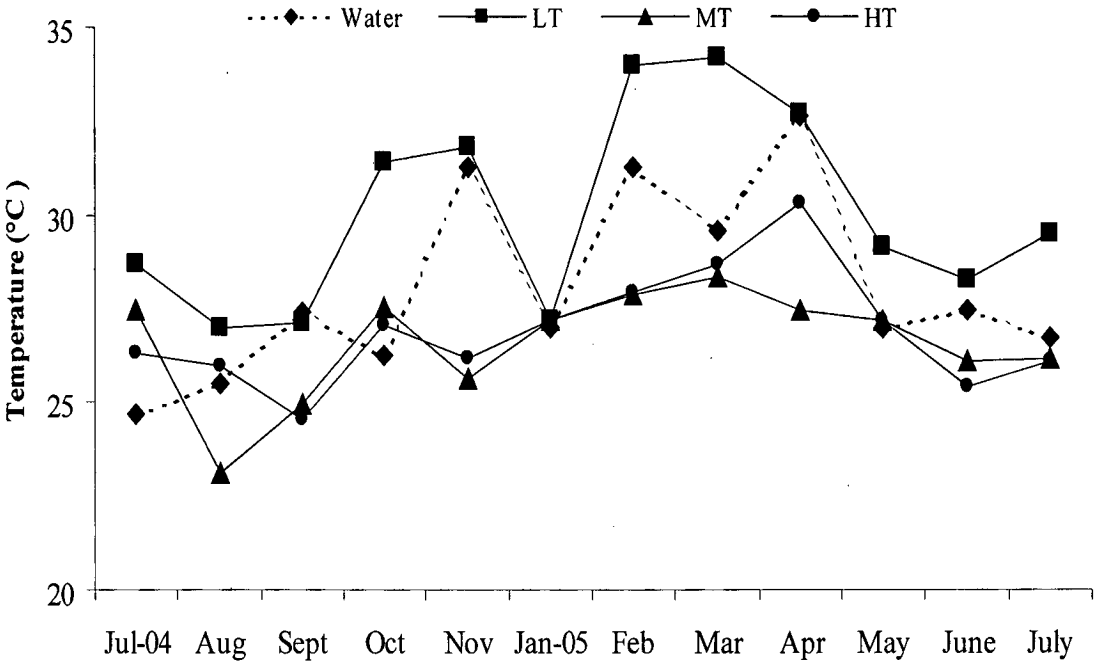


Fig. 4.1: Monthly variation in pore and estuarine water temperature at Chorao island

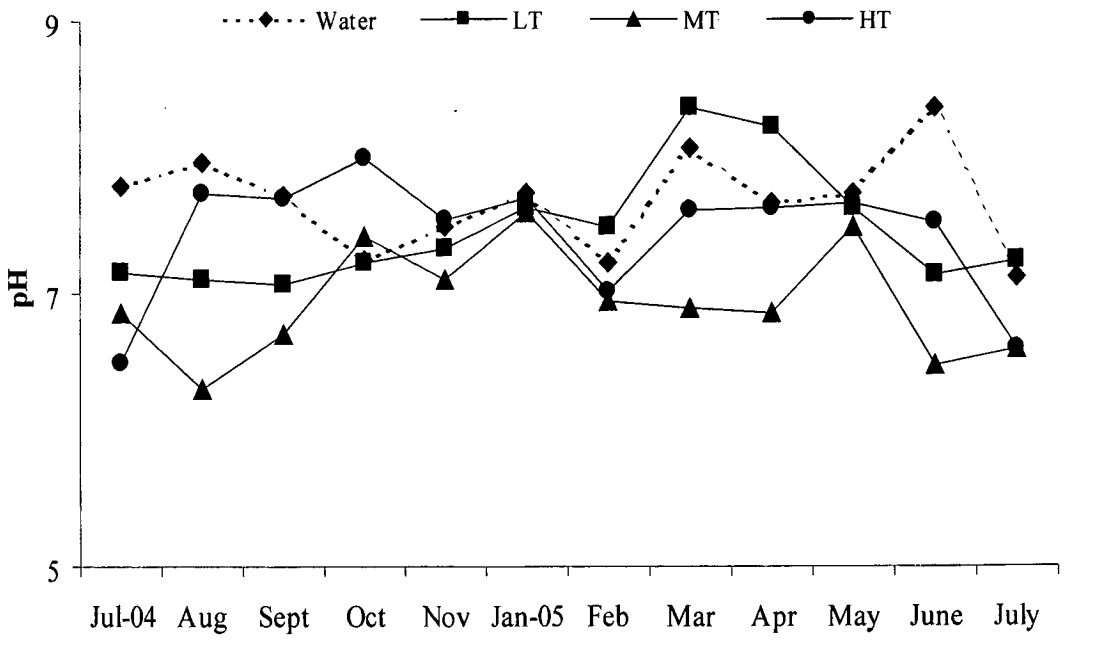


Fig. 4.2: Monthly variation in pore and estuarine water pH at Chorao island

4.5.3 Salinity

The maximum salinity of the estuarine water was observed in May (31.6 psu) and minimum in Sept (10.7 psu). Salinity of the pore water was lowest in Sept 2004 (14.2 psu) at LT, (14.6 psu) at MT and (15.2 psu) at HT and highest in May (30.8) at LT, March (30.3) at MT and 31.3 in May at HT (Fig. 4.3). There were no wide variations in salinity between the tide levels.

4.5.4 Dissolved Oxygen (DO)

The minimum and maximum values for dissolved oxygen (DO) in the pore water were recorded at HT (0.1 mg/l) in July and LT (3.4 mg/l) in June respectively. Annual averages did not vary and were of the same order at the tide levels. Estuarine water DO ranged from 3.1 to 5.9 mg/l recorded in the month of May and July respectively. The seasonal variations in DO are well marked with maximum DO content observed in the monsoon and lower values in the pre- and post- monsoon (Fig. 4.4).

4.5.5 Nutrients (NO_2^-, NO_3^-, PO_4^-)

Concentration of NO_2^- in the estuarine water ranged between 0.049 µmol/l (Apr) and 1.642 µmol/l (June) (Fig.4.5), of NO_3^- between 0.10µmol/l (May) and 3.89 µmol/l (Aug) (Fig.4.6) and PO_4^- between 0.05 µmol/l (Apr) and 2.2 µmol/l (Aug) (Fig.4.7). The nutrient concentrations in the estuarine water were high during the monsoon with decreasing values in the post- and the pre- monsoon. The minimum concentrations of NO_2^-, at LT level (0.038 µmol/l) were observed during May and of NO_3^- and PO_4^- in Apr (0.21 and 0.09 µmol/l respectively) and maximum in July (2.26, 3.84 and 2.7 µmol/l, respectively). At MT, the maximum values for NO_2^-, NO_3^- and PO_4^- were recorded in July (3.41, 4.32 and 3.0 µmol/l respectively). The minimum concentrations of NO_2^-, NO_3^- and PO_4^- were observed in May (0.1µmol/l each). At HT, NO_2^-, and NO_3^- were highest in July (3.5 and 3.9µmol/l respectively) and PO_4^- was highest in Sept (4.37µmol/l) whereas

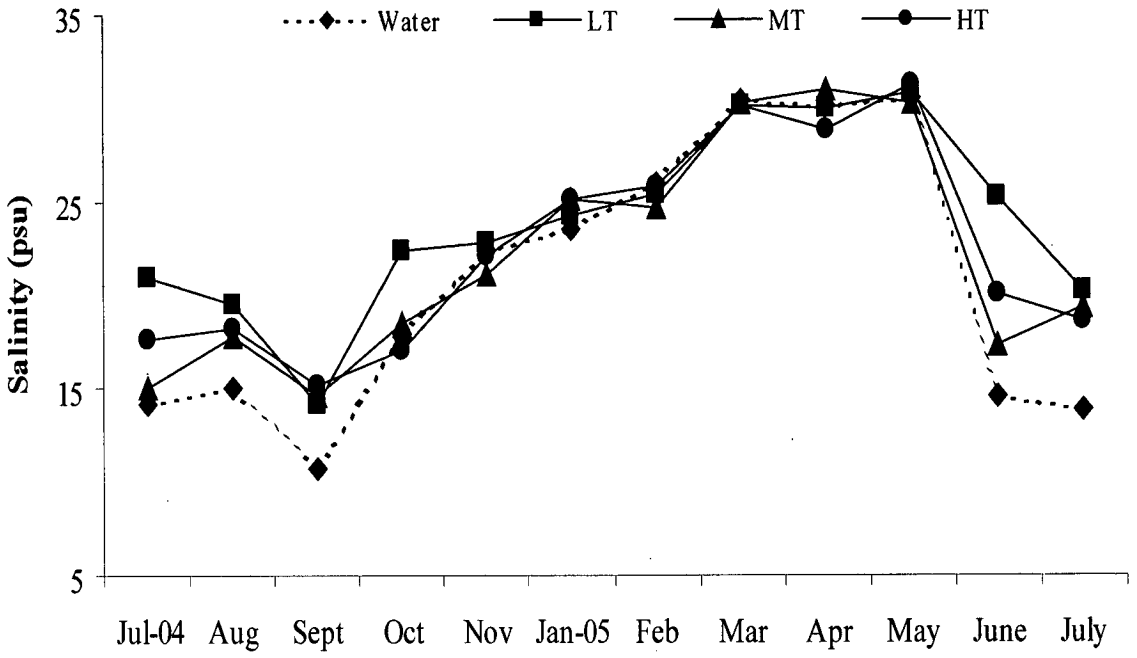


Fig. 4.3: Monthly variation in pore and estuarine water salinity at Chorao island

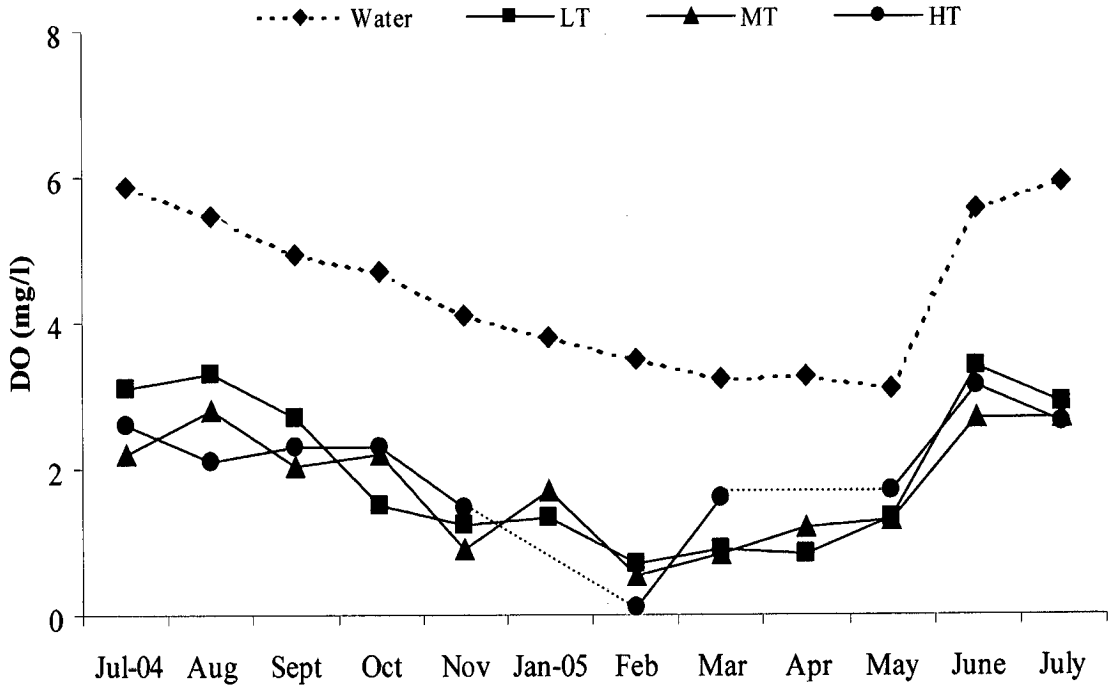


Fig. 4.4: Monthly variation in pore and estuarine water DO at Chorao island

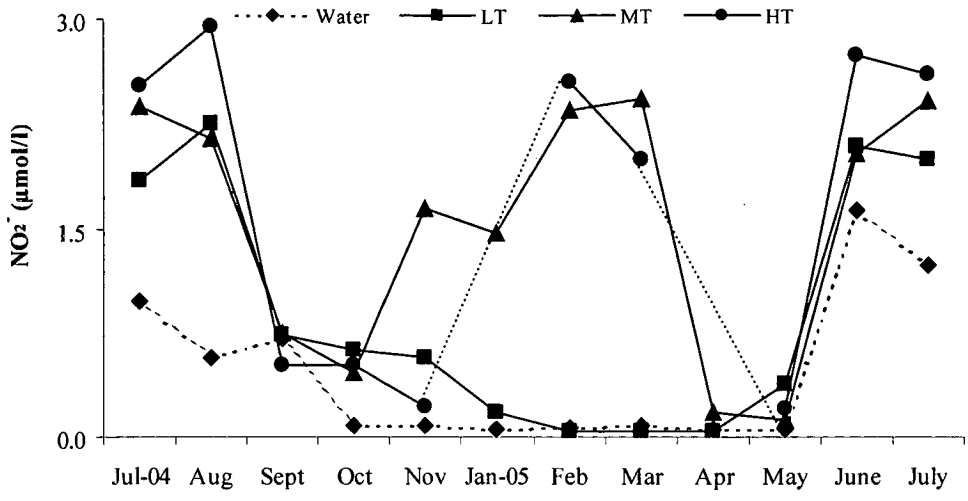


Fig. 4.5: Monthly variation in pore and estuarine water nitrite concentration at Chorao island

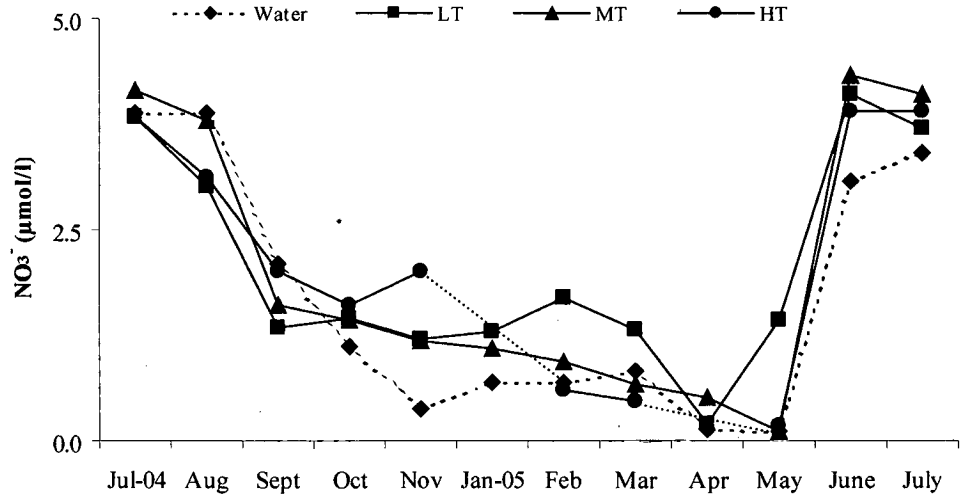


Fig. 4.6: Monthly variation in pore and estuarine water nitrate concentration at Chorao island

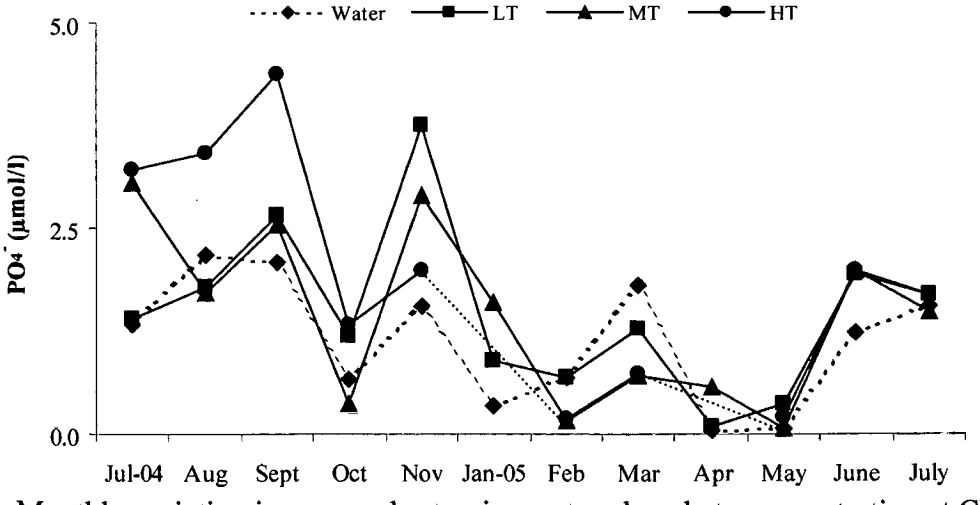


Fig. 4.7: Monthly variation in pore and estuarine water phosphate concentration at Chorao islan

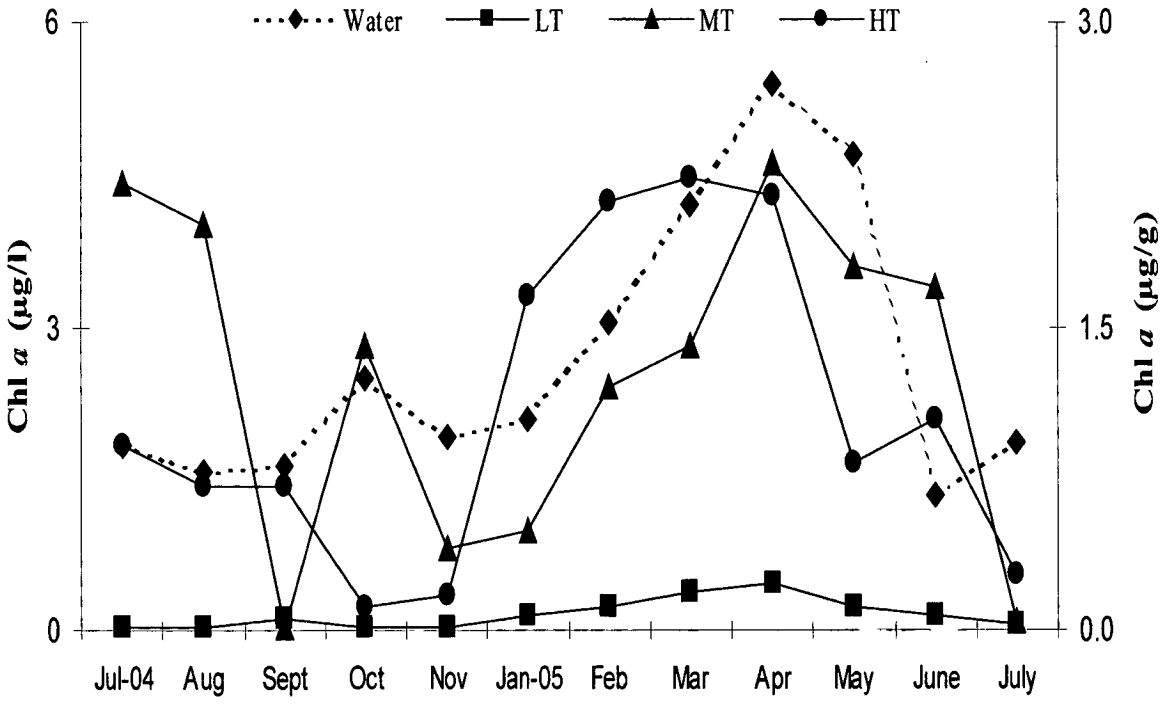


Fig.4.8: Monthly variation of Chl *a* in estuarine water and surface sediment at Chorao island

4.5.7 Gut content analysis of *P. erosa*

The total length (TL) of the clams studied for gut content analysis varied from 63-88 mm. The gut weight of each clam ranged between 0.00417 to 0.1444 g. The gut content comprised of phytoplankton species belonging to 13 diatom genera. Among these, the most dominant was *Cosinodiscus* spp. and *Navicula* spp. followed by *Melosira* sp., *Thalliosionema* sp. and *Cocconeis* sp. (Plate 4.1). The total counts of the phytoplankton species observed in the gut ranged from 1852 – 9121 cells/clam (Table 4.1). Though the highest total count of phytoplankton was recorded in the clam with the highest gut weight, it was not consistent as the lowest counts were not observed in clam with the lowest gut weight.

4.5.8 Relationship between the environmental parameters and *P. erosa*

Table 4.2 gives the Pearson's product moment correlation matrix for the different environmental variables measured and the clam growth and condition index. Water temperature showed a significant relationship with salinity, chl *a*, nitrite and nitrates with the strongest correlation with salinity. Salinity in turn was strongly correlated with the levels of nitrites, nitrates than phosphates with a very strong association with water chl *a*. The chlorophyll content was related to the nutrients (NO_2^-, NO_3^- and PO_4^-) with the strongest association with phosphates, and nitrates than nitrites. Similarly, the nutrients showed close associations between themselves. However, the dissolved oxygen concentration (DO) and pH concentration were associated neither with the temperature, salinity nor chlorophyll and nutrients. Chl *a* was the only parameter among the environmental parameters to show a correlation with clam weight ($r=0.6$, $p=0.039$ for wet weight and $r=0.61$, $p=0.034$ for dry weight). *P. erosa* is a filter feeder (Morton, 1976) and it was seen from the gut content analysis that the primary diet of this species consists of phytoplankton. As shown in table 4.1 and plate 4.1 it feeds mainly on

Table 4.1: Phytoplankon cells (nos./clam) in the gut of *P. erosa* at Chorao island

	Clam no.												
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**	**SD**	**%**
Amphiprora sp.	480	80	0	0	0	0	80	0	0	0	64	149.9	2.0
Amphora sp.	0	0	0	80	0	0	0	80	0	0	16	33.7	0.5
Cocconeis sp.	480	80	0	80	0	160	480	80	400	160	192	189.3	6.0
Coscinodiscus sp.	3840	640	1120	800	1200	800	2400	320	880	720	1272	1059.6	39.5
Cymbella sp.	0	80	0	0	80	0	0	80	0	80	32	41.3	1.0
Grammatophora sp.	0	80	0	80	160	80	0	160	0	160	72	70.0	2.2
Gyrosigma sp.	320	80	0	80	0	0	80	0	0	0	56	100.1	1.7
Melosira sp.	640	0	320	240	400	720	480	400	480	320	400	203.1	12.4
Navicula sp.	2160	160	320	560	480	720	1200	400	480	480	696	584.3	21.6
Nitzschia longissima	320	0	0	160	80	80	160	80	0	0	88	102.9	2.7
Nitzschia sp.	160	0	0	80	80	0	80	0	0	80	48	55.9	1.5
Pleurosigma sp.	0	0	160	80	0	0	0	0	0	0	24	54.0	0.7
Thallasiosira sp.	720	240	320	160	0	0	0	240	480	400	256	234.9	7.9
Total density	9121	1442	2243	2404	2485	2566	4967	1848	2729	2410	3221.5	2270.7	100.0

Table 4.2: Pearson's product moment correlation coefficients between the environmental variables at Chorao island and *P.erosa* growth (wet and dry tissue wt.) and Condition Index (CI)

Significant coefficients are in bold

	Temperature	**pH**	**Salinity**	**Chl *a***	**DO**	**NO_2^-**	**NO_3^-**	**PO_4^-**	**Wet wt.**	**Dry wt.**	**CI**
Temperature	1										
pH	-0.13	1									
Salinity	**0.74**	0.37	1								
Chl *a*	**0.69**	0.18	**0.85**	1							
DO	-0.25	0.21	-0.29	-0.26	1						
NO_2^-	**-0.64**	-0.39	**-0.82**	**-0.63**	0.36	1					
NO_3^-	**-0.62**	-0.45	**-0.90**	**-0.71**	0.34	**0.95**	1				
PO_4^-	-0.48	-0.20	**-0.67**	**-0.73**	0.28	**0.62**	**0.67**	1			
Wet wt.	0.51	0.16	0.53	**0.60**	-0.18	-0.35	-0.38	-0.51	1		
Dry wt.	0.48	0.13	0.47	**0.61**	-0.11	-0.29	-0.31	-0.46	**0.98**	1	
CI	0.41	0.28	**0.70**	**0.78**	0.04	-0.57	**-0.59**	**-0.67**	0.39	0.41	1

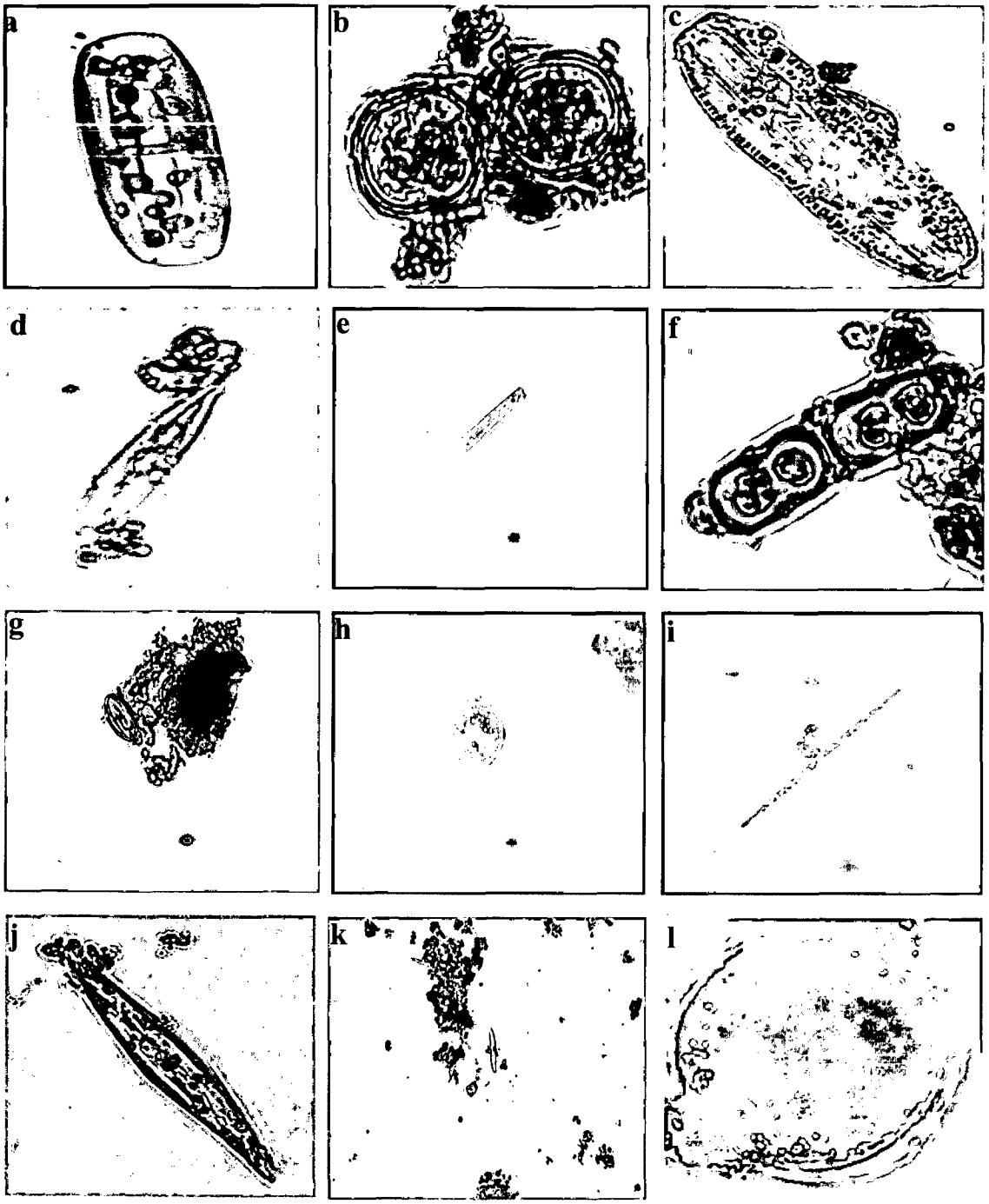


Plate a-h: 10 µm i: 20 µm j-k: 50 µm l: 100 µm

Plate 4.1: Phytoplankton species observed in the gut of *P. erosa*
a: *Amphiprora* sp.; b: *Melosira* sp.; c: *Amphiprora* sp.; d: *Navicula* sp.; e: *Grammatophora* sp.; f: *Melosira* sp.; g: *Cocconeis* sp.; h: *Thalassiosira* sp.; i: *Nitzschia longissima*; j: *Gyrosigma* sp.; k: *Pleurosigma* sp.; l: *Coscinodiscus* sp.

diatoms with *Coscinodiscus* spp. and *Navicula* spp. species being the dominant species in the gut content.

The environmental parameters were ordinated by Principal Component Analysis (PCA), which showed that the 8 variables were reduced to only two factors or principal components (Table 4.3 and Fig. 4.9). The two factors together explained 77% of the total variation in the environmental variables (Table 4.4). The first factor explains 60% of the variation and comprised of temperature, salinity, chl *a* and nutrients. As shown in table 4.4 and figure 4.9, the first factor formed two clusters related to temperature, salinity and chl *a*, which have positive coefficients and the nutrients (NO_2^-, NO_3^- and PO_4^-), which have negative coefficients. The second factor explains 16.69% of the variation with high positive loadings for pH followed by a weaker contribution by DO. The communality coefficients were high for the variables studied, ranging from 0.60 to 0.95 (Table 4.3), confirming that the original variables are well explained by the factors.

Since the environmental parameters were measured over a period of 12 months, the factor scores revealed that month of June, July, Aug and Sept had very low scores on PC1 or factor 1 ie temperature, salinity and chl *a* tend to decrease and the nutrient load is increased in these months, whereas, the months Mar, Apr and May had high scores on PC1 ie temperature, salinity and chl *a* increased while; the nutrients tend to decrease in these months (Table 4.5). However, most of the months had a lower score on PC2 with June to Aug having higher scores, which shows high pH in these months compared to the monsoons wherein the pH tends to decrease (Table 4.5).

Table 4.6 presents the best-fit model from regression analysis (statistically significant at $p < 0.05$) explaining the highest variation in dry weight of the clams in terms of 5 environmental parameters. The order of importance for the five predictor variables for dry weight of the clam meat was (1) pH (β=0.438, t=3.822,

Table 4.3: The coefficients of the linear combination of the environmental variables making up the 2 principal components or factors studied at Chorao island.

Bold numbers are coefficients for the most influential variables on each factor

Variable	Factor 1	Factor 2	Communalities
Temperature	**0.738**	0.405	0.809
pH	0.372	**-0.871**	0.678
Salinity	**0.959**	-0.023	0.941
Chl *a*	**0.859**	0.128	0.812
DO	-0.360	-0.618	0.363
NO_2^-	**-0.910**	0.061	0.924
NO_3^-	**-0.951**	0.119	0.958
PO_4^-	**-0.783**	-0.062	0.608

Table 4.4: Eigen values for the Principal component analysis of the environmental variables studied at Chorao island

Factors	Eigen value	% Total Variance	Cumul. Eigen value	Cumul. %
1	4.8248	60.3107	4.8248	70.310
2	1.3354	16.6930	6.16030	77.003

Table 4.5: Factor Scores for the Principal Component analysis of the environmental variables studied at Chorao island

Month	Factor 1	Factor 2
July	-1.285	0.176
Aug	-1.152	0.828
Sept.	-0.952	-0.566
Oct	0.153	-0.141
Nov	0.021	0.194
Jan	0.534	-1.336
Feb	0.686	1.382
Mar.	1.043	-0.262
April	1.476	-0.533
May	1.228	-0.726
June	-0.768	1.065
July	-0.985	2.049

Table 4.6: Model from multiple linear regression analysis that best explain the variation in for *P. erosa* growth (tissue dry weight)

	B	S.E.	t	p
Constant	-6.268	1.738	-3.607	0.001
Chl *a*	0.615	0.062	3.297	0.016
DO	-0.253	0.09	-2.242	0.066
pH	0.438	0.186	3.822	0.009
PO_4^-	0.363	0.066	2.386	0.055
Temperature	0.459	0.031	3.067	0.002
Regression		F=17.411		0.002
R^2		0.882		

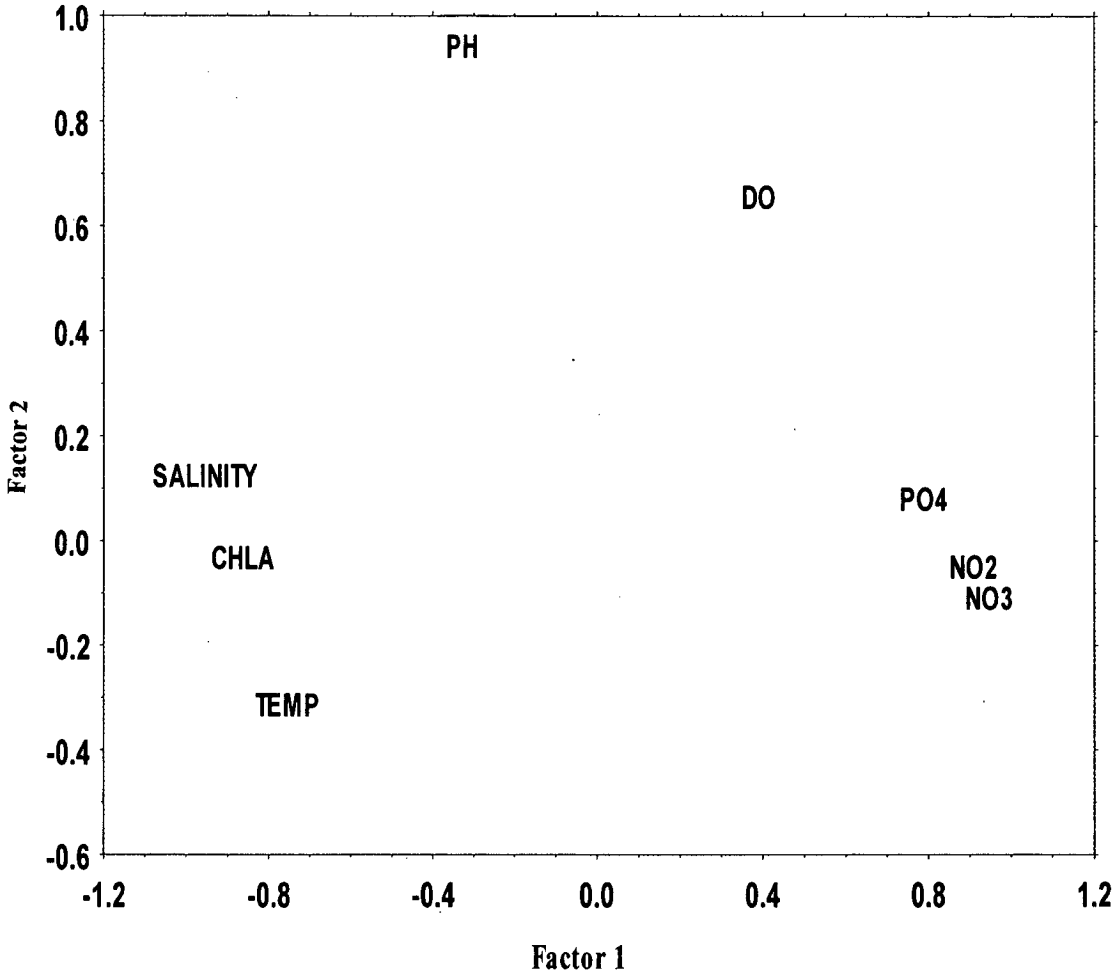


Fig 4.9: PCA ordination plot of two factors for environmental variables of Chorao island

p=0.006) (2) chl *a* (β=0.615, t=3.297,p=0.016) and (3) temperature (β=0.459, t=3.067, p=0.022). However, although the model is highly significant overall (p<0.002) with the 5 variables, it suggests that the dry weight tends to decrease with increasing DO concentration (β=-0.253, t=-2.242, p=0.066) and increase with increasing phosphate levels (β=0.363, t=2.386, p=0.054), there is insufficient evidence to conclude that this is a real relationship. However, the single environmental variable that best describes the clam growth is salinity, which explained 67.1% of the variability (Table 4.7).

4.5.9 Effect of temperature, salinity and exposure to air

Specimens of *P. erosa,* when exposed to air survived for more than five weeks at room temperature whereas survival time contrasted when the effect was observed in a warm place (about 3 weeks) than a cooler place (about 4 weeks). The clams could survive for more time (approx. 5 weeks) when not exposd directly to sunlight than when exposed to high temperature (around three and half week). However, when the clams were exposed to freezing temperatures, they died within 2-3 hours. Though no mortalities occurred in 18 and 30 psu during the experimental period, clams died in the freshwater condition after about 5 – 6 days. *P. erosa* showed different activity in the different salinity conditions. When the clams were exposed to different salinities for short periods, in freshwater, they closed their valves tightly, but when the salinity was increased to about 18 psu, the clams were seen to breathe with their siphon extended outside. When the salinity was increased to about 30 psu, the clams could function normally. However, when the effect was studied for 10 days, clams died after 5 – 6 days in fresh water, whereas in 18 psu and 30 psu conditions no mortalities were observed (Table 4.8).

Table 4.7: Model from stepwise multiple linear regression analyses that best explain the variation in the observations for *P. erosa* growth (tissue dry wt.)

Dry weight				
Predictor	**B±S.E.**	**r^2**	**F**	**p**
Constant	0.756 ± 0.242			0.01
Salinity	0.837± 0.011	0.671	23.416	0.001

Table 4.8: Effect of salinity, temperature and air exposure on *P. erosa* under laboratory conditions

	% mortality in days/hours					Remarks
	20	**40**	**60**	**80**	**100**	
Salinity (psu)						no mortality for short time but close valves tightly
0 psu	-	-	~72 hrs	-	~5-6 days	
18 psu	-	-	-	-	-	function normally
30 psu	-	-	-	-	-	function normally
Temperature (30 ± 1°C) Under dark conditions	-	-	~31 days	33 days	~35 days	Survived 100% upto 30 days
Direct sunlight (12 dark:12 light)	~18 days	-	~23 days	-	~ 21-28 days	100% mortality after 28 days
Freezing temperature (~ -4°C)	~1 hour	-	-	2 hours	2-3 hours	do not survive for more than 3 hours
Exposure to Air (without water & sediment)						
Room temp (28 ± 3 °C)	~ 28 days	-	-	-	>35 days	no mortalities upto 35 days
Warm place (with additional light source -36-40°C	-	~15 days	-	~18 days	~ 21 days	
Cool place (dry plate inside glass container with water)	~ 23 days	~ 25 days	-	-	~28 days	mortality after 28 days

4.6 Discussion

Salinities were mesosaline and were similar at all the stations. The salinity in Mandovi estuary is largely determined by the fresh water runoff due to the onset of monsoons. As runoff increased the salinity was lowered. The DO concentration varied from very well oxygenated waters in the estuarine water to lower dissolved oxygen values occurring in the pore waters wherein the minimum values were recorded for the LT stations. However, the other physical characteristics of the sediment in the LT and at HT and MT were similar. The key factors, influencing dissolved oxygen concentrations include excess nutrients, phytoplankton growth, decomposition and freshwater and salt-water inflow (Murphy, 2007). The decomposition process results in utilization of oxygen and thereby decreasing its concentrations. The pH was slightly higher in the warmer months than in the wet season. Studies by Thomas and Ragethaman (1987) have recorded the tendency of slight decrease in pH in the estuary along Hajira coast due to river water incursion and excessive land drainage. While, Kannan and Kannan (1996) reported that high pH recorded could be due to the removal of CO_2 by photosynthesis. The only apparent difference between sediment characteristics in the LT, MT and HT area were the slightly higher values for temperatures as well as higher pH observed in the low tide area towards the seaward region than in the landward region.

The values for nitrate in pore water were slightly higher compared to the values from the water column. The higher rates of net primary production and slower rates of benthic mineralization in mangrove forests (Alongi, 1998) suggests that many nutrient elements are more efficiently conserved or immobilized within mangrove forests. The presence of nitrate deep in the mangrove forest floor is probably due to several factors, including nitrification in the rhizomes and oxidative inputs of intense bioturbation and desiccation (Kristensen et al., 1998). Phosphate concentrations were slightly higher in the HT and MT region than the

LT and estuarine water column. Earlier studies involving experiments with sewage waters have found a high retention of phosphate in the mangrove sediments (Wong et al., 1997). Alongi (1992) pointed out that clay such as kaolinite, which is abundant in tropical sediments, are very efficient in phosphate adsorption. Furthermore, when the conditions are oxic, the phosphate is adsorbed onto iron oxides and pore water concentrations are low (Mortimer et al., 1998) and when conditions become sub-oxic (-ve Eh) the iron oxides are reduced releasing phosphate into the pore water. Hence, the low oxygen concentration at HT and MT could have resulted in increased concentrations of phosphate in the region.

Growth limiting nutrients such as phosphate and inorganic nitrogen affect the population dynamics of phytoplankton in an aquatic environment (Rhee and Gotham, 1981). The importance of nitrate lies in its ability to regulate primary production as a new nitrogen source for primary producers (Malone et al., 1983). The seasonal maximum of nitrates in the monsoon season, characterized by high concentrations during June – Aug, when salinity levels are low, indicates input of freshwater. However, at the end of monsoon season, low salinity does not correspond to high nitrate values. This is because at the beginning of the monsoon season, the freshwater is highly charged with NO_3^-, while in Sept, though the salinity is still low, the incoming water is less enriched with nitrate (Fig. 4.6 and 4.3; Heredia, 2000). The low concentrations in the pre- and post- monsoon seasons can be attributed to biological processes occurring within the system. The significant negative correlation of nitrate and chl *a* concentrations ($r=-0.708$, $p<0.01$, $n=12$; Fig. 4.10) supports the nitrate uptake by phytoplankton during this period. The gradual decrease in nitrate concentrations from post-monsoon to pre-monsoon could be due to the tight coupling between nitrate production and utilization by the phytoplankton. The significant negative correlation between Condition index (CI) and NO_3^- ($r=-0.599$, $p=0.044$, $n=12$; Fig. 4.11) also points towards the fact that nitrates are used by phytoplankton which is the main food of

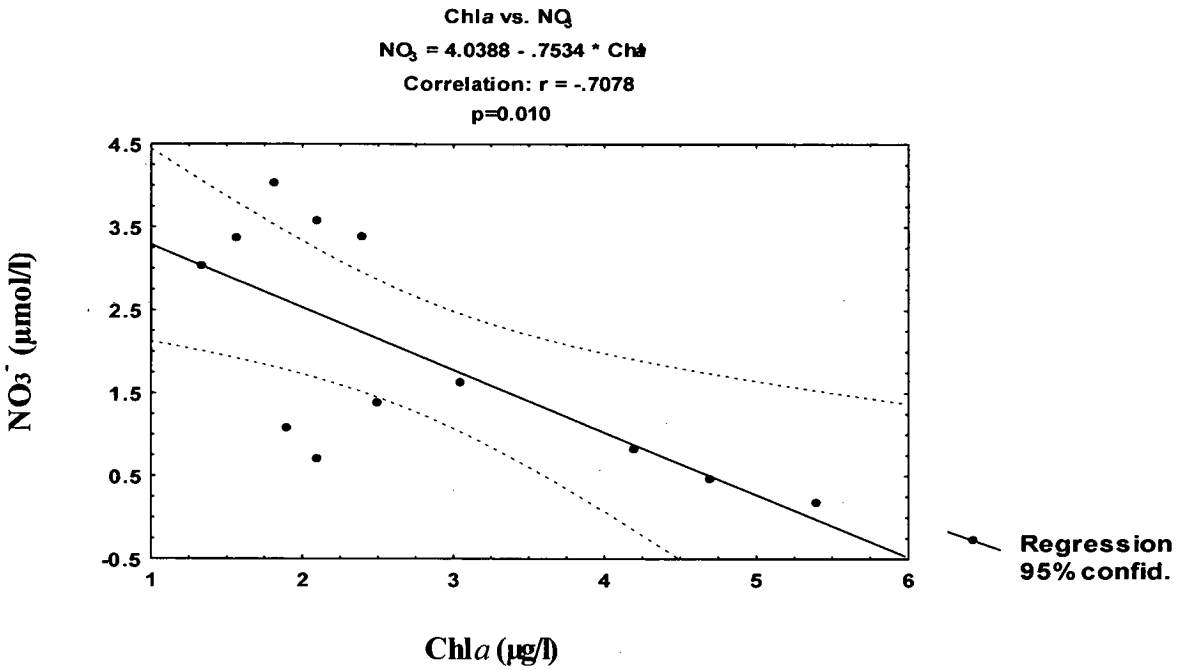


Fig 4.10: Relationship between estuarine water Chl *a* content and nitrate concentration

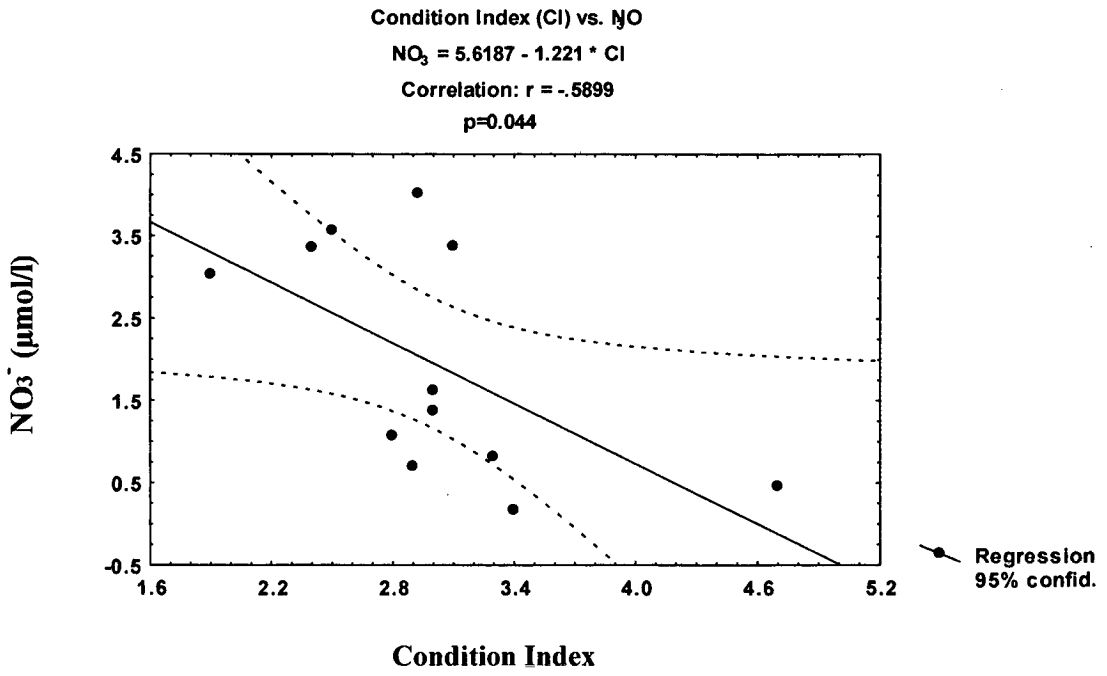


Fig 4.11: Relationship between Condition Index of *P. erosa* and estuarine water nitrate concentration

this clam (Table 4.2 and plate 4.1) and that is reflected in the CI. A low CI value indicates stressed or diseased conditions (Lucas and Beninger, 1985). Studies have shown that the development of phytoplankton communities is mainly based on nitrate (Gilbert and Garside, 1992; Dauchez et al., 1996). The importance of nitrate lies in its ability to regulate primary production as a new nitrogen source for primary producers (Malone et al., 1983).

Reports of nitrite concentrations in the mangrove ecosystems are scarce. In the Achara creek, along the west coast of India, the nitrite concentrations ranged from 0.002 to 0.057 μmol/l (Heredia, 2000). The nitrite concentrations at Chorao were much higher than those of the mangroves of Achara creek. The seasonal changes in nitrite concentrations did not follow a pattern similar to that of nitrate, except for the peak values in the monsoon months. At Chorao, nitrite concentrations were higher in the pore water of MT and HT region compared to the water and low tide area (Fig. 4.5). The photic zone is a region of minimum nitrification activity due to the fact that marine nitrifiers are inhibited by light (Eriksson, 2001). Marine nitrifiers can grow and oxidize their substrate at very low oxygen (Goureau et al., 1980). Also the production of nitrous oxide (Goreau et al., 1980) and nitric oxide (Lipschiltz et al., 1981) is enhanced at low oxygen concentrations. In the oxygen minimum zone off Peru, high nitrite concentrations upto 23 μM were recorded (Codiposti et al., 1986). Also high values of nitrites are reported in the coastal waters of Goa where DO values are relatively low (Naqvi et al, 2006). Hence low oxygen recorded at MT and HT may have accounted for the higher nitrite concentration at MT and HT compared to the LT region (Fig. 4.4). It has been observed, that low temperatures (Kuai and Verstraete, 1994) and salinity (Mevel and Prieur, 2000) may inhibit growth of nitrifiers and nitrification rate decreases leading to low nitrite with decrease in temperature and salinity. However, in the monsoon months, the nitrite concentrations increased considerably. Thus, the high nitrite values coincident with low salinity in the monsoon indicate that nitrite addition during this time is essentially through the

riverine advection. Further, phosphate uptake by phytoplankton (Saha, 2006) during high production in the non-monsoon months must have resulted in low phosphate values in this period (Fig.4.7). Moreover, the high concentrations of phosphates when salinity is low are due to the land run off and freshwater input.

A statistically significant correlation between temperature and chl *a* ($r=0.688$, $n=12$, $p<0.013$; Fig.4.12), is obvious, as temperature is known to influence phytoplankton. Other than the nutrient limitation, population dynamics of phytoplankton also change with seasons, latitude and water depth and these changes are due to factors like temperature, light and day length (Rhee and Gotham, 1981). Temperature stress may be one of the most important factors which may interact with nutrient limitation in nature, since the phase transition of lipids, phase conformation of macromolecules and the kinetics of physiochemical reactions are all profoundly affected by it (Rhee and Gotham, 1981). Numerous studies on growth of phytoplankton in the laboratory have demonstrated the dependence of cellular pigment concentration and growth rate upon temperature (Kiefer and Cullen, 1991). From observations of species-distribution in nature, it has been supposed that, temperature can act as a major variable influencing the quality of phytoplankton in space (altitude, latitude) and time (seasonal periodicity; Butterwick et al., 2005). Temperature has a strong influence on the chemical composition of marine phytoplankton. A common characteristic of several species is a minimum nutrient content (as nitrogen or carbon) per cell at the temperature optimum for cell division, with increasing cellular biomass at lower and higher temperatures (Goldman, 1977).

The highly significant positive relationship between salinity and chl *a* (Fig. 4.13; $r=0.85$; $p<0.001$) can be explained by the importance of salinity for phytoplankton. Salinity is regarded as an important factor affecting phytoplankton growth and distribution (Day et al., 1989). Though the physical factor, irradiance and the chemical factors, major nutrients are known to be the primary factors

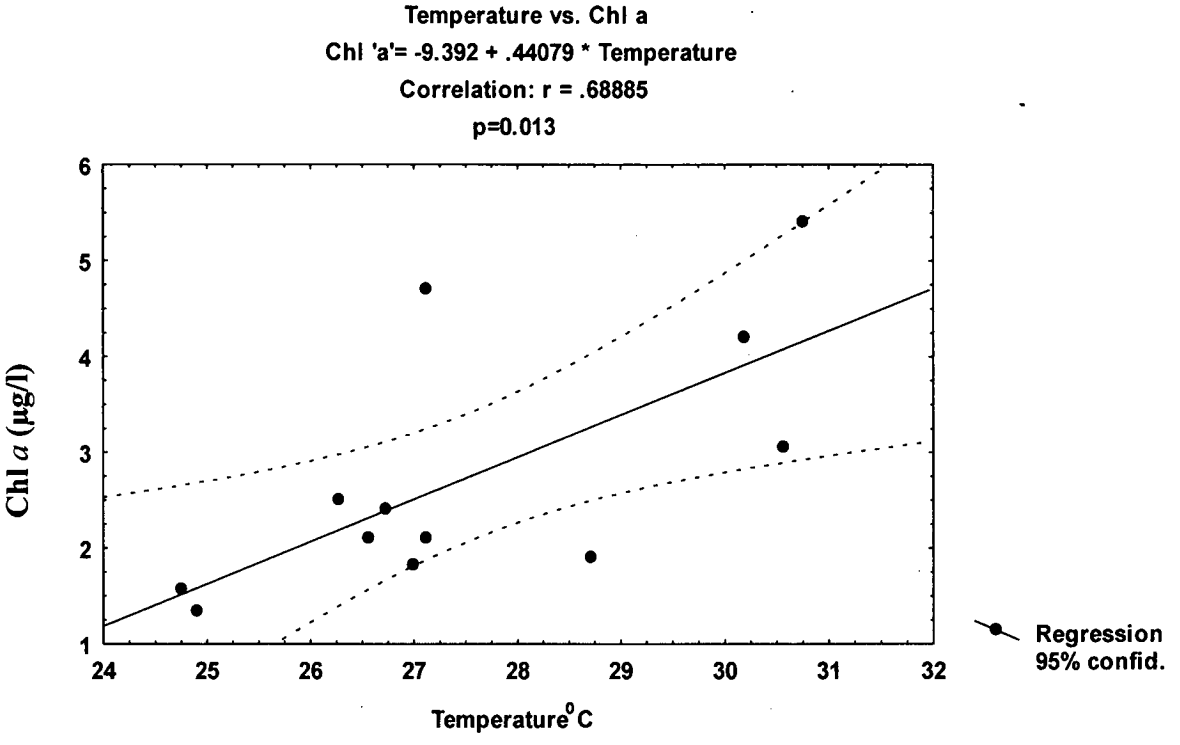


Fig 4.12: Relationship between estuarine water temperature and Chl *a* content

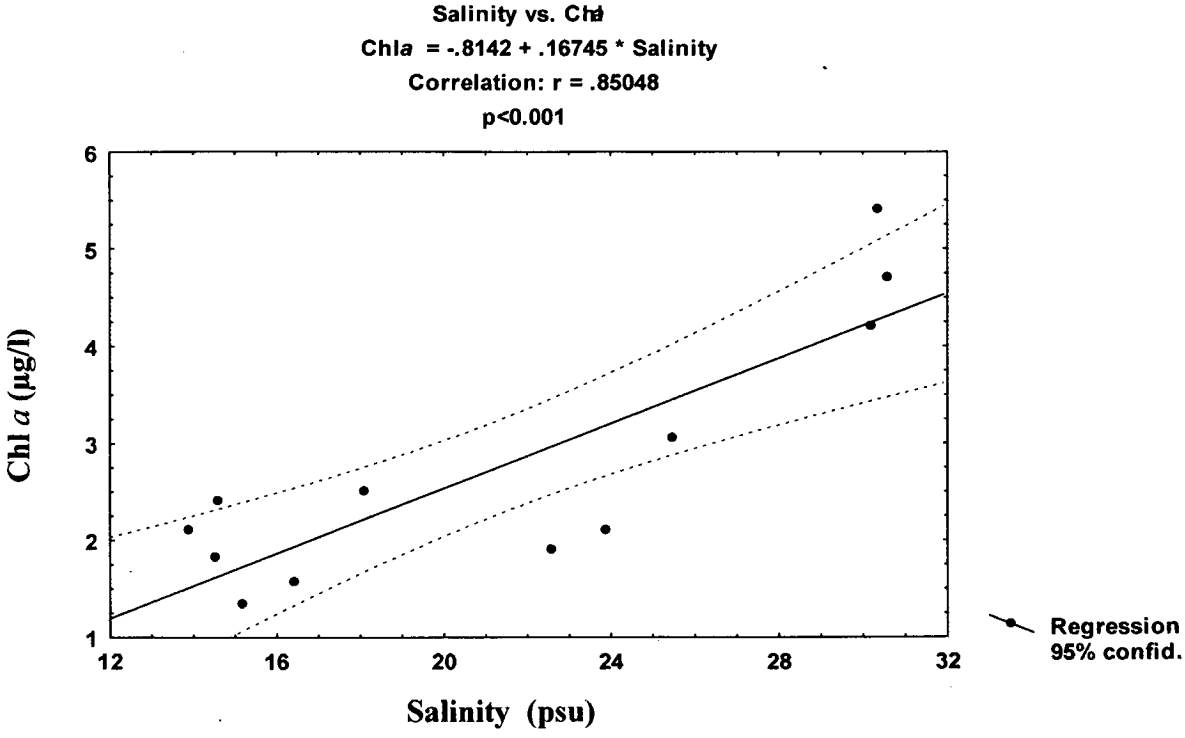


Fig 4.13: Relationship between estuarine water salinity and Chl *a* content

associated with phytoplankton growth (Leland and Berkas, 1998), experimental studies have suggested that, nutrient limitation of phytoplankton may change depending on salinity changes (Wurtsbaugh, 2005). The type of phytoplankton found in a particular season is also reflected by salinity. Studies have shown that, at high salinities, diatoms and green algae dominate, but at low salinities, nitrogen-fixing cyanobacteria dominate (Wurtsbaugh, 2005). While studying the phytoplankon dynamics, Devassy and Goes (1989) observed that, salinity plays an important role in controlling phytoplankton abundance and primary production in Mandovi estuary.

The significant correlation of both wet weight as well as dry weight of the meat of *P. erosa* with chl *a* confirms that it feeds on the phytoplankton ($r=0.600$, $p=0.039$, $n=12$; Fig. 4.14 and $r=0.613$, $p=0.034$, $n=12$; Fig. 4.15). Gut content analyses revealed that phytoplankton, especially diatoms, *Cosinodiscus* sp. and *Navicula* sp. forms the dominant component of the gut in *P. erosa*. *Cosinodiscus* sp. is the most dominant phytoplankton species in the Mandovi estuary in the vicinity of the study area (Matondkar et al., 2007). Moreno-Ruiz et al. (1994) have reported that benthic diatoms form an important constituent in the diet of several species of marine bivalves although pelagic diatoms are also important. The dominance of *Navicula* spp. within the benthic diatoms in coastal sediments of Goa is reported by Mitbhavkar and Anil (2001). Dominance of *Navicula* sp in the muddy sediments of the Gulf of Kachchh have also been reported by Ingole and Goltekar (2004). Thus, pointing towards the fact that the availability of *Cosinodiscus* sp. and *Navicula* sp. in higher abundance was the main reason for *P. erosa* to feed on these phytoplankter. However, further detailed work need to be done to get a clear view of *P. erosa* feeding. Moreover, dominance of certain species like *Cosinodiscus* sp. in the gut of *P. erosa* (Fig.16) indicate that, even though the clams consume a range of seston and particulates as a consequence of filter feeding, there is a high degree of selectivity for phytoplankton, which provides the highest quality food as observed in many studies (Newell and Field 1983).

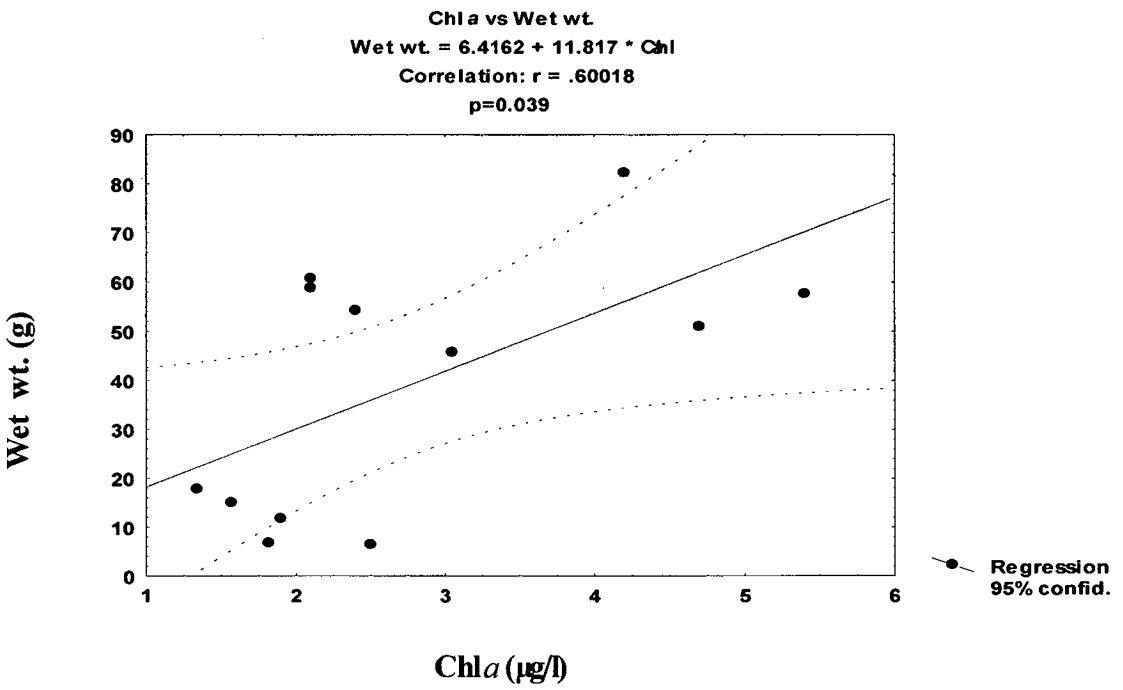


Fig 4.14: Relationship between wet tissue weight of *P. erosa* and Chl *a* content

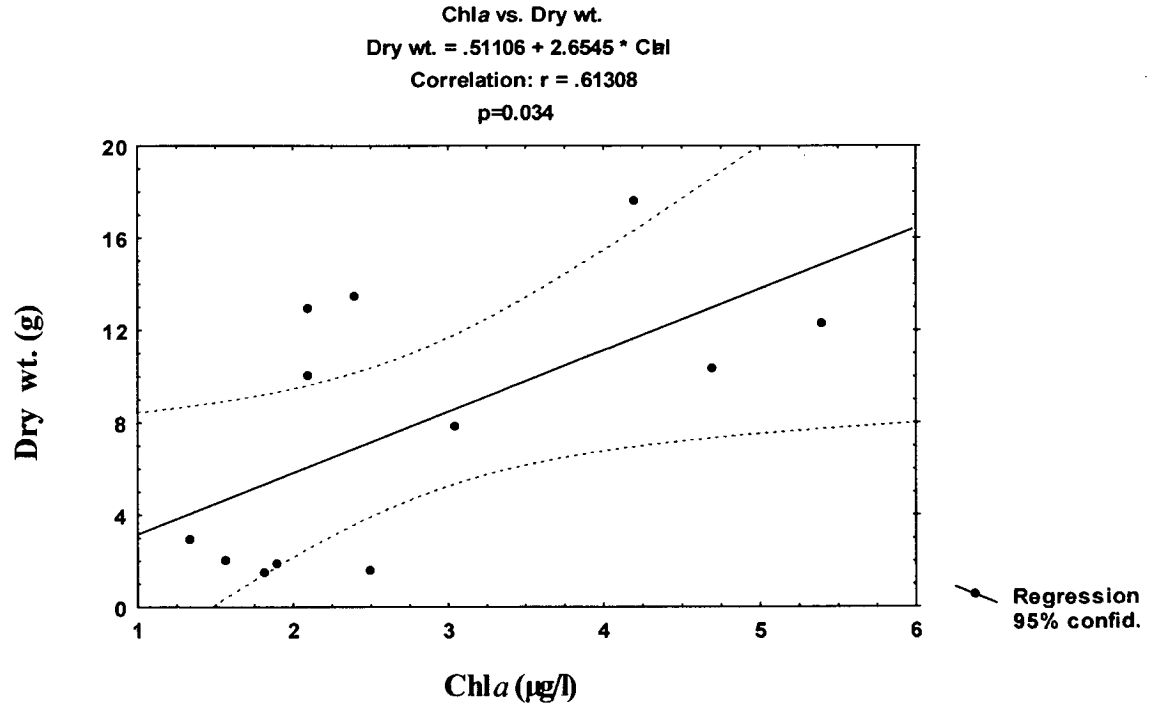


Fig 4.15: Relationship between dry tissue weight of *P. erosa* and Chl *a* content

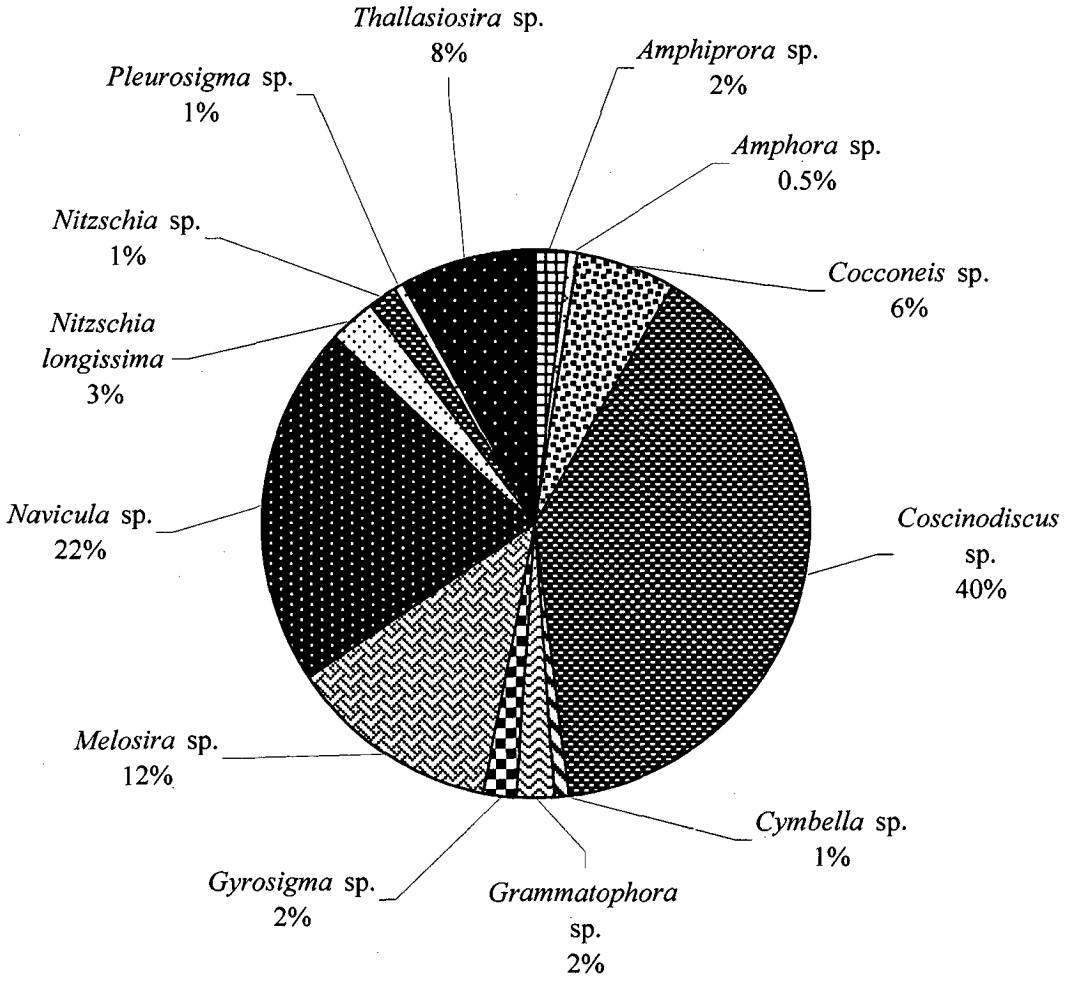


Fig. 4.16: Phytoplankon species in the gut of *P.erosa* from Chorao island

Menge et al. (1997) found striking differences in the growth of *M. californianus* to be strongly related to the persistent differences between the sites in food concentration (indexed by chl *a* measurements). Bertness et al. (1991) also documented significantly higher growth and reproductive output in the barnacle *Semibalanus balanoides* in location of higher food and higher net flux of food.

The PCA analysis (Fig. 4.9) showed that most of the variability in the environmental parameters at Chorao island can be derived from only two factors comprising of temperature, salinity, chlorophyll, nutrients and pH. So also, the environmental parameters that affect the clam growth most were pH, chl *a* and temperature and the principal environmental factor that affects clam growth was salinity. These correlations are obvious, considering that *P. erosa* inhabits the mangroves. In its natural habitat, salinity fluctuates with tidal cycles, rainfall and with drainage from adjacent terrestrial sites. The biological effects of variations in temperature and salinity are considered to be among the most important factors influencing marine organisms (Ponce-Palafox et al., 1997). Furthermore, temperature is considered to be the most important modifier of energy flow and hence growth, while salinity imposes the greatest additional load on metabolic requirements of aquatic animals (Ingole, 1994). Apart from salinities, range of temperatures, both diurnally and seasonally, ranges of pH and oxygen tension is much wider in estuaries than in the sea.

These clams are sessile benthic animals and as such are continually exposed to physico-chemical modifications of the environment. Conditions during exposure also differ considerably from those experienced in water as regards desiccation stress.

4.6.1 Emersion and *P. erosa*

4.6.1.1 Effect of Dessication

Water loss from the tissues is the main cause of mortality of intertidal organisms during dessiccation (Hummel et al., 1994). Conditions such as extreme temperatures are likely to occur, during exposure for long periods at times of low tide in the high zone of the mangroves towards the landward region where *P. erosa* inhabits. Hence, when their mortality was considered in air, it was seen that at room temperatures *P. erosa* could survive for more than five weeks (Table 4.8). This shows that *P. erosa*, is better able to tolerate aerial exposure and this could be due to the ability of this clam to close the shell valves as soon as exposed to air, which in turn prevent rapid water loss from the mantle cavity. The soft body tissue is very small in relation to the size of the clam and this probably is the reason for such an adaptation in order to maintain a very large amount of water. The large volume of water in the mantle cavity of *P. erosa* is observed in also reported by Morton (1976) and Gimmin et al. (2004). The large volume of water in the mantle cavity is part of the survival strategy of this species.

4.6.1.2 Effect of exposure on the survival of clams

The survival of *P. erosa* without water for prolonged periods (even more than a month) indicate that this clam take benefit from being able to take air into the mantle cavity during exposure. When in air, it can achieve aerial respiration via mantle margin (Morton, 1976). In this situation, *P. erosa* gaped widely and extended the foot widely. The ability to tolerate these anoxic conditions, however, does indicate that *P. erosa*, as well as displaying air breathing, can in particularly stressed conditions, resist anaerobic conditions. This feature has also been, recognized in littoral air-gaping animals (Boyden, 1972). The ability to utilize oxygen from air is widespread among intertidal molluscs, but the patterns of

activity under air exposure vary between species, reflecting the different forms of adaptation to aerial conditions, such as type of gill and degree of vascularization of the mantle cavity. Widdows et al. (1979) have shown that ability of intertidal bivalves to maintain aerobic metabolism in air depends on behavioural responses such as intermittent air gaping. The epifaunal *Mytilus edulis* and *Mytilus galloprovincialis* either do gape, or have a reduced valve gape, thus relying mostly on anaerobic metabolic pathways to save energy and avoid desiccation. The infaunal bivalves *Cerastoderma edule* and *Modiolus demissus* remain partially open and extract oxygen from the atmosphere. Widdows and Shick (1985) found that *C. edule* maintains a fully aerobic metabolism when exposed air, without resorting to major utilization of reserves through anaerobiosis.

Upon emersion, water is actively expelled by *P. erosa* from the mantle cavity by valve movements and replaced by air. Such behaviour is known to be exhibited by many shore organisms (Barnes and Reese, 1960). However, when discussing the capacity of *P. erosa* to air - breathe, it could be argued that the clams have no opportunity to air-breathe when buried in the substratum. Many individuals do occur buried in wet mud in the field, and these clams obviously do not get to air breathing by valve gaping. *P. erosa* in common with many other lamellibranches possess the ability to tolerate anoxic conditions, and thus if oxygen is lacking they must be employing anaerobic pathways. Breathing would not seem therefore to be an essential requirement of the species, but is an important adaptation to aid life between tidemarks. During aerial exposure a reduction in the level of metabolism of various intertidal molluscs has been shown to occur which is suggested to be correlated with reduced availability of oxygen and that it leads to economy of available oxygen (Trueman, 1967).

4.6.1.3 Effect of temperature changes

Temperature is a very important factor limiting bivalve distribution, affecting their activity level and energy balance. Temperature tolerance can be modified by physiological and behavioural acclimation of temperature regime of the animal's environment. Studies on the effects of different temperature on a closely related species *P. caroliniana* (Gainey and Greenberg, 1977) have shown that following acute temperature changes from 5 to 20°C and 30°C, showed stable metabolic rates in a matter of hours. However, the same clam when exposed to temperatures as low as 0 to –1°C, died only after 4 hrs (Hackney, 1985).

Since *P. erosa* is able to survive in the harsh conditions of changing temperatures during emersion, it must be coping with this in a manner similar to *P. caroliniana.* Since *P. erosa,* when exposed to freezing temperatures showed mortality within 3-4 hrs (Table 4.8). It appears that the optimum temperature is 24 –30°C, observed from the clam bed at Chorao island. The maximum size of *P. erosa* recorded at Singapore and Hong Kong (90 mm) (Morton, 1976), is much smaller than that obtained at Chorao island (102 mm). This reduction in maximum size is mainly due to the lowering of the energy input (i.e. food consumption) as a result of a decline in feeding rate, which could be due to elevated temperatures. It is therefore worth mentioning that, high temperatures (above 30°C) are stressful to the clams, as seen by the small sizes of clams in regions with higher temperatures than that of comparatively lower temperatures. Animals living in the intertidal zone are exposed not only to seasonal fluctuations but also to wide short-term (12 – 24 hours) variations of temperature (i.e. 10-25°C) and are able to maintain their feeding and respiratory rates relatively independent of these fluctuations in environmental temperature (Bayne et al., 1976). Wilson and Elkaim (1991) reported regulation of respiration by *Macoma balthica* within the temperature range of 15-30°C.

It can be thus said that, *P. erosa* can regulate temperature changes above 5°C normally. However, they are intolerant to extreme cold temperatures, which could be one of the primary limiting factors in its tropical distribution. Nevertheless, though the clams favour high temperatures, elevation in temperature above optimum level results in the reduction of scope of growth.

4.6.1.4 Effect of salinity changes

Most bivalves respond immediately to changes in salinity by closing their shells and isolating themselves from the external salinity environment. This isolation helps to reduce the rate of associated changes in cell volume and allows iso-osmotic intracellular regulation to commence (Hawkins and Bayne, 1992). When the salinity is suddenly changed, the physiological processes such as metabolism and osmoregulation are altered in marine animals (Ingole, 1994; Kim et al., 1998). Thus, following, a sudden change in salinity, physiological rates of feeding and respiration are depressed, but gradually the animal regains normal function. The ability of marine mollusks to control their metabolic activity at reduced salinity levels are well documented (Bayne et al., 1976). The mangrove clam *P. erosa*, are subjected to low salinity during the heavy rain season in their natural habitat. At Chorao island, this species occurs in the high zone of the mangroves with salinity levels ranging from 14.3 to 30.7 psu observed during August and April respectively. Literature shows that *P. erosa* can osmoregulate at salinities from 31 psu down to 8 psu (Gainey and Greenberg, 1977). Morton and Chan (1990) have also confirmed that *P. erosa* can osmoregulate a wide range of salinities from 31 psu to freshwater conditions except at 0 psu. The results obtained in the laboratory experiment confirm that, *P. erosa* can osmoregulate across a wide range of salinities (Table 4.8). However, with a reduced ability to tolerate freshwater conditions though it can osmoregulate for a certain period but that at a point it becomes difficult and death ensues. *P. erosa* is an oligohaline species with a reduced ability to tolerate freshwater was reported by Morton and Chan (1990).

Marine bivalves can withstand marked changes in salinity by closing their shell valves for several days (Akberali, 1978). In the laboratory conditions, *P. erosa* also shows valve closure on exposure to 0 salinity. This behaviour has been interpreted as a mechanism for gradually diluting the mantle fluid, thus reducing the osmotic shock to the tissues, to prolong survival (Dame, 1996). In the field also *P. erosa* must be reducing osmotic shock to its tissues by shell closure upon large salinity changes. It is also known that, *Polymesoda* regulates hypo-osmotic stress much faster than hyperosmotic stress (Gainey, 1978). Hence, it can be said that, *P. erosa* is oligohaline, but with a reduced ability to tolerate freshwater (Morton and Chan, 1990). Studies have shown that bivalves can adapt to very low salinities at their optimum temperatures, except at abnormally elevated temperature (Yaroslavtseva and Sergeeva, 2006). Bivalves under conditions of optimum salinity regulate even the oxygen consumption at reduced oxygen tension. The Corbiculidae (a freshwater family) are assumed to arise from a marine, inshore, veneroid ancestor (Morton, 1988). From the marine environment the successful exploitation of the freshwaters must have been preceeded by the successful occupation of brackish waters, by species like *P. erosa* due to their enhance powers of osmoregulation. Hence, *P. erosa* can be considered as the transitional species from a marine environment to the freshwater.

4.7 Correlation of *P. erosa* with the environmental parameters

The growth of *P. erosa* in terms of weight (dry wt.) is directly dependent on chl *a* content. The chlorophyll content of the water is influenced by salinity with high values during summers when the maximum temperatures are recorded. Studies have shown that bivalves can adapt to very low salinities at their optimum temperatures (Yaroslavtseva and Sergeeva, 2006). Temperature is a key factor controlling tolerance of bivalves like mussels to low oxygen, not only because DO declines as temperature increases, but because as poikilotherms, mussel metabolism is dependent on temperature. It is seen that, oxygen regulation ability appears to be related to the degree of hypoxia a species normally experiences in its habitat type, and it is enhanced at low temperature (Chen et al., 2001).

Bivalves under conditions of optimum salinity and temperature regulate oxygen consumption at even reduced oxygen tension. Regulation of respiration in declining oxygen tension decreases with decreasing salinity and increasing temperature. Maximum respiration occurs at moderate salinity and 30°C at all oxygen tensions (Dame, 1996). Studies show that cessation of feeding occurs at relatively high temperatures (Dame, 1996). Although, the rate of growth is shown to increase with temperature (Loosanoff, 1959) on the other hand, the growth decreases with temperature increase of a few degrees within the viable range (Loosanoff, et al., 1951).

Water chlorophyll, salinity, nitrite and nitrate showed direct correlation with temperature ($p<0.05$; Table 4.1). Among all the parameters studied only chlorophyll showed statistically significant correlation with the growth of the clams (both with wet wt. and dry wt.; Fig. 4.14 and Fig. 4.15 respectively). The stepwise regression analysis showed that growth had highest coefficient of correlation (dry wt; $r=0.67$, $p=0.001$) with the salinity parameter, however the high degree of intercorrelation between the environmental parameters suggest that the environment as a whole will affect the levels of chlorophyll and that the growth of the clams. It is seen that temperature influences salinity and salinity shows a strong correlation with chlorophyll content which in turn affects the clams growth. Since temperature and salinity directly affects chl *a*, the growth of *P. erosa* is indirectly affected by temperature, salinity and nutrients which affect phytoplankton production which in turn have a direct influence on this clams. It is apparent from the foregoing discussion that, salinity and temperature has a profound effect on the clam growth. Further, it is seen that gametogenesis in *P. erosa* occurs when both temperature and salinity is high with spawning coinciding with decline in these parameters. The interaction of salinity, temperature, availability of food in a particular environment is complex and it is difficult to isolate the effect of a particular environmental parameter. Moreover, salinity showed a direct correlation with clam growth and since temperature affects

salinity changes, it is ultimately the temperature, which indirectly affects the clam's survival. Thus, it can be concluded that the major environmental factor determining survival and growth of *P. erosa* is temperature and temperature must be the primary limiting factor in its distribution in other parts of the world other than the tropical and subtropical mangrove ecosystems.

CHAPTER 5

DISTRIBUTION & ABUNDANCE OF *P. EROSA*

5.1 Introduction

Ecosystems are organized assemblages of plants and animals in complex interaction with each other and their physical environment. While genetic and physiological processes govern individual species, their existence in nature is conditioned by the total environment and in turn influences the environment of which they are a part. Not only can abiotic factors limit the abundance and extent of the biota, but also the living components can influence the physical environment. The environmental characteristics affect the distribution of benthic organisms by two interrelated ways directly by allowing organism to establish and survive (Bradshaw and Scoffin, 1999; Miller and Curran, 2001) and indirectly by modifying their ecological interactions (Nomannn and Pennings, 1998).

Intertidal areas have been widely used as model systems for studying the role of environmental factors (Dayton, 1971) and biological interactions (Peterson, 1991; Bruno et al., 2003) in determining patterns of species distribution and abundance. The importance of negative (eg. competition and predation) and positive interactions (eg. facilitation) can be modified by the nature and configuration of environmental factors (Callaway and King, 1996). A variety of bivalve molluscs are prominent members of many diverse marine systems. These animals have reached their greatest abundances in shallow coastal waters and estuaries. Different workers (Cantera, 1991; McGuinness, 1994) have proposed that subtrata wetness due to tidal influence, salinity, wave energy, light, land of substratum, competition, predation relationship pattern of larval distribution and food distribution are the most important factors controlling the distribution of mangrove mollusc.

The factors responsible for the species zonation pattern observed in the intertidal shores are a subject of much investigation (Underwood, 1985). The relative importance of physical factors (e.g. wave exposure, temperature and dessication)

and biological factors (e.g. competition, predation, herbivory and recruitment) affecting community structure has been widely discussed (Underwood, 1985). Several models based on the importance of variations in these factors had been proposed by many workers (Menge and Olson, 1990). Much of the evidence and hypotheses generated concerning shore community, have been derived from studies on rocky shore and salt marshes (Menge et al., 1986; Williams, 1994). In comparison, the structure of tropical mangrove ecosystems has received scant attention (Ronnback et al., 2002) although attempts have been made to study the community structure of mangroves (Ronnback et al., 2002). Most of these studies on community structure of mangroves are related to the crustaceans and work on mollusc as such is very limited. Moreover, work on the factors responsible for the overall community structure of *P. erosa* in particular in the mangrove ecosystem is very scarce. After the casual observation of Meehan (1982) who reported that *P. erosa* is mostly found in the vicinity of the *Avicennia* sp. but there is no detailed work done on the distribution of *P. erosa* in its habitat. Studies on the community structure of other species of *Polymesoda* are reported earlier (Daiber, 1982; Heard, 1982; Duobinis and Hackney, 1982). The problematic nature of sampling among the extensive mangrove root system is probably the main reason for the limited scientific information on the species utilizing the intertidal forest as habitat. Consequently, the knowledge of distribution pattern within the intertidal forest is even scarce, which makes it difficult to assess the relative importance of different ecological types of mangroves. From a fisheries management perspective, one key parameter is to identify the microhabitats within the different ecosystems (riverine, estuarine and mangrove habitats). It could also be said that any discussion of the functional role of mangroves as habitat should be built on baseline information of how fauna is distributed within the system.

P. erosa is reported to occur in abundance in the vicinity of *Avicennia* sp. (Morton, 1976; Meehan, 1982) but no studies have attempted to get a clear view of the distribution patterns. This is a shortcoming of the earlier studies, if the

habitat preference for this clam has to be determined. Hence, the present study was conducted with main objective of studying the distribution of *P. erosa* in the mangroves in relation to the different tidal level elevations: low tide area without any mangrove trees, mid tide area with dominating *Rhizophora* species, the high tide level with dominating *Avicennia* sp. The study was to test the hypothesis that mud clams are distributed with high abundance and biomass in the high density *Avicennia* zone of the mangrove forest.

5.2 Materials and Methods

To study the general distribution and density of *P. erosa*, mangrove habitats along the central west coast of India between Kumta and Ratnagiri were surveyed in different seasons (Fig. 2.1).

Three transects approximately 500 m long and 20-40 m apart were established. Three replicate sites were randomly selected within each transect and the individual replicates were separated by at least 10 m. Once each month from July 2004 through July 2005, triplicate samples along each transect were collected. For this purpose, clams were recorded within 9 to 12 quadrants of 1 m^2 each from a plot of approx. 100 m^2. Juvenile clams are very small in size, it was not possible to count them, and hence, a marked area of 0.25 m^2 was sampled by taking the upper 5 cm layer of sediment (Plate 2.5). All the material was sieved on a 300 μm mesh sieve and preserved in 5% Rose – bengal formalin solution. The adult clams were measured for length, width, height with a Vernier calliper, (±0.1mm precision). Biomass (dry flesh mass) of the clams was estimated after drying the samples for 72 hours in the oven at 60°C. Since the distribution of clams was similar at all the different locations sampled, the difference in clam abundance and biomass at different tide levels, was studied only at Chorao island.

The following environmental parameters were randomly recorded in triplicate at low tide in each plot: temp, pH, salinity, dissolved oxygen (DO), nutrients (NO_2^-, NO_3^- and PO_4^-) from the interstitial water and also from the surface water of the adjacent estuarine water.

5.3 Data analyses

Clams were described using abundance and biomass. Differences in these univariate measures were tested using one-way analysis of variance (ANOVA). ANOVA was applied to test for differences in abundance and biomass between sampling dates and among different tide levels. Multiple linear regression analysis was used to estimate and fit a structural model to explain the variation in the dependent variables i.e. observations in clam abundance and biomass that were explained by the predictor variables ie in terms of the environmental variables. Variables were checked for colinearity using the Pearson's product moment correlation coefficients. The selected variables were temperature, pH, chlorophyll *a* (chl *a*), DO, salinity and dissolved nutrients. All variables were checked for normality using the Shapiro Wilk's and Levene's test (Sokal and Rohlf, 1995).

5.4 Results

At all the sites surveyed (Fig. 5.1), clams were observed towards the landward side with high density in the high tide level. The density of clams varied between 1 – 51 individuals/m^2. The lowest density of adult clams, with 1 individuals/m^2 was recorded at Kalbadevi mangroves in Ratnagiri. The average number of clams recorded at the different sites is given in fig. 5.2. The highest density of clams is observed among the mangroves at Chorao. The abundance as well as biomass was significantly different for the clams collected from different locations ($F=24.8$, $df==65$, $p<0.001$, $F=7.51$, $df==51$, $p<0.001$; Table 5.1). However, there was no significant difference in the size classes recorded from the different locations

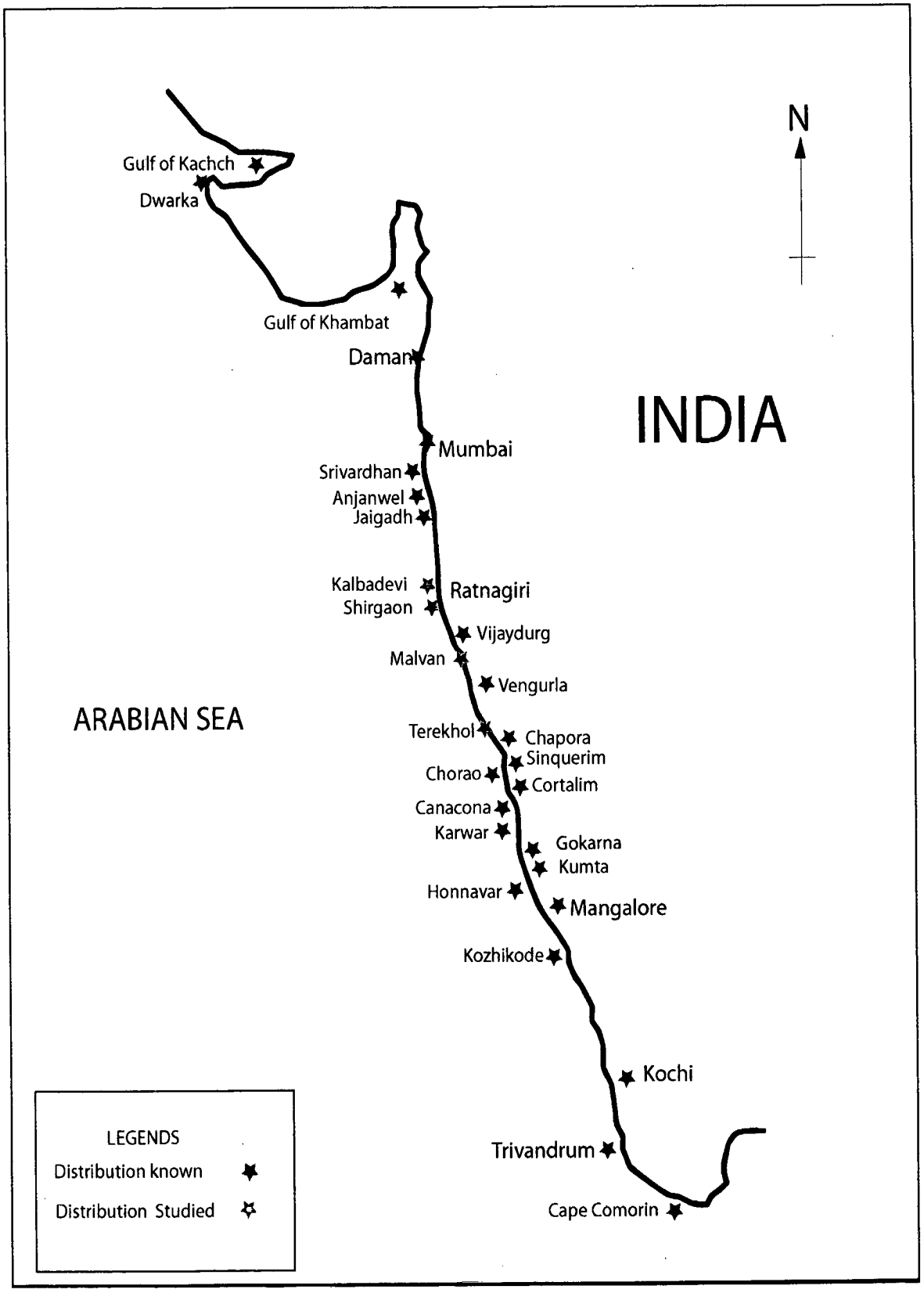


Fig 5.1: Distribution of mangrove clam *P. erosa* along the west coast of India

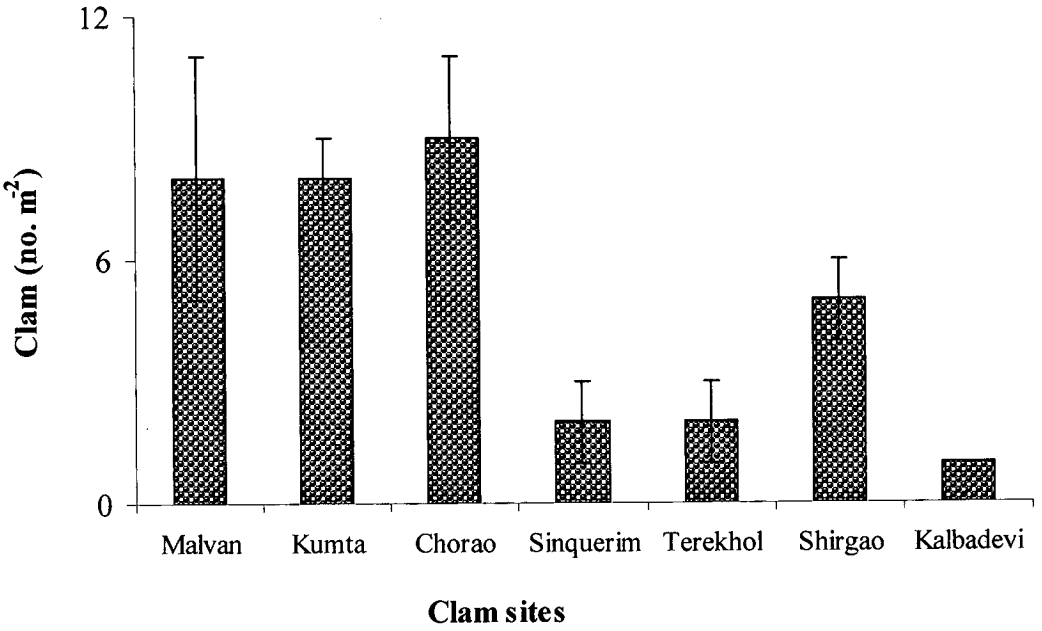


Fig 5.2: Density of *P. erosa* at different locations along the central west coast of India

studied (F=2.250, df=34, p>0.05, Table 5.1). At all the sites surveyed almost all clams were observed in the high tide region inside the *Avicennia* forest. A summary of the clam's abundance and biomass at Chorao is given in Table 5.2. At Chorao, the clams are located >7m above mean - tide level and were thus inundated only during the spring tide. In the area where the clam bed is observed, the vegetation is mainly composed of *Avicennia sp.* The area is visited by several benthic organisms (e.g. gobiid fish, crabs, shrimps), which sometimes remain in puddles during low tide. The permanent epibenthic community mainly consisted of gastropods (*Telescopium telescopium*), oysters (*Saccostrea cucculata*), *Cerithidea* sp. and crabs (Pers.obs.).

Among the tide levels studied, adult clams were observed only in the high tide region (HT) with a mean abundance of 9±3 clams m^{-2} at Chorao island (Fig. 5.3). In the MT and LT region, no adult clams were observed, though juveniles (<35 mm) are recorded in these areas. There were distinct differences in the size range of the clams recorded in the two tidal levels. In the high tide *Aviccenia* forest, wide range of size classes (30.1-40 to 100.1-110 mm) were recorded (Fig. 5.4) and only 0.5% were smaller than 35 mm in shell length and no clams with shell length over 102 mm were recorded. In the low tide level, only juvenile clams with size less than 32 mm were recorded. Abundance and biomass data showed significant differences between tidal levels (Table 5.3). For abundance, no significant differences were observed in different months, for biomass; however, statistically significant differences were found between months (Table 5.4). High-tide level had the greatest adult clam abundance than the low tide and mid tide level. Biomass also was higher at the high-tide level than the low tide and mid tide level.

The means and ranges of the physico-chemical parameters assessed at the different tide levels are given in Table 5.5 and Fig. 5.5 – 5.12. Of the environmental factors studied, only temperature, pH, showed a significant

Table 5.1: Results of ANOVA among sites on clam (a) abundance, (b) biomass and (c) size classes at Chorao island

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
(a) **Abundace**					
Site	767.4518	7	109.636	24.848	p<0.001
Residual	255.911	58	4.412		
(b) **Biomass**					
Site	63.132	5	12.626	7.518	p<0.001
Residual	77.252	46	1.679		
(c) **Size classes**					
Site	377.771	6	62.961	2.250	p>0.05
Residual	783.2	28	27.971		

Table 5.2: The abundance and biomass of adult *P. erosa* at Chorao during the study period

Months	Mean density (indivi./m^2)	SD	Biomass (g/m^2)	SD
Jul-04	12	14	16.8	9.1
Aug-04	9	4	11.1	10.3
Sep-04	8	5	14.7	5.1
Oct-04	9	6	14.8	11.4
Nov-04	12	6	21.1	9.5
Jan-05	7	4	12.4	6.6
Feb-05	9	4	18.9	11.3
Mar-05	7	3	18.5	12.2
Apr-05	7	3	17.1	7.1
May-05	7	4	16.6	6.5
Jun-05	9	2	15.5	8.9
Jul-05	8	4	12.2	6.9

Table 5.3: Results of ANOVA for effects of tidal level and months on the abundance of *P. erosa* at Chorao island

Abundance					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***
Tidal level	626.316	2	313.158	415.488	p<0.001
Residual	24.872	33	0.753		
Months	315.599	11	28.690	0.864	p>0.05
Residual	3417.583	103	33.180		

Table 5.4:Results of ANOVA for effects of tidal level and months on the biomass of *P.erosa* at Chorao island

Biomass					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Tidal level	490.307	2	245.153	22.694	p<0.001
Residual	356.474	33	10.802		
Month	41.216	11	3.746	3.193	p<0.001
Residual	152.520	130	1.173		

Table 5.5: Mean (±SD) values of the different environmental parameters in different tide levels at Chorao island

	LT	MT	HT
Temperature°C	30.3± 3.6	26.6± 1.5	27.1± 1.5
Salinity (psu)	25.2± 5.9	21.4± 6.0	23.4± 8.2
pH	7.7± 0.3	7.2± 6.0	7.1± 0.6
DO (mg/l)	1.1± 0.6	2.0± 0.4	1.3± 1.1
NO_2^- (µmol/l)	1.1± 0.7	1.6± 1.2	1.6± 1.5
NO_3^- (µmol/l)	1.8± 1.1	2.4 ± 1.6	1.6± 1.6
PO_4^- (µmol/l)	1.5± 1.4	1.4 ± 1.1	1.5± 1.3
Chl *a* (µg/l)	0.10± 0.10	0.60 ± 0.79	0.71± 0.68

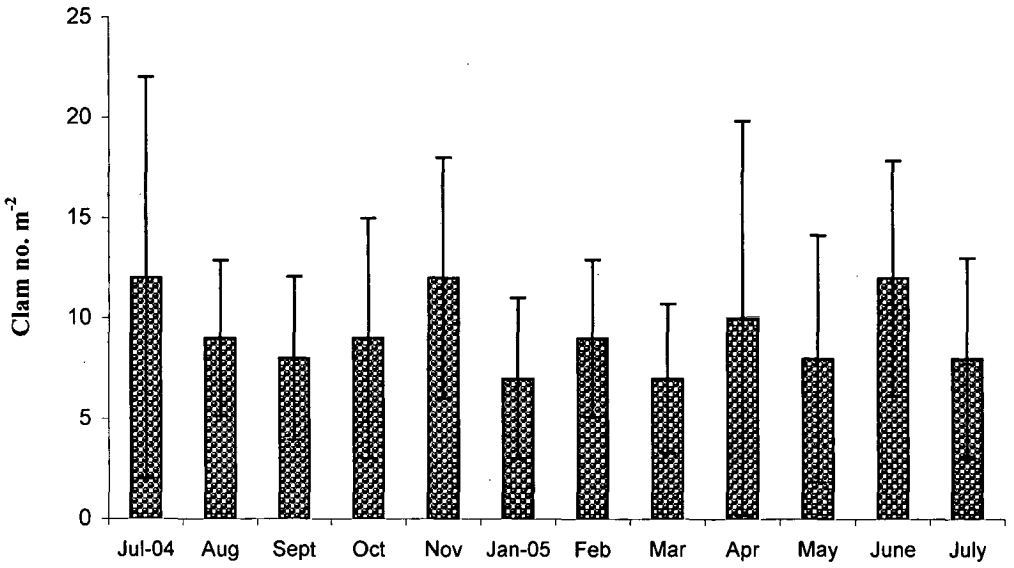


Fig. 5.3: Mean density of *P. erosa* at Chorao island

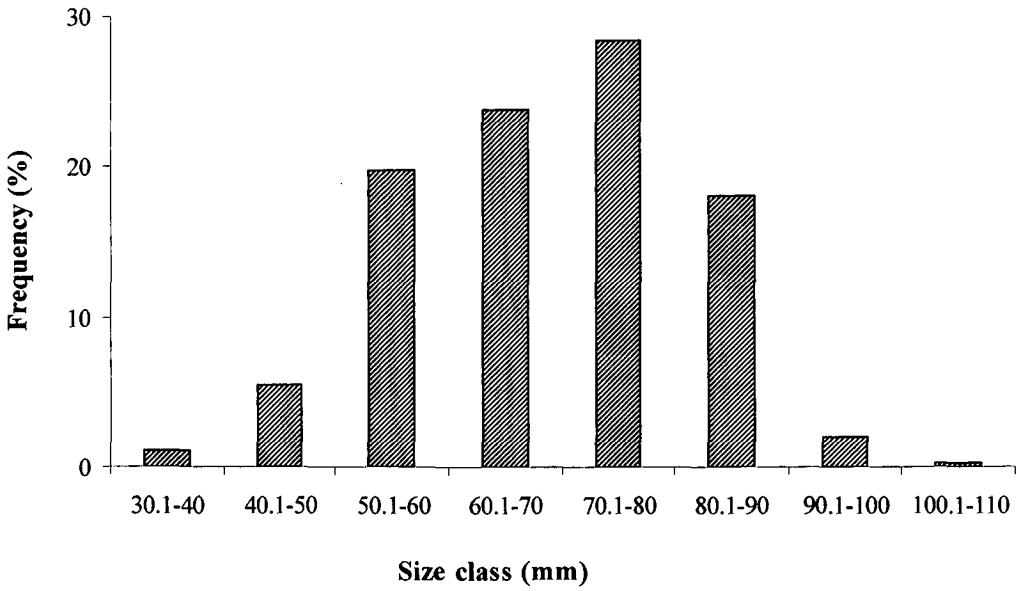


Fig. 5.4: Frequency of *P. erosa* in different size classes at Chorao island

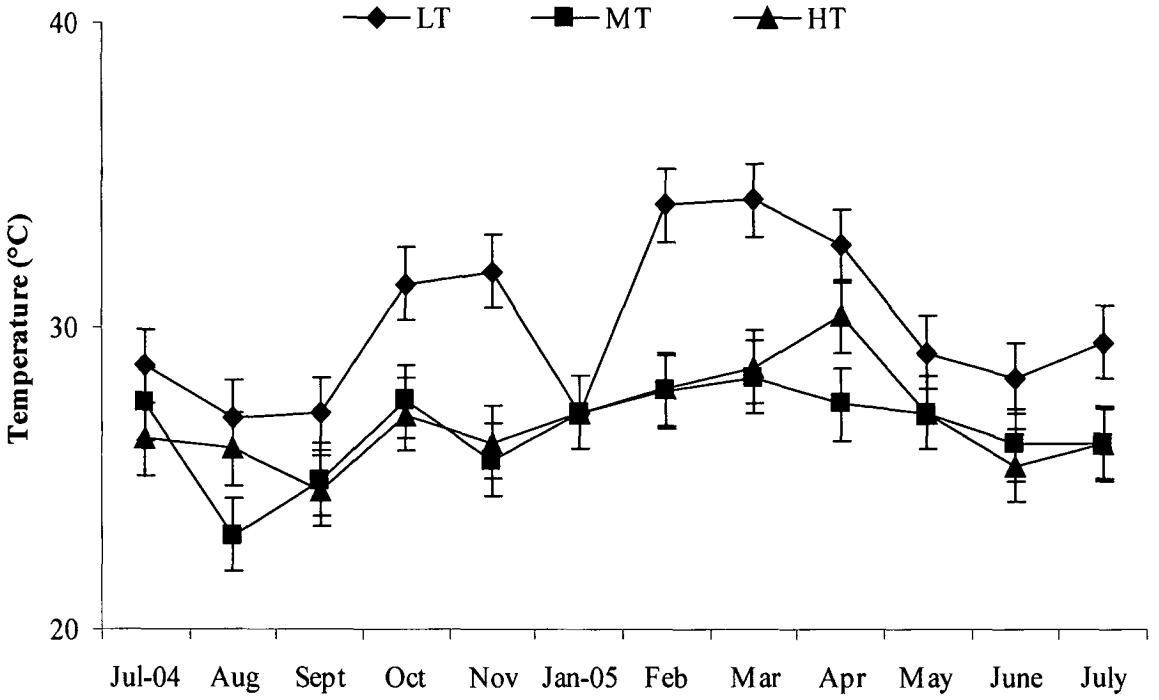


Fig.5.5: Monthly variation in temperature at different tide levels in Chorao island

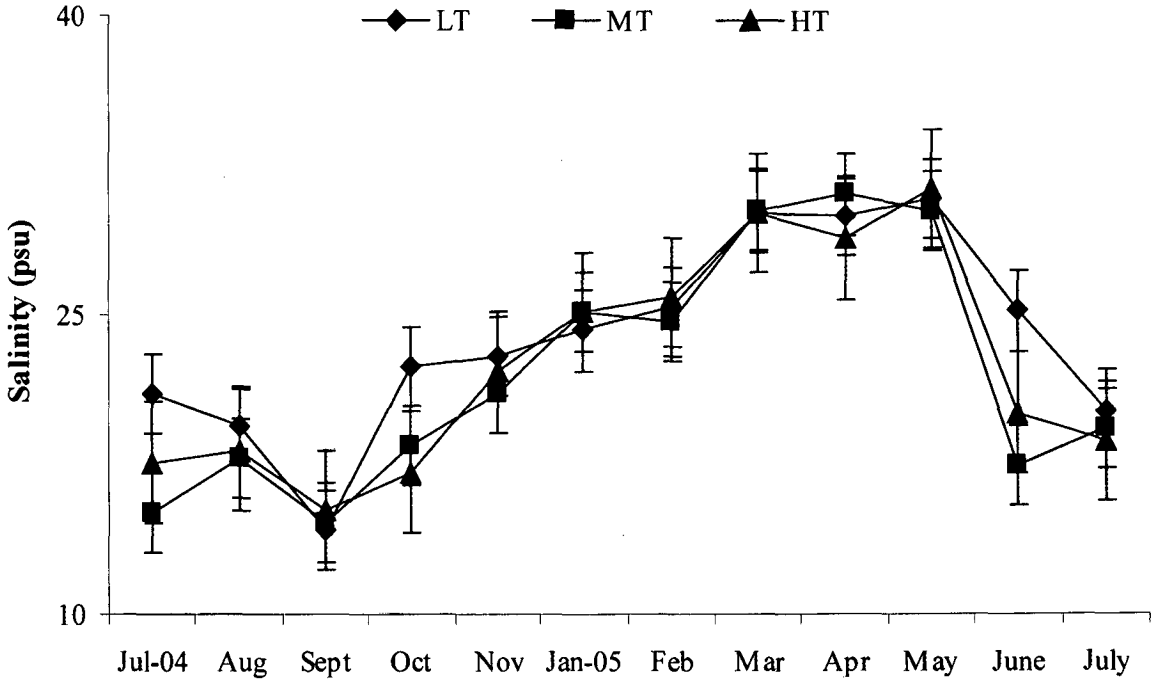


Fig. 5.6: Monthly variation in pore water salinity at different tide levels in Chorao island

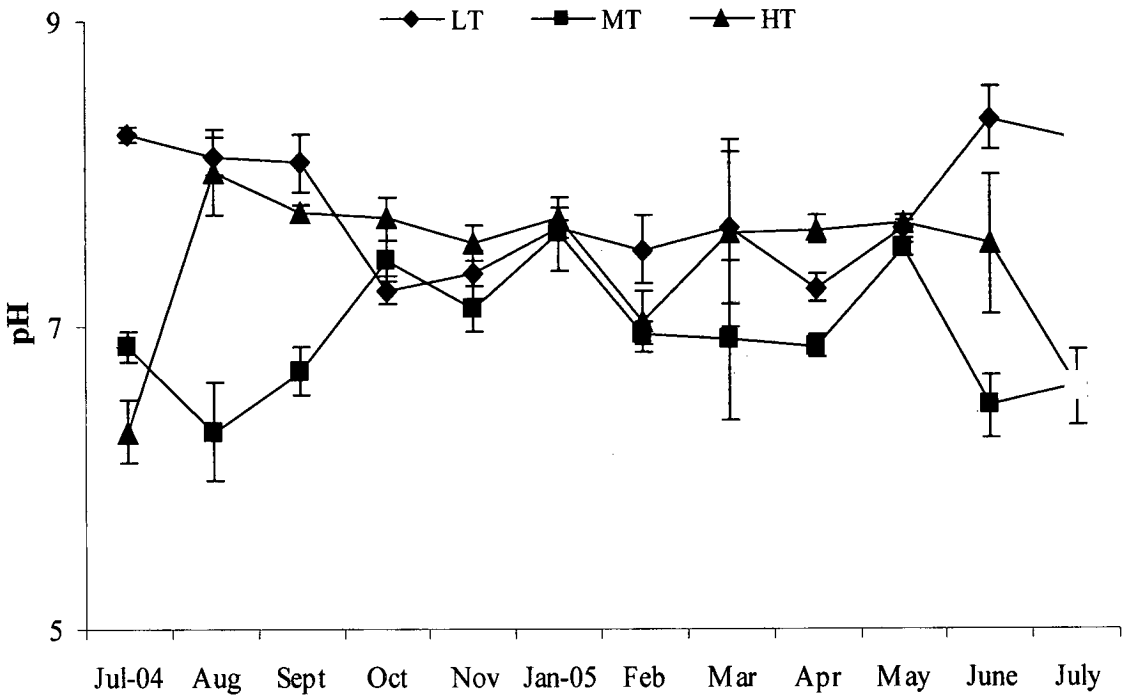


Fig. 5.7: Monthly variation in porewater pH at different tide levels in Chorao island

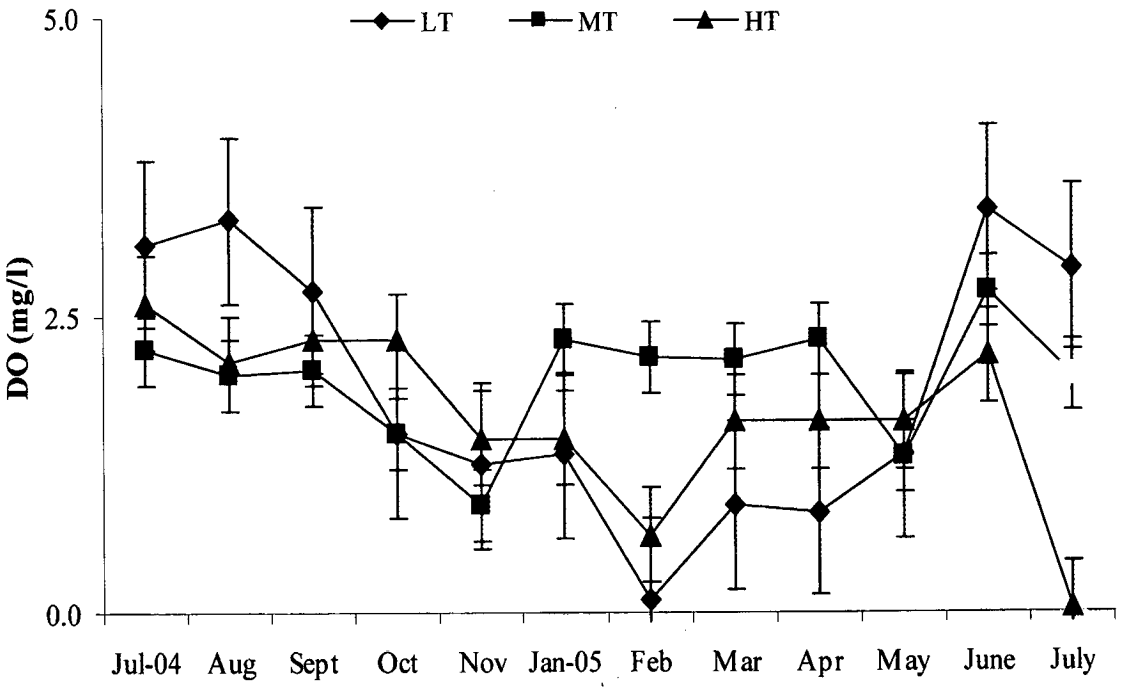


Fig. 5.8: Monthly variation in porewater DO at different tide levels in Chorao island

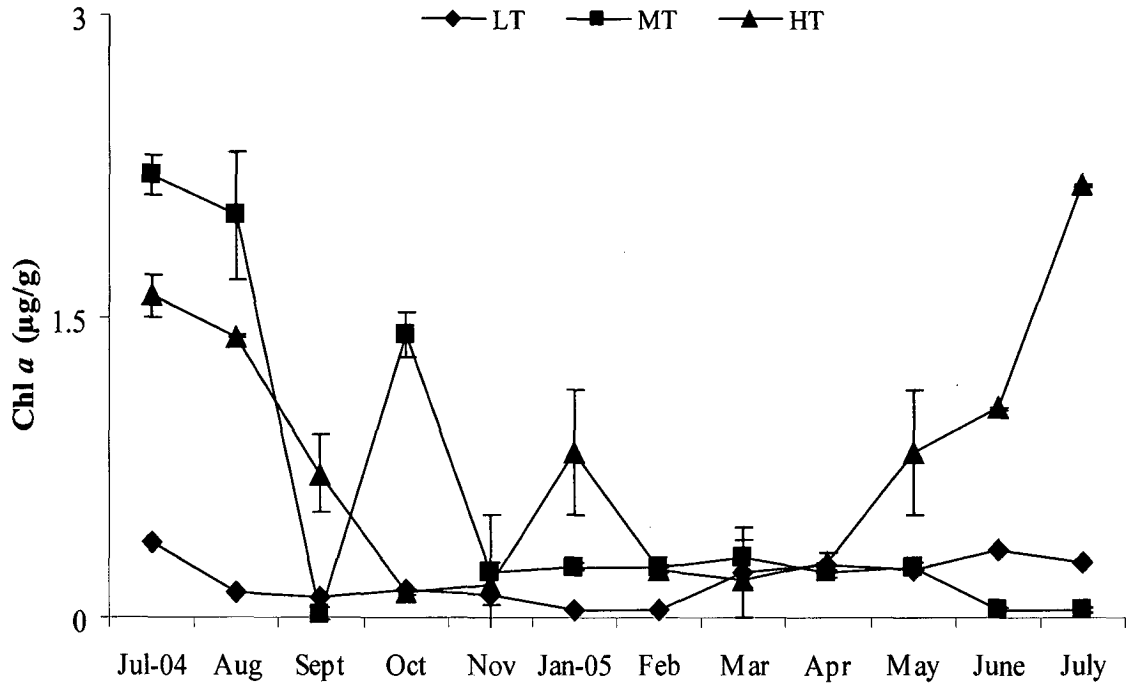


Fig. 5.9: Monthly variation in sediment Chl *a* at different tide levels in Chorao island

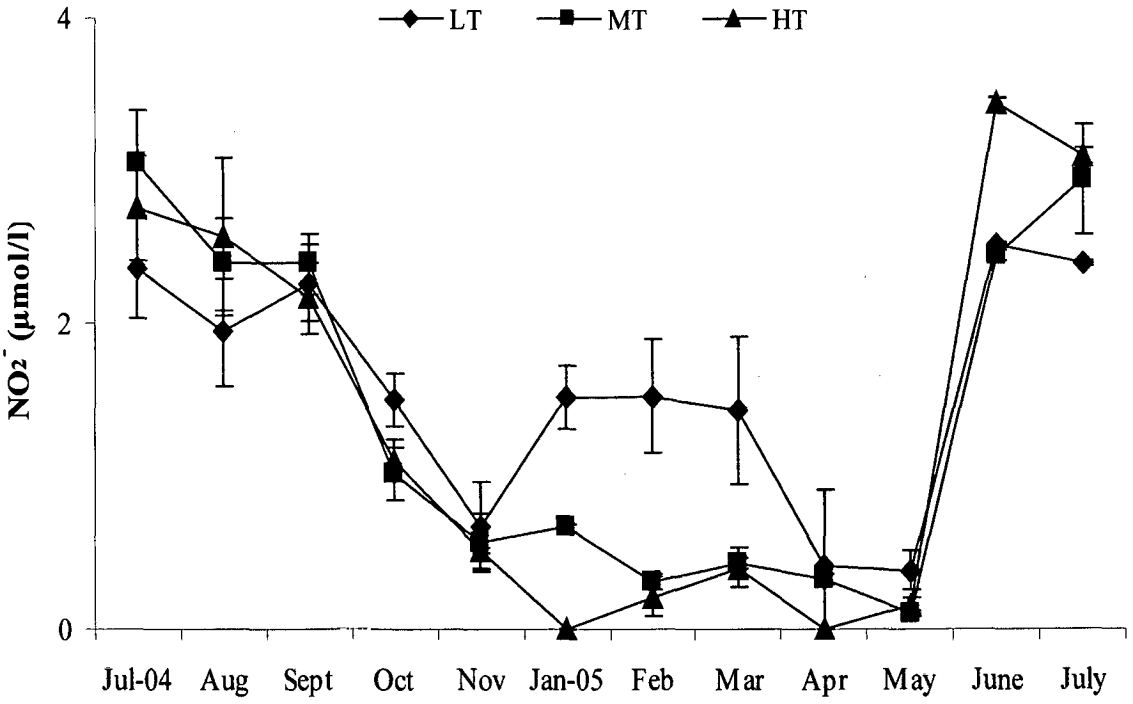


Fig. 5.10: Monthly variation in porewater nitrite at different tide levels in Chorao island

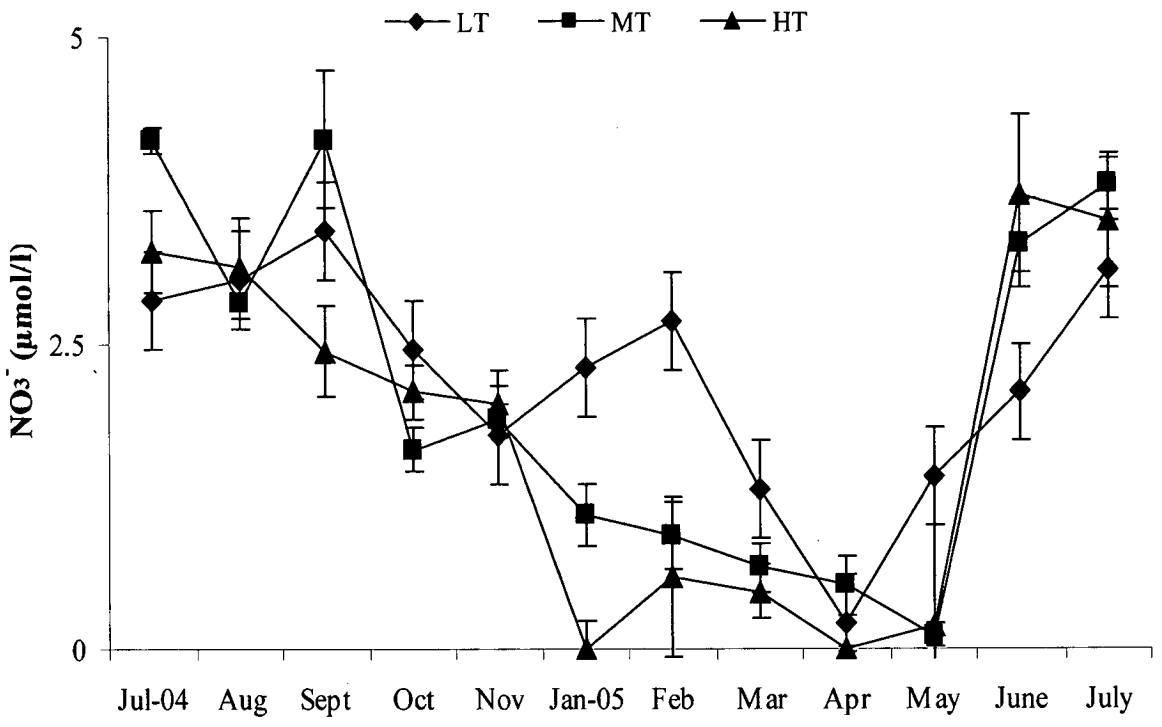


Fig. 5.11: Monthly variation in porewater nitrate at different tide levels in Chorao island

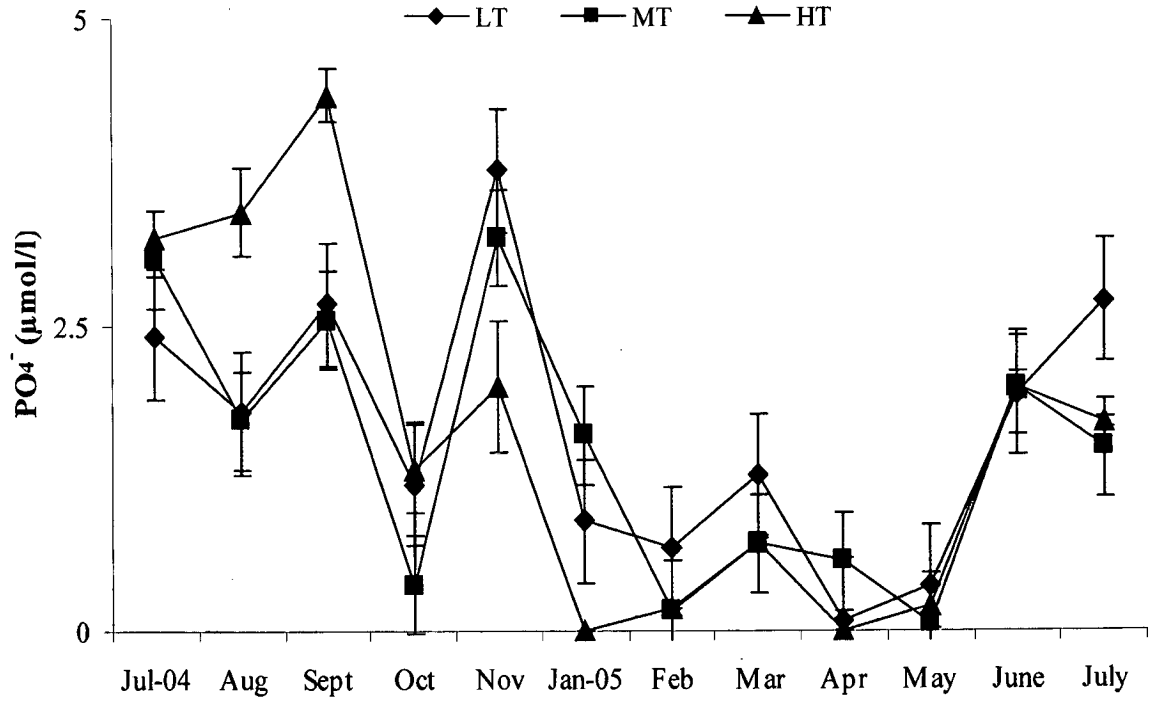


Fig. 5.12: Monthly variation in porewater phosphate at different tide levels in Chorao island

difference between tide levels (Table 5.6). High temperature was recorded at the low tide level than the mid- and high-tide area. The pH was more basic in the LT area compared to the HT area. However, as shown in figure 5.7, pH in most of the months was slightly on the acidic scale in the MT area.

Table 5.7 and 5.8 presents the best-fit model from regression analysis (statistically significant at $p < 0.05$) explaining the highest variation in abundance and biomass in terms of 3 environmental parameters. In the Chorao island, 70.5% of the total variation in abundance of *P. erosa* was explained by temperature, pH and salinity. The order of importance for the three-predictor variables for clam abundance was (1) temperature (β=-1.381, t=-4.462, p=0.002); (2) pH (β=-0.082, t=-3.647, p=0.007) and (3) salinity (β=0.867, t=2.623, p=0.031; Table 5.7).

Among the environmental variables studied, 77.5% of the total variability in the clam biomass was explained by the same three-predictor variables. The order of importance for the predictor variables for biomass was temperature (β=0.478, t=2.317, p=0.044) (2) pH (β=-0.354, t=2.322, p=0.046) and (3) salinity (β=0.426, t=2.043, p=0.045; Table 5.8). The variables temperature and pH both influences the abundance and biomass of *P. erosa* at Chorao island. Among the environmental parameters studied, however, temperature and salinity were the single best predictor variables for abundance and biomass respectively with temperature explaining 36.9% variability and salinity explaining 67.1% variability (Table 5.9). It can be generally noted that stations located in areas with high *Avicennia* mangroves, present high values of abundance and biomass. Thus, the hypothesis of higher biomass and abundance in areas of higher density of *Avicennia* could not be rejected.

Table 5.6: Results of ANOVA among tidal level on (a) Temperature and (b) pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
(a) Temperature					
Tidal level	90.15768	2	45.078	11.735	0.00014
Residual	126.7655	33	3.841		
(b) pH					
Tidal level	4.134	2	2.067	10.406	0.00031
Residual	6.555	33	0.198		

Table 5.7: Models from multiple linear regression analysis that best explain variation in *P. erosa* abundance

	B	S.E.	t	p
Constant	67.118	12.865	5.217	0.001
pH	-0.802	1.270	-3.647	0.007
Salinity	0.867	0.074	2.623	0.031
Temperature	-1.381	0.230	-4.462	0.002
Regression		F=9.748		0.005
R^2		0.705		

Table 5.8: Models from multiple linear regression analysis that best explain variation in *P. erosa* biomass

	B	S.E.	t	p
Constant	-5.525	2.362	-2.339	0.047
Chl *a*	0.426	0.069	2.043	0.075
pH	0.354	0.248	2.322	0.049
Temperature	0.478	0.043	2.317	0.049
Regression		F= 13.632		0.002
R^2		0.775		

Table 5.9: Models from stepwise multiple linear regression analysis that best explain variation in *P. erosa* abundance and biomass

	Predictor	B±S.E.	r^2	F	p
Abundance					
	Constant	22.156±4.932			0.001
	Temperature	0.653±0.178	0.369	7.427	0.021
Biomass					
	Constant	0.76±0.242			0.011
	Salinity	0.837±0.011	0.671	23.416	0.001

5.5 Discussion

P. erosa is a mangrove clam that shows spatial heterogeneity in its abundance. Along the low tide to the high tide level elevation, the mean density of clams varied from 0 to 9±3 individuals/m^2. The variation in temperature is coupled with the variation in the density of clams as well as the biomass. However, temperature may be the main important factor for the abundance of *P. erosa*, whereas the biomass is related to the food availability and intake, which is reflected in the coupling of biomass with salinity. The relative importance of each variable was different, depending whether abundance or biomass is considered. The relationship between the abundance and environmental characteristics indicates that the spatial heterogeneity in distribution of *P. erosa* can, in part, be explained by a relationship with salinity, pH and temperature.

Reduced salinities are known to depress physiological rates of feeding and respiration even though marine mollusks has the ability to control their metabolic activity at reduced salinity levels (Bayne et al., 1976). Regulation of respiration in declining oxygen tension decreases with decreasing salinity and increasing temperature. Maximum respiration occurs at moderate salinities and 30°C at all oxygen tension. The interaction of the two factors (temperature and salinity) with various bivalve processes can describe the potential habitat of a given animal (Dame, 1996). Though *P. erosa* can osmoregulate even in freshwater conditions (Morton and Chan, 1990), the abundance as well as biomass is shown to have a positive relationship with salinity. Higher salinities are conducive for this clam growth as it feeds on phytoplankton. *P. erosa* shows a positive relation with salinity. Being oligohaline, with a reduced ability to tolerate freshwater (Morton and Chan, 1990), with high salinity, a positive salinity-dependent pattern in the density of clams would be expected. As this is not the scenario in the distribution of salinity in the interstitial water with any significant difference between tidal levels, the spatial variation in the clam abundance appears to be more of the effect

of temperature. However, the occurrence of *P. erosa* definitely has a strong correlation with salinity, as they are limited only in the estuarine regions and are never found in the freshwater conditions. Among salinity and temperature, it is temperature which is the most important as studies have shown that bivalves can adapt to very low salinities when temperatures are optimum, except at abnormally elevated temperature (Yaroslavtseva and Sergeeva, 2006).

The increase in physical stress to marine organisms related to elevated tidal height has been well documented (Wolcott, 1973). By independently manipulating environmental parameters within tidal heights, it can be seen that temperature and food (chl *a*) have important influence on *P. erosa* survival and not tidal height per se. Specifically, temperature influences *P. erosa* by regulating its feeding rate. Decline in feeding rate and sometimes inhibition of feeding with elevated temperatures beyond the optimum level has been observed for many bivalves (Newell and Branch, 1980). High temperature (>30°C) observed at the low tide level compared to the mid and high tide level (which although are emersed for longer periods compared to the low tide region, are shaded by the mangrove trees present in these areas) are thus stressful to the clams. However, being a filter feeder, *P. erosa* would have benefited being in the mid-tide level, which is shaded as in the case of high tide level and is more frequently inundated than the high tide region. The lack of clams in the mid-tide region, suggests that the physical conditions at mid tide, despite shading, do not allow *P. erosa* population to develop. This may be due to the more acidic pH conditions existing there compared to the low- and high-tide region. Acute acidific pH disturbs the rhythmic valve activity of mussels by changing the normal pattern of successive active/inactive (open/closed) periods (Pynnonen and Huebner, 1995), which implies that, feeding in bivalves will be affected by changes in pH. The acidic pH of the sediments also affects the clam by dissolution of the shell (Isaji, 1995). The corrosion of the umbonal beaks in *P. erosa* is very prominent as observed in this study, as well as reported elsewhere (Morton, 1976). The shell being the most

important structure of this clam in thriving in the harsh conditions of mangroves, *P. erosa* will be at a great risk, if settled in an area with low pH.

As expected, the biomass of *P. erosa* was related to the temperature, pH and chl *a* content. *P. erosa* is a filter feeder and it is seen that the clam feeds mainly on diatoms (Table 4.3 and Plate 4.1). The growth of *P. erosa* in terms of weight is directly dependent on chlorophyll concentration in the estuarine water (Fig 4.14 and Fig 4.15). Although the occurrence of high pH in marine waters may not be uncommon, pH has generally not been considered an important determinant of pelagic processes and hence related work is sparse. However, a few studies that have been carried out indicate that pH indeed may have an effect on phytoplankton growth and that this effect drives species succession (e.g. Schmidt and Hansen, 2001). The work of Schmidt and Hansen (2001) suggested that marine phytoplankton cultures grown in a standard phytoplankton growth medium are limited by high pH rather than inorganic nutrients such as nitrogen and phosphorus. Hence, pH must be one of the important factors affecting phytoplankton growth.

The availability of primary production is limited by the solubility of Fe (III) in seawater. At decreasing pH level, the solubility of Fe (III) increases (Liu and Millero, 2002). Acidification of the water could therefore potentially make iron more available to phytoplankton, which in turn could increase the growth rates. However, the biomass of *P. erosa* will be ultimately determined by the amount of food taken inside and as discussed earlier, the temperature again governs that. Dame (1996) suggests that, temperature not only limits the spatial but is also a major controlling factor in many physiological rate processes e.g. feeding and growth. Daniel and Robertson (1990) related temporal differences in epibenthos of mangrove to hydrographic changes with the wet- and dry season.

Given that, phytoplankton is the main food of *P. erosa* (Morton, 1976), the chlorophyll content of the water should have been the main predictor. However, this is not the case and when it comes to the single best explanatory variable for biomass, it is salinity. Food availability is obviously an important factor influencing clam growth. The primary diet of *P. erosa* consists of a wide range of phytoplankton, diatoms as discussed in chapter 4. Menge et al. (1997) found striking differences in the growth rates of the mussel *Mytilus Californianus* to be strongly related to the persistent differences between the sites in food concentration (indexed by chl *a* measurements). Sanford and Menge (2001) found that growth of the barnacle *Balanus glandula* was correlated with high levels of phytoplankton. However, not all studies support food availability as a major factor influencing growth. Philiips (2007) found the differences in mussel growth to be completely unrelated to any corresponding variability in food supply. It suggest that, though the food is ultimately responsible for the biomass, just the availability of food only does not ensure its intake but the physiological condition of the clam ultimately determines feeding. Salinity explained 67.1% of the total variance observed for biomass. Salinity is regarded as an important factor affecting phytoplankton growth and distribution (Day et al., 1989). Salinity has a profound effect on the phytoplankton production. Though the physical factor irradiance and the chemical factors major nutrients are known to be the primary factors associated with phytoplankton growth (Leland and Berkas, 1998), experimental studies have suggested that nutrient limitation of phytoplankton may change depending on salinity changes (Wurtsbaugh, 2005).

Studies have shown that, at high salinities, diatoms and green algae dominate, but at low salinities, nitrogen-fixing cyanobacterium dominates (Wurtsbaugh, 2005). The feeding as well as respiration rates of bivalves are depressed at low salinity, (Dame, 1996). Since, *P. erosa* is a suspension feeder, feeding on phytoplankton, the production as well as intake of which is based on salinity, must be the reason for salinity to be the single most predictor for biomass of *P. erosa.*

However, there is an important amount of variance (at least 20% for abundance and 30% for biomass) that remained unexplained by the variables considered. This can be due to other variables not considered in this study or to behavioral plasticity under stable conditions (Miller and Curan, 2001). Moreover, sediment composition is another physical parameter that seems to play a role in spatial distribution of bivalves (Rhoads and Young, 1970), an aspect not evaluated in this study. Generally, deposit-feeding bivalves are prevalent in finer sediments, and filter-feeding bivalves are common to coarser sediments (Dame, 1996). Although, in some bivalve spatial, variation is due to local hydrodynamics and food availability, some is due to specific species ability to live on the surface of changing sediments or burrow into the sediments. Because sediments are often in particle size gradients; it is not unexpected to find identifiable zones inhabited by different communities of bivalves in intertidal sands and muds (Peterson, 1991).

It has long been recognized that, benthic suspension feeders and deposit feeders exhibit reciprocal spatial distributions. In environments, where one type of bivalve is abundant and diverse, the other is reduced. Rhoads and Young (1970) found that deposit feeders, especially, bivalves, intensively rework surface sediments and produce the following changes: (1) uncompacted sediment consisting of fecal pellets and reworked material of semiconsolidated mud, (2) a surface of biogenic sand size particles of low bulk density, and (3) sediments of high water content. These modifications of the sediment affect the physical stability of the bottom by increasing interface roughness and lowering critical erosion velocity. This physical instability of the surface sediments is proposed to be stressful to suspension feeding bivalves by: (1) clogging filtering structures (2) resuspending and burying newly settled larvae and (3) discouraging the settlement of suspension feeding larvae. Rhoads and Young (1970) further argue that this explanation is limited to areas of high primary production, where food is not limiting to bivalve filter feeders (is applicable to the present study area) because

ultimately it is the availability of food for benthic suspension feeders that may be limiting their success.

Specifically, may be a physical site characteristic – the availability of compact sediment in the high intertidal allows *P. erosa* to persist despite otherwise high potential levels of starvation whereas in the low tide area, the presence of uncompacted sediment could be the main reason, why *P. erosa* despite of settlement in the earlier stages does not inhabit it as an adult. In the present study, since food is not limiting, the above reasons seem to be the probable causes of *P. erosa* to be not found in the low tide region. Moreover, *P. erosa* were also not found at the mid-tide level, though it is characterized by the presence of mangrove trees.

Nevertheless, it is interesting to note that though, the mid tide region is similar to the high tide region with mangrove vegetation as compared to the low tide region which is without any mangrove vegetation, *P. erosa* are found, only in the high tide region near *Aviccenia* sp. This implies the importance of taking into account factors related to *Avicennia* sp. in studying *P. erosa* and must look beyond the usual physico-chemical and biological parameters and acknowledge this relationship in habitat preference.

CHAPTER 6

REPRODUCTION IN *P.EROSA*

6.1 Introduction

The process of reproduction is the generation of new individuals that have the potential to become members of the population. Reproduction is integrated into the life cycle of benthic organisms and is one of the few instances where the planktonic gamete and larval stages are linked to the post-settlement juvenile and adult stages. Reproductive cycles of marine bivalves comprise a gametogenic phase, spawning and larval development and growth. The cycle may be annual, semiannual, or continuous, depending upon the species and location (Sastry, 1979). Studying the reproductive cycle is essential to establish the time of spawning in any species. This, in turn, represents the starting point for recruitment, age and growth studies, which provide basic information to manage a species.

The reproductive strategies of an organism play a major role in the dynamics and the biogeography and continuity of a species (Ramirez-Llodra, 2002). Reproductive patterns such as production and release of gametes, fecundity and external factors controlling breeding activity have a crucial role in the continuity of populations and their adaptations to the environment (Litulo, 2005). Thus, the knowledge of reproductive and spawning behavior is fundamental in understanding the recruitment and population dynamics of marine species. The two most important strategies oriented towards the management of the marine ecosystem implies a more rational exploitation of the natural resources and aquaculture as an aid to increase the production of commercially important species. A thorough knowledge of the reproductive cycle provides; (1) the establishments of close seasons in keeping with the spawning periods; (2) optimization of the breeding conditions aimed towards the purpose of expanding sustained development and (3) the genetic selection of varieties with higher reproductive efficiency and more resistant to pathologies and stress related to reproduction (Remacha-Trivino and Anadon, 2006).

Given the extensive use of the mangrove clam in the diet of many tropical islanders (Muller, 2003), the potential exists to exploit this clam commercially. In India, this species could possibly be of commercial value even though relatively very few studies have undertaken to assess their economic potential (Morton, 1976; Meehan, 1982; Ingole et al., 1994 and 2002). An understanding of their reproductive biology is an important prerequisite for assessing the regeneration capacities of natural stocks and interpreting growth patterns. The reproduction of *P. erosa* has never been the subject of any comprehensive studies, unlike of other species in this genus, whose reproductive cycle was investigated (*P. radiata, P. caroliniana, P. solida*). No studies on the reproductive biology of *P. erosa* deal only with some preliminary descriptions of the spawning season (Ingole et al., 2004; Gimmin et al., 2004) and reproductive strategy (Morton, 1985) but there are no studies dealing with the reproductive cycle of this species from Indian waters.

Determining seasonal patterns of gametogenic development and spawning of any marine bivalve is essential for developing management strategies for potential fisheries. Specifically, this knowledge may be critical for managing those species that have undergone substantial decline even without knowing their biology. The underlying factors that affect reproductive success in *P. erosa* and consequently the potential role of reproductive factors in the continued supply of clams are poorly understood. Detailed knowledge of these factors is required for the effective management of this important marine resource. In view of the fact that reproduction is a determining factor of the population dynamics in bivalves, the objective of this study was to present the main features of the reproductive biology of *P. erosa* population at Chorao island, Goa. The description is based on microscopic examination of the gonads of both sexes. Quantitative analysis of oocyte diameter and number was also used to verify the patterns observed in the microscopic stagings for female clams.

6.2 Materials and Methods

Clams were collected monthly over a 12 month period from July 2004 to July 2005 for the study of reproductive biology. Size of the clams was not restricted for a standard size and specimens representing all the size classes were analyzed. Size classes were based on 10 mm interval. A total of 85 individuals were used for fecundity studies. After collection, the clams were brought to the laboratory, washed of all the mud and towel dried. Immediately, the clams were opened and sexes were determined based on the colour of gonads. The gametogenic development of *P. erosa*, was investigated by microscopic observation of the gonad. The males to females ratio was determined from the colour of the gonad and the Gonadosomatic Index (GSI) was calculated following (Stead et al., 2002):

$$GSI = \frac{\text{Gonad weight (g)}}{\text{Total body weight}} \times 100$$

Clams were deemed sexually mature if gametes were present. Gonads from both male and female clams were placed into five qualitative categories, namely 1 = early active, 2 = late active, 3 = ripe, 4 = partially spawned and 5 = spent, (adapted from Shaw, 1964; Ropes, 1968; Morton, 1985 and Peredo et al., 1987). The gonadal state of each clam was described as one of the five stages based on the most dominant stage present in the clam samples analyzed. Each gonad was examined under the microscope and assigned to one of the above stages.

For female clams, monthly mean oocyte diameters and monthly mean number of eggs were determined microscopically. For fecundity study, three portions (0.01 g) of the ovary from the anterior, posterior and the middle region were taken. A sample of 100 oocytes was measured for diameters, but oocytes present were counted from all the three regions of the gonad. An analysis of variance was used to compare the number and diameter of oocytes sampled during different months.

Quantitative analyses were not used for male mud clams. Spawning activity was recognized as recently spawned gonads containing much water, decreases in gonad indices, and evidence of spawning and recovery from microscopic observation.

6.3 Results

Sexes are separate in *P. erosa* with no incidence of hermaphroditism at Chorao island. Even though, *P. erosa* is a dioecious species, there is no external sexual dimorphism and sex can be determined only in adult stage. Sex is only determined by the appearance and colour of the gonads. When fresh the female gonads are black in colour and male creamish white (Plate 6.1, a and b). The sex ratio in *P.erosa* does not differ significantly 1:1 (χ=2.1, df=1, p=0.1743). The gonad is made up of interconnected gonadal alveoli and surrounds the digestive gland and the gut, infiltrating the muscular tissue of the foot (Plate 6.2).

6.3.1 Description of the gonadic phases:

Different gametogenic stages observed are illustrated in Plate 6.3 and can be explained as follows:

Early active stage (Plate 6.3.1A and 6.3.2A):
Gonads at this stage contain abundant, round alveoli, with very little interalveolar space. Oogonia and spermatogonia line the inner wall of follicles. Follicles show irregular forms and almost empty lumens. The spermatozoa become arranged with tails pointing toward the center of the lumen.

Late active stage (Plate 6.3.1B and 6.3.2B):
The follicles are increased in size with narrow lumina. In females, prominent oocytes can be seen attached to the inside of the follicle wall and in some

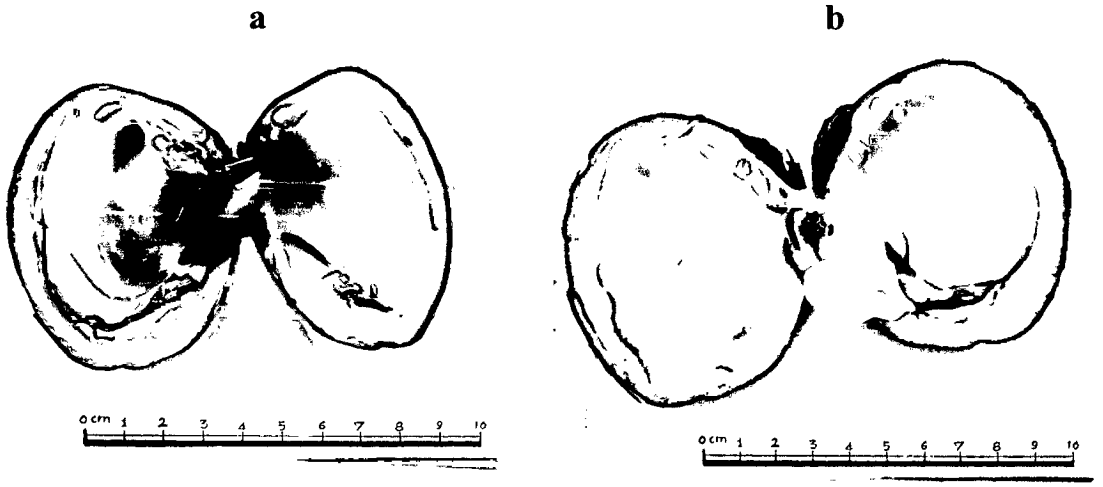
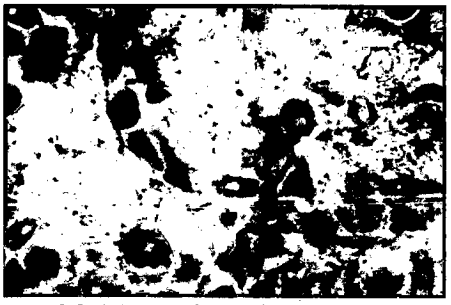


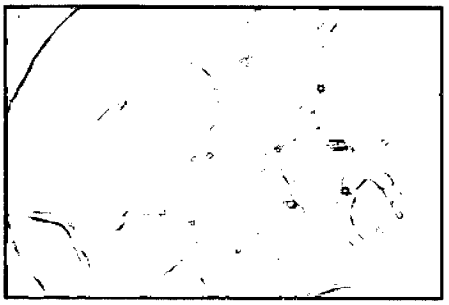
Plate 6.1: The female and male *P. erosa* with mature gonads

Plate 6.2: Position of gonad in *P. erosa*

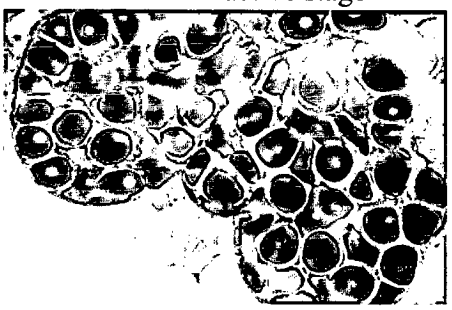
FEMALE



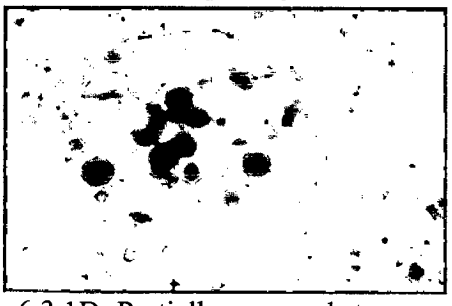
6.3.1A: Early active stage



6.3.1B: Late active stage



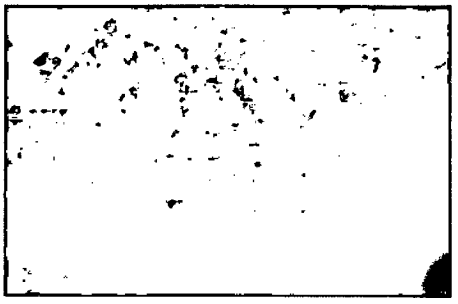
6.3.1C: Ripe stage



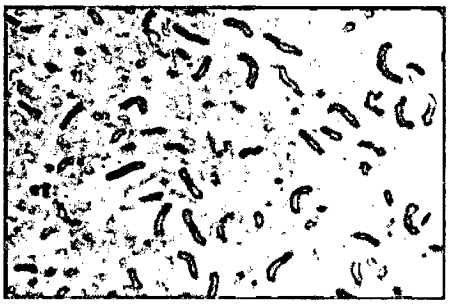
6.3.1D: Partially spawned stage

6.3.1E: Spent stage

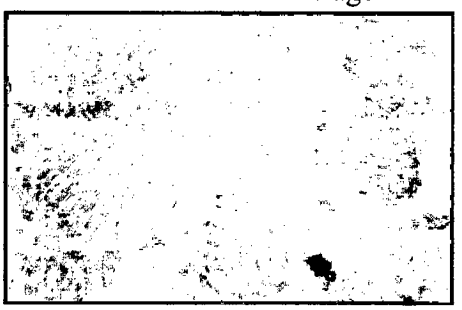
MALE



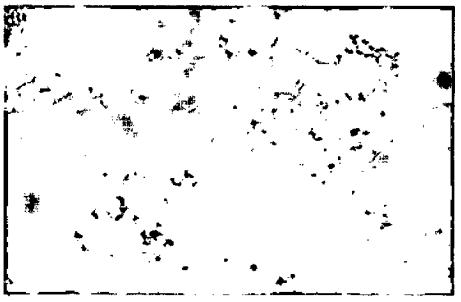
6.3.2A: Early active stage



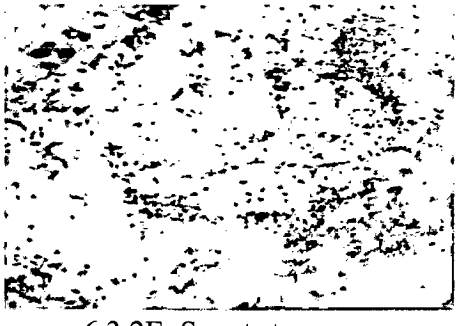
6.3.2B: Late active stage



6.3.2C: Ripe stage



6.3.2D: Partially spawned stage



6.3.2E: Spent stage

Plate 6.3: Maturity stages observed in female and male *P. erosa*
All plates are to the scale bar (250 µm) except 6.3.1B (50 µm)

pedunclate oocytes were observed attached to the wall. In males, spermatozoa with some spermatids are in dense packs.

Ripe stage (Plate 6.3.1C and 6.3.2C):
In both males and females the follicles have increased in size. Fully-grown mature oocytes that have reached their maximum size are spherical and unattached to the follicle packed inside the lumen. The spermatozoa form dense masses occupying almost all the follicles, often with tails pointing towards the lumen. A close view of mature oocytes and sperms is given in Plate 6.3.1Ca and Plate 6.3.1Cb.

Partially spawned stage (Plate 6.3.1D and 6.3.2D):
There is noticeable decrease in the number of oocytes and the spermatozoa are less densely packed. Empty spaces are observed in the lumen due to gamete release. The number of oocytes and area covered by spermatozoa as well as the empty spaces in the lumen depend on the stage of spawning. Few oogonia and spermatogonia could be present and continuing their development. This stage is difficult to distinguish from the early active stage, the only difference lying in the somewhat disorganized state of the spermatocyte and spermatid and oogonia and the irregular shape of the alveoli due to their partial contraction.

Spent stage (Plate 6.3.1E and 6.3.2E):
Follicles small with thickened walls. In males, some unspent gametes may be present in the follicle and in females follicles may be empty or may contain very few large unspent ova or mature oocytes.

6.3.2 Reproductive cycle

The gametogenic development in *P. erosa*, monitored for one-year period was synchronous between the sexes (Fig 6.1), so only a combined reproductive cycle is described. Relative frequencies of the maturity stages for *P. erosa* at Chorao

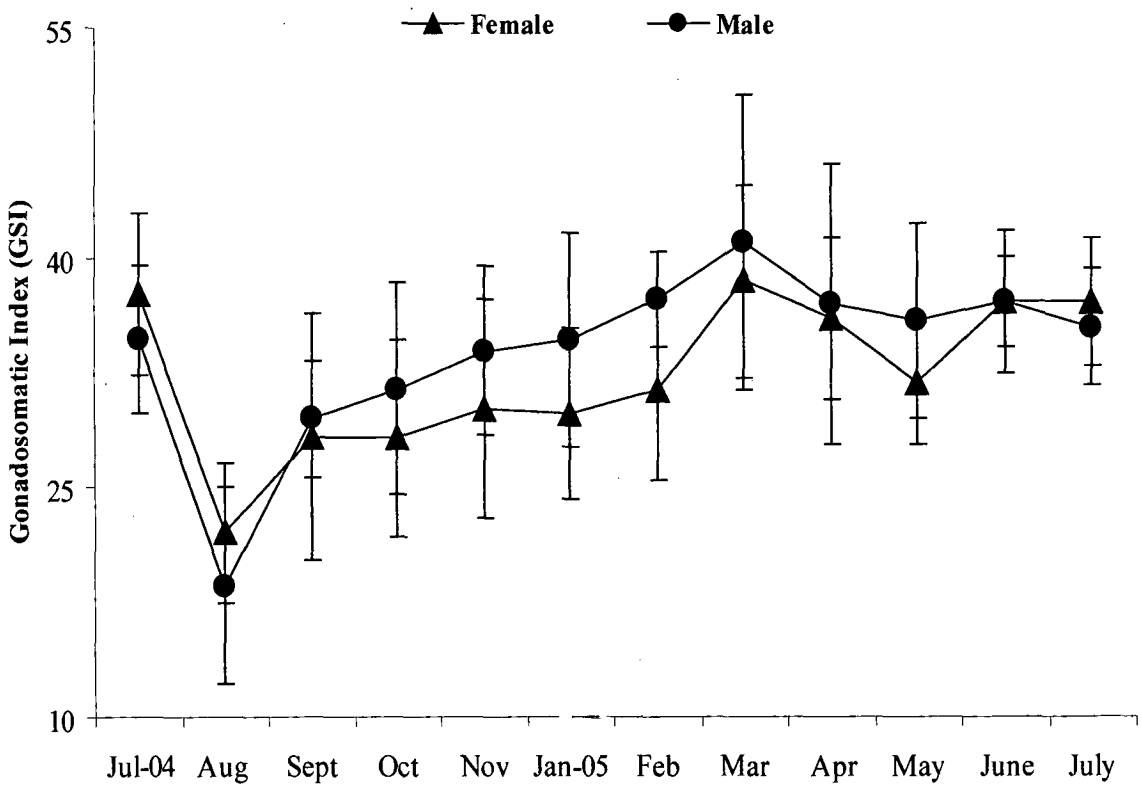


Fig.6.1: Monthly variation in the Gonadosomatic Index (GSI) of male and female *P. erosa* at Chorao island

Plate 6.3.1Ca: Close view of ripe sperms in *P. erosa*

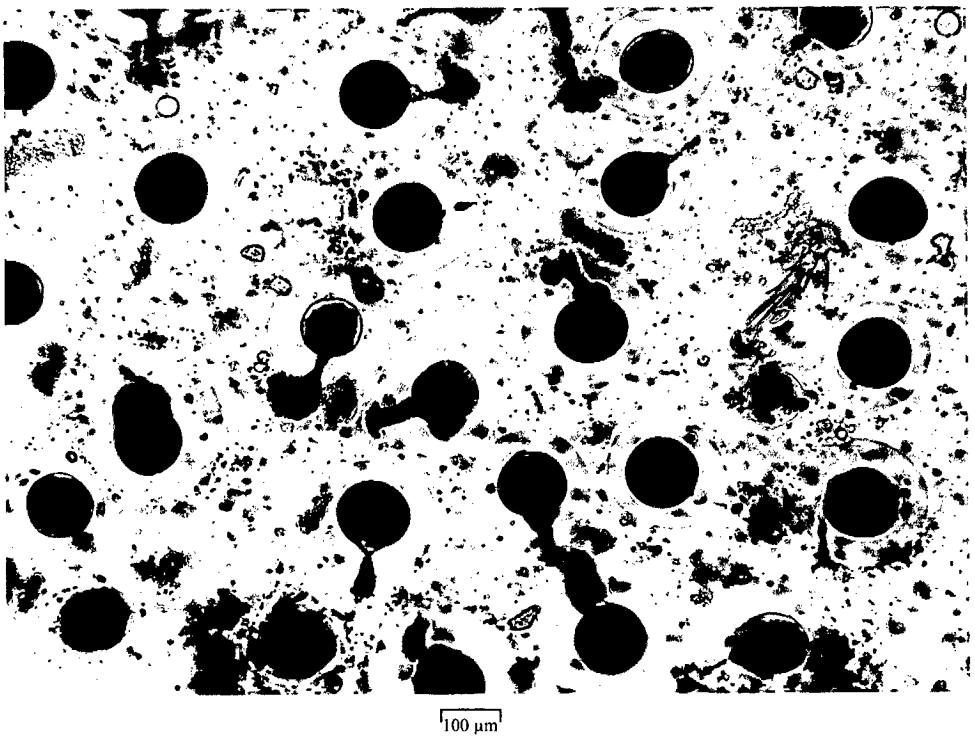


Plate 6.3.1Cb: Close view of ripe eggs in *P. erosa*

Island are illustrated in fig.6.2. Although, gametogenesis started as early as October and the clams developed gametes, the gonads of virtually all specimens were in an early active stage (Fig. 6.2). Active maturation commenced in the month of Jan with advanced gametogenesis, and gametes matured quickly so that Mar-Apr found mature gametes with majority of the clams in the ripe stage (Fig 6.2). During Mar to July, the gonads were generally maturing, and the ripe/mature gonads first became prevalent in May with 90% ripe stage. An approximately equal number maturing with a few partially spent stages was observed during June and July. Spermatogenesis and oogenesis appears to continue to some extent through the breeding season in parallel to spawning. From Aug until Sept, the majority of the gonads were spent, the follicle progressively occurring with fewer and fewer mature gametes. Spawning occurred from Aug to Sept. A small percentage of partially spent clams appeared in July, when water temperatures were at their lowest (Fig. 6.2), although the majority of spawning occurred in Aug – Sept with a large percentage (17-76%) of clams either partially or completely spent.

The distinction between the matured phase and the phase of maturity is not very clear because, with very few exceptions, a variable percentage of individuals in each of the five stages were found from Apr through Sept (Fig 6.2). During this period, spawning thus occurs successively in a certain number of individuals. Two instances of more massive spawning were recorded in the month of Aug and Sept. It was seen that partial spawning is taking place in the population during the period preceding massive spawning. From June onwards, the *P. erosa* population at Chorao island is thus characterized by nearly continuous partial spawning, though only in Aug and Sept does spawning occur simultaneously in a large number of individuals. As shown in Plate 6.3.1D, significant numbers of mature oocytes were in the interior of the alveoli, indicating that spawning was only partial.

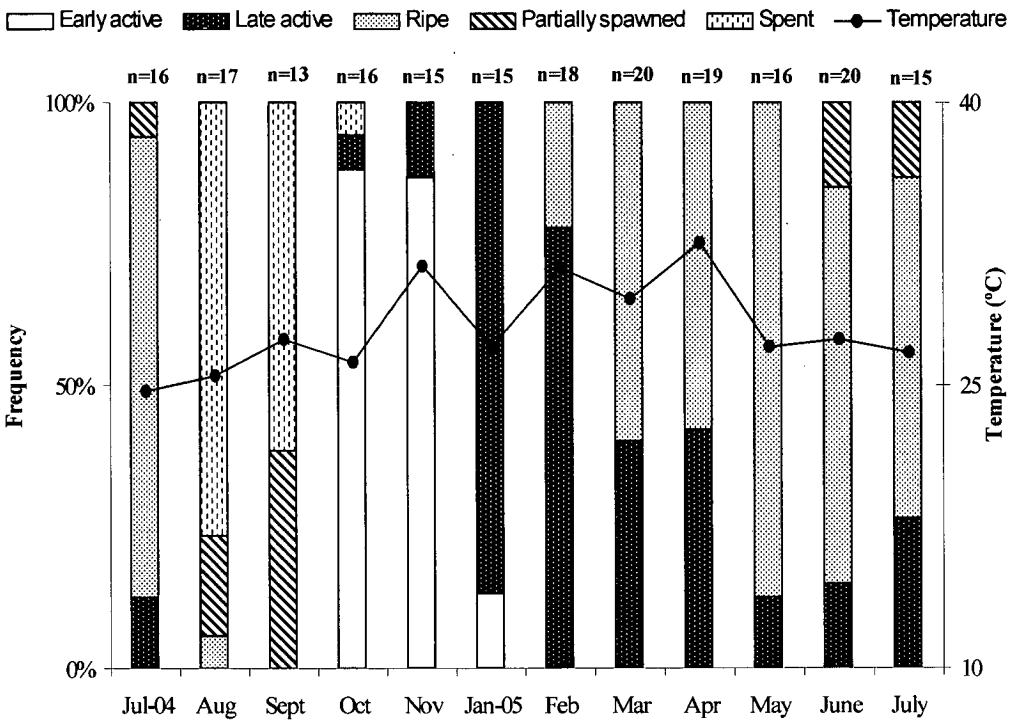


Fig. 6.2: Relative frequency of maturity stages of *P. erosa* and monthly variation in estuarine water temperature

As depicted in fig 6.3, average GSI values were lower from Oct to Jan and then increased to new maxima in April. A slight drop occurred in May, with low and stable variation in gonad weights, leading to minimum values in August (22.1) and Sept (24.0). After this, there was an increase in the number of individuals with ripe gonads, which is reflected in the GSI values. This increase continued with minor variations until Aug 2004, when there is a sudden fall in the percentage of ripe specimens. There is a rapid maturation of gonads in these clams between Jan and Apr, which was further confirmed by the high GSI values observed for these months with the peak value of 39.4 in April (Fig. 6.3). Massive spawning between Aug and Sept followed rapid decline in GSI. The spent stage dominated in Aug and Sept while start of gametogenesis/early active stage dominated during Oct to Nov. From the minimum GSI values a rapid rebuilding was seen between Jan to Apr, as the gonad indices and the ripe stages increased to the maximum of the annual cycle. With the exception of Nov, the total gonad weight was consistently higher at Chorao Island (Fig. 6.4). These two periods closely correspond with periods of maximum increase in dry tissue weight in summers and of decrease in tissue weights between Aug and Sept (Fig 6.5), the latter decrease being accompanied by a uptake of water into the tissues as the gonad regresses leading to maximum values of water content (Fig 6.6).

Estimated fecundity values for *P. erosa*, ranged from 31,85,230 to 44,16,954 oocytes recorded in clams between 68.8 to 58.53 mm shell length with a mean value of 12,88,6645±1, 22, 92,077 SD (Fig 6.7). The oocyte density peaked from minimum 31, 85,230 oocytes per female in Aug to a maximum of 30,398,841 oocytes per female in May 05. The values decreased again in the following months. The temporal pattern of oocyte density and oocyte diameter (Fig 6.8), closely follow the events of the cycle of maturation and spawning described above. An analysis of variance showed significant difference in egg number ($F= 3.886$, $df=83$, $p<0.001$) as well as egg diameter ($F= 103.8$, $df=1199$, $p<0.001$) between different months.

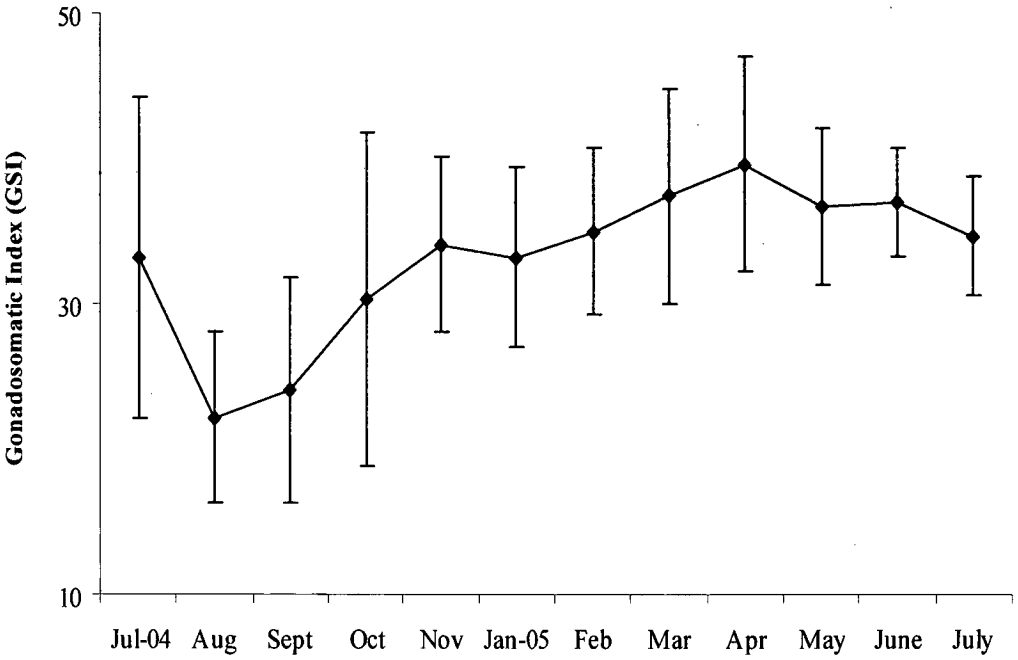


Fig. 6.3: Monthly variation in the Gonadosomatic Index of *P. erosa* combined for both sexes

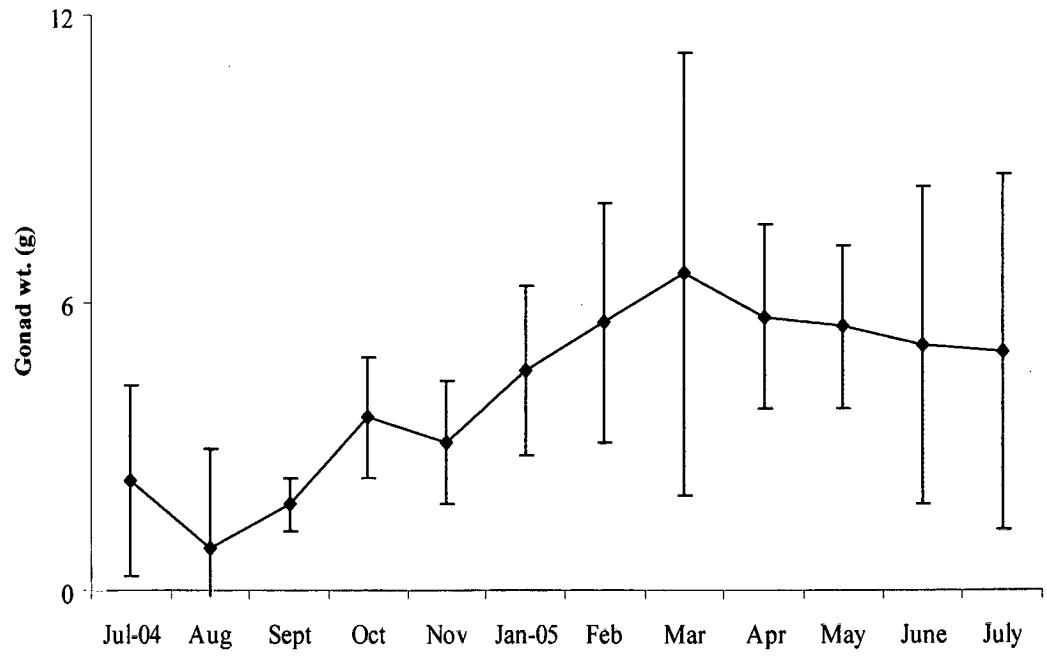


Fig. 6.4: Monthly variation in gonad weight of *P. erosa*

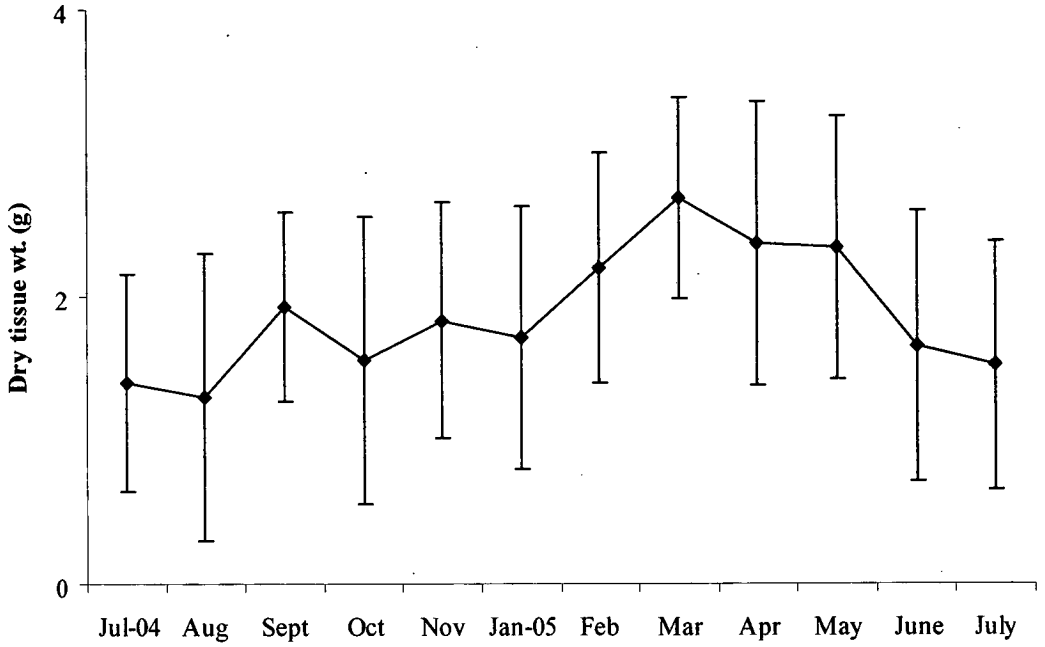


Fig. 6.5: Monthly variation in dry weight (soft tissue) of *P. erosa*

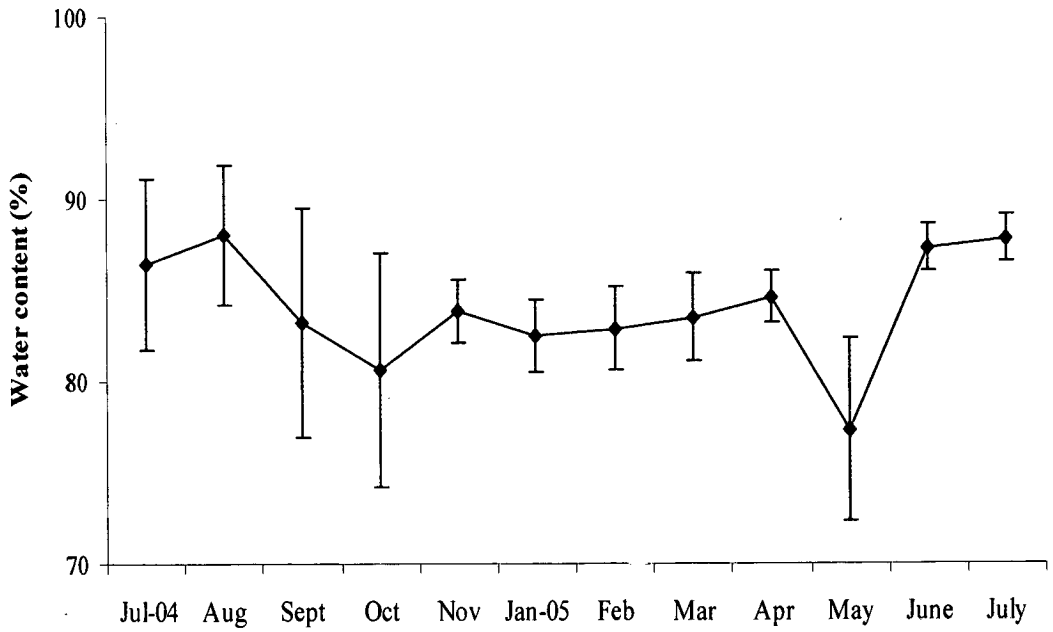


Fig. 6.6: Monthy variation in the water content (soft tissue) of *P. erosa*

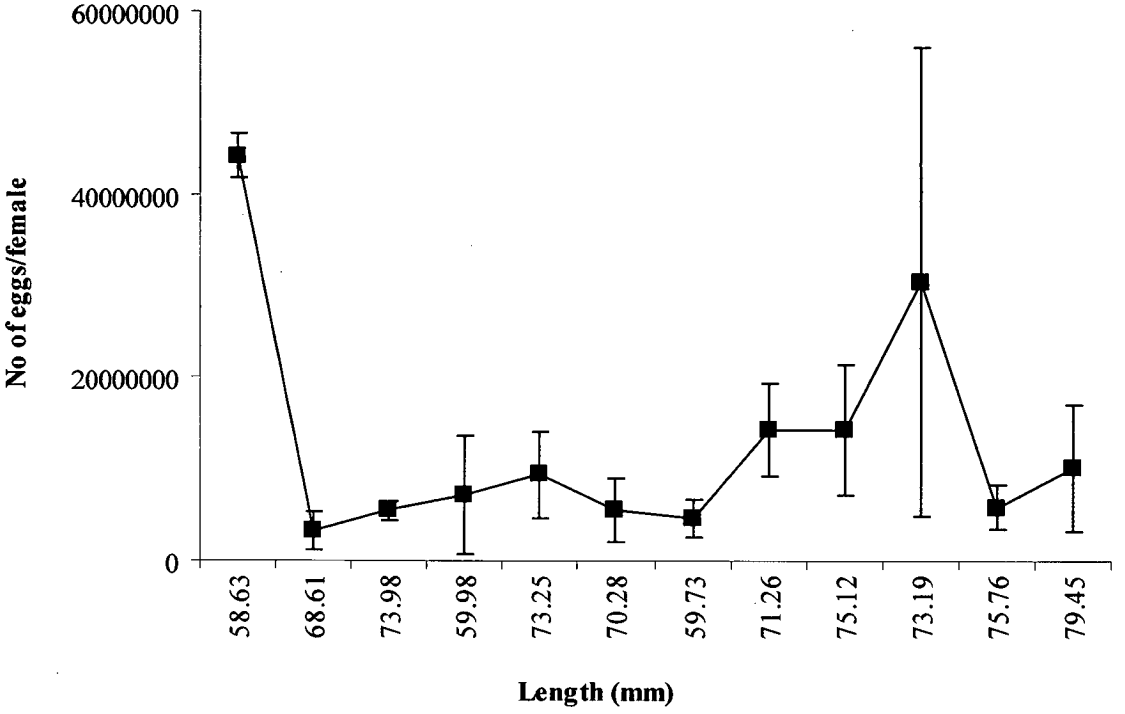


Fig 6.7: Fecundity of *P. erosa* in relation to different shell length

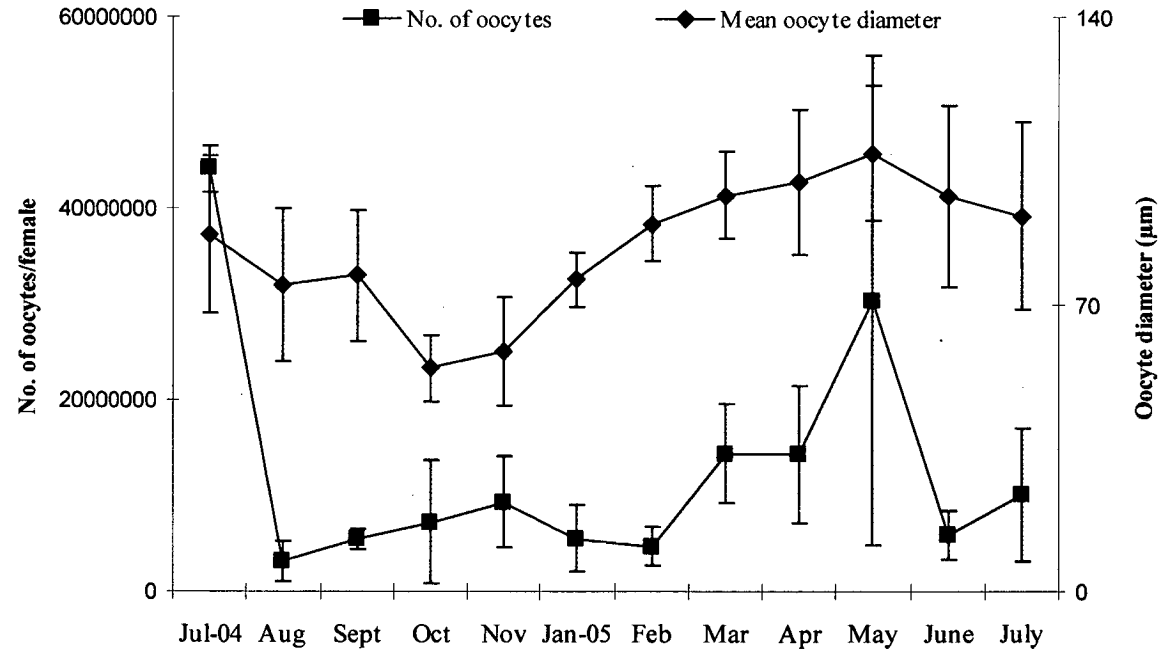


Fig 6.8: Monthly mean oocyte number and diameter of *P. erosa*

Size-frequency distributions of the oocytes of *P. erosa* in the present study are shown in Fig. 6.9. In Oct, the average oocyte size had dropped considerably, and large oocytes (<90 μm) were almost absent (1%), with most oocytes between 50 and 60 μm. Oocyte diameters ranged from 5 to 140 μm with an average diameter of 84±5 SD, n=12 (Table 6.1). Quantitative measurements of oocyte development support the patterns observed in the qualitative staging (Plate 6.3). The start of gametogenic cycle (Oct-Nov.) was characterized by a high percentage of small oocytes (50 μm, Fig 6.9) and very low monthly mean oocyte diameters. By Jan/Feb the majority of oocytes increased to larger size classes (>60 μm) with few small oocytes present. Monthly mean oocyte diameters and number of oocytes were highest during Mar-May, corresponding with the ripe stage of clams observed in the qualitative stagings.

6.4 Discussion

The gonads in *P. erosa* are composed almost entirely of gametogenic cells. Therefore, temporal changes in standardized gonad mass can be reliably interpreted as changes in the actual amount of gametes, thus providing an ecologically meaningful measure of reproductive output.

The Gonadosomatic Index (GSI) has been used in this study to follow the gametogenic cycle (Fig. 6.3). This index increased before spawning due to the gametogenic development that produced an increase in the size of the gonad, which resulted in a rapid increase of the index throughout the post- and pre-monsoon until monsoon. From Aug to Sept the index decreased due to the spawning period. It is interesting to note that, the GSI increased immediately after spawning which indicates a rapid recovery and an accumulation of reserves that may be used in future gametogenesis. This recovery may be related to the higher

Table 6.1: Oocyte diameters of *P. erosa* during July 2004-2005 from Chorao island

	Egg Diameter (µm)										
Month	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**Total no. of eggs**
Jul-04	1	5	35	13	9	15	10	12	0	0	100
Aug-04	3	31	44	9	9	4	0	0	0	0	100
Sep-04	6	16	21	32	14	7	0	3	1	0	100
Oct-04	70	23	3	3	0	1	0	0	0	0	100
Nov-04	60	19	6	6	8	1	0	0	0	0	100
Jan-05	0	2	42	49	7	0	0	0	0	0	100
Feb-05	0	4	0	19	51	26	0	0	0	0	100
Mar-05	0	2	2	9	19	52	16	0	0	0	100
Apr-05	0	1	13	4	18	29	12	16	8	0	100
May-05	2	2	0	2	16	12	35	25	3	3	100
Jun-05	1	5	18	12	9	13	16	16	10	0	100
Jul-05	2	4	30	17	3	5	13	22	4	0	100

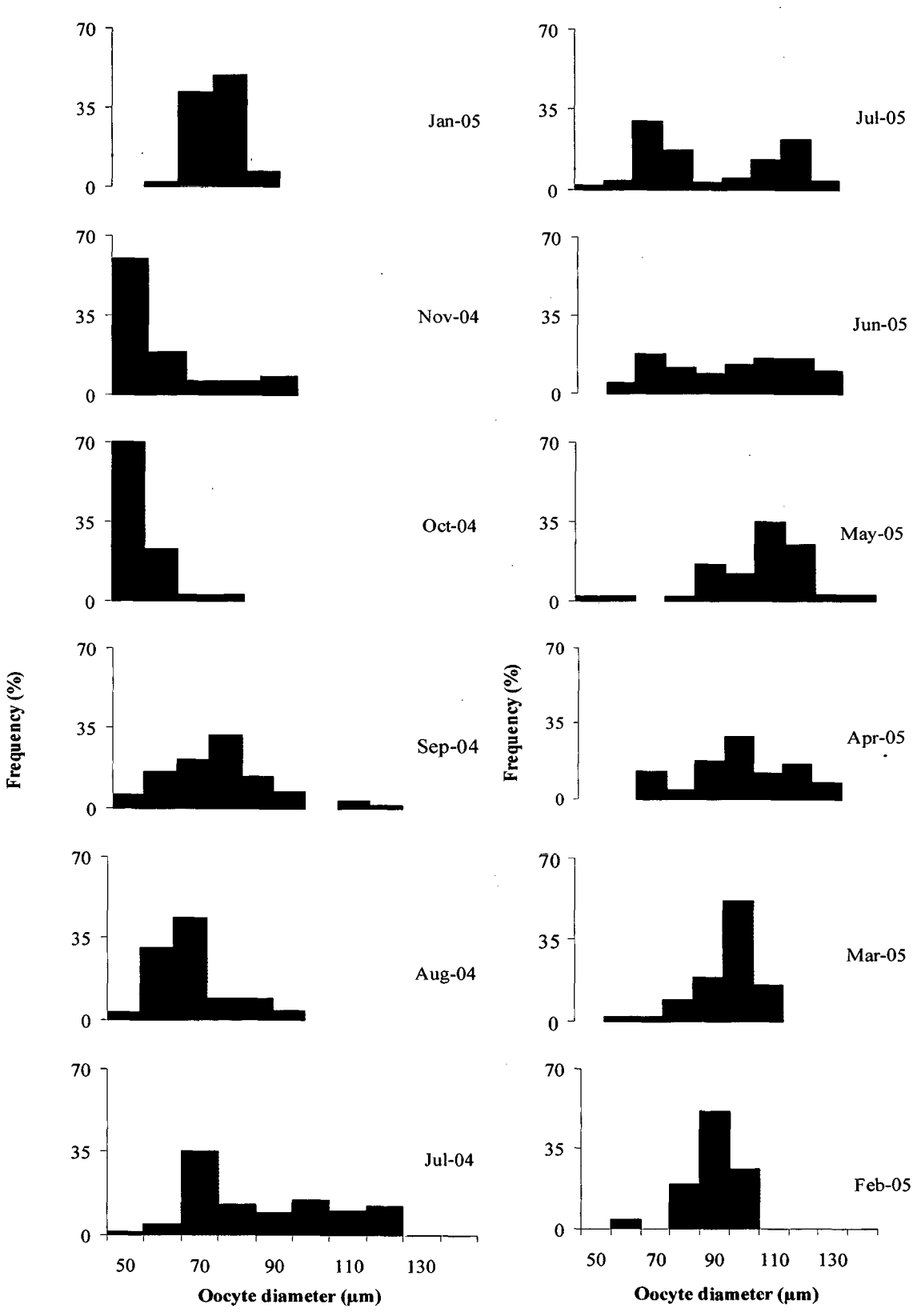


Fig. 6.9: Size frequency distribution of *P. erosa* oocytes

production of phytoplankton during the postmonsoon. The evolution of the GSI suggests that *P. erosa* have a single protracted spawning period starting from end of May to Sept, although the major peak occurs during Aug-Sept. Infact, protracted breeding and spawning in *P. erosa* has been reported by Morton (1985) in Hong Kong and Gimmin et al. (2000) in Australian mangroves. The gametogenic cycle of *P. erosa* from Chorao island is a continuous process with a complete gonadal restoration after the end of the reproductive season and no resting period. The sequence of events forming the reproductive cycles of invertebrates has been known to be strongly affected by physical and biological environmental factors. The growth rate of the gametes thus varies with individuals, suggesting a specific response to the environmental factors. Previous authors have linked the occurrence of successive individual spawning to the presence of gametes at all stages of maturity in the gonads (Shafee and Lucas, 1980).

The present study suggest that, the spawning season of *P. erosa* at Chorao mangroves is restricted to around 4 months beginning from June to early Oct with major events occurring during Aug–Sept (Fig. 6.3). It is well known that the duration of the spawning period varies in a species occurring in different parts of its geographic range. The timing of spawning of *P. erosa* at Chorao is similar to that reported by Morton (1985) and Gimmin et al. (2004) in Hong Kong and Australia, respectively, but there was no indication of a second (minor) spawning at Chorao island as observed for a population from Hong Kong (Morton, 1985). Nevertheless, the occurrence of late active stages (10-20%) simultaneous with spent stages (Fig. 6.2), do indicate the possibility of sporadic spawning at Chorao.

Various studies on the reproductive biology of bivalves have demonstrated that temperature and food are the most important exogenous factors influencing the reproductive cycle (Sastry, 1979; Beer, 2000; Morriconi et al., 2002). The chl *a* levels in estuarine water and the sediments did not show exceptionally high

variation (Fig. 4.8), indicating the availability of potential food items throughout the year (Dalal and Goswami, 2001). Devassy and Goes (1989) reported an excess stock of phytoplankton available in the Mandovi estuary. Maximum values of chl *a* in the present study were observed during summer months (Fig. 4.8). Since the role of food supply is vital in the development of gonad (Williams and Babcock, 2004), thus the net increase in body weight or in metabolic reserves in *P. erosa* coincided closely with the periods of high food abundance (Fig. 6.10). Accordingly, the availability of food can be considered as a major factor determining the seasonal gonadal cycle (Fig. 6.11 and 6.12). However, the existence of chl *a* in the water column that is always adequate for gamete maturation seems to be an important factor for protracted continuous reproductive activity of this species at Chorao island. The first major period of body weight increment in *P. erosa* coincides with the highest chl *a* content. This strongly advocates that feeding resulted in rapid increment in body weight, and there was a period when body weight was reduced due to spawning (Fig 6.3). The subsequent rise in body weight in Sept was accompanied by an increase in phytoplankton (chl *a*). Gamete production in marine species of bivalves is known to require a great deal of energy (Bayne, 1985), suggesting a close relationship between the reproductive cycle and energy available for growth. Hence, food although not directly responsible for sexual maturation of the clams, conditions the rate of egg development. A direct relationship between food availability and acceleration of the reproductive process is found in other studies also (Delgado and Camacho, 2005). Experimental studies also have shown that the amount of available food influences the rate of gonadal maturation of bivalves (Delgado and Camacho, 2005). Generally, gametogenesis is "opportunistic", being supported by feeding alone (Hawkins et. al., 1985). In fact, differences in the feeding conditions could partly explain interannual variations (Navarro et al., 1989) or variability between geographical points in the reproductive trend of a species. The spawning period in bivalves is related with high food levels rather than temperature, and as reported by Seed (1976), the spawning period in bivalves could be synchronized with the

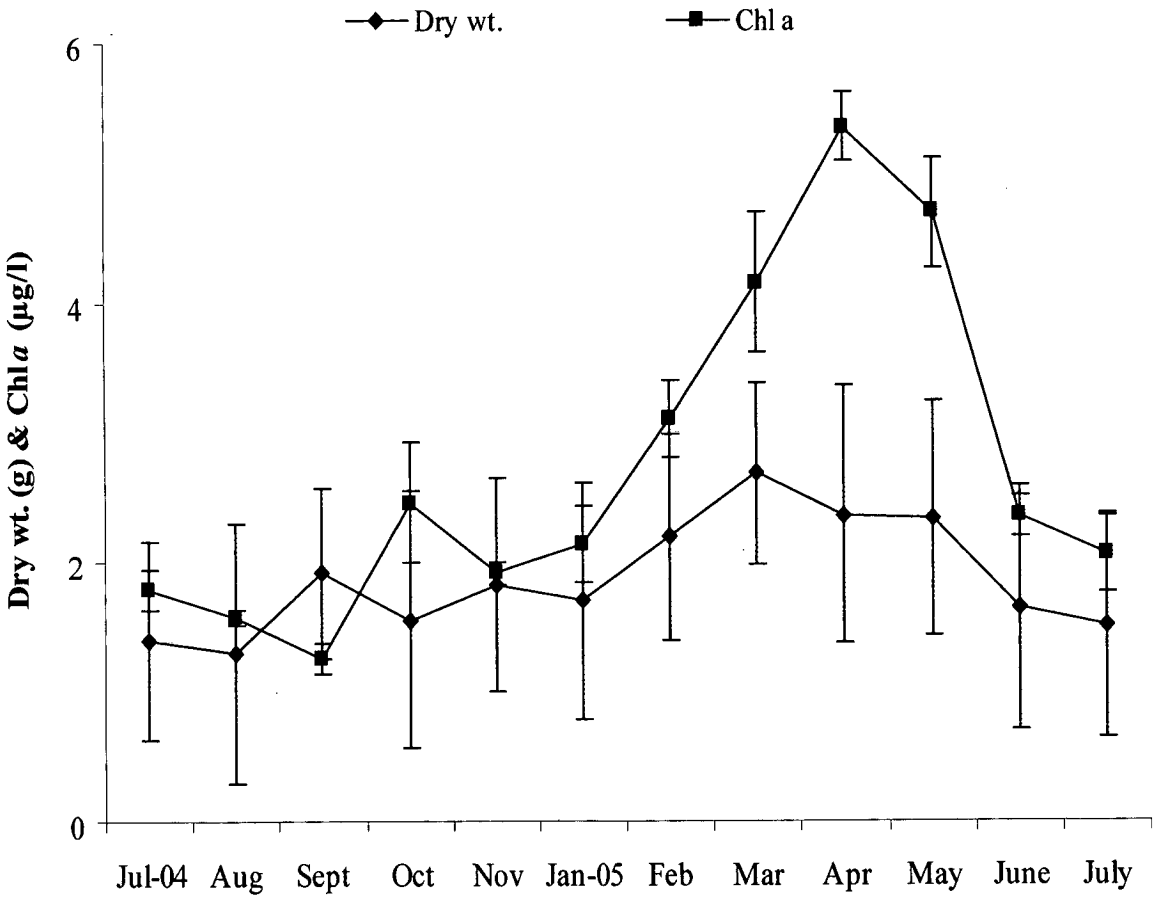


Fig. 6.10: Variation in Chl *a* content of estuarine water and dry tissue wt. of *P. erosa*

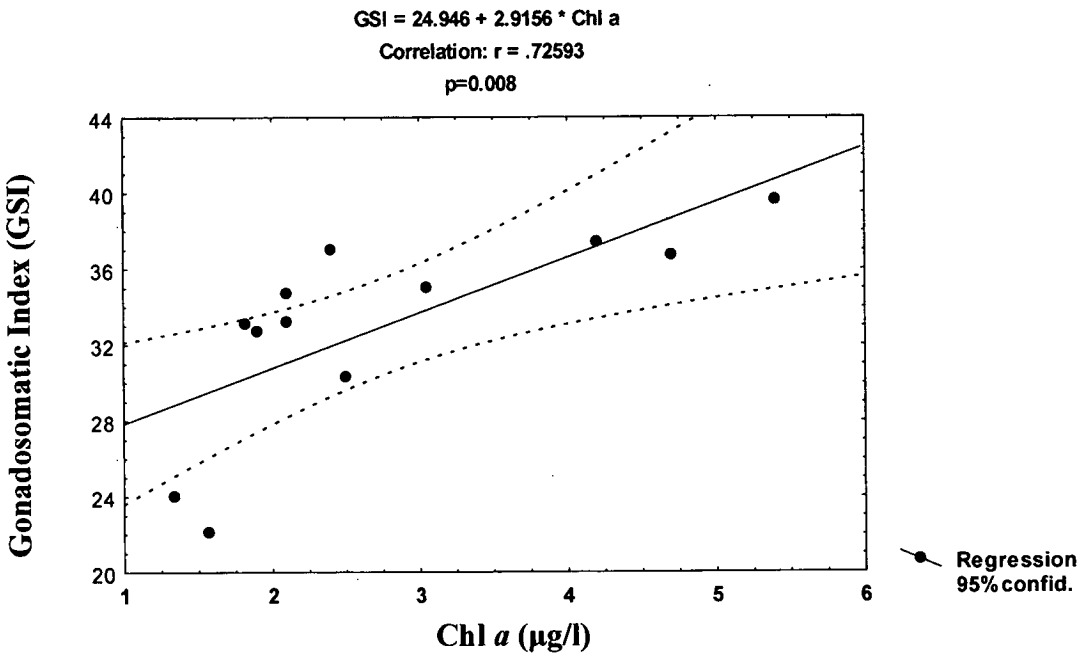


Fig. 6.11: Relationship between GSI of *P. erosa* and Chl *a* content of the estuarine water

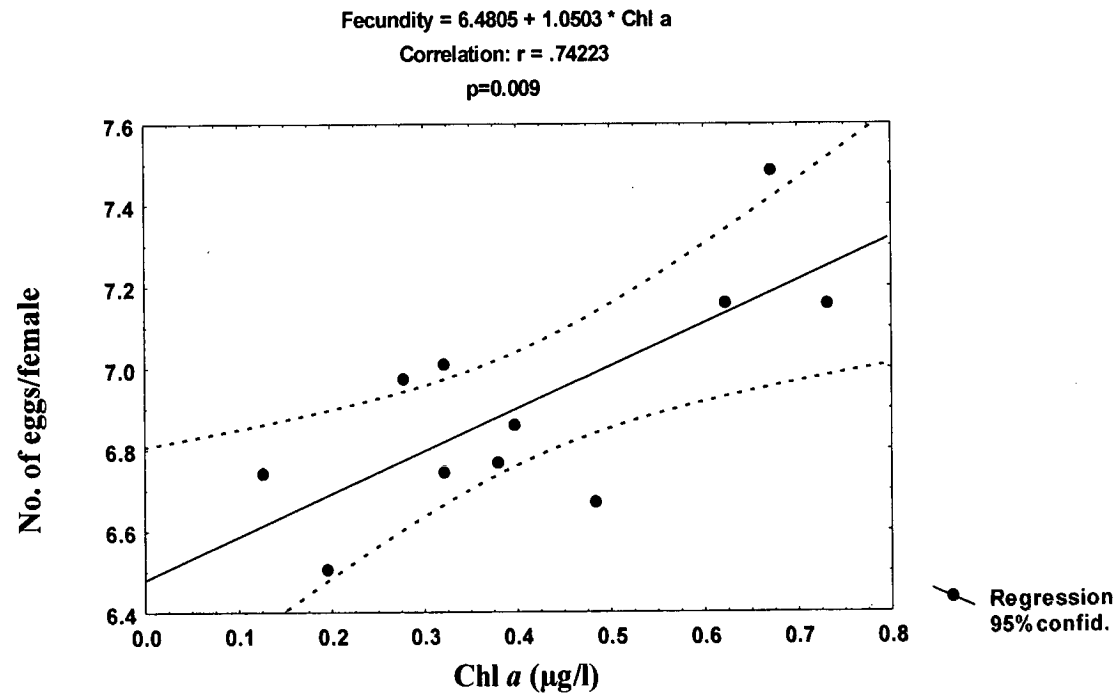


Fig. 6.12: Relationship between fecundity of *P. erosa* and Chl *a* content of the estuarine water

maximum food abundance for favoring the post development of larvae (Morriconi et al., 2002).

Nevertheless, several workers described the role of temperature as one of the most important exogenous factors for reproduction of a species (Ingole, 1987; Grant and Creese, 1995). Further, as depicted in figure 6.3, GSI was low during Oct-Jan with very high percentage of clams with early active and late active maturity stages, whereas the GSI increased to a maximum in Mar, with maturation of gonads occurring only during Mar-May (Fig. 6.2). Thus, it confirms that, the food availability might have resulted in the increase in body weight (somatic weight) suggesting active feeding during this period. At the same time, gonad weight remained low and development (Fig 6.4) of gametes did not go beyond late active stage (Fig 6.2) thus suggesting that though surplus energy was available, the optimum temperature required for the further differentiation of gametes had not reached. Generally, temperature needs to exceed a threshold value for vitellogenesis to proceed (Amaro et al., 2005). Gametogenic cycles of marine invertebrates usually include a 'rest' period of reproductive quiescence following spawning. This is probably due to the fact that the optimum temperature is still not reached. It has been demonstrated that many bivalves require a minimum threshold temperature for activation of the oocyte growth phase and although oogonia can develop below this threshold level further differentiation only takes place at warmer temperatures (Williams and Babcock, 2004). Sastry (1963) suggested that, above this threshold the rate of gamete maturation is temperature dependent, whereas fecundity (Fig. 6.12) and size of the gonad is primarily determined by food availability. Experimental works have further evidenced that gonad size is strongly affected by dietary level whereas gonad condition varies more with temperature (Heasman et al., 1996; Ingole, 1988). Temperature also affects the transfer of nutrients needed for oocyte growth (Sastry, 1979; Rodriguez-Jaramillo et al., 2001). In temperate areas, temperature plays a very important part in triggering bivalve gametogenesis and spawning (Shafee and

Lucas 1980; Hadfield and Anderson, 1988; Harvey and Vincent, 1989). In tropics, however, temperature variations over the year are less marked; on the other hand, wide and periodic salinity variations may occur, particularly in areas affected by the monsoon (Ingole nad Parulekar, 1998). Many authors have demonstrated the impact of the combined action of temperature and salinity on the reproductive cycles of molluscs (Broom, 1983; Jayabal and Kalyani, 1987). In Chorao, gametogenesis of *P. erosa* also peaks when temperatures are highest (Fig 6.13). Similar observations are reported for *Anadra scapha* in the Phillippines (Tord-Baza and Gomez, 1985), thus temperature definitely appears to affect reproductive patterns in this clam, at least during part of the year. In the Mandovi estuary, salinity variations in the seaward part are very minor and vary between 33 and 36 psu (Dalal and Goswami, 2001). The present study site also happens to be in the seaward region. Hence, the effect of salinity on the onset and speed of gametogenesis in *P. erosa*, therefore appears negligible (Fig 6.14), although short-lived salinity fluctuations after heavy rains may act as a cue for spawning. In addition, studies showing differences in the reproductive cycles of different species exposed to similar temperature and salinity conditions tend to confirm that bivalve reproduction is partly controlled by endogenous factors (Hadfield and Anderson, 1988).

The protracted breeding season of tropical bivalves, often features one or two peak reproductive periods a year (Tord-Baza and Gomez, 1985). When such peaks occur in a population, the parameters governing the reproductive cycle are easier to determine. The observed seasonality in fact results from a similar response by a large number of individuals who previously responded more or less independently to the existing environmental factors. The GSI confirms that the main spawning events were primarily annual with major spawning occurring during the mid monsoon months of Aug–Sept 2004 (Fig 6.3), which coincides with low water temperatures and low chl *a* concentrations in surface waters. Spawning coinciding with low water temperatures and chl *a* content has been

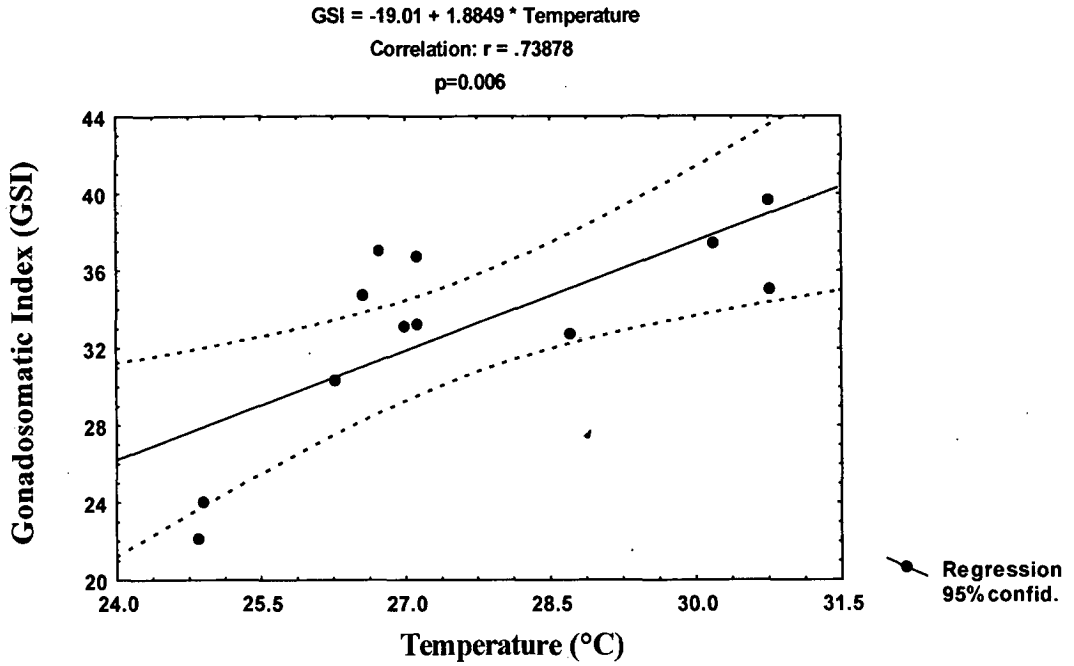


Fig. 6.13: Relationship between GSI of *P. erosa* and temperature of the estuarine water

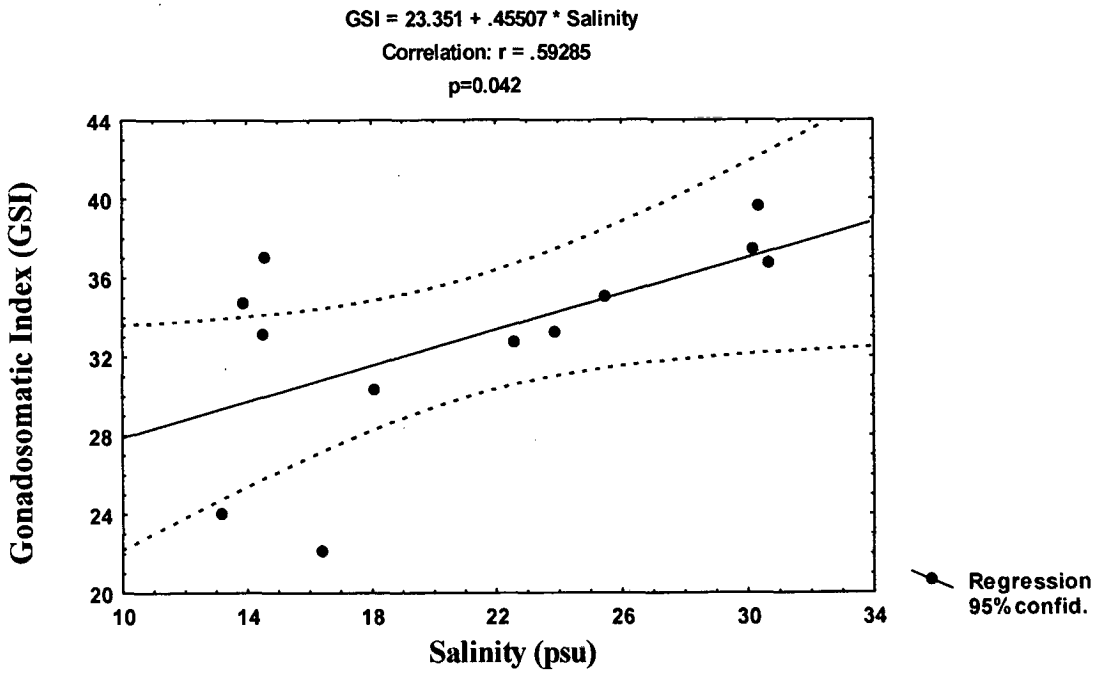


Fig. 6.14: Relationship between GSI of *P. erosa* and salinity of the estuarine water

observed in other bivalves also (Boon and Duineveld, 1998). The daily temperature fluctuations to which intertidal organisms are exposed are much sharper in the warm season, when the effect of the sun is strongest, and these fluctuations of variable magnitude may well trigger spawning in bivalves. However, the fact that spawning also occurs at other times of the year shows that temperature is not the only factor affecting gametogenesis. Metabolites released from phytoplankton have also been identified as proximal cues for spawning in benthic marine invertebrates (Starr et al., 1990). Changes in temperature or phytoplankton concentration could be distinctive inducers to synchronize spawning among individuals and may result in gametes being expelled into water masses favorable for larval survivorship. Further studies are therefore required to determine whether there is a consistent correlation between synchronous spawning in *P. erosa* and the changes in the water column.

Reproductive synchrony is the most fundamental requirement for achieving fertilization and therefore it is expected that both sexes spawn synchronously. To ensure fertilization success and the production of larvae, individuals must spawn synchronously and presumably, in close proximity to each other. Spawning is generally thought to be synchronous within individual populations, or at least within aggregated groups (Levitan, 1995). Experimental evidence suggests that fertilization success increases with both increasing population size and degree of aggregation (Levitan, 1995). The present results support this expectation, because simultaneous changes were observed in the gonads of both male and female clams (Fig. 6.1). However, it appears that *P. erosa* has asynchronous or patchy spawning within a population. Asynchronous spawning that appears to be unrelated to seasons is evident in many species (Williams and Babcock, 2004). It may be reasonable to suggest that patchy and partial spawning could still result in successful fertilization, if at least some individuals spawn synchronously in close proximity to each other, but empirical data from other free spawning species suggest that lack of synchrony will jeopardize reproductive success (Levitan,

1995). Nevertheless, such a 'patchy' spawning strategy could help to explain variability in the timing of *P. erosa* larval settlements which is reflected in the difference in juvenile sizes observed at same time (discussed in the following chapter).

Several studies using quantitative measures indicate that periods of maturation and spawning tend to coincide with maximum oocyte diameter values (Hefferman and Walker, 1989; Gribben et al., 2001). Both monthly mean egg diameters and mean number of eggs were good quantitative descriptors of the reproductive development of *P. erosa* population at Chorao island. However, the egg number appeared to be more sensitive to changes in the reproductive cycle. The egg diameters initially appeared to follow the development of oocytes but did not follow the timing or duration of the spawning season. Similar findings are reported in other bivalves (Morsan and Kroeck, 2005). The fact that new oogonia continue to develop during the spawning season could have resulted in decrease in the average egg diameters observed during the spawning season. As seen in figure 6.8, the decrease in oocyte number after May 2005 is a clear indication of gamete release by partial spawning (Morsan and Kroeck, 2005). However, though the oocyte density decreases by July 2005, the preceding year the density is at its peak in the month of July and this seems to be the result of either very high fecundity in that year or partial spawning was very meager with massive spawning occurring in August.

While there is no published information on *P. erosa* oocyte size from Indian coasts, in the Hong Kong mangroves, the ripe oocytes diameter of this species are 60 μm (Morton, 1985), which is much smaller than that observed in the present study. While studying the growth of bivalve, *Macoma balthica,* Beukema et al., (1977) recorded largest eggs at the lowest intertidal station and related it to the better feeding conditions (longer daily foraging times), higher growth rates, and higher body masses at the lower tidal levels. A more direct relationship between

egg size and food availability was found in Canadian *Macoma balthica* populations, with somatic growth rates being higher and eggs being larger in areas where the chlorophyll content of the sediment was higher (Harvey et al., 1993). Lowerre – Barbeiri et al. (1996) gave similar views, that female with higher condition factor (k), which is associated with the nutritional state results in the production of larger hydrated oocytes. The plausible reason that clams in Hong Kong mangroves have smaller oocytes could be the continuous destruction of the mangroves (Morton, 1985) that might have resulted in poor condition of this habitat thereby affecting its reproductive biology of the associated fauna. Intraspecific differences in the reproductive characteristics of several bivalves have been described for populations occurring under a variety of environmental conditions or degrees of stress (MacDonald and Thompson, 1986). There are evidences of reduced fecundities, low gonad indices and less synchronous spawning in populations from impoverished sites as compared to those from a nutritionally favorable site (Nichols and Barker, 1984). There is no doubt that, Chorao mangrove forest is one of the well-protected areas. The study of reproductive biology of *P. erosa* from Chorao as compared to those from Hong Kong mangroves points towards the fact that variations in these more flexible reproductive characteristics may be good predictors of anthropogenic and natural stress (Bayne, 1985).

In most morphological respects, *P. erosa* is unspecialized in terms of reproduction in the extreme environment of mangroves. However, its simple reproductive strategy in such harsh conditions points towards the fact that there must be some behavioural specializations for its reproductive success. In view of all this, further detailed study is needed to understand its biology. For e.g. according to Morton (1985) fertilization could take place in the maze of the subterranean burrows that connect individuals with each other and not as in the typical veneroid in the sea. Since such activity could not be observed at Chorao island population, detailed field and laboratory experiments are required to understand such behaviour.

CHAPTER 7

RECRUITMENT OF *P. EROSA*

7.1 Introduction

The processes that lead to the colonization of substrata by larval invertebrates are among the most important in determining the ecology of marine communities. Recruitment is the successful colonization of the bottom/substrate by bivalves and implies the passage of time with survival and post settlement mortality (Seed and Suchanek, 1992). A fundamental process shaping community structure in most habitats is the recruitment. This initial process is responsible for the supply of individuals to existing assemblages as well as the re-colonisation of denuded areas or newly created space. The recruitment events of marine sedimentary benthic communities involve a series of processes that vary in time and space and act simultaneously at different biological and physical scales. The integration of these various processes is critical in the establishment and continuity of adult communities.

Most benthic invertebrates have a planktonic larval stage; a critical step in the life cycle of these animals is the transition from a planktonic to a benthic existence. Variation in the spatial and temporal patterns of larval recruitment may be attributed to a multitude of factors that are brought into play, before or after, or coincident with settlement. Pre-settlement include the reproductive behaviour of adults (Barry, 1989), the availability of competent larvae (Farrell et al., 1991) and larval distribution in the water column (Mathivat-Lallier and Cazaux, 1990). After settlement, juveniles may be subject to differential mortality or migration that will consequently alter their adult distribution (McCann and Levin, 1989). Settlement in a favourable benthic site increases the likelihood of survival, while settlement in an unfavourable site could lead to high post–settlement mortality due to predation or physiological stress (Welch et al., 1997).

Since the early 1980's patterns of distribution and abundance in the arrival of propagules or larvae in the habitat of the adult have been emphasized as important

in determining the patterns of adult organisms particularly in open systems such as aquatic environments. A positive relationship has been found between larval supply and settlement and supply and recruitment of some species (Underwood and Fairweather, 1989). One of the most basic problems in benthic ecology is in understanding why variability in spatial and temporal patterns exists in soft-sediment communities (Snelgrove and Butman, 1994). One explanation for this variability is that active habitat choice for a specific sedimentary environment, in the form of habitat selection by settling larvae, may increase the likelihood of placing the offsprings into that habitat. However, differences in larval supply through passive transport (Butman, 1987) as well as post-settlement processes (Wilson, 1991) offer equally viable reasons. It is of utmost interest to determine the mechanisms causing the spatial patterns of larvae, which is responsible for the distribution of adult population.

Despite the potential importance of relocation by juvenile bivalves in determining adult distribution, there have been few experimental tests of habitat selection by juveniles. In marine systems, very few quantitative studies have been conducted on either rates of dispersal or the spatial and temporal scales over which animals move and, in marine soft sediments in particular, the role of dispersal in patch dynamics remains poorly understood (Commito et al., 1995). To a large extent this is due to the small and cryptic nature of most juvenile benthic invertebrates, which makes them difficult to study, hence patterns of dispersal are generally inferred from studies on recruitment, overall dispersal rates and fluxes or spatial pattern. There are very few studies in which juvenile invertebrates have been trapped directly in the field and there have been no attempts to identify the movement of individuals. Thus, while we often know which species move, generally we have little idea how far, or the proportion of the local population they represent over space and time scales, commonly exploited in sampling soft sediment organisms. Quantitative studies on the dispersal of species are imperative if we are to understand the dynamics of population in time and space.

Many marine organisms are associated with particular substrate types. An obvious proximate explanation for such relationships is active habitat selection by settling larvae (Butman, 1987). Species-substrate relationships provide evidence for habitat selection. Although they might not be able to establish the actual causal reasons since other mechanisms may be operating. For example, passive settlement of larvae will correlate a soft-sediment species with sites where sediments with similar fall velocities, initially settle (Hannan, 1984).

The study of larval settlement in soft bottom habitats may not help in determining the patterns of later stages. Unlike hard bottom environments, where organisms are more or less sedentary, juvenile organisms associated with soft bottom sediments may not stay in the areas where initial settlement occurs (de Montaudouin, 1997). For this reason the term "settlement" does not necessarily apply to a single event in the life of a soft bottom species (in contrast to its use for most hard bottom organisms). Here the term is used to mean alighting onto, and burrowing into, the sediment surface from the water column, something that may happen, many times in the lives of bivalves. Therefore, the composition of infaunal communities may be determined, in part, by dispersal and deposition of postlarvae and juveniles, and where movement is high, initial settlement may have little bearing on later abundance (Hunt et al., 2003).

Capture fishery is collapsing all over the world (Pauly et al., 2002; Myers and Worm, 2003), with bivalve fishery being no exception. One of the most common reasons for this is the continuous degradation of the habitat. Many marine organisms are associated with particular substrate types and the recruitment process affects the adult distribution. In view of this fact, effective management of these resources in an age of escalating reclamation of their habitats, it becomes imperative to study the recruitment of an organism, as the success of recruitment shapes the population. For successful recruitment, however, pristine habitats are a basic necessity. So also, recruitment studies help in understanding the overall

ecology of an organism (Pawlik, 1992), which can be useful to maintain satisfactory environment for the benthic populations of the clam.

Due to their high protein content and delicacy, mud clam provides basis of an artisanal fishery, which is the main activity in many islands of the tropical and sub- tropical region (Meehan, 1982; Muller, 2003; Karam, 2004). In India, the mangrove clam is distributed along the west coast (Ingole, et al., 1994 and 2002). Perusal of the available literature suggests that this species is mostly found in the high intertidal area of the mangrove forests (Meehan, 1982; Clemente and Ingole, 2006). Except the preliminary account by Clemente and Ingole (2006), no studies on the recruitment of the mangrove clams *P. erosa,* has been reported till date. However, information on the recruitment aspects of some species belonging to this genus is available (Bishop and Hackney, 1980; Wakida-Kusunoki and Mackenzie Jr, 2004). In view of the commercial importance of this species and its potential for aquaculture, information on its recruitment has implications in the selection of suitable site for cultivation. The aim of this study was to quantify the relationship between the distribution and abundance of settlers, juveniles/recruits and adults at different spatial scales in the mangrove forest and evaluate how the settlers' behaviour may influence any non-differential supply into these habitats. This study describes the recruitment of *P. erosa* from a population in Chorao island Goa.

7.2 Materials and Methods

Field sampling was carried out monthly (July 2004-July 2005) from the Chorao island. The sampling of benthic phases of *P. erosa* in the intertidal region was conducted along the three tidal levels.

7.2.1 Sampling for settlers, juveniles and adult population at Chorao Island

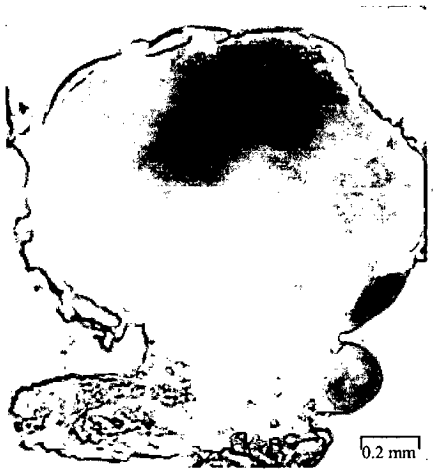
New settlers are individuals of less than 0.3 mm in size that were recorded in the cages after completing the planktonic stages (Plate 7.1a). Juveniles have a shell length of 0.3 mm or more but less than 30 mm (Plate 7.1b). Adult *P. erosa* has a shell length of ≥30 mm and their sex could be determined from their gonads (Plate 7.1c). Density of settler, juvenile and adult population of *P. erosa* was estimated and compared between the tidal levels by sampling at 3 vertical elevations (low-, mid- and high- tide levels).

7.2.1.1 Sampling the newly settled population (field experiment with cages):

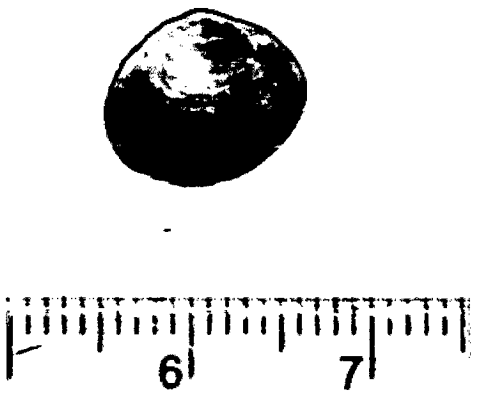
Field evidence of habitat selection in settling population of *P. erosa*, was studied by conducting a field experiment. For this purpose, ten metallic cages of 60×30 cm size were prepared with the help of MS iron (0.5 mm∅) and a net material of 200 μm mesh. These were set up in the field in July 2004 approximately 2 months prior to the main spawning period. As shown in Plate 2.6, three cages were set along each tide level. Cages were deployed at the height of 15 to 20 cm above the ground. Retrieval of the cage material was done every month. The material settled on the cages was washed in a large tub and sieved on 0.3 mm sieve and preserved in 10% buffered formalin Rose- bengal solution. In the laboratory cage, samples were again washed in running water and examined under stereozoom microscope (Olympus B061).

7.2.1.2 Sampling the juvenile population:

Juveniles are aggregated largely within the upper 5.0 cm of the sediment. Hence, triplicate sediment samples were collected at each location of the cages from a marked area of 0.25 m^{-2} of top 5.0 cm sediment section. Samples were than sieved through a mesh of 300 μm sieve in the field (Plate 2.5) and were fixed



a



b

c

Plate 7.1: (a) New settler (b) Juvenile and (c) Adult of *P. erosa*

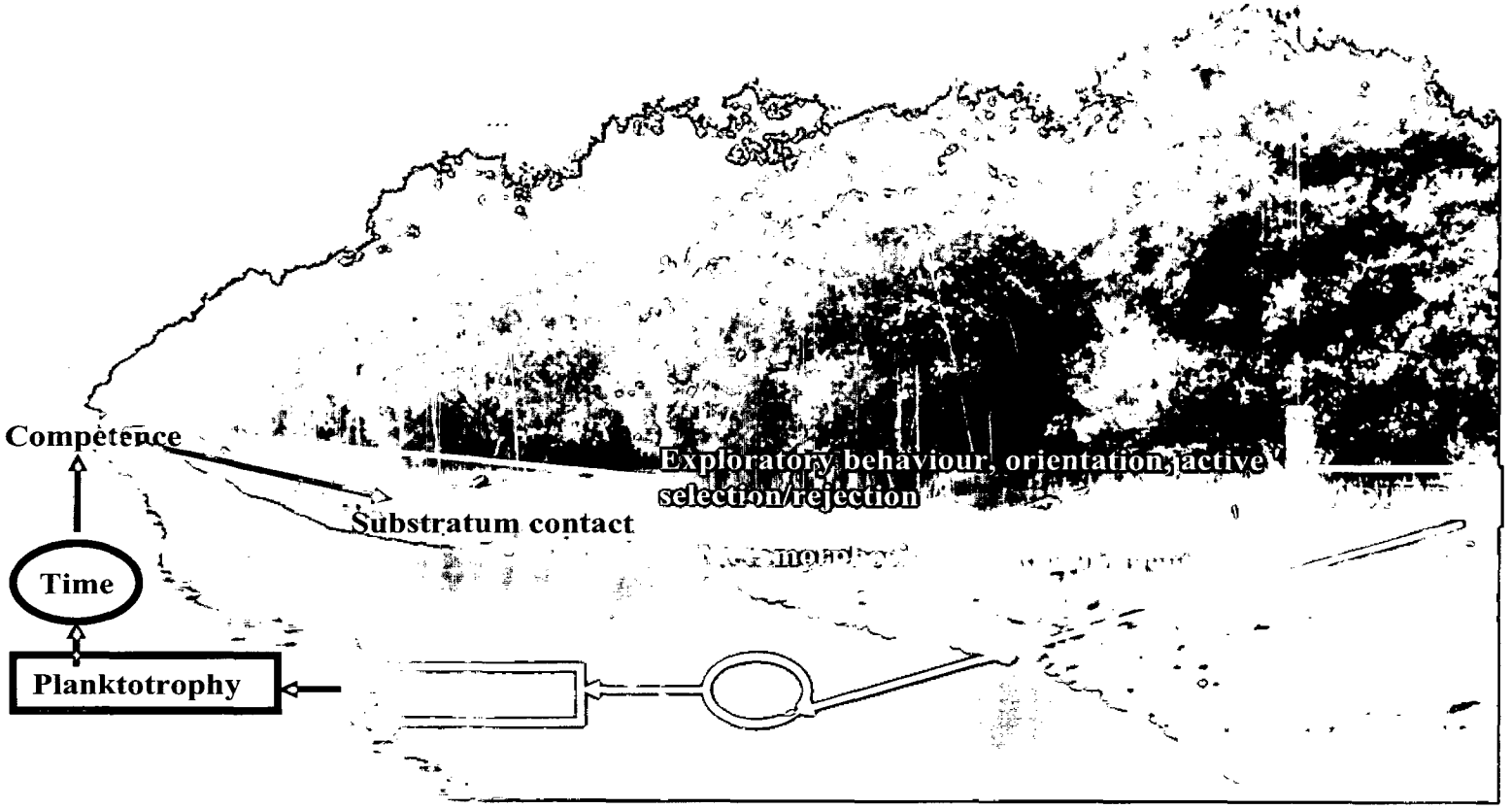


Plate 7.2: Schematic representation of recruitment in *P. erosa*

immediately with 5% buffered formalin Rose bengal solution to facilitate sorting. All the new settlers were sorted and identified. The shell length was measured to the nearest 0.1 mm with an ocular micrometer for new settlers and to the nearest 0.1 mm with Vernier callipers for the juveniles.

7.2.1.3 Sampling the adult population:

Adult population of *P. erosa* was sampled randomly by handpicking (Plate 2.4). All specimens were measured to the nearest 0.1 mm with Vernier callipers. The density of settlers was estimated as the number of clams present in each cage during each sampling. The density of juvenile and adult clams was estimated as the number of *P. erosa* present in 1 m^2 in each month. The density of all different stages of *P. erosa* was estimated as individuals per m^2. Densities of juveniles and adults were compared between different tidal levels, by sampling three replicates in each representative tide (low-, mid- and high-tide) level.

7.2.1.4 Data analyses

The variation in abundance of *P. erosa* among tide levels was examined using Analysis of variance. Differences in settlement at different tide levels were examined by the proportion of settlers in cages and were compared between tide levels. ANOVA was used to examine spatial and temporal variation in abundance of settlers, juveniles and adults of *P. erosa* in relation to different tide levels as well as among different months. Parametric tests were used throughout the study except for some cases wherein the non-parametric Kruskal-Wallis test and the Mann-Whitney U test was used to evaluate variation in the mean density of juveniles and adults in different tide levels as well as between the settlers, juvenile and adult. A significance level of $p< 0.05$ was considered throughout the study.

7.3 Results

7.3.1 Settling population of *P.erosa*

At Chorao island, settlers were observed at all the three tide levels. Newly arrived settlers were found in the cages from Sept to Nov (Fig 7.1). Their maximum density was recorded in Sept (28 nos. m^{-2}), which reduced subsequently to 4 nos.m^{-2} in the month of November. Initial settlement of *P. erosa* population at Chorao island was highly variable in different months (F=3.28, p=0.0085, df=11), (Table 7.1) but did not showed a significant difference in different tide levels (Kruskal Wallis test, H=1.22, p=0.5432, n=24). However, though the density of settlers did not vary significantly between the tide levels, more settlers settled on cages located in the low- tide level than the mid- and high- tide level (Fig 7.2). Majority of the settlers were observed at the low- tide level during Sept 2004. In Oct 2004, the cages at the high- tide level (HT) recorded some settlers. A comparison of the mean densities of settlers indicates that all except at one occasion (Oct 2004) at one site, the seaward zone had a greater density of settlers than the landward zone (Fig 7.1). Among tidal levels in the seaward zone, the density of settlers was higher at the low- than at the mid - tide level. Settlers density was approximately 2 times greater in the mid tide level and were about 4 times higher than those recorded at the high- tide level. (Fig.7.2).

7.3.2 Juvenile population of *P. erosa*

Juveniles were found throughout the sampling period except Sept and Mar (Fig 7.3) and their density peaked two times in July 2004 and Nov 2004. The juvenile density in different months did not show significant variation (F=1.17, p=0.36, df=11), (Table 7.1), but differed significantly at different tide levels (Kruskal Wallis test, H=7.87, p=0.195, n=24). Except February 2005, more juveniles were observed at the low tide level than at the high- tide level (Mann-Whitney U test, U=113, p=0.0173, n=24) but there was no statistically significant difference

Table 7.1:Results of ANOVA between months on density of *P. erosa* (a) new settlers, (b)juveniles and (c) adults at Chorao island

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
(a) New settlers					
Month	2518.382	11	228.943	3.281	0.00851
Residual	1534.898	22	69.768		
(b) Juveniles					
Month	190.222	11	17.292	1.172	0.35900
Residual	324.444	22	14.747		
(c) Adults					
Month	15.333	11	1.393	1.218	0.33182
Residual	25.166	22	1.1439		

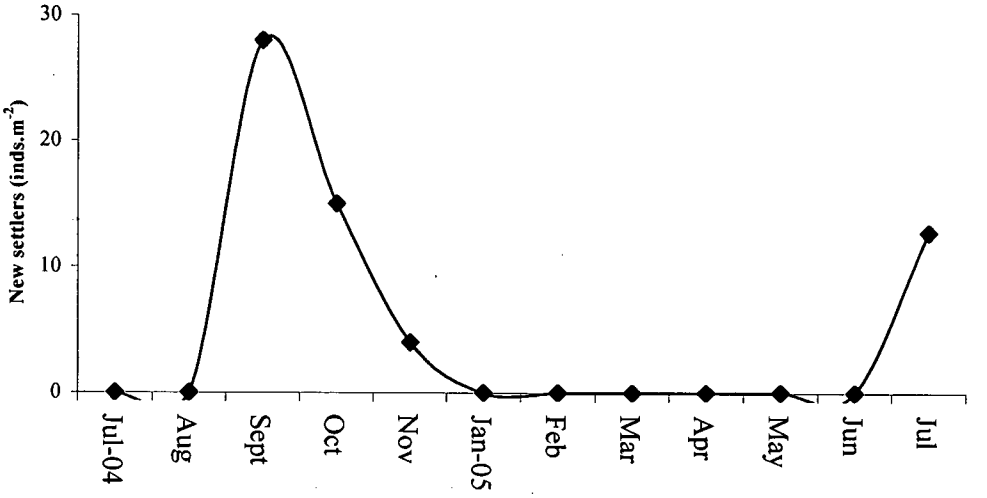


Fig. 7.1: Density of new settlers of *P.erosa* at Chorao island in different months

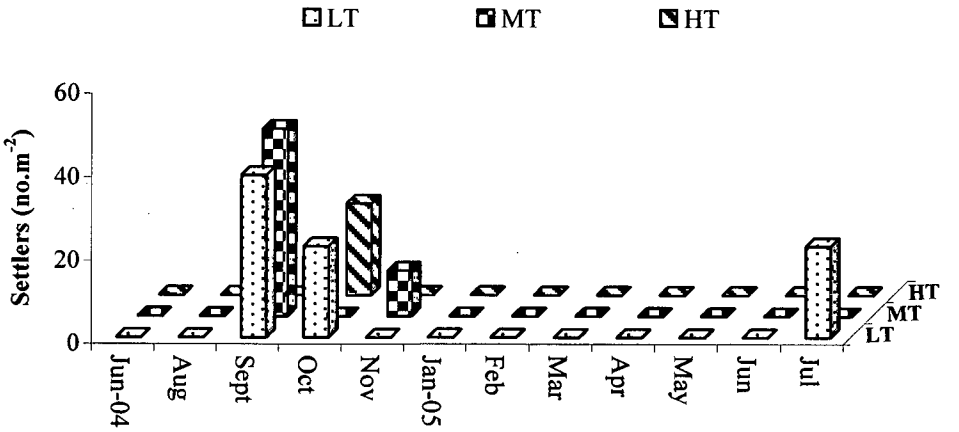


Fig. 7.2: Density of new settlers of *P. erosa* in different tide levels at Chorao island

between the low- and the mid-tide (Mann-Whitney U test, U=100.5, p=0.1135, n=24) as well as mid- and high-tide (Mann-Whitney U test, U=88.5, p=0.377, n=24). Comparison of seasonal changes in density of new settlers and juveniles revealed that the density peak of juveniles during early July 2004 originated from new settlers in June 2004. While a peak in juvenile population observed in Nov 2004 originated from that of the newly settled in Sept 2004. It suggests that seasonal changes in juvenile density are attributed to the density of new settlers. The densities of juveniles were twofold in the landward zone than the seaward zone (Fig 7.4). Among the tidal levels, in the landward zone, the densities of juveniles were greater at the high-tide rather than at the mid – tide level.

7.3.3 Adult population of *P. erosa*

Adult *P. erosa* were found throughout the study period in Chorao mangroves. Their density did not fluctuate remarkably with the season (Fig 7.5) and no statistically significant difference was observed between the different months (F=1.218, p=0.331, df=11; Table 7.1). As for the distribution of adults is concerned, it varied highly between the tide levels (Kruskal Wallis test, H=28.98,p=0.0001, n=24). The density was significantly higher in the high- tide than the low- tide (Mann-Whitney U test, U=1440, p=0.0001, n=24). Adult *P. erosa* showed more selectivity, being found exclusively in the landward region (MT and HT) inside the mangrove forest (Fig 7.6). Seasonal change in adult density was much higher compared to the density of new settlers and juveniles. Even though high density of juveniles was observed towards the landward zone, there was a more or less similar pattern for the settlers and juveniles but the adults showed a completely different pattern. The density of adult *P. erosa* in the landward zone was approximately 4 times the settler and 2 times the juveniles observed. In the seaward region, at the low-tide levels, adult are completely absent (Fig 7.7). The highest density of adults was observed towards the landward fringe with lesser counts towards the seaward fringe.

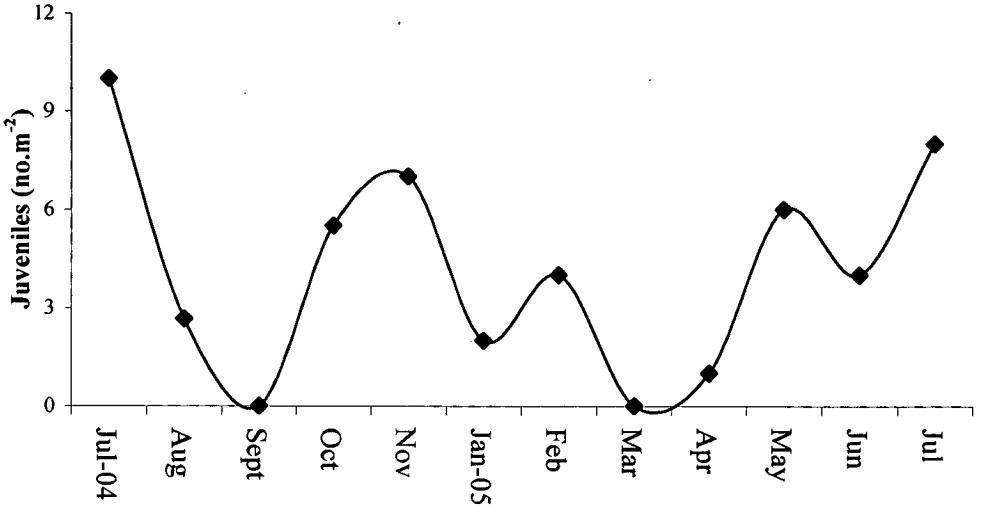


Fig 7.3: Density of juvenile *P.erosa* at Chorao island in different month:

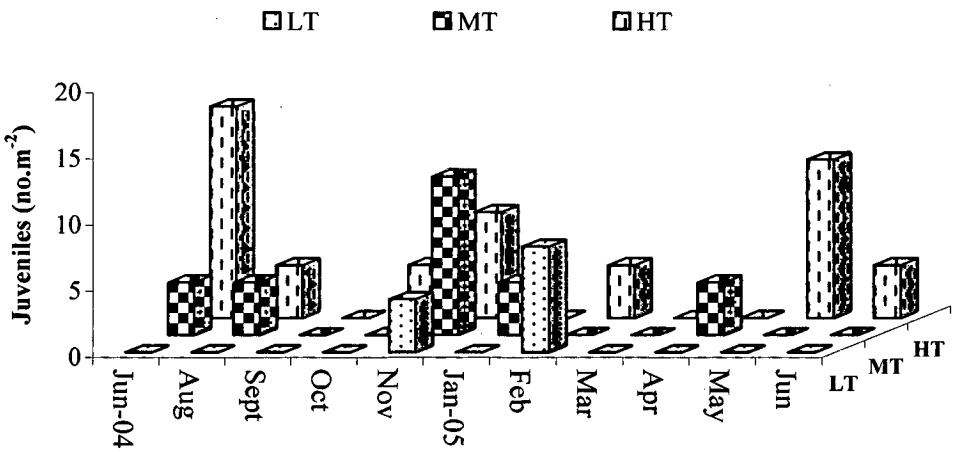


Fig 7.4: Density of juvenile *P.erosa* in different tide levels at Chorao island

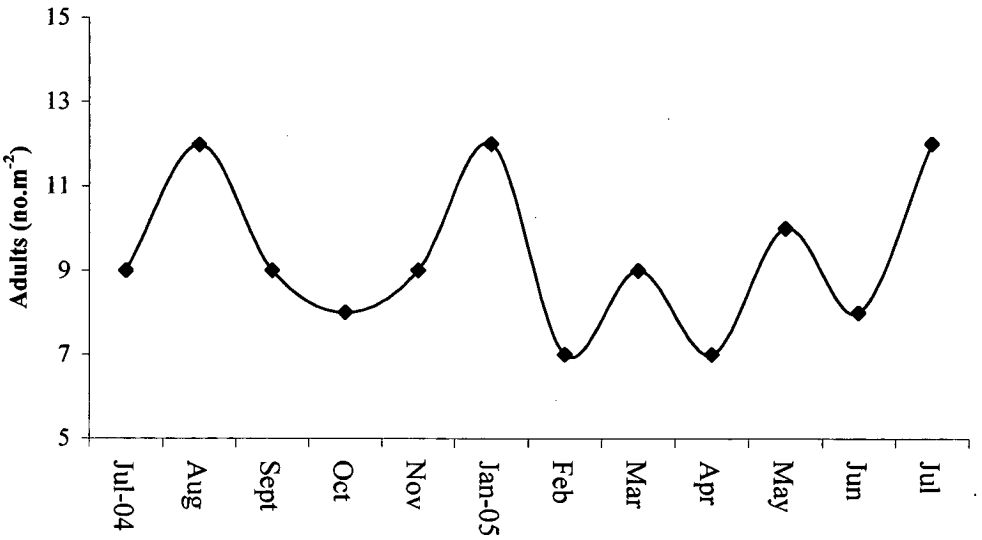


Fig 7.5: Density of adult *P.erosa* at Chorao island in different months

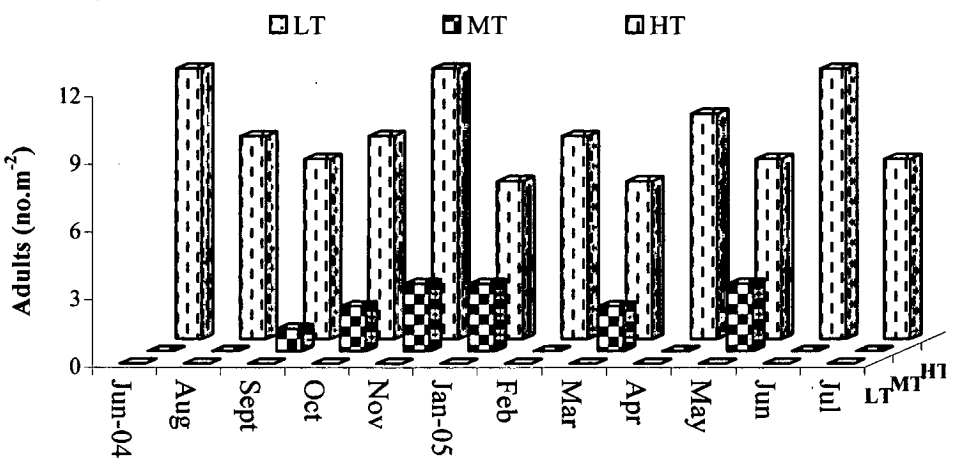


Fig. 7.6: Density of adult *P.erosa* in different tide levels at Chorao island

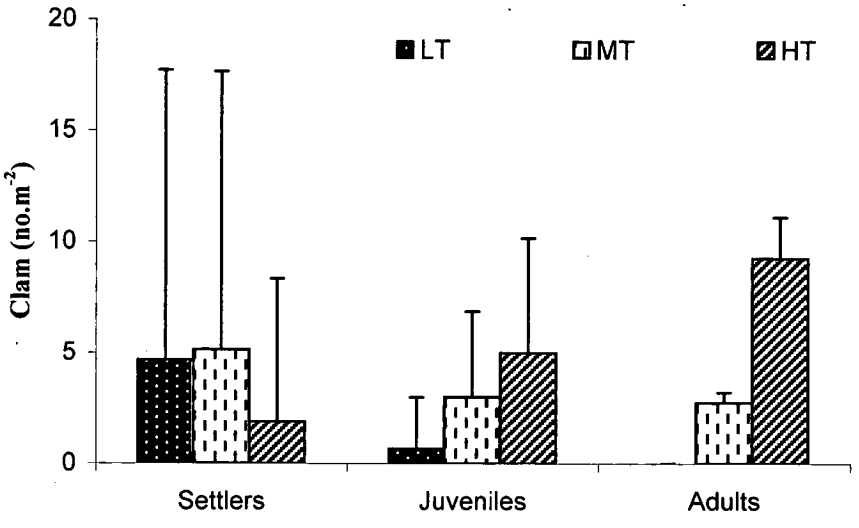


Fig.7.7: Density of new settlers, juveniles and adults of *P. erosa* in different tide levels

The present study indicated that juvenile and adult *P. erosa* have higher habitat specificity than the initial settlers. There were no significant differences between the number of juveniles and adult individuals (Mann-Whitney U test, U=-101, p=0.1005, n=24) as well as the density of settlers and juveniles (Mann-Whitney U test, U=48, p=0.1782 n=24). However, the density of settlers was significantly lower than that of the adult individuals (Mann-Whitney U test, U=33, p=0.0242, n=24).

7.4 Discussion

The population of settlers observed during Sept to Nov 2004 and in July 2005, are a result of spawning of *P. erosa* during the monsoon (discussed in chapter 6). Considering that major spawning occurred in Aug 04 must have resulted in the high number of settlers in Sept 2004 (Fig.7.1), as the larvae of this species have a short planktonic phase with a very short dispersal distance (Foale and Manele, 2003). However, as shown in figure 7.2 and 7.6, the distribution of early settlers contrasted sharply with that of adults. In all months, majority of the settlers were confined to the seaward zone while adults were found conspicuously towards the landward zone. In contrast, juveniles were found at comparable densities in the seaward and landward zone. The reason for such dissimilarity pattern between settlers and adults appeared to be due to the differential pattern of distribution of settlers between the tidal levels.

Earlier studies have shown that in a mangrove forest, the mangrove trees may act as a filter, with relatively few larvae arriving in the landward zone (Gaines and Roughgarden, 1985). In addition predation in the water column may occur throughout the mangrove forest, depleting larval abundance resulting in a few larvae reaching the landward zone (Young, 1990). The structural features or predators in the forest act as a filter with larvae relying on tidal amplitude to

transport them to the upper reaches of the mangrove forest. Larval supply in general is considered as the major factor structuring populations of epifaunal organisms with lecithotrophic larvae in mangrove forest (Bingham, 1992). Such explanations consider larvae as passive particles being transported to the habitat of the adult. Bivalve larvae are known to act like passive particles entrained by hydrodynamic factors (Bertness et al., 1996), relatively unable to influence their distribution and abundance on the shore at a large spatial scale. Thus, at large spatial scales, the mechanisms of physical transport are good predictors of the spatial patterns of larvae and settlers on ashore (Bertness et al., 1996). Larval *P. erosa* must also be acting as passive particles, since the settlers were observed at all the tide levels (though the densities were low towards the landward region). Hence, the same physical processes must have determined initial settlement and distribution of larval *P. erosa* that maintain the distribution of sediments with similar fall velocities. Further, though settlers were recorded at all the tide levels, it was seen that more settlers settled on cages located in the low- tide level than the mid- and high- tide level. The differential settlement of the larvae with low densities towards the landward region could be due to the initial mortalities of the settlers due to their location in an unfavourable site (Gosselin and Qian, 1997). Differential settlement of larvae may act as a mechanism to avoid fatal post-settlement interactions (Bushek, 1988). In the present study, the most plausible reason for low densities of settlers in the high- tide region compared to the mid- and low-tide region appears to be the high degree of desiccation at high tide level. This implies the importance of hydrodynamic, rather than behavioral processes in determining early distribution and is supported by the results of cage experiment since one finds settlers in the cages irrespective of the tidal zone.

Furthermore, though the, settling stages were recorded at the low- and mid-tide level, the adults were found only in the high-tide region (Plate 2.3, Fig. 7.6), with a few clams in fringe of the mid-tide very close to the high-tide level. It is very interesting to note that the clams recorded in the mid- tide region (dominated by

Rhizophora mangroves) were found only near the *Avicennia* species among the other species of the mangroves. According to Raimondi (1991), larval behaviour plays a very important role in determining patterns of settlers at smaller spatial scales. Thus it, appears that habitat selection by the juveniles might be occurring following post-larval migration but the initial settlers might be settling according to the hydrodynamic processes (Armonies, 1996). From this it appears that while *P. erosa* inhabits the high-tide region as adults, it utilizes the lower intertidal expanse as a primary recruitment site. The overall schematic representation of the recruitment phenomenon in *P. erosa* is illustrated in Plate 7.2.

Similar pattern of recruitment has been observed in *Mytilus edulis* including mass settlement to a primary site with secondary recruitment to preferred adult habitat (Bayne, 1964). Many laboratory studies showed active choice for habitat selection by number of organisms for particular sediments (Butman, 1987). However, most of these experiments were conducted at small spatial scales in still waters (Butman, 1987; Jonsson et al., 1991). Hence, it is unclear how selective behavior operated in nature, because few choice experiments were conducted under realistic flow regimes. Snelgrove and Butman (1994) demonstrated active choice for sandy sediment by the clam *Spisula solidissima* in natural habitat under flow conditions, but found no relationship in still water, with higher settlement sometimes observed in mud. In addition, many studies with field experiments suggest that active habitat selection of recently settled individuals is rare and may not explain the distribution of adult species in soft-sediment habitats (Huxham and Richards, 2003; Mathews and Fairwheather, 2006). However, it should be noted that transplantation experiment (Marelli, 1990) involving the use of defaunated sediment, which was designed to examine settlement processes of the infaunal bivalve *Polymesoda caroliniana* in a north Florida estuary, showed that settlement of juveniles did correspond with the distribution of adults and that they selected intertidal zone rather than subtidal sediments. In accordance with this finding, the distribution of adult *P. erosa* at Chorao island can be attributed to

active habitat selection by the juveniles. The movement of *P. erosa* settlers from the initial site i.e. lower intertidal to the high tide region probably could be moving up shore by byssus drifting. Bivalves can actively enter the water column by moving to the surface of the sediment by secreting a thread from the byssus gland. This byssus thread increases the viscous drag exerted on the bivalve, enabling it to be transported on relatively small currents, and is termed as 'byssus drifting' (Sirgudsson et al., 1976). The post larval stages of many benthic species, even those unable to swim actively, have been reported in the water column (Baker and Mann, 1997). In the present study also, post-larval stages were collected in the plankton samples, though were not studied quantitatively (Plate 7.3). Post larval transport has been noted for a number of bivalve species including *Cerastoderma edule* (Armonies, 1994) and *Macoma balthica* (Armonies, 1994). Upon contact with benthic substrata, larvae discriminately screen the substratum for the cues that indicate substratum suitability and and if site is not suitable, larvae re-enter the water column (Dahm et al., 2004). Hence, active sediment choice during relocation could be the best explanation for the non-random, patchy distributions of *P. erosa* found at Chorao mangrove and elsewhere. Such selection could occur quickly through individuals being capable of 'testing' the sediment before settlement or more slowly through the rejection of unsuitable sediment by suspending some time after settlement (Huxham and Richards; 2003, Lundquist et al., 2004). In an earlier study, Gosselin and Qian (1996) found that the patterns established by initial settlement of bivalve spat, persisted for upto 2 weeks in some species for e.g. *Macoma balthica*, before being changed by subsequent processes, including byssus drifting. It is suggested that, initial patterns can persist for a number of days (Armonies, 1992) and that juvenile bivalves may not immediately leave unsuitable habitats. The waiting of juveniles in the initial settling place can have different reasons. Present study suggests that, the availability of adults in the landward zone is a result of settler's behavior. The presence of few juveniles at the low- tide level can be explained, that the larvae, which do settle, may not recruit there. The most conspicuous

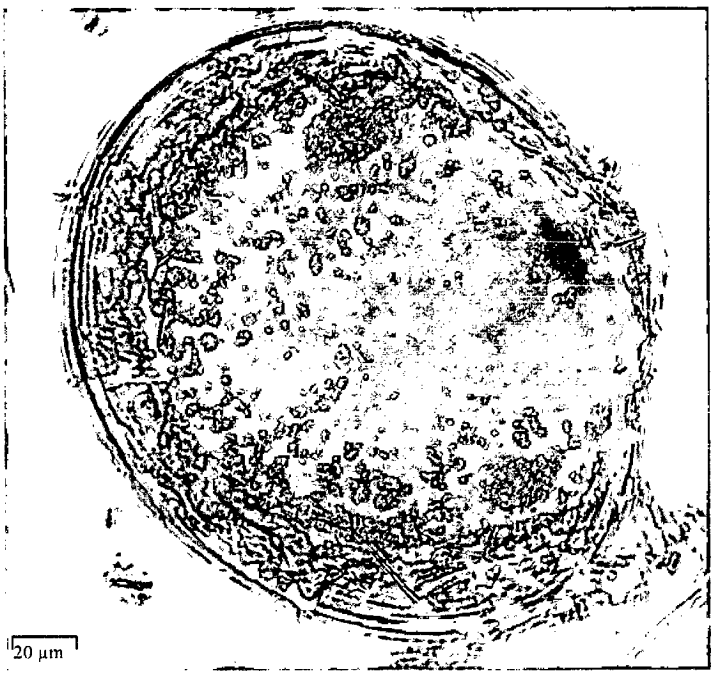


Plate 7.3: Post-larval stage of *P. erosa* found in the plankton samples

difference between the low- tide and both the mid- and high- tide level is the absence of vegetation or mangrove trees in the low- tide region. The adult clams in the present study were confined to the area near the *Avicennia* species and showed a strong association with the particular mangrove species found in the high-tide region. Therefore, the movement of juveniles from the low-tide to the high-tide region for permanent settlement appears to be the plausible reason. Interestingly, the sizes of the juveniles observed at the high- tide region were always larger than those observed at the low-tide region. The higher density of settlers at the low- and mid- tide levels must be due to their higher mortality at high- tide level. Eventhough, the actual factors causing the mortality at high-tide level are unknown, increased desiccation may be one of the reasons.

Reviews on mortality of juvenile invertebrates have suggested that desiccation and predation may often be the most important causes of juvenile mortality (Gosselin and Qian, 1997; Hunt and Scheibling, 1997). Most aquatic organisms are highly vulnerable to mortality factors during the early juvenile period. Earlier works have established the fact that juvenile mortality during the first hours or days may be due to a rapid elimination of individuals located in unfavourable sites and beyond this it could be largely dependent on body size, a major determinant of vulnerability (Gosselin and Qian, 1997). Inhabitants of mangrove intertidal zone are exposed to predators, but also to factors that do not occur in subtidal habitats or in most freshwater habitats such as dessication. Dessication is of particular interest in mangroves because it is often the most severe and is often the only physical factor most likely to cause mortality (Ross, 2001; Fiot and Gratiot, 2006). Individuals generally begin juvenile life with minimal or incomplete structures such as shell, carapace, or integument. Vulnerability generally scales inversely with body size, rapid growth during the early juvenile period is also considered to be an important strategy to reduce the likelihood of mortality by minimizing the time spent in the smallest, most vulnerable size classes (Vermeji, 1987). If rapid growth is a priority, early juveniles should use

habitats that offer the most favourable growth conditions. Hence, the distribution of motile early juveniles might be expected to correlate with food availability, either in terms of abundance or value of food items to the juvenile. The adult *P. erosa* are found in the highest tide level, which gets inundated only during the high waters of spring tide. Being a filter feeder, it can feed only during immersion, and as such the presence of settling stages at that place would suggest that they are at a greater risk of mortality. Since juvenile survivorship is regulated by the availability of food so as to gain maximum size in shortest time possible, the assurance of food availability is a priority.

Experimental studies on the effect of food concentration on growth and morphological differentiation of bivalve larvae have shown increasing growth with increased food concentration (Pechenik et al., 1990). In addition, temperature is also known to affect the growth. However, both food and temperature generally affect growth differently. According to Bayne (1965), increased temperature accelerates growth rate more than overall differentiation and increasing food concentration has considerable impact on differentiation rather than on growth. Hence, the observed distribution of settlers and juveniles in the low tide levels where there is frequent inundation, providing food as well higher temperatures (discussed in chapter 5, Fig. 5.5) appears to be the main reason for their high density. Increased temperatures and higher food availability (water chl *a*) actually helps to attain the critical sizes at which vulnerability to physical and biological constraints is substantially reduced (Vermeji, 1987).

Generally the adult population was higher per unit area in *Avicennia* mangroves compared to other mangrove species. However, no evidence was found as to what mechanisms are responsible for the non – random, plant – specific distribution of adult *P. erosa* population in the *Avicennia* zone of the mangrove forest. Among invertebrates, examples of positive chemical cues for settlement include gregarious settlement of larvae using chemical cues released by adults (Zimmer-

Faust and Tamburri, 1994; Welch et al., 1997). Nevertheless, why *P. erosa* is distributed in *Avicennia* region is not known. This type of behavior (habitat selection) is assumed to be a response to the habitat itself (Leber, 1985), but the underlying advantage may be in terms of any of the several ecological factors, including increased living space and food availability. Therefore, it is possible that *P. erosa* may respond directly to such or any other factors. However, given that a variety of factors may be involved, several possible mechanisms have been proposed. In such cases predation is the most likely explanation. The clam's ability to live relatively high up in the intertidal zone may limit predation by most species. Post-settlement predation has been demonstrated to be major structuring force in soft-sediment environments (Gosselin and Qian, 1997). Therefore, predation may play a role in limiting recruitment in mid and lower intertidal zones. Juvenile macrofauna generally live close to the sediment surface and are often particularly vulnerable to predation by epibenthic organisms (Hunt and Scheibling, 1997). They are also vulnerable to ingestion by deposit feeders (Elmgren et al., 1986). However, there is not enough information about the interaction between the mangrove clam and deposit feeding species occurring in the mangroves to accurately determine the role this interaction plays in mediating community level impacts. The importance of predation is yet to be tested for *P. erosa* in the Chorao island. Furthermore, to date no specific predator of *P. erosa* has been identified and documented. Physical properties associated with the substratum may also be important. Settlement preferences have been demonstrated for variations in the contour, texture and thermal capacity of substrata (Raimondi, 1990; Walters and Wethey, 1991) grain size of sediment (Gray, 1974), sediment cover (Hodgson, 1990), and water flow next to the substratum (Wethey et al., 1988). However, studies by Mihm et al., (1981); LeTourneux and Bourget (1988) showed that for most species, the importance of physical aspects of the substratum appear to be secondary to biological and chemical characteristics.

If the absence of vegetation was the only problems for the clams, then the mid-tide region should have provided the ideal situation with mangrove vegetation. Typically very few or no clams were observed at this tide level. An observation worthy of consideration here is that the mid- tide level is dominated by *Rhizophora* species. The most probable explanation for the existence of the clam *P. erosa* with *Avicennia* species seems to be either a coincident that both prefer same habitat with similar characteristics or there is some characteristic associated with *Rhizophora* species that deters these clams from settling near them and there is something related to sediments inhabited by *Avicennia* that attracts *P. erosa* to settle in the *Avicennia* zone. However, both these aspects need more detailed investigation. Nevertheless, studies have shown that the distribution of organisms differs in relation to plant species. Mangrove soils are sulphidic in nature (Alongi et al., 1993) and different mangrove forests differ in sulphide concentration because the roots (pneumatophores) of some species of mangrove can oxidize the surrounding soils while others do not have this ability (Lacerda et al., 1993). *Rhizophora* species can survive better in mangrove soils having high sulphides but *Avicennia* species are less tolerant to sulphide (Kathiresan and Bingham, 2001). Studies have shown that the rhizosphere of *Avicennia marina* is highly oxidized with virtually complete absence of sulphide (Lyimo et al., 2002). *A. germinans* is able to bring air to roots growing in anaerobic substrate through its root aerenchyma (Scholander et al., 1955). Although not investigated, it appears that sulphide concentrations probably must be lower in the sediments near *Avicennia* compared to *Rhizophora* and hence offer better habitat *P. erosa.*

Different types of bacteria inhabit the mangroves, such as sulphur bacteria, methanogenic bacteria, iron oxidizing and iron reducing bacteria (Panchanadikar, 1993). The sulphate reducing bacteria reduce the activity of methane producing bacteria. Methanogenic bacteria are abundant in sediments where *Avicennia* species dominate (Mohanraju and Natarajan, 1992). The composition of microbial communities living within the sediments may influence the settlement and

distribution of soft-sediment fauna (Snelgrove and Butman, 1994). Many bacteria live symbiotically with bivalves thriving in extreme conditions such as mangroves and deep-sea hydrothermal vents (Dame, 1996). The members of bivalve family Lucinacae have endosymbiotic sulphur-oxidizing bacteria in sulphide-rich muddy mangrove areas (Kathiresan and Bingham, 2001). Since, methanogenic bacteria are abundant in *Avicennia* dominated areas (Mohanraju and Natarajan, 1992) and *P. erosa* also prefers the same area and is able to cope with the extreme conditions of prolonged emersion, it can be speculated that this clam might be having methanogenic bacteria as endosymbiont which helps the clam to survive during prolonged emersion. The distribution of *P. erosa* around the *Avicennia* mangroves may be therefore attributable to differences in the composition of microorganisms that inhabit the sediments.

The density of *P. caroliniana* in different tidal marshes of the Cape fear estuary, North Carolina is known to differ only with plant species composition (Capehart and Hackney, 1998). Plant roots affect infaunal marsh species through root exudates or by removal of water from the substrate as a result of evapotranspiration (Capehart and Hackney, 1989). In the case of *Spartina alterniflora,* the potential for a microoxidized zone around root tips has been made (Teal and Kanwisher, 1966), which when combined with the large quantities of water removed from sediments (Dacey and Howes, 1984) creates a very different chemical environment in the sediment. There are many other compounds that may be extruded by living plant roots. However, such processes in the mangroves and their impact on *P. erosa* are not known. Moreover, based on the limited data set, generalizations cannot be made about the importance of a specific mangrove plant species to the distribution of this clam. Only large data sets from a variety of mangroves in different geographic areas will help to understand the role of a particular mangrove species in structuring the *P. erosa* community.

CHAPTER 8

BIOCHEMICAL COMPOSITION OF *P. EROSA*

8.1 Introduction

Some food species are regularly used as a subsistence food source because of their abundance. If such species are to be considered for commercial use, it is important to take into account whether it has the potential to be used as a food source. Molluscs, especially bivalves provide good scope for developing new food resources in the estuaries and backwaters.

In India, the development of molluscan fisheries is very important especially in Goa, where almost 90% of population relishes seafood. During southwest monsoon when fishing in the open sea is suspended due to inclement weather, clams, oysters and mussels substitute marine fishes. These include the mangrove clam *P. erosa* also, though its local fishery is restricted to only the mangrove-surrounding areas. Artisanal fishery of *P. erosa* is a main activity in many islands of the tropical and sub- tropical region and some times is the major and only source of proteins in their diets (Muller, 2003). In addition to its food value, studies have shown that *P. erosa* is also a potential source of antiviral drug (Chatterjee et al., 2002). These attributes lend a high potential for commercial exploitation of this clam species.

There is a copious amount of literature available on the biochemical composition of bivalves, which points towards the fact that interest in bivalves as food for man existed for ages. Seasonal changes in the biochemical composition of bivalve molluscs have been widely studied in species in their natural habitat. Information on the seasonal variation in biochemical composition of bivalves can be found in the works of Beninger and Lucas (1984); Baker and Hornbach (2001); Wenne and Styczynska-Jurewicz (2004). Biochemical composition of different marine bivalves from Indian coasts has been studied by Rahaman (1965); Nagabhushanam and Mane (1978); Laxmanan and Nambisan (1980); Jayabala and Kalyani, 1986). No study to date, however, has been reported on the biochemical aspects of *P. erosa*, inspite of the fact that *P. erosa* has been eaten

traditionally by the local people (Ingole et al., 1994). The only work on the biochemical composition of bivalves belonging to the genus *Polymesoda* worldwide cited in the literature is by Ruiz et al. (1998) and Hiong et al. (2004).

In general, variations in biochemical composition are closely related to the reproductive cycle, as emphasized by studies seasonally carried out in various species of bivalves (Berthelin et al., 2000). Several authors have shown that seasonal variation in biochemical composition of molluscs is directly dependent on environmental parameters such as temperature, available phytoplankton and factors such as timing of reproductive cycle and rate and turnover of stored energy (Beningar and Lucas, 1984). Studies with same species in different areas have shown that the pattern of biochemical parameters is quiet similar in two different places; highlighting the pre-dominant role played by the reproductive and physiological characteristics of the species.

Many studies of marine invertebrates show that the reproductive cycle, environmental conditions and quality and quantity of available food are reflected by weight variations and by the biochemical composition. The nutritional and energy demands of marine animals are not constant and are affected by endogenous factors such as energy demands for production or converted into various biochemical components. Lipids represent an important energy reserve because of their high calorie contents; they are mainly used in chronic stress conditions. Proteins, the most abundant biochemical component tissues may be subjected to metabolic transformations, although they do not undergo such high accumulation processes as lipids and carbohydrates (Gabbott, 1976). The lipids and glycogen are both substances of energy reserve and studies of energy metabolism involve with the ways in which an organism uses major carbohydrates, lipids and proteins to produce energy. Most determinations of the biochemical composition of marine bivalves have been concerned with gross changes in protein, lipid and carbohydrate contents.

The present work is aimed to evaluate the gross biochemical composition and energy values in *P. erosa* population from the Chorao Island. In the present study, the total protein, lipid and carbohydrate contents were measured. An overall physiological status of the clam population studied was also obtained by evaluating the Condition Index (CI), which is recognized as a useful biomarker able to reflect the ability of bivalves to withstand adverse natural/or anthropogenic stress. (GSI): Since reproductive cycle is the most important parameter, Gonadosomatic Index (GSI), which gives a general status of the reproductive cycle, was determined.

8.2 Materials and Methods

On an average about 15-20 clams were used every month for the analysis of total proteins, lipids and carbohydrates. Clams were collected monthly from July 2004-July 2005, randomly by handpicking from a marked area of ~350 km^2. After sampling, the clams were transported to the laboratory and placed in running water for 2-3 hours in order to purge mud and pseudofaeces from their gut contents.

- The clams were grouped in different size classes of 10 mm interval. The intact bivalves were washed and blotted dry
- The total length, width and height were measured. All measurements were made to the nearest 0.1 mm using Vernier callipers
- Total weights to the nearest 0.01 g were determined after drying the shell with paper towels and after blotting the excess fluid
- Sexes were determined based on the colour of the gonads. It is black in female and creamish white in males
- The wet tissues were blotted and their weight was measured to the nearest 0.01g. The dry weights of the tissues were recorded after drying the tissues in the oven (60°C) to a constant weight for 72 hours.

The above parameters were determined from the soft tissue by following standard methods:

8.2.1 Protein

Total protein was estimated colorimetrically using the Folin-phenol method (Lowry et al. 1951). Absorbance was read at 750 nm, calibrated against a blank solution. A standard curve of Bovine Serum Albumin (BSA) was run concurrently.

Principle

The phenolic group of tyrosine and tryptophan residues (amino acid) in a protein will produce a blue purple color complex, with Folin-Ciocalteau reagent, which consists of sodium tungstate molybdate and phosphate. Thus, the intensity of color depends on the amount of these aromatic amino acids. Most proteins estimation techniques use Bovin Serum Albumin (BSA) universally as a standard protein.

Procedure

For standard

Different dilutions of BSA solutions were prepared, by mixing stock BSA solution (1mg/ml) and 1N NaOH. From these different dilutions, 1 ml was diffused to different test tubes and 2 ml of alkaline copper sulphate reagent (analytical reagent) was added. The solutions were mixed well and incubated at room temperature for 10 minutes. To this, 0.5 ml of reagent Folin-Ciocalteau solution (reagent solutions) was added to each tube and incubated for 15 min for colour to develop (blue colour). Colorimeter was zeroed with blank and the optical density was read at 750 nm.

For samples

For 10 mg of sample, 1 ml of 1N NaOH was added and the mixture was kept in a water bath for half an hour. Then 1 ml of 1N HCL was added and centrifuged at 2000 rpm for 10 minutes. From this, 1 ml of supernatant was taken and the same procedure as for the standards was run.

8.2.2 Carbohydrate

Carbohydrate was measured colorimetrically using phenol-sulphuric acid method (Dubois et al., 1956). Absorbance was read at 490nm calibrated against a blank solution. A standard curve of glucose was run concurrently.

Principle

The phenolic group of tyrosine and tryptophan residues (amino acid) in a protein will produce a blue purple color complex, with Folin-Ciocalteau reagent, which consists of sodium tungstate molybdate and phosphate. Thus, the intensity of color depends on the amount of these aromatic amino acids.

For standards

Different dilutions of glucose solutions were prepared by mixing glucose powder and water (1 mg/ ml). To 1ml of each of these dilutions, 2 ml of 80% concentrated H_2SO_4 (analytical reagent) was added, mixed well and incubated at room temperature for 1 hour. Then 2 ml of 3% Phenol reagent solution was added to each tube and further incubated for 30 min. The colour change from yellowish to brown was read on colorimeter with optical density at 490 nm.

For sample

For 10 mg of sample, 2 ml of 80% concentrated H_2SO_4 was added and kept at room temperature for 1 hour after well mixing. From this, 1 ml of solution was taken and the same procedure as for the standards was run.

8.2.3 Lipid

Lipid was estimated from a pre-weighed amount of tissue (approx. 10mg) using Chloroform–Methanol extraction method of Folch et al., (1956) and measured gravimetrically.

Procedure

For 10 mg of sample, 10 ml of Chloroform–Methanol mixture (1:5) was added in and grounded in a pestle and mortar. The mixture was then transferred to a test tube and let it stand for 10 minutes for settling. The contents were filtered into another test tube and allowed to stand for 20 minutes. To this solution, 5% Kcl solution was added using a bulb dropper (this separates the non-lipid layer - the top layer). The upper layer was discarded and the lower phase was transferred to pre-weighed test tube and dried in an oven for 1-2 days. The test tube with lipid was weighed and the weight of the test tube was subtracted from the latter. This will give the lipid content.

8.2.4 Data analyses

Following Ansell (1972), the biochemical data has been converted by application of the calorific factors to give values for the calorific content of the tissues of *P. erosa*. Percentage of water content was calculated as a difference between the wet and dry weight of tissue. Linear regressions were used to determine the possible relationship between the biochemical content (protein, carbohydrate, and lipid) and the size of the clams (TL). As biochemical content (protein, carbohydrate,

and lipid) were found not to be related to the size of the organisms analyzed in this study, an ANOVA was performed to evaluate the null hypothesis of no difference between seasons in the biochemical content in the clams. The assumptions of normality and homogeneity of variances were tested, and the appropriate transformations were applied when necessary (Sokal and Rohlf 1995; Zar 1984). Pearson's correlation was calculated between absolute values of all biochemical variables and condition index, dry weight and salinity, temperature and chlorophyll.

8.3 Results

Carbohydrates, proteins and lipid content (expressed as percentages of the flesh dry weight) are given in figure 8.1. Regression of total proteins, lipids and carbohydrates with the shell length did not yield any significant results (Table 8.1 and Fig 8.2 to 8.4). So also when the biochemical components were analysed in different size classes, no significant differences were found ($F=2.435, df=23, p=0.111$; Table 8.2 and Fig 8.5), however, all these components varied between months over the study period with a statistically significant difference ($F=35.94, df=61, p<0.001$; Table 8.2). Pearson's correlation matrix for gross biochemical composition, dry tissue weight, Condition Index, Gonadosomatic Index, water chl *a*, temperature and salinity is given in table 8.3.

The sexes in all the specimens observed were easily distinguishable. Since reproductive cycle is the most important parameter that affects the biochemical composition, Gonadosomatic Index (GSI) was determined as a measure of the reproductive status. Though GSI measure changes in the overall morphology of the gonad, it cannot provide information on cellular changes. Measuring temporal changes in GSI is a method commonly used to identify spawning events detected by significant decreases in the mean GSI between consecutive sampling months. From the GSI, it is revealed that between Oct 2004 and Jan 2005, the gonads of *P.*

Table 8.1: Relationship of shell length (TL) and biochemical components of *P. erosa*

Relationship	n	a	b±SE	r^2	F*
Length (mm)					
Protein vs Length	12	5.824	-4.4205 ±1.431	0.008	0.076
Carbohydrates vs Length	11	0.308	0.999±0.802	0.4370	9.536
Lipids vs Length	12	2.546	-0.305 ±1.110	0.147	1.552

Table 8.2: Results of ANOVA for effects of months and size classes on the biochemical composition of *P. erosa* from Chorao island

Abundance					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***
Size class	55.725	2	27.8629	2.4353	p>0.05
Residual	240.266	21	11.44127		
Months	2747.322	5	549.464	35.9363	p<0.001
Residual	1009.137	66	15.289		

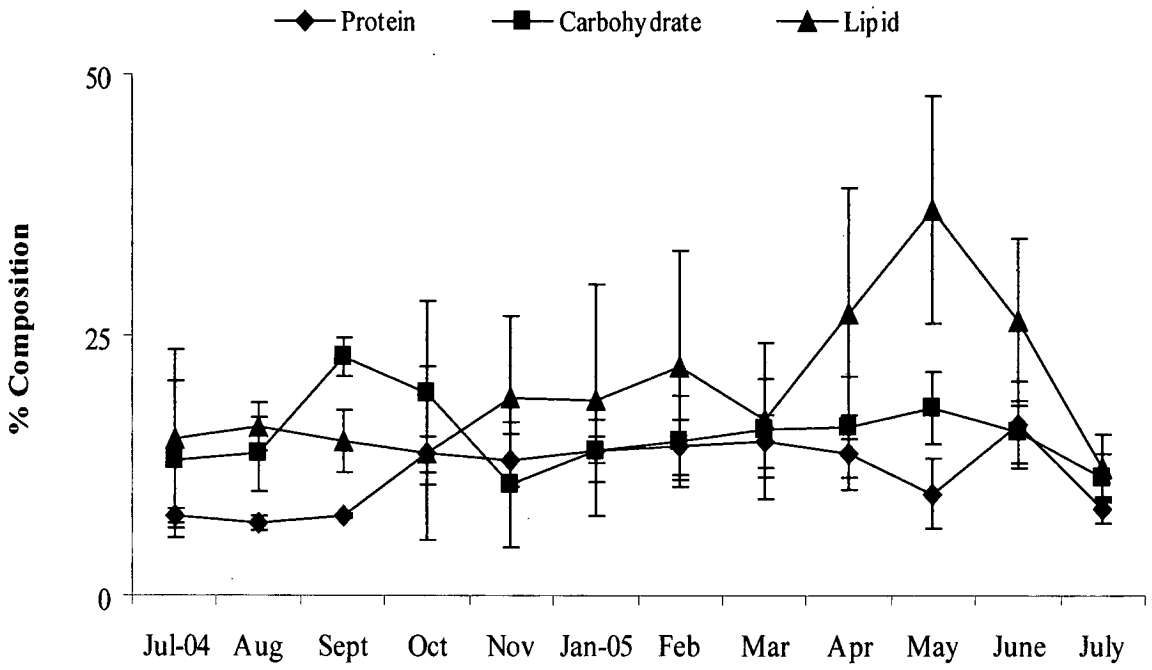


Fig. 8.1: Monthly variations in gross biochemical composition of *P. erosa*

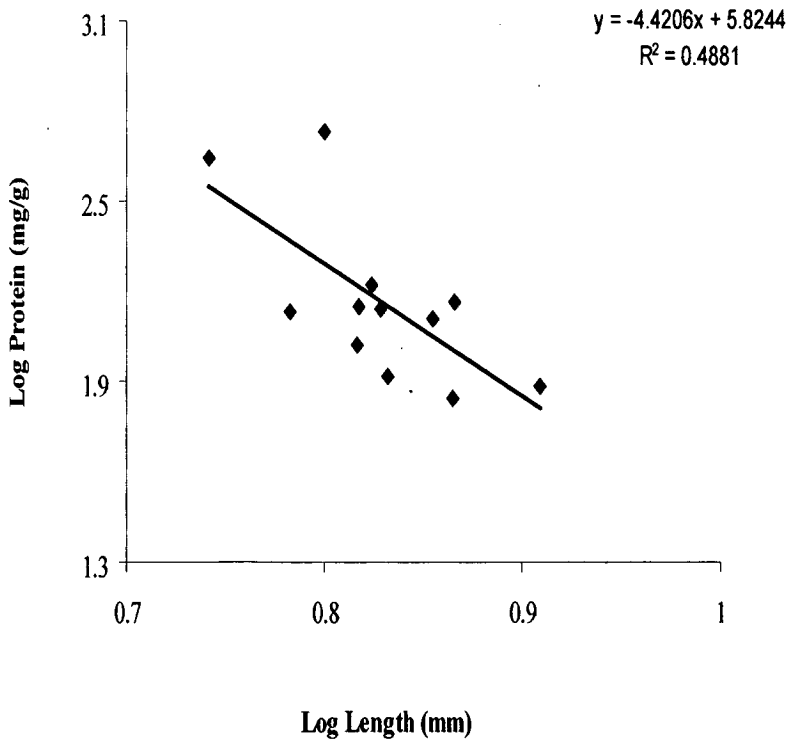


Fig. 8.2: Regression between proteins and shell length of *P. erosa*

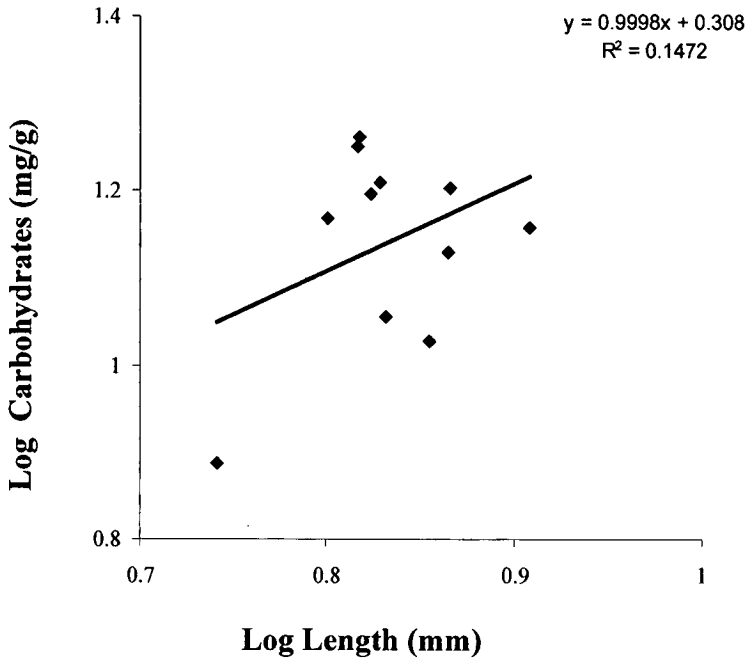


Fig 8.3.: Regression between carbohydrates and shell length of *P. erosa*

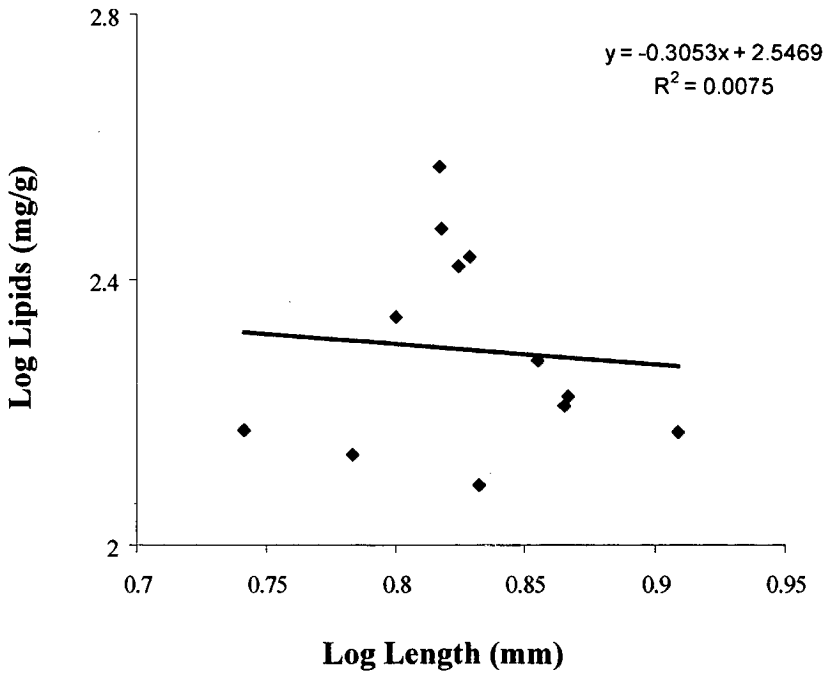


Fig 8.4: Regression between lipids and shell length of *P. erosa*

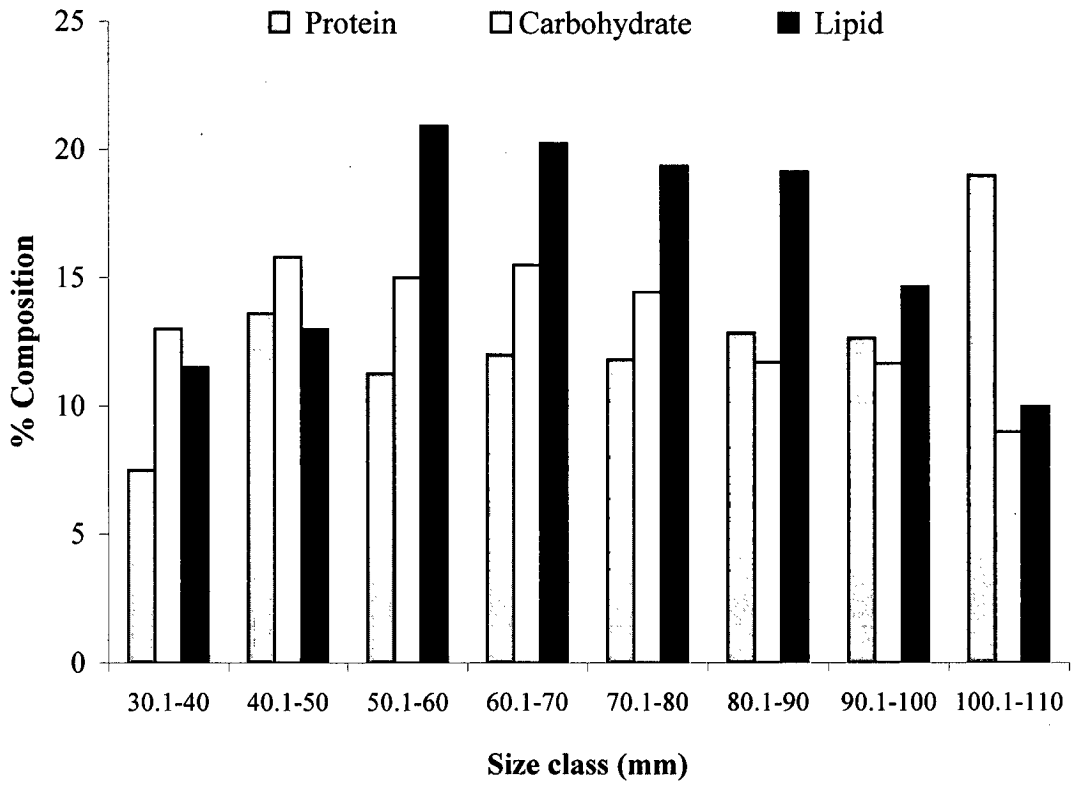


Fig. 8.5: Biochemical composition in different size classes of *P. erosa*

erosa were not well developed and maturation was not yet initiated. However, there was rapid increase in the number of individuals with fully developed gonads from Feb 2005 and in the population as a whole. This increase continues until Aug 2005 when there is a sudden fall in the number of developed gonads. There is a rapid increase in the maturation of the gonads in *P. erosa* between Jan and May 2005 (Fig. 6.3).

8.3.1 Condition Index

The condition index varied in different months with a statistically significant difference ($F=8.58, df=150, p<0.001$) corresponding to the variation in the biochemical components. The average condition index (CI) in different months varied from 1.9 in Sept 2004 to 4.7 in Mar 2005. The CI showed the lowest value in Sept 2004 (Fig. 8.6). Thereafter, withstanding the slight fall in September 2004 it remained fairly high. In each length group the range of variation and the mean of CI were more or less same over the length range studied. Analysis of variance showed that the CI between the length groups is not significantly different ($F=1.385$, $df=52$, $p>0.05$). In other words, the CI does not vary with growth.

8.3.2 Changes in body weight

Seasonal changes in body weight (dry wt.) are summarized in figure 6.5. Body weight is low from the end of Jan 2005 to June 2005 whereas, in the month of Aug 2005, the weight fell to the minimum observed for the annual cycle. During Feb 2005 – May 2005 there was a rapid increase in body weight, the dry weight rising to a peak in Mar 2005 (2.7 mg) representing an increase of 12.3 %. The sexes became easily distinguishable at a fairly advanced stage with this increase, but it was accompanied throughout by a gradual proliferation and differentiation of the gonad. The dry weight decreased by July 2004, mainly due to spawning, and reached its minimum in Aug 2004 resulting in an abrupt drop in body weight.

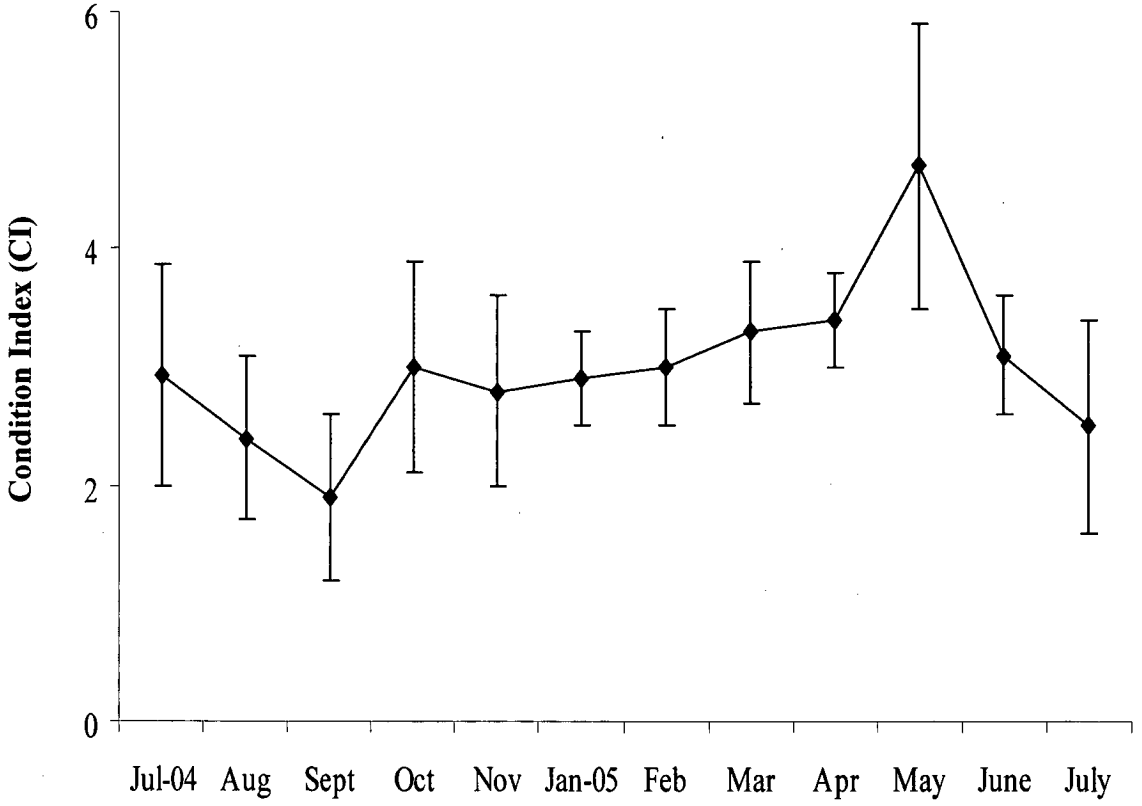


Fig. 8.6: Monthly variation in the Condition Index (CI) of *P. erosa*

Following spawning there was again although not regular, a slow increase in body weight from Sept 2004 to Jan 2005. The result for the *P. erosa* samples taken in Oct 2004 appears anomalous; apparently suggesting that the dry weight of the clams continues to decrease even it increased in Sept 2004. The probable reason for this could be that most of the specimens collected in Oct 2004 were in the spawning phase.

As depicted in figure 6.3, GSI values were low in Aug (22.1) and Sept 2004 (24.0), which confirms the major spawning that occurred during this time (as discussed in chapter 7). There was an increase in the number of individuals with ripe gonads that is reflected in the values of GSI and this increase continues with minor variations until Aug 2004, when there is a sudden fall in the number of ripe animals, marking the end of the reproductive period. There is a rapid maturation of gonads in *P. erosa* between Jan 2005 and Apr 2005, which is again confirmed by the high GSI observed for these months with the peak value of 39.4 in Apr 2005 and similarly rapid decline in maturity and ripeness between Aug-Sept 2004. These two periods closely correspond with periods of maximum increase in dry tissue weight in summers and decrease in tissue weights between Aug and Sept 2004, the latter decrease being accompanied by a great uptake of water into the tissues as the gonad regresses leading to maximum values of water content.

8.3.3 Relationship of tissue weight changes to the reproductive cycle

The difference in wet and dry weight estimated as the amount of water present suggested that, summers is accompanied by a decrease in water content (Fig. 6.6), while, thereafter increases in water content reflect spawning activity during Aug – Sept 2004. Changes in the CI are shown in figure 8.6. The changes as would be expected reproduce closely the cycle in percent dry tissue weight. Higher values were observed from Oct 2004-May 2005, decreasing progressively from

2004 to June 2005 when the minimum was reached. However, in July 2004, the CI was almost equal to that of Oct 2004.

8.3.4 Biochemical components

The correlation matrix (Table 8.3) showed the relationship between the absolute values of all biochemical components and both the condition index and dry weight of the clam and salinity and temperature. It is worth noting that, except lipids none of the biochemical variables were significantly correlated with salinity and temperature over the sampling period. Lipid content was strongly related with estuarine water salinity ($r=0.6165$, $p=0.033$; Fig. 8.7) as well as chl *a* ($r=0.5764$, $p=0.054$; Fig 8.8). The very close correlation of lipids with CI is worthy of note ($r=0.749$, $p=0.005$; Fig 8.9). Similar correlations of biochemical components have been observed for other bivalves (Mann, 1978; Beninger and Lucas, 1984). Percentage composition of different biochemical components is given in figure 8.1. Among the different components, carbohydrates were highly variable. The increase starts in Jan 2005 and continues until a peak is reached in June 2005 (19.4 %). A minimum value for carbohydrates is observed in Nov 2004 (10.6 %). Lipids were characterized with the presence of two peaks, one in Jan 2005 (32.3 %) and another in May 2005 (37.1 %) both followed by a decrease. A minimum was observed in July 2005 (12 %). Proteins showed the least variation during the study. The seasonal pattern of protein content showed monsoon minima (7.0 %) observed in Aug 2004 and a summer maxima (14.7 %) in Mar 2005. The lowest values were recorded from July 2004 Sept 2004 and again similar values were observed in July 2005. The total calorific content varied between 2.1 and 4.8 Kcal/g. dry wt. of soft tissue. The lowest values were observed in July 2005 increasing from Jan 2005 to June 2005 to a maintained high level from Apr 2005 to June 2005, after which it fell rapidly. There was little seasonal change in the calorific content although the highest values were found in Apr 2005 - May 2005, coinciding with the maximum lipid content of the tissues. The calorific content

Table 8.3: Pearson's correlation matrix for gross biochemical composition, dry tissue wt, Condition Index, Gonadosomatic Index, water Chl *a*, temperature and salinity

NS,p>0.05; *p<0.05; **p< 0.01; *** p<0.001

	Chl *a*	Temp	Salinity	Dry tissue wt.	GSI	CI	Protein	Carbohydrates	Lipids
Chl *a*									
Temperature	0.682**								
Salinity	0.865***	0.750**							
Dry tissue wt.	0.806**	0.727**	0.804***						
GSI	0.726**	0.739**	0.593*	NS					
CI	0.0784**	NS	0.726**	NS	0.669**				
Protein	NS	NS	NS	NS	NS	NS			
Carbohydrates	NS	NS	NS	NS	NS	NS	NS		
Lipids	NS	NS	0.616*	NS	NS	0.749**	NS	NS	NS

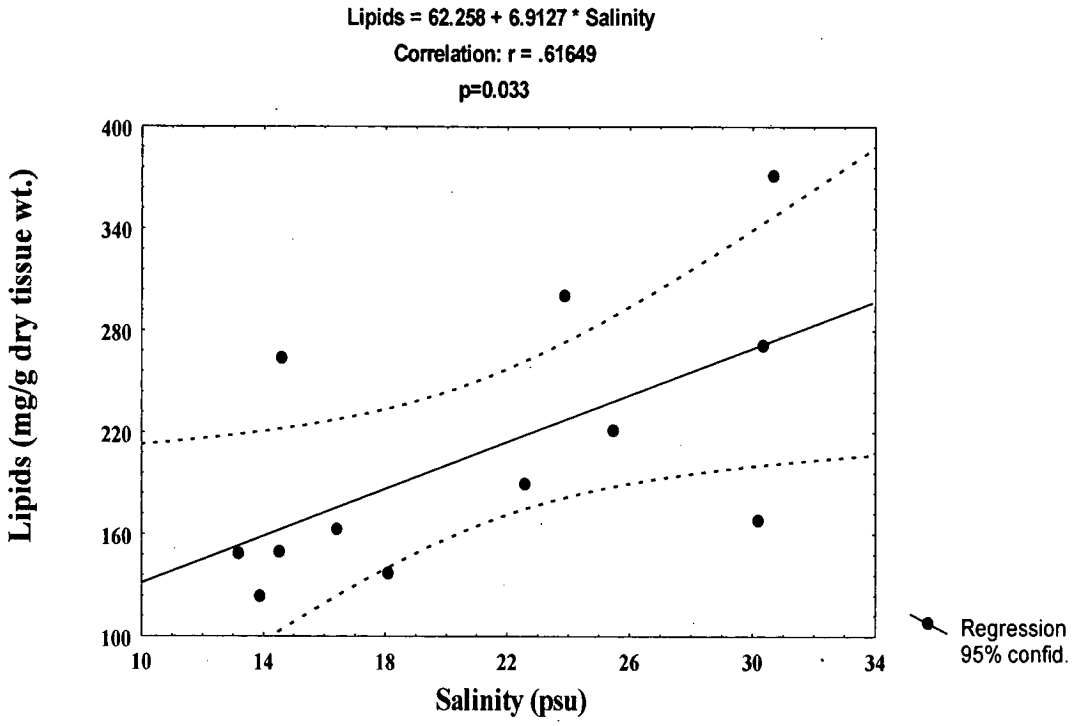


Fig. 8.7: Relationship between lipid content of *P. erosa* and salinity of the estuarine water

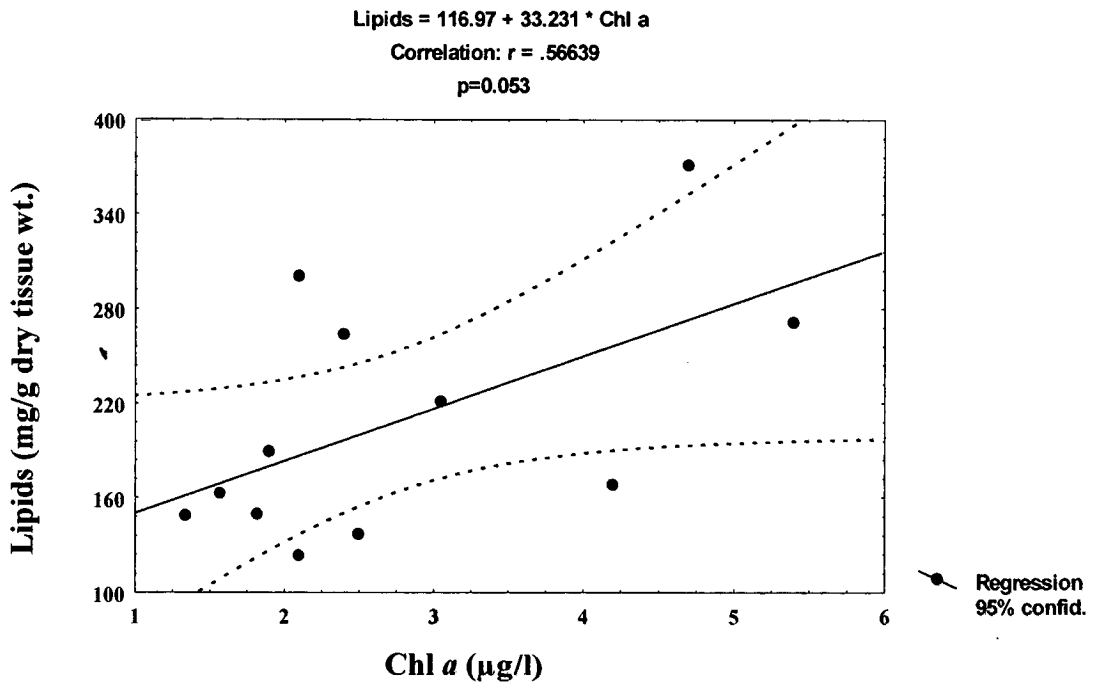


Fig. 8.8: Relationship between lipid content of *P. erosa* and Chl *a* of the estuarine water

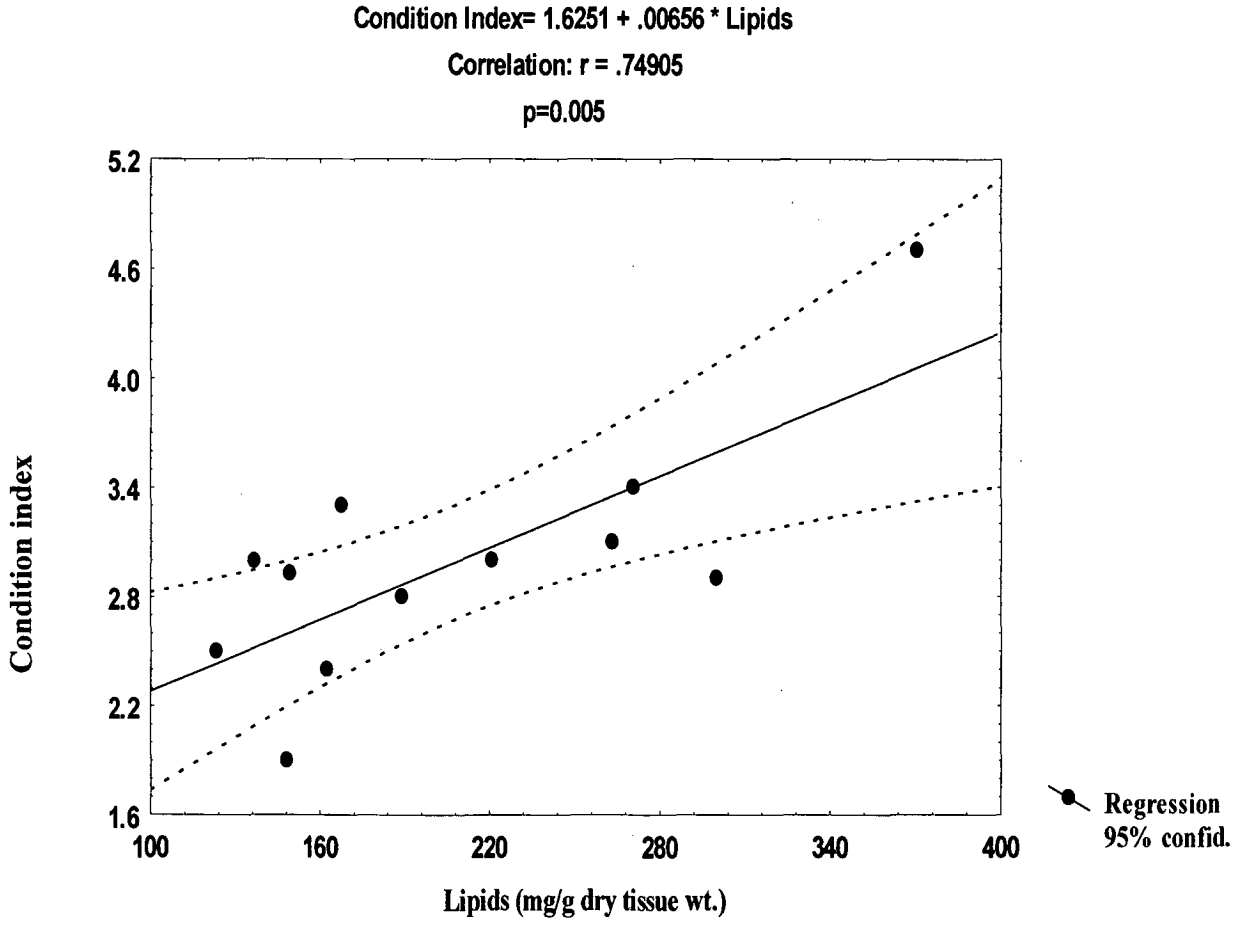


Fig. 8.9: Relationship between lipid content and Condition Index (CI) of *P. erosa*

decreased in July and then increased rapidly to a pre-spawning peak in May 2005. The mean calorific value varied between 3.1 and 5.9 Kcal/g dry wt. (mean: 4.1±0.8 sd Kcal/g.dry wt.) with clear seasonal changes. The total calorific content of *P. erosa* was lowest in the monsoon (July), increased between Nov and May to a maintained high level between Mar to May and thereafter decreased rapidly (Fig. 8.10).

8.4 Discussion

In the present work, good agreement can be found between the pattern of biochemical parameters, condition index and the reproductive cycle. The relative content of protein, lipid, and carbohydrates of *P. erosa* from Chorao island vary seasonally. These changes are principally related to the reproductive cycle. Similar characteristics have been observed in other bivalves such as *Euvola* (*Pecten*) *ziczac* (Lodeiros and Himmelman 2000), *Lyropecten* (*Nodipecten*) *nodosus* (Lodeiros et al., 2001). The high lipid content in *P.erosa* observed here is comparable to that observed in other bivalve species (Lomovasky et al., 2004) thriving in extreme environmental condition, as is the case in the present study. The pattern of lipid variation corresponds to that previously observed in other marine bivalves (Beukema and De Bruin, 1979; Ansell et al., 1980). In all the cases cited, maximum levels corresponds to the maturation period, reflecting the fact that lipid is a major component of bivalve oocytes (Morriconi et al. 2002; Lomovasky et al., 2004). The reproductive cycle of *P. erosa* showed the presence of mature gonads for major part of the year in both sexes, corresponding with the high levels of lipid content around the year. However, the number of males and females in the *P. erosa* population were equal collected at a given time from Chorao Island (as discussed in chapter 3.5).Hence, the possibility of high lipid content only due to the mature females in the population is ruled out, although lipids tend to accumulate as a major component of oocytes in females and can be attributed to the survival strategy of this species in mangrove habitats. The

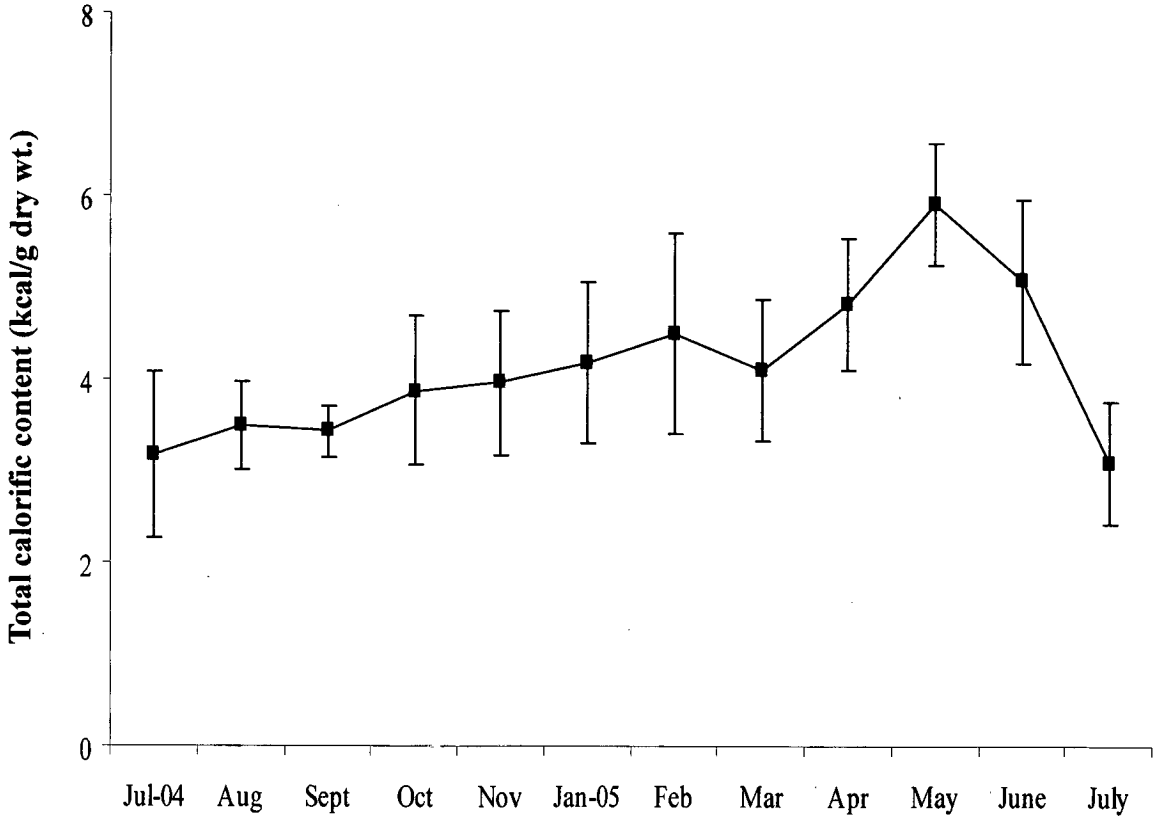


Fig. 8.10: Monthly variation in the calorific content of *P. erosa*

importance of lipid as a storage product may be especially acute in variable environments (Gallagher et al., 1998). It was also confirmed from the significant positive relationship between lipids and salinity (r=0.6164, p=0.033). As discussed elsewhere, the growth of *P. erosa* in terms of weight is directly dependent on chl *a* content as *P. erosa* feeds on phytoplankton (discussed in chapter 4). Studies in highly seasonal (pulsed food supply) systems have shown annual cycles in lipid content of long-lived benthic invertebrates (Hopkins et al., 1993). Furthermore, *P. erosa* is an oligohaline species with a reduced ability to tolerate freshwater (Morton and Chan, 1990). According to Beninger and Lucas (1984), lipids form part of the reserves during periods of nutritional deficiency. Lipids represent an important energy reserve because of their high calorie contents; they are mainly used in chronic stress conditions, whereas glycogen reserves are generally used during gametogenetic processes when lipids are not available, (Gabbott, 1976). *P. erosa* is always found at the highest tide level, which is only inundated during very high spring tides, consequently the clams may be feeding only during inundation, surviving on the energy reserves during the exposed period. Moreover, glycogen also has been long recognized as the principle energy reserve in juvenile and adult bivalve, under unfavorable environmental conditions (Beukeme and De Bruin, 1977).

The increase in carbohydrates in May and September in the present study comply well with earlier findings of carbohydrate increase immediately preceding and during gonad maturation (Ansell et al., 1980). Variations in carbohydrate content show an inverse relationship with the state of gonad maturity (Martínez et al., 1993). As can be seen from figure 8.1, following the spawning event in Aug 2004, there was a sudden increase in carbohydrates in Sept 2004. While discussing the biochemical composition of *Meretrix meretrix*, Nagabhushanam and Deshmukh (1974) showed that glycogen content was related to gonadal development with maximum values observed during gonad maturity.

In most bivalves, the protein content level remains relatively high except during the breeding season (Deshmukh, 1972). In the present study, among the three components, the protein content was much lower than the lipids and carbohydrates and showed the least fluctuation (Fig. 8.1). Proteins, the most abundant biochemical component in tissue, may be subjected to metabolic transformation, although they do not undergo such high accumulation processes as lipids and carbohydrates. As described, the proteins showed the lowest values throughout the year, suggesting that it did not have an important function as substrate for energy reserves in *P. erosa*. While discussing the biochemical composition in *Euromahlea exalbida*, Lomovasky et al. (2004), also suggested that low glycogen content in the bivalve was due to its inability to use glycogen as a substrate.

The maxima in gonad weight was observed during Mar 2005 – Apr 2005 could be correlated to the peak in phytoplankton (indexed as chl *a*) in Feb 2005 (Fig 6.11). At this time the animals may be having surplus energy to allocate for their metabolism as well as gamete development. According to Sastry (1979) and Navarro et al. (1989) gonadal changes are related to energy supply either directly from the ingested food or from previously stored reserves. Under conditions of positive energy balance, the amount of food ingested provides sufficient energy for both metabolic consumption and the accumulation of reserves (Camacho et al., 2003). Maturation and high GSI were observed to begin during the warming of water in the summer months (Fig 6.13). The GSI was highest, especially at the end of Mar 2005 when ripe individuals were observed and lowest GSI values were recorded during Aug 2004 – Sept 2004, due to spawning. Howeve the recovery of gonads commenced immediately in Oct 2004. In general, changes in each biochemical component are closely linked to the state of sexual maturity of the mollusc (Sastry, 1979; Navarro et al., 1989). The calorific values recorded for *P. erosa* in the present study (Fig. 8.10) is comparable with edible bivalves studied (Beninger and Lucas, 1984; Baker and Hornbach, 2001).

In some bivalves the Condition Index (CI) in relation to length/volume varies significantly (Narasiham, 1984). However, in *P. erosa* the Condition Index (CI) did not vary in different length groups indicating that the proportion of meat weight to total weight is uniform during growth. The CI values were low during the spawning period with high values during the summer months when the gonads are in the maturing stages. According to Lucas and Beninger (1985), a low CI value indicates that a major biological effort has been expended either as maintenance of energy under poor environmental conditions or disease or in the production and release of gametes. From the correlation of CI with lipids, it can be suggested that the energetic variations in CI observed in *P. erosa* could principally be related to the lipid content variations produced by gamete emission in monsoon and gamete maturation in the summer season (Morriconi et al., 2002). Moreover, this type of index is a superior indicator of physiological condition, than those based on the ratio of dry flesh weight to internal shell volume, as these have been shown to be poorly correlated with some gross biochemical component levels (Beninger and Lucas, 1984). The CI has also been shown to be positively related with salinity (Table 8.2) and as described above, phytoplankton tend to positively correlate with salinity. Ansell et al. (1980) reported that, the differences in CI are mainly due to the differences in the seasonal availability of phytoplankton. In the present study, lipids are shown to reflect the CI, which is ultimately influenced by chl *a* ($r=0.576$, $p=0.054$; Table 8.2). Thus, it appears that lipid is the major biochemical component of *P. erosa*. Lipids provide twice the reserve energy than carbohydrates under prolonged and severe situations of energy imbalance (Beninger and Lucas, 1984).

It can be concluded, that weight and energy resources (carbohydrates, lipids and protein) decreased during spawning (July 04 - Sept 04), whereas they increased during Jan 05 -May 05, concomitant with the gonadal growth. Consequently, the animal attained their best condition in quality of flesh weight and high-energy

values during Mar 05 - May 05. Considering the large size of the clams (>100 mm) and high calorific content (4.8 Kcal/g dry wt.), it could be worthwhile to exploit this clam resource on a commercial scale. Further, based on the calorific content and the reproductive status of the clams, it can be recommended that a harvesting season extending from Jan 2005 – Apr 2005 will be profitable for *P. erosa* at Chorao Island. As discussed in the preceding chapters, *P. erosa* can withstand long periods of desiccation, which is a major asset when considered for commercial fishery, as bivalve mortality is typically high during, transfer from the site to the market.

CHAPTER 9

CONCLUSION

closing the shell prevents water loss from the tissue. A large volume of water is maintained in the mantle cavity due to which the soft tissue is maintained small in size compared to the whole clam size. The optimum temperature for this clam appears to be 24°-30°C and can regulate temperature changes above 5°C normally. However, they are intolerant to extreme cold temperatures, which could be one of the primary limiting factors in its tropical distribution. It is an oligohaline species with optimum temperature range from 24° to 30°C, with a reduced ability to tolerate freshwater. Consequently *P. erosa* can be considered as a member of a marine group that has adapted to brackish water. Optimum pH range is 6.3-8.4. Growth of *P. erosa* in terms of meat weight fluctuates closely in relation to phytoplankton (indexed as chl *a*). However, high degree of intercorrelation between the environmental parameters suggest that the environment as a whole may have concomitant effects in addition to the direct effect of chl *a*. Gametogenesis in *P. erosa* occurs when both temperature and salinity is high with spawning coinciding with decline in these parameters. A combination of moderate salinity, warm temperatures and a substrate of sand, mud, and vegetation appear to be the most favorable habitat for the mangrove clam.

At all the sites surveyed, adult clams were observed towards the landward side with high density in the high tide level with almost all clams observed in the high tide region inside the *Avicennia* forest. The density of adult clams varied between 1 – 51 individuals/m^2. The lowest density of adult clams, with 1 individuals/m^2 was recorded at Kalbadevi and highest at Chorao island. Among the tide levels studied, adult clams were observed only in the high tide region (HT) with a mean abundance of 9±3 sd clams m^{-2} at Chorao island. One obvious reason for the distribution of clams near the *Avicennia* species could be that both *Avicennia* and *P. erosa* coincidentally prefer similar habitats. The bacterial flora in sediments around *Avicennia* probably is very important for the survival of mangrove clam. However, these aspects need to be studied in details.

P. erosa being a filter feeder serves to link primary producers and secondary consumers in estuarine areas. They are non-selective filter feeders; ingest large quantities of phytoplankton and detritus and thus transform large quantities of plant detritus and phytoplankton into clam biomass. In turn, fishes, crustaceans and birds, depending on the mangrove habitat, consume this biomass. The shells also provide hard substrate for epifaunal attachment such as barnacles and oysters. The soft tissue in *P. erosa* does not change much although the clamshell grows steadily and growth in *P. erosa* in terms of total weight is less variable than growth in soft tissue. The fully-grown shell of this species makes the clams heavier, either because of increased shell mass or a higher amount of water inside the shell. This is related to the survival strategies of the species. The large thick shell constitutes excellent characteristics to inhabit the extremely adverse conditions of the mangroves. The need for strong shells and a high capacity to live in adverse conditions might direct more energy to shell growth than the growth of the soft tissue. Hence, the total weight of the clam should be used as the primary measure of allometric relationships in this species.

The clam appears to grow at a faster rate during early life stage and the growth is considerably retarded in the later period of life span. It is seen that, 0 year/age class individuals of 0-10 mm size, attains a length of 80-90 mm by the end of one year. The estimated life span of *P. erosa* at Chorao mangrove is approximately 4 years but need further confirmation. Sexes are separate in *P. erosa* with no incidence of hermaphroditism. The gonads do not develop in clams with <30mm size. All sizes above 35 mm are sexually matured and only adults can be identified as males and females as there is no sexual dimorphism. In a year class, males are always smaller than females. Sex differentiation takes place at the size of 30-35mm and sexual maturation could occur around 40 mm sizes. Mean shell length (TL) for males and females was 65.8 (±6.5) mm and 69.5 (±6.8) mm, respectively and no significant difference was observed in the mean TL of males and females. Both male and female clams were most abundant in the 60.1-70 mm

disperse is uncertain. Based on the present study, it appears that the larvae are transported to upstream areas in an incoming tide, or by swimming during low flow or both. It is seen that juveniles are capable of selecting substrate for settling and prefer substrates near the *Avicennia* in the high intertidal region. This study adds to our growing understanding of the recruitment processes in soft-sediment habitats. In the absence of earlier data, it can be accepted as the first study that has examined the recruitment of *P. erosa*. Several studies on recruitment of bivalves attribute some of the differences in spatial and temporal abundance of settlers to variation in the supply of larvae in the water column. Differential larval supply has been predicted as an important factor in structuring the populations in environments with calm wave action. This study has shown that differential pattern of the distribution of settlers was due to local hydrodynamic processes and the non-patchy distribution of adults was by relocation of juveniles. However, it has not considered the variation in settlers due to larval supply. Also, paucity of direct evidence for substrate selection by settler's behavior and consequently the importance of juvenile relocation determining the adult distribution are some of the major shortcomings of this study. Generalizations about the importance of juvenile behaviour to the structure of a population need to be done by conducting sediment choice experiments in the field. The significant association of *P. erosa* with a particular sediment type could possibly have been a result of active rejection, rather than active choice of a particular habitat. However, no evidence was found as to what mechanisms are responsible for the non–random, plant–specific distribution of adult *P. erosa* population in the *Avicennia* zone of the mangrove forest, which is beyond the scope of this study. The mangrove clam moves little after settling in the natural habitat, which was also confirmed in the laboratory. It can be suggested that *P. erosa* is capable of vertical movement in the sediment, since they move from the surface into the sediments and remain buried.

Maximum length recorded was 102 mm for *P. erosa* from Chorao island, Goa. The size in *P. erosa* in terms of length does not show any significant relation with the environmental parameters studied. However, the meat weight increases with increase in salinity and temperature, though above a threshold level it is limiting. Clams living in mangrove areas with high abundance of *Avicennia* species were found to be typically larger than those living in a region with low abundance of *Avicennia* species.

This study essays to be useful for the commercialization of *P. erosa* as a food source. Hence, the total proteins, carbohydrates and lipids were analysed for soft tissue. This study indicates that *P. erosa* has a high lipid content (20%) compared to the protein (11%). However, the protein content in this species is more stable making it an ideal species for commercial exploitation. The total calorific content varies between 2.1 and 4.8 Kcal/g. dry wt. of soft tissue with very little seasonal change. The Condition Index (CI) in *P. erosa* does not vary in different length groups indicating that the proportion of meat weight to total weight is uniform during growth. It is seen that weight and energy resources (carbohydrates, lipids and protein) in *P. erosa* decrease during the spawning period (July-Sept), whereas they increase during Nov–May, concomitant with gonadal growth. Considering the large size of the clams and high calorific content, it could be worthwhile to exploit this resource on a commercial scale. Further, based on the calorific content and the reproductive status of the clams, it can be recommended that a harvesting season extending from Dec–Mar prior to gamete maturation, when the somatic growth decreases, will be profitable for *P. erosa*. This species can withstand long periods of desiccation (> 30 days), which is a major asset when considering it for commercial fishery. This aspect is especially important, as bivalve mortality is typically high during transfer from the site to market. However, some aspects of the fishery potential including the stock assessment and resource potential need to be evaluated before commencing the commercial exploitaion. This is particularly very important, as the present study site is a protected area. As a consequence *P.*

erosa population is also protected. Moreover, frequent occurrence of *P. erosa* in the local market indicates the exploitation of this species, probably from other mangroves. It is therefore recommended to initiate a state level resource assessment of this species, which will help in effective utilization and management, if exploited commercially.

Commercializing this species in the future will necessitate continuous supply, either from natural beds or by artificial culture, which demands maintaining the optimum conditions. Hence, choice of location, which provides an ideal environment for the growth, and culturing of *P. erosa* becomes a priority. In this context, the present study can serve to provide basic information about the favorable conditions for optimum growth and survival of this species. In addition, the fact that *P. erosa* is morphologically and physiologically well equipped with adaptations for extreme conditions, would enable the entrepreneurs to be better able to manage even when conditions are extreme, thus making *P. erosa*, one of the sturdiest candidates for aquaculture. However, more information is needed about the ecology of this species as an aid in increasing and maintaining their production. Future research should therefore concentrate on a better understanding of 1) conditions involving recruitment, 2) predation upon the clams, and 3) the ecological requirements related to the sediment characteristics. The present record of the production of this species might be increased by making population-abundance surveys in all the mangrove areas along the west coast as opposed to the limited areas surveyed in the present study, to determine whether high abundances of clams are present elsewhere.

In many parts of the world, *Polymesoda* have occupied a marked place in the affairs of man from time immemorial in his affairs of economy, mind and aesthetic values, religion and rites of worship. Most importantly it forms the major source of protein in their diet. Among the mangrove bivalves, researchers

have collected detailed information on oysters, which is largely due to its food value.

There exist many species such as *P. erosa*, which are sometimes not known that they even exist. In view of declining commercially exploited clam resources it becomes apparent to popularize those species, which are not known to the people other than the locals. This will add a new resource in addition to sustaining the already dwindling clam species. The need to popularize as food very is essential, particularly in a country like India where provision of cheap nutritious food is a long-standing problem and any means to tackle it should be tried. However, despite their economic importance and food value, mangrove clams have received little attention. Available information is not sufficient to meet state wide planning goal, hence the present study should help at least in part in bridging the gap

One of the important diverse groups found in the mangrove habitat is the mollusc which, plays an important role in these systems. The composition of the molluscan assemblage can be used to assess the health of mangroves, as there is a close association (mutualism) between the invertebrate epifauna and mangroves. There is a great need to better understand the effects of environmental change and pollution on mangrove flora and fauna. Animals those are highly dependent on mangroves need additional study so that it can be linked to better management of mangroves. Unfortunately, increased urbanization and agro-industrialization in a major way has led to mangrove destruction. It has reached a point where preservation and conservation of genetic diversity and marine living resources of the mangrove ecosystem becomes imperative. The utilization of mangroves in a sustainable manner, maintaining the ecological processes, life supporting system and protecting such areas with high diversity is the need of the hour. Since *P. erosa* is confined to mangrove habitats, more efforts are needed to conserve this important resource in the light of this changing scenario.

Lastly, each species plays its due role in the conservation of biodiversity. There is hardly any room for neglecting any particular living being. Marine ecosystem is indeed very complex, depending for its delicate balance on innumerable species, each of which has a critical role to play in the food chain. So any deficit or extinction of the species inevitably disrupts or breaks the food chain, adversely affecting, directly or indirectly, the aquatic and terrestrial forms. In the interest of continued existence of mankind, it is therefore essential that *P. erosa* be protected from deficit or extinction. Advocacy and awareness towards their protection should be built up in right earnest, which will require that the resource is understood, carefully managed and protected. Involvement of local communities in conservation and education in wise use of this valuable resource will ensure that this species survives and prospers for the future generations to come.

"Thus the present study, though a small drop in the Ocean of Conservation of Biodiversity, will go a long way in the conservation of *P. erosa* in particular and bivalves as a whole"

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