STUDIES ON THE ECOLOGY OF WADER BIRDS IN THE MANDOVI ESTUARY OF GOA, INDIA.

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........to my parents

.....for developing in me a thirst for Knowledge

..........and a hunger for inquiry.

DEPARTMENT OF ZOOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "Studies on the ecology of wader birds in the Mandovi estuary of Goa, India", submitted by Ms. Sonali Divina Borges, for the award of the Degree of Doctor of Philosophy in Zoology, Goa University, Taleigao Plateau, is a record of research done by her in the Department of Zoology, under my supervision and guidance. The thesis or part thereof has not previously formed the basis of the award of any degree, diploma, associateship, or any other similar titles.

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STATEMENT

This is to certify that the thesis entitled " ***Studies on the Ecology of Wader Birds in the Mandovi Estuary of Goa, India****", is my original contribution and that the same has not been submitted on any previous occasion for any other degree or diploma of this University or any other University/Institute. To the best of my knowledge, the present study is the first comprehensive study of its kind from the area mentioned. The literature related to the problem investigated has been cited. Due acknowledgements have been made wherever facilities and suggestions have been availed of.*

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Sonali Divina Borges

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Sonali Divina Borges

CONTENTS

PREFACE

Wetlands have from time immemorial provided man with a wealth of raw material for his endless needs of food, clothing and shelter, in the process supporting many burgeoning civilizations. The Tigris civilization acclaimed till date, as the 'cradle of civilizations' was one such enormous community that flourished on the Tigris-Euphrates river delta. The most prosperous civilizations of ancient times, the Harrapa and Mohenjodaro civilizations and the Mesopotamian civilization, were the gifts of the Indus and Nile respectively. The vital link between terrestrial and aquatic environments has made wetlands one of the most diverse and productive natural systems of the world whose existence is critical for the survival of many plants and animals that benefit the human race in more than one way. The high productivity of wetlands has made them a goldmine of biological diversity and a natural gene bank of many plant/animal species. Their indispensable contribution to the global diversity has thus made the wetlands one of the important places for conservation of species.

Wetlands have been credited as the lifelines of the global natural equilibrium. They play the critical role of maintaining the water quality by arresting pollutants and other toxic substances, flood amelioration, erosion control, maintenance of shoreline stability, recycling nutrients for the biogeochemical cycles besides sustaining the richest natural resources and microcosms. However, with the burgeoning population, expanding urban limits and rapid industrialization, wetlands have fallen easy prey to man's growing apathy and astute advances. Rapid reclamations of wetlands, paving way for settlements, agriculture, aquaculture, industries and extension of urban limits have taken a heavy toll of wetlands. It was only when the quality of the natural environment began noticeably deteriorating, that an awakening as to their valuable contributions came to light, first in America and then worldwide. Since then wetlands have been gaining increasing importance and have been considered worthy enough for the society to be concerned about their alteration/ degradation.

Waterbirds constitute an integral part of the wetland ecosystem. The wetland definition put forth by Paijmans *et. al.* (1985) and accepted later as the 'Australian Wetland Definition' potrays birds as a prerequisite to define wetlands, in the words, "Wetlands are lands permanently or temporarily under water or waterlogged. Temporary wetlands must have surface water or waterlogging of sufficient frequency and/or duration to affect the biota. Thus, the occurrence, at least sometimes, of hydrophytic vegetation or **use by waterbirds are necessary attributes**". In view of the dictates of this definition, a little more need be said about the dependence of the waterbirds and the wetlands on each other. Estuarine tidal mudflats and sandflats constitute an important wetland type in the tropics of which the waders and shorebirds form an inseparable part. While the mangroves fringing these mud/sandflats provide roosting/nesting sites for both resident as well as migratory waterbirds, the abundant invertebrate fauna of the mud/sandflats provide a nutrient rich food source to thousands of avian denizens, some of which transverse transcontinental boundaries to winter in the tropics (Howes, 1989). The birds in turn, being at the highest level of the trophic pyramid play a crucial role in the mass and energy fluxes between the terrestrial and aquatic food webs.

Goa, the smallest motif on the peninsular map of India, with an area of barely 3,705 Km^2 lies on the western seaboard of the country. The 400 year long colonial Portuguese yoke lifted only in December 1961 had for long starved the state of scientific pursuits, more so ecological inquiry. It was only in the year 1966, with the establishment of the National Institute of Oceanography with its headquarters in Goa, that oceanic/estuarine research off the coast/ within the state got a leap frog thrust along with the rest of the country

(Kucchal, 1991). It was only during the nascent years of this national laboratory, considerable work was undertaken in the estuarine regions of the country on a larger scale as the organization did not have its own contingent logistic support by way of ocean/high sea worthy research vessels. With the acquisition of such ocean bound vessels and the formation of a separate Department of Ocean Development at the center, as a policy the near-shore/estuarine investigations were relegated to coastal universities/research institutions. Even during this intervening phase, the research activities by the NIO revolved more around studying the physical, chemical and biological aspects centering on the invertebrate fauna of the subtidal regions and intertidal banks. Thus the higher vertebrate fauna of the estuaries in the state particularly the birds remained totally unattended.

Interestingly, the first ever report on the birds of Goa was by none other, than the legendary Dr. Salim Ali and his associate way back in 1976 (Grubh and Ali, 1976). The marginal additions and corrections made to the list subsequently (Ripley, 1978; Saha and Mukherjee, 1981; Rane, 1984) were compiled by the Zoological Survey of India (Saha and Dasgupta, 1992). However, all these reports/amendments were based on short-term duration opportunistic survey of forested regions not exceeding 16 days, with the authors themselves admitting the inadequity of the surveys in the words "the following list is obviously incomplete. It does not include many other species which might certainly occur in Goa, either as residents or as migrants and it is hoped that further more extensive surveys will be possible for the record to be completed". It was only recently that a more extensive list of the birds of Goa, emerging out of numerous visits spanning over a longer period was published (Lainer, 1999 a & b). At this point it need be noted that all the above mentioned reports including that by Lainer are in the form of mere checklists based on sight/sound records, at the most accompanied by morphometric annotations of some of the early collections rather than on a totalitarian ecological perspective. Information regarding the wetland birds of the state is mostly in the form of compilations of the Asian Midwinter Waterfowl Census and outline information in the Directory of Indian Wetlands (Gowthaman and Gramopadhye, 1993; Sardesai *et. al.* 1995). All these contributions were however based on extremely short visits with many of the compilers themselves being skeptic about the plan and modalities of the census (Menon, 1990).

The first ever comprehensive ecological study on wetlands and their associated avifauna of the state carried out till date is on 3 freshwater bodies of the Tiswadi taluka of north Goa namely Carambolim Lake, Santa Monica Lake and Pilar Lake (Walia and Shanbhag, 1999; Walia, 2000; Shanbhag *et. al.* 2001; Shanbhag *et. al.* 2002). Nevertheless, there still exists a vast lacuna in the holistic information regarding the avifaunal ecology of the estuarine wetlands of the state.

The Mandovi estuary with its extensive mudflats/sandflats and dense mangroves has been registered in both the Asian Wetland Directory as well as the Wetland Directory of India as harboring a huge waterbird population. A part of the Chorao Island, the largest island of the estuary was lineated as a bird sanctuary, the only one in the state in the year 1988. But information regarding the avifauna of the sanctuary in particular and the estuary in general is very patchy/fragmentary. The interactions between the avifauna particularly the migrant waders and their immediate environment are yet lesser known. Hence an ardent need was felt for the baseline data on the avifauna of the only bird sanctuary of the state. Birds being highly mobile a little could be accomplished by restricting the study only to the sanctuary portals. Hence the exposed mudflats/sandflats of the neighbouring deltaic islands/banks i.e. Chorao Minor, Diwar, Ribandar and Miramar, that could potentially provide food sources to the birds were also encompassed in the present study.

Walia (2000) reported that large flocks of migrant Pintail ducks visit the Carambolim Lake of the state during winter. She speculated that these ducks which feed actively in the lake by day moved to places 'hitherto unknown' in the early evenings. There were also popular reports as to the occasional presence of large flocks of these anatids in the Mandovi estuary, which were neither confirmed nor ruled out by the earlier works from this laboratory, centered around freshwater wetlands (Walia and Shanbhag, 1996, Shanbhag *et. al.*, 2001). Therefore, it was interesting to learn as to whether the pintail ducks, one of the principal migrant waterbirds to the state did utilize the Mandovi estuary and if so, in what way.

In this background, the present work was undertaken to study the ecology and diversity of the birds along the Mandovi estuary from a holistic perspective and their interactions with their immediate environment. The study, the first of its kind in the state provides insights into the prey preferences, resource partitioning and niche specialization among the migrant waders and the resident birds of the estuary. The study also helps plug the long standing void in the information regarding the avifauna of the only bird sanctuary of the state.

Chapter 1:
INTRODUCTION

Estuaries have been described as zones of transition or ecotones between freshwater and marine habitats. Interestingly however, most of their physical and biological attributes are not transitional but unique (Odum, 1971). Owing to this unusually harmonious blend of two diagonally diverse habitats estuaries have been referred to as zones of high productivity of both invertebrate and vertebrate fauna. Siegfried (1981) opined that the high invertebrate productivity of the estuarine environment promotes higher densities of vertebrate predators among which fish and birds predominate. Hence estuarine wetlands, regions formed by increased sedimentation and growth of vegetation, have become increasingly important as habitat for large number of both resident and migratory birds.

Tropical estuaries have been classified into 2 types 1) mixed estuary, wherein complete mixing of the sea water and fresh water takes place 2) stratified estuary, where the marine water enters the estuary in the form of a tongue causing vertical stratification of the water column, with the saline water being sandwiched between a layer each of freshwater at the top and the bottom of the column. The 'mixed' or 'stratified' nature of the estuary has a lasting impact on the physical, chemical and biological characteristics on the estuarine ecosystem (Day, 1981; Reseck, 1988). The resultant variations arising in the overlying water column hence are bound to have a direct bearing on both the biotic and abiotic components of the estuarine sediment.

The grain size and the composition of the major textural components of the sediment namely sand, silt and clay not only influences its water retention capacity and level nutrients but also to a great degree play a vital role in structuring the benthic community (Harkantra, 1982). Disturbances caused due to episodic flooding, tidal waves and monsoon currents may alter the sediment texture in favour of sand (Reish, 1979). The textural composition of the sediment however depends largely on disturbances occurring in the overlying waters. Tranquil waters and longer days, resulting in increased productivity of the water column and the sediment, favours silt (Mohanty and Dash, 1982; Agarwal, 1993). On the other hand tranquil waters accrued sedimentation and the resultant increased detrivory and saprobic activity augments clay (Srivastava and Singh, 1996).

The nutrient status of the sediment depends on the amount of organic matter laid down in it (Wilson *et. al.,* 1993). The subsequent remineralisation of the organic matter in the sediment which is largely due to bacterial action, temperature, diffusions and sediment resuspension (Klump and Martens, 1983; Mortimer, *et. al.* 1998), influences the quality of organic carbon, phosphates and nitrates in the sediment. The nutrient concentration in the sediment is also a consequence of the sediment characteristics (Parsons & Wilson, 1997). Clay and fine silt owing to their small grain size, large adsorption surface and colloidal nature have been considered to be a reservoir of organic carbon (Nelson *et. al.,* 1990). The greater affinity of clay to phosphates has also been widely demonstrated (Golterman, 1973; Egborge, 1981). Nitrogen in the sediment arises from degradation of organic matter as also from the excretion of aquatic forms spanning across benthic, planktonic and nektonic domain. Nitrogenous waste excreted by the waterbirds serves as yet another source of nitrogen into the estuarine environment.

The sediment is inhabited by a variety of invertebrates principally annelids, arthropods and molluscs all of which interact in some or the other way with their substratum (Brinkhurst, 1974; Klump & Martens, 1983; Nixon, 1981). The trophic status, mobility and the survival strategies adopted by the organisms further determine the intensity of this interaction. Thus, the velocity of lotic waters, type of substrate and food availability in the form of organic matter plays a decisive role in the configuration of benthic macroinvertebrate community (Rhoads and Young, 1970; Rabini & Minshall, 1977; Reice, 1980).

On the other hand, the quality and the quantity of the food availability facilitates various interspecific and conspecific interactions in turn leading to modulations in the structure and abundance of many benthic organisms (Brinkhurst, 1974).

The benthic community along with its substratum constitutes an indispensable part of the estuarine ecosystem. All living organisms from the water column on their death sink to the bottom and become inputs for the benthic community. Decay and putrefaction of these organisms brought about by the saprobic bacteria and benthic polychaete with ideal substrate conditions in addition to providing nourishment to the detritivores also releases trapped nutrient ions into the sediment/water thus setting forth the cyclic process. The excreta of the benthic organisms also provides nutrients into the system (Tatrai, 1986). Vertical and horizontal movement of benthic invertebrates sets forth 2 processes, bioturbation and irrigation both of which play a vital role in regulating the estuarine environment. Thus, one of the major components of the estuarine system, the benthic macroinvertebrates provide important link between primary production and higher trophic levels (Schell & Kerkes, 1989).

Paine (1966) opined that the species diversity in the ecosystem is directly related to the predator-prey relationships. A higher concentration of prey is therefore expected to harbour a better predator diversity. Gut content studies, dropping analysis and analysis of the regurgitated pellets have shown that benthic macroinvertebrates particularly polychaetes form an important constituent of the diet of most shore birds (Moreira, 1995; Hurtado *et. al.*, 1997). Barbosa (1997) opined that tidal mudflats provide the migrant shorebirds with the essential proteinaceous diet essential to take on the migratory journey, failing which the complex phenomenon of migration itself would not be possible. In view of these arguments it would be expected that the tropical wetlands like the one under study would harbour a rich avian diversity. The sediment, constituting the immediate environment of the benthic fauna plays an important role in structuring not only the benthic macroinvertebrate community but also in deciding the wader community by influencing the predator-prey interaction between benthic macroinvertebrate and waders.

Scientific literature is rife with numerous definitions of wetlands (Cowardin *et. al.,* 1979; Vijayan, 1986). The most important consideration of all these definitions was the presence of shallow water during some phase of the annual meteorological cycle. Thus, in view of all the prerequisites of the various definitions, Parish (1987) rightly categorized estuarine lowlands as wetlands.

Wetlands were for long shunned as wastelands. It was only after the Ramsar convention held at Iran in 1971, that, their precious contributions towards sustaining the global climatic equilibrium and biological diversity was recognized. Since then, wetlands have been attached with their due importance as repositories of biological diversity. The Ramsar convention became all the more symbolic to the avian ecologist as in addition to emphasizing the values of wetlands and promoting their conservation, it was also instrumental in identifying wetlands as primarily waterfowl habitats on an international scale. Birds in general and waterfowl in particular besides being categorized as completely dependent, less dependent and opportunistic users of the habitat (Vijayan, 1986) have come to be considered as integral faunistic components of the wetland ecosystem. Martinez (1993) impressively documented the multifarious significance of birds in aquatic environment as 1) consumers at different level of the tropic chain 2) suppliers of organic matter especially in the various roosting sites and nesting colonies 3) transporters/ exchangers of materials between aquatic and terrestrial environment 4) modifiers of environment through the utilization of aquatic biota and bioturbation of sediment during feeding and locomotion 5) Causal transporters of living organisms including pathogens across distant geographical areas.

Estuarine mudflats and sandflats together with their adjoining mangroves constitute one of the most important wetland systems in the world, of which Asia alone contributes 30%. Estuarine lowlands and mangrove forests are known to be rich in organic matter and hence serve as natural nursery grounds for many fish and invertebrate species which have an estuarine phase in their life cycle (McNae, 1974; Snedakar, 1978; Achutankutty & Nair, 1982; Parish, 1987; Jayson, 2001). The increased input of organic matter into the estuarine system also sustains an equally diverse benthic community. This diverse and abundant population of invertebrates and fish in the estuarine wetland provides a rich source of food to large number of birds. Hence owing to its high protein value and strategic locations, along the migratory pathway, estuarine wetlands serve as stopovers for millions of shore birds, where they feed and renew their energy reserves before continuing their arduous migratory journey (Davis & Smith, 1998). Owing to the vital role they play in sustaining bird diversity, Myers (1983) stated, " Areas such as these are critical for continuance of migration and ultimately for the survival of many shorebirds". In view of the above factors a lot of stress is presently being laid to study these unique ecosytems as treasure throves of avian diversity (Silvius and Parish, 1987; Erwin, 1996). Although a fair amount of studies are presently being carried out in America, Europe and Fareast (Hicklin and Smith, 1984; Boshoff and Piper, 1993; C ayford and Waters, 1996; Howes, 1989; Dubowy, 1999), in India such studies on a comprehensive ecological plane are limited.

In addition to this, the dense mangroves fringing the mudflats provide vital roosting sites for these visitors. Yet other waterfowl use these areas of abundant food and fewer disturbances as moulting sites where they can renew their flight feathers. However, although these birds carry out a major part of the life activities on their wintering grounds, only a few attempts have been made to understand their intricate association with the environment on their wintering grounds. **In view of this glaring void Burton (1996) lamented "little thought is given to what migratory birds do in their wintering homes. Most scientific research has been concentrated on the departure of birds and on their journeys. Only recently has attention been turned to the details of how they live in their homes, perhaps half a world away, in very different conditions of climate and habitat and where they may spend more than half of each year".**

The opportunistic use of diverse niches on the wintering ground by shorebirds in a bid to exploit various food resources to supplement their diet is an intriguing phenomenon. Skagen and Knopf (1994a& b) hypothesized that shorebirds may have evolved flexible behaviors that allow them to exploit variable and unpredictable food resources which include invertebrates found in dynamic ecosystems. Nevertheless, little attention is being paid to investigate these intricacies of their survival on the migratory shores. Wootton (1997) rightly opined that " very little is known about the details of the interaction between estuarine birds and their prey population and a lot need yet to be learnt".

Birds, depending on their varied food habits occupy different trophic level in the food web and play a significant role in the specialized environment in which they live, in more than one way (Woltsencroft *et. al.,* 1989, Hussain & De Roy, 1993 & Gopal, 1995). Although the feeding habits of the waders have been widely studied (McNeil *et. al.,* 1995; Halse *et. al.,* 1996; Solis *et. al.,* 1996) very little efforts have gone into understanding this delicate cyclicity which forms the crux of the biological richness in the estuarine environment (Wootton, 1997). Waterbirds particularly waders often concentrate at sites of high invertebrate productivity and hence may be used as indicator species for rapid assessment of coastal areas (Silvius & Parish, 1987). It was only in 1997, that Moreira acknowledged this important role played by birds in the mass and energy fluxes across estuarine food webs and acknowledged that 'very little is known about the details of the interaction between estuarine birds and their prey population'.

The Mandovi estuary, a tropical estuary along the West Coast of India, comprising of dense mangroves and extensive mudflats has been registered in both the Asian Wetland Directory (Gowthaman and Gramopadhye, 1993) and the Directory of Indian Wetlands (Hussain and De Roy, 1993). The only bird sanctuary in the state, notified in the year 1988, is a part of Chorao, the largest island in the Mandovi estuary. Although considerable work has been carried out on the physical, chemical and biological parameters of the estuary (Kamat and Sankaranarayanan, 1975; Bhattathiri *et. al.*, 1976; Shirodkar and Sengupta, 1985; De Sousa and Sengupta, 1986), information regarding the avifauna of the estuary in general and the bird sanctuary in particular is fragmentary and patchy and limited only to the occasional midwinter census (Perennou *et. al.*, 1994; Lopez and Mundkur, 1997). Due to this vast lacuna in information regarding the only bird sanctuary in the state, many popular 'naturalist' reports have raised skepticism about the health of the sanctuary. However little can be attained by conservation in isolation. Knowledge concerning species composition, migration chronology, habitat selection and feeding ecology is essential for development and management of all conservation studies on birds (Davis & Smith, 1998). Hence, in order to assess the status of the sanctuary and the adjoining islands it was all the more essential that the bird fauna of the estuary be studied from a totalitarian outlook.

In this background, the present study was undertaken to analyze the ecology and the biodiversity of birds along the mud/sandflats of the Mandovi estuary and their interaction with the environment from a holistic perspective. The study, first of its kind in the state provides insights into the prey preferences and niche specialization's of the migrant waterfowl particularly waders, as well as the resident birds inhabiting the estuary. The study is also aimed at providing baseline data on the only bird sanctuary of the state in an attempt to fill the long-standing void about the same.

Chapter 2:
STUDY AREA

Goa ($14^0 53'54"$ to $15^0\ 48'33"$ N and $73^0\ 40'33"$ to $74^0\ 20'13"$E) the second smallest state of the Indian Union is located along the west coast of the country at a height of 1,022m above mean sea level. It lies wedged between the states of Maharashtra to the north, Karnataka to the south and the east and the Arabian Sea to the west. The state is drained by 7 westwardly flowing rivers originating in the Western Ghats. Of these the 2 major rivers, Mandovi and Zuari are linked together through the narrow Cumbharjua canal to form the Mandovi-Zuari estuarine complex ($15^0 25'$ to $15^0 31'$ N and $73^0 45'$ to $73^0 59'$E) the single largest estuarine complex of the state.

The Mandovi estuary, one of the major components of the Mandovi-Zuari estuarine complex, lies in the northern district of the state and extends for a length of 68km. It has a waterspread of 5,564 ha. and a mangrove area of 700 ha. The estuary opens out into the Arabian Sea at the Aguada Bay and has a sand bar at its mouth. The width of the estuary at the mouth is 3.2km and narrows down gradually to about 0.5Km upstream. Saline inflow occurs upto 67km inshore in May and reduces to 15-20km upstream in monsoon. Strong wave currents and tidal action is seen upto 14 km upstream. The tidal amplitude varies from 0.01-3m with a mean sea level of 1.3m. The otherwise 'well mixed' estuary evolves into a 'stratified' estuary during monsoons. The Mandovi River is used as an inland waterway for the transport of mineral ore by barges all through the year accept during monsoons.

The Mandovi Estuary is studded with 5 deltaic accretion islands. Interestingly some are still under formation while the others like Chorao and Diwar are inhabited and as such they are centered with all the activities associated with civilization such as ferrying, motorized transport, agriculture, horticulture, aquaculture and fishing. A part of the largest island, Chorao has been declared a bird sanctuary. The lower and middle reaches of the estuary on either banks of the river and the peripheral regions of the island are laid with extensive sand/mudflats and mangroves. These sand/mudflats and mangrove belts are under the continuous influence of alternate submergence and exposure all through the high/low tides, hence truly fitting in the category of estuarine wetlands. During initial reconnaissance surveys all these sites were found to be utilized by waterbirds to varying degree. Therefore six such sites namely Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar within a stretch of 17km from the river mouth were chosen for the present study on the ecology of waders. The sites were chosen depending upon the comparable expanses of exposed areas during the low tide, accessibility to the site by road or boat or both, their gross variability in terms of presence/ absence or expanse of mangroves and perceptible dominance of sand, mud or silt in the sediment. The layout of the study area is provided in Figs. 2.1 and 2.2.

Ribandar lies on the southern bank of the river in the immediate vicinity of Panaji, the capital city of the state. The mudflat lies at a distance of 7.5 km from the mouth of the river. When exposed, the Ribandar mudflat (Fig. 2.3) measures approximately 3.1 x 0.29Km. Two small backwater creeks entering the river disrupt the continuity of the mudflat. The mudflat runs parallel to National Highway, NH 4A, along its southern edge while the interstate private bus terminus lies to its immediate west. The Ribandar village borders the eastern side of the flat. The region surrounding the mudflat is used extensively for fishing with the use of stake nets especially during high tide.

Chorao (Fig. 2.4) is the largest island in the Mandovi estuary and bifurcates the River into 2 parts, the Mapusa tributary to the north and the Mandovi River to the south. The island, which lies 8.9km inshore, has a mudflat length of 6.3 x 0.25 km when exposed. A ferry wharf, adjacent to the eastern border divides the mudflat into two parts. The Chorao mudflats are bordered by mangrove vegetation all along its length except for a small 0.67 km stretch, 10.3km upstream from the estuarine mouth. The western part of the Chorao Island houses the Dr. Salim Ali Bird Sanctuary, the only bird sanctuary of the state with an area of 1.8 Km^2 while the inhabited village of Chorao is situated on the eastern part of the island. The sanctuary region comprises of dense mangrove forests and is interrupted only by a number of small water streams winding their way into the sanctuary.

Minor C and Minor D are the northern and southern banks of Chorao Minor, a small, uninhabited accretion island between Chorao and Diwar. Chorao Minor is situated at a distance of 14.6km, from the mouth of the river on the Narve branch of the Mandovi River. The condition of the island during low tide and high tide is shown in Figs. 2.5 & 2.6 respectively. Minor C is the bank towards Chorao while Minor D is the bank towards Diwar. The length of the exposed mudflat at Minor C was 3.5 x 0.61km while that of Minor D was 2.7 x 0.4 km.

Diwar, was the only other inhabited island of the Mandovi estuary, which divides the Mandovi tributary into two smaller branches namely the Narve branch towards its north and the Mandovi River towards the south (Fig 2.7). It has a mudflat area of 3.2 x 0.4 km located 16km inshore and fringed by mangroves all along its length. Adjacent to the northern side of the Diwar sandflat, on the bank of the Narve branch is a bed of *Meretrix casta* and *Meritrix ovum* while to the west is a bed of *Crassostrea edulis.* The mudflats of Chorao, Minor C, Minor D and Diwar were accessible only by boat from the riverside.

Miramar was an open sandy stretch, 4 km south west of the capital city of Panaji. It is situated close to the estuarine mouth, 3.5km inshore. Marginal fishing activity by beach seines is carried out on the beach during the morning hours. The Miramar beach is one of the major tourist attraction of the state and in thronged by tourist all through the year.

Climate

Goa, like all other subtropical regions has a seasonal climate strongly influenced by the southwest monsoon precipitation occurring normally from June to September. The seasons therefore are thus categorized as pre-monsoon, monsoon and post monsoon. However, in the present study, vortexed around waterbird ecology, considering the fact that sizeable populations of waterbirds in the tropics are winter visitors, the post monsoon period is differentiated into post- monsoon and winter while the pre-monsoon period is treated as summer. Summer is the hottest period of the year and experiences occasional showers towards the end. The atmospheric temperature shows two peaks annually, one in October, immediately after the monsoons and the other in May, the hottest month of the year. During summer the temperature fluctuated between 24 ^{0}C to 32 ^{0}C. The state annually receives on an average 3200mm rain. The southwest monsoon is normally active in the region from June to September. But may start as early as May and extend as late as October. The season is characterized by strong westerly winds reaching a speed of 13km/hr. The relative humidity may range from 63% to 90% and is highest in monsoons. The intervening period of October and November, between the active monsoon and winter is considered as post-monsoon. During this period the temperature ranged from 21^{0}C to 32.2^{0}C. Seasonal variations in the climatological parameters during the period of the present study as obtained from the Indian Meteorological Department, Goa Observatory, Panaji, Goa, is provided in table 2.1. While the monthly variations in the same have been provided in graph 2.1.

Temperature

Maximum atmospheric temperature during the present study ranged between 28.3 ^{0}C in July to 33.6 ^{0}C in November. On a seasonal basis, it was highest in summer, followed by post-monsoon, winter and monsoon. The minimum atmospheric temperature fluctuated between 19.8 ^{0}C in December to 26 ^{0}C in April.

Sunshine hours

The total sunshine hours varied from 73.5 hours in July to 299.2 hours in January. The total sunshine hours were highest in winter and lowest in monsoon.

Rainfall

During the study period the state experienced the highest rainfall in June 1999 contributing 1586.4mm to the precipitation. Towards the end of June and the beginning of July 1999, the state experienced cyclonic storms leaving the estuarine mud/sandflats submerged all through the month. The months of February and March experienced no rain at all. During the year 1999-2000, the monsoon extended from May to November while in the next year, mild pre-monsoon showers were experienced in April. During this year, the state also experienced northeasterly precipitation from November to January.

Relative Humidity

The mean relative humidity through the period of investigation oscillated between 63% in December to 93% in June. On a seasonal basis, it was highest in monsoon and lowest in winter.

Wind Speed

The mean windspeed during the study period varied from 7 Km/hr to 14 Km/hr. It was highest in monsoon and lowest in post monsoon.

Vegetation

The mud/sandflats of Ribandar, Chorao, Minor C, Minor D and Diwar were fringed by mangrove vegetation but at Miramar the vegetation was restricted to sand dune plants. The dominant mangrove plant species comprising the vegetation of Ribandar, Chorao, Chorao Minor and Diwar has been shown in Figs 2.8-2.12.

The mudflats of Ribandar were interspersed with about 15 short trees of *Rhizophora mucronata* all along its length. However, towards the eastern embankment, numerous saplings of *R. mucronata* had started taking root.

At Chorao, the vegetation comprised of dense mixed mangrove trees showing some level of succession. The regions of more saline sediment immediately bordering the mudflat, were occupied by *R. mucronata.* This was followed by a mixed stand of *Kandelia kandel* and *Sonneratia alba*. The deeper regions of the mangrove forests particularly the Dr. Salim Ali Bird sanctuary was dominated by *Avicennia marina. A. officinalis, Excoecaria agallocha, Bruguiera parviflora, B. conjugata, Aegiceros corniculata, Sonneratia caseolaris, S. apetalla, Acanthus ilicifolius* and *Derris trifoliata* were the other mangrove plant species present interspersed with the dominant vegetation of Chorao. The grass *Chloris quinquesetica* was present is small patches near the ferry wharf. The drier parts of the estuarine wetlands were dominated by *Caesalpinia nuga.*

Minor C and Minor D were separated by a cluster of mangrove trees comprising largely of *R. mucronata* and measuring 660x 420m^2. Two *Sonneratia alba* trees were also found intermittent with the *R. mucronata.*

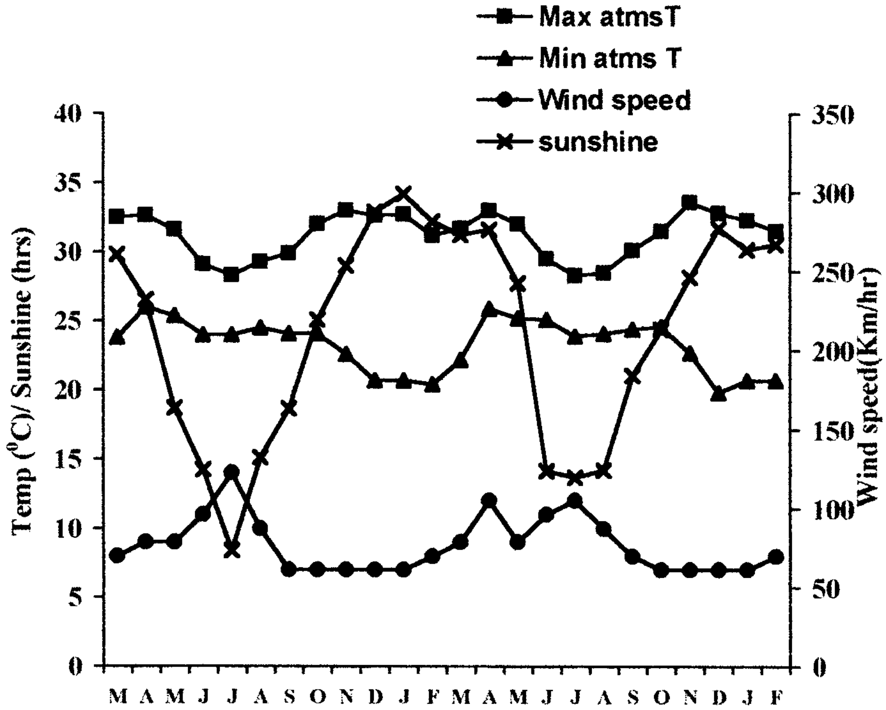
Avicennia marina stand bordered the sandflats of Diwar. The other dominant plant species bordering the estuarine wetland was *S. alba.* In addition to these, *A. officinalis, A. illicifolius* and *S. caseolaris* were present on the northern side of the island while *K. candel, E. agallocha* and *S. caseolaris* were present on the southern side of the island. The drier inner reaches of the estuarine wetland were dominated by *Clerodendron inerme, Caesalpinia nuga and the grasses Cyperus malaccensis, C. rotundus* and *C. quinquesetica.*

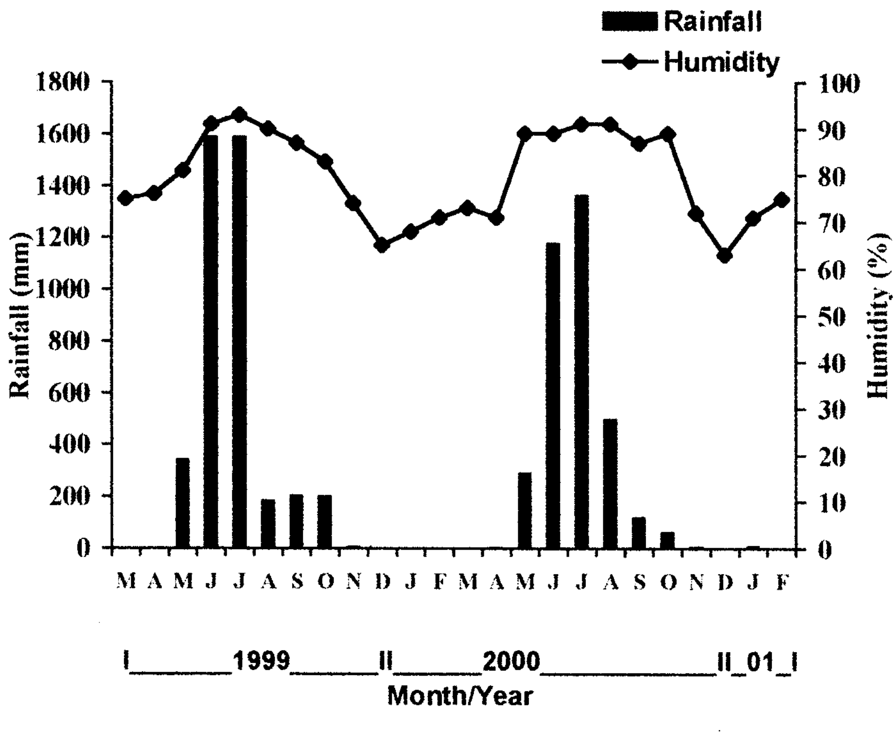
The sand dune runner *Ipomea biloba* and *Spinifex* sp. made up the vegetation at Miramar. However, both the plants were restricted to the supratidal zone.

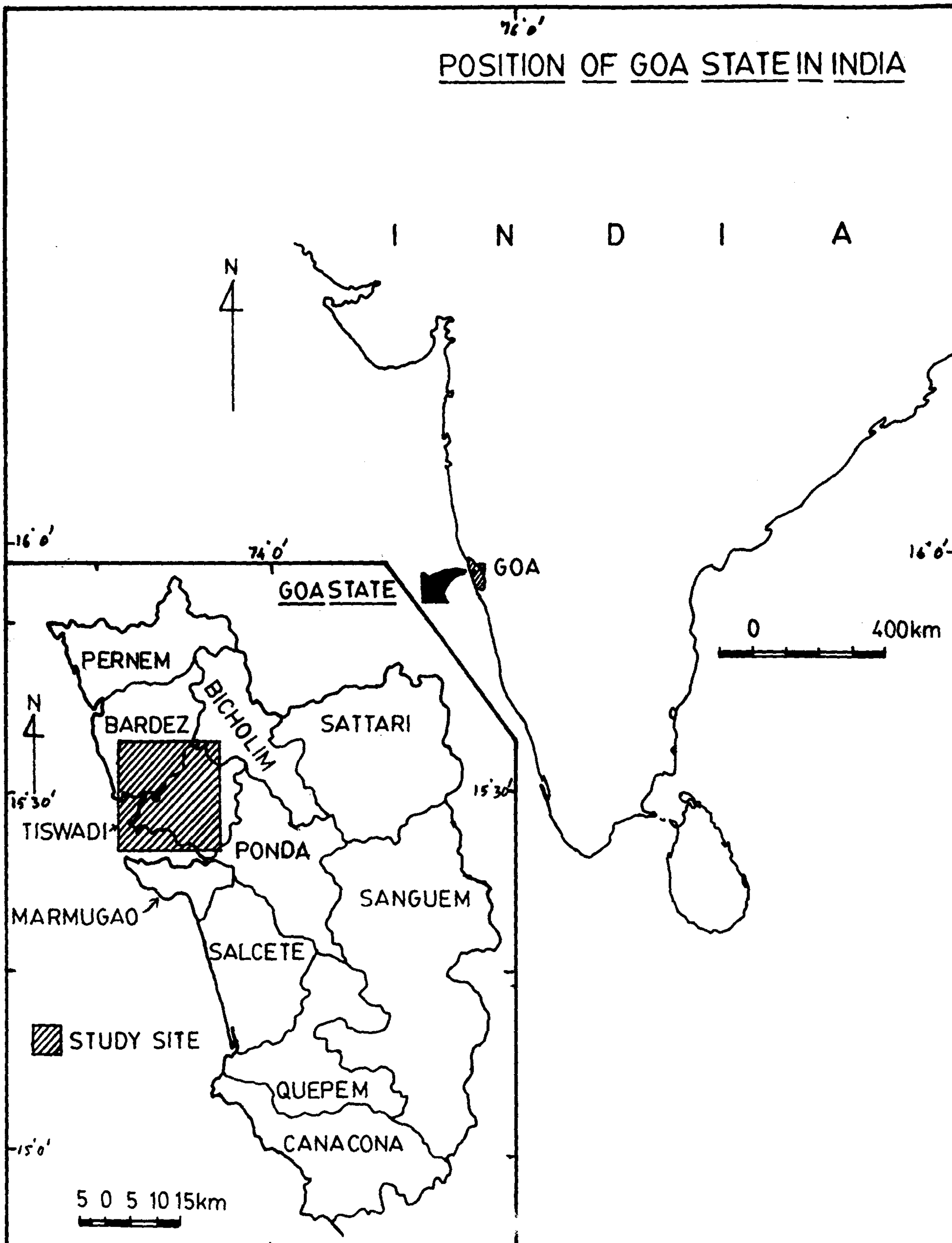
Table 2.1: Seasonal variations in the climatological parameters in Goa from March 1999 to February 2001.

Years/ Seasons	Max. Temp. (^{0}C)	Min Temp. (^{0}C)	Sunshine (Hrs)	Relative humidity (%)	Wind speed (Km/hr)	Rainfall (mm)
1999-2000						
Summer	32.23±0.31	25.07±0.60	218.80±27.90	77.33±1.80	8.67±0.30	113.90±110.21
Monsoon	29.43±0.33	24.20±0.11	140.13±18.65	89.33±1.25	9.33±1.44	657.40±402.29
Post Monsoon	32.50±0.50	23.35±0.75	236.60±17.00	78.50±4.51	7. 00±0	102.10±98.59
Winter	32.17±0.47	20.60±0.10	289.57±4.98	68.00±1.67	7.33±0.30	0.00±0
2000-2001						
Summer	32.23±0.38	24.43±1.10	264.17±10.30	77.67±5.51	10.00±0.97	97.00±92.75
Monsoon	29.10±0.42	24.38±0.26	138.03±15.43	89.50±0.96	10.25±0.85	788.50±290.35
Post Monsoon	32.55±1.05	23.65±0.95	230.05±16061	80.50±8.52	7.00±0.00	33.05±28.63
Winter	32.20±0.37	20.40±0.29	269.50±3.89	69.67±3.41	7.33±0.32	2.97±2.63

Graph 2.1
Monthly fluctuations in the climatological parameters in Goa from March 1999 to February 2001

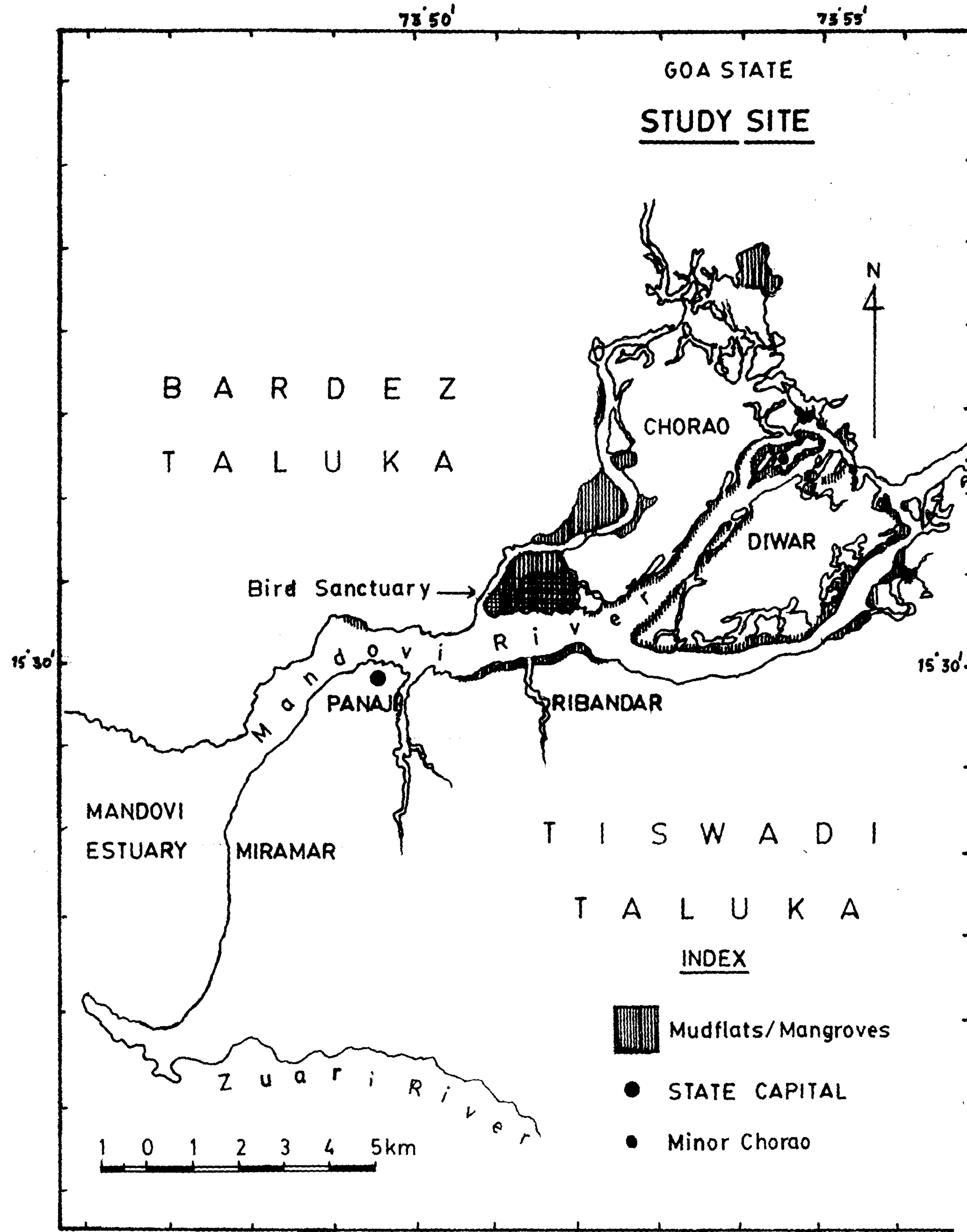






76°0'
POSITION OF GOA STATE IN INDIA
I N D I A
N
16°0'
74°0'
GOA
GOA STATE
16°0'
0
400km
PERNEM
BICHOLIM
N
BARDEZ
SATTARI
15°30'
15°30'
TISWADI
PONDA
SANGUEM
MARMUGAO
SALCETE
STUDY SITE
QUEPEM
CANACONA
15°0'
5 0 5 10 15km
74°0'

Fig. 2.1



73°50'
73°55'
GOA STATE
STUDY SITE
N
BARDEZ
TALUKA
CHORAO
DIWAR
Bird Sanctuary
Mandovi River
15°30'
15°30'
PANAJI
RIBANDAR
MANDOVI
ESTUARY
MIRAMAR
TISWADI
TALUKA
INDEX
Mudflats/Mangroves
STATE CAPITAL
Minor Chorao
Zuari River
1 0 1 2 3 4 5km
73°50'
73°55'

Fig. 2·2

Fig 2.3 :A view of the exposed mudflat at Ribandar during the low tide. A course of the backwater creek can be noted in the foreground while the stakes of the stakenet fishery, extensively practiced in the region can be seen in the background.

Fig 2.4 : A view of the Chorao Island along with the ferry wharf as seen during high tide. The dense mangroves, the characteristic features of the Salim Ali Bird Sanctuary, by the edge of the Island can also be noticed.

FIG:2.3

FIG:2.4

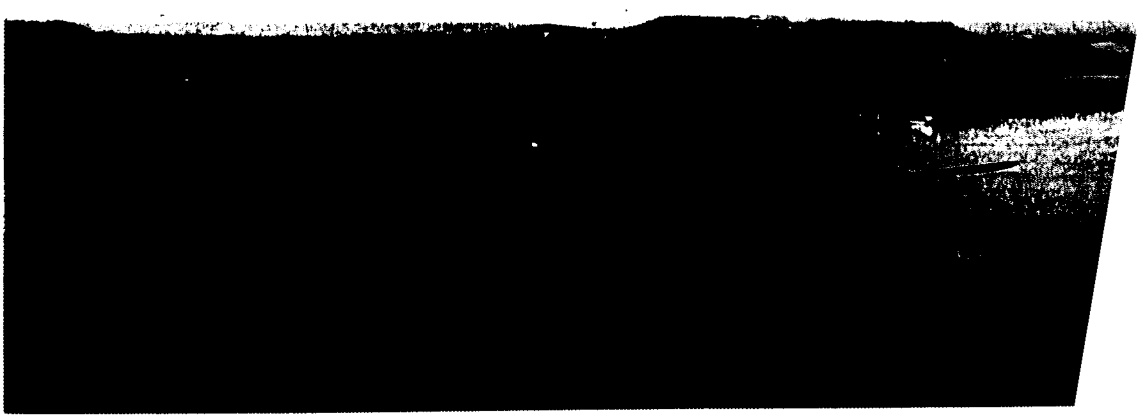


Fig 2.5 : An aerial view of Chorao Minor, a small uninhabited, accretion island between Chorao and Diwar during low tide, showing the expanse of the mudflats around it.

Fig 2.6 : A birds eye view of Chorao Minor, during high tide when the entire island is represented by a single cluster of *Rhizophora mucronata*

FIG: 2·5

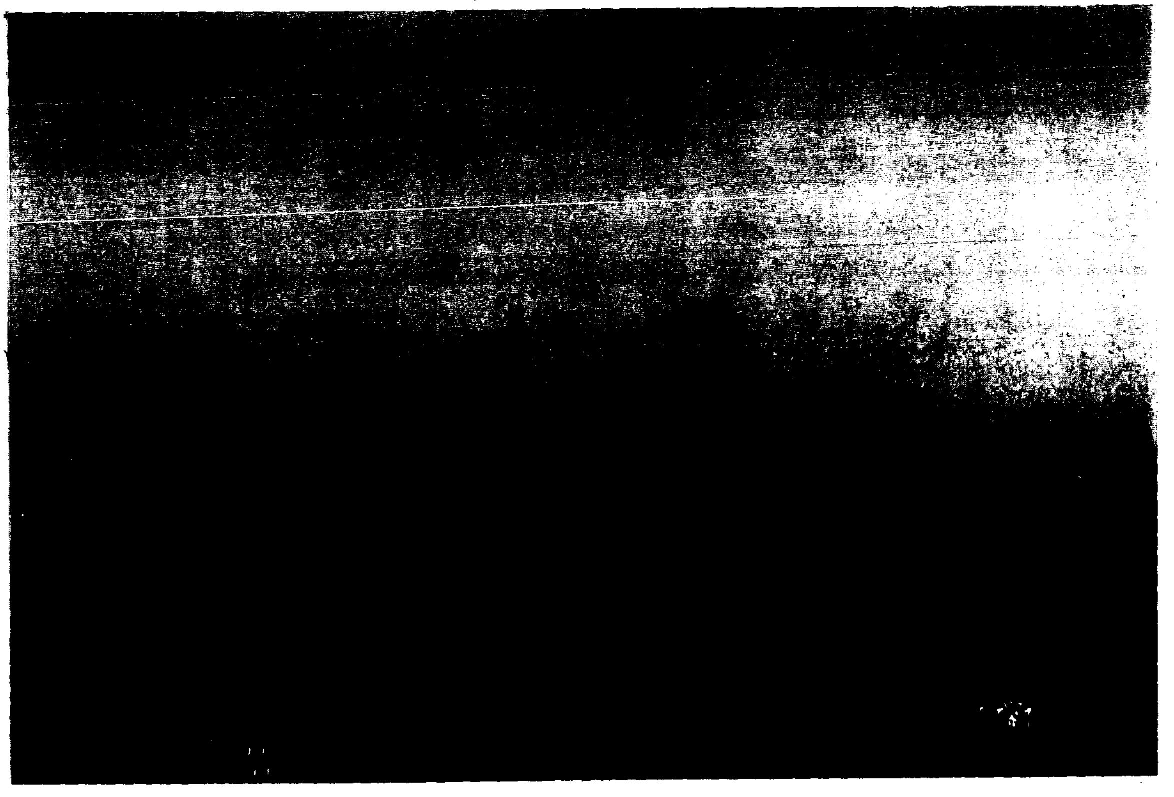


FIG: 2·6

Fig 2.7 : A view of strategic location of the Diwar island dividing the Mandovi River into two branches, Narve branch & Mandovi river proper. On the left, a part of the mudflats Minor D can also be noted.

FIG:2·7

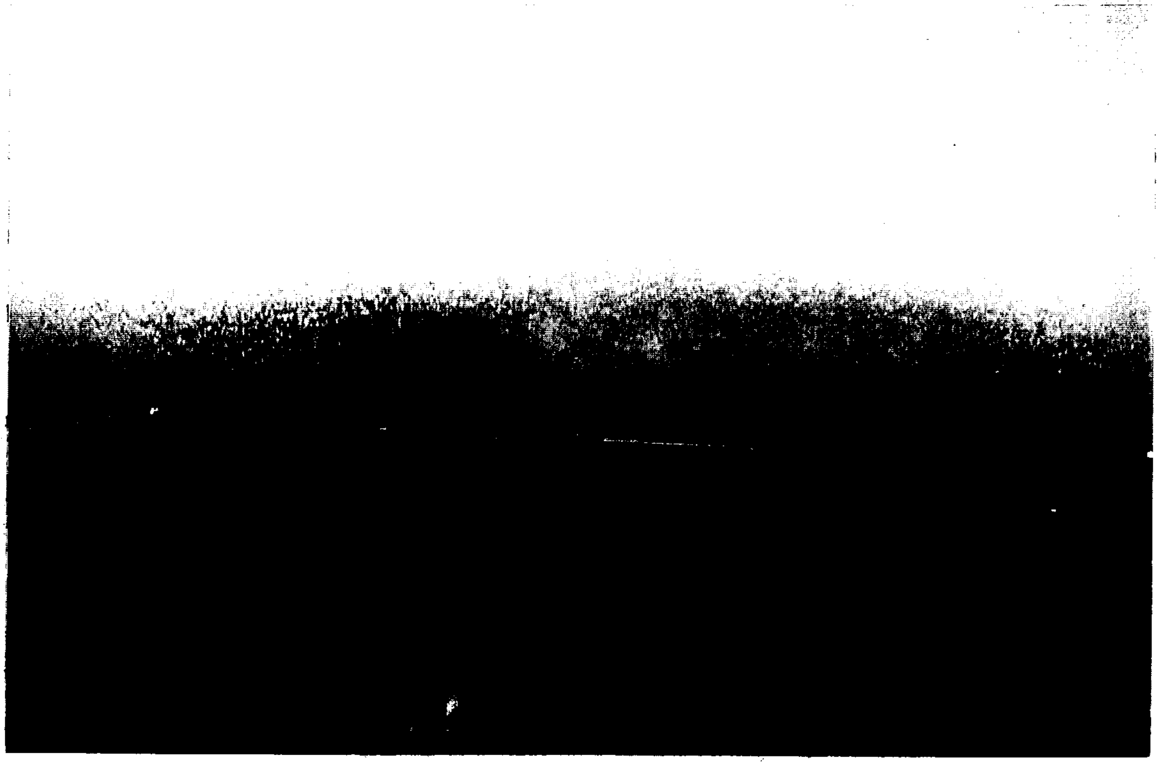


Fig 2.8 : *Rhizophora mucronata,* the most dominant plant species at Chorao Minor. The stilt roots, the characteristic feature of the family Rhizophoraceae can be seen distinctly.

Fig 2.9 : *Aviccenia marina*, the most dominant mangrove tree species found at all the sites in the middle estuary. The negatively geotrophic pneumatophores of the plant facilitate its survival even in anoxic conditions.

FIG:2·8

FIG:2·9

Fig 2.10 : *Kandelia kandel*, a mangrove species found at Chorao. The green radicles of the seedlings in the shape of the candel hanging from the viviparous parent tree can be prominently seen.

Fig 2.11 : *Sonneratia apetella*, is the tallest mangrove tree occurring in the Salim Ali Bird Sanctuary. These trees were used largely as roosts by the ardeids & ciconids. They were also used as nesting platforms by some ardeids.

FIG:2·10

FIG:2·11

Fig 2.12: *Acanthus ilicifolius*, a spring shrub growing in to thickets on the inner edges of mangrove stretches at Chorao and Diwar.

FIG:2·12

Chapter 3:

MATERIAL & METHODS

Sampling Techniques

Based on preliminary boat surveys conducted along the entire length of the Mandovi estuary, 6 study stations namely Chorao, Chorao Minor C, Chorao Minor D, Diwar, Ribandar and Miramar were identified depending upon the expanse of their mud/sandflat coverage and the density of the bird species therein. On each of the 6 study stations, 3 sampling spots were marked on the exposed mud/sandflats. The sediments for the analysis of sediment characteristics such as sediment texture, physico-chemical parameters and sediment nutrients as well as for the study of the benthic macroinvertebrates were collected at monthly intervals. The sediments from these sites were obtained by adopting the core sampling technique as described by Holme and MacIntyre (1971). The sediment was scooped by pushing a 30 cm long acrylic core of 5cm. diameter into the mudflat on either sides of the surfline. At each sampling spot 5 sediment cores/m^2 area were thus collected randomly.

At every sampling spot, 2 sets of sediment samples were seperately collected, pooled and stored in polythene bags for the analysis of physicochemical parameters and benthic macroinvertebrates. The sediments for the analysis of physicochemical parameters were dried in laboratory at 90^0C overnight, powdered and stored in airtight plastic containers for further use.

The sediments for the analysis of benthos were pooled together in a polythene bag, mixed and immediately fixed with 10% formaldehyde containing Rose Bengal stain in the field itself. To study the variations, if any, in the benthic macroinvertebrates inhabiting the different strata, a single sediment core was cut at depths of 5,10 and 20 cms from the surface. 5 such cores were randomly scooped at each sampling site. The sediment of each strata was fixed in the field and stored separately in polythene bags. Further analysis of the benthos was carried out in the laboratory.

Analysis of Physicochemical Parameters

Sediment Texture

The relative composition of sand, fine, medium and coarse silt and clay was estimated using the International Pipette Method as described by Briggs (1977). Oven dried sediment weighing 20g was soaked overnight in water containing a 4-6 drops of teepol. The sample was then stirred for 30min using a magnetic stirrer and placed in a 1000ml-measuring cylinder. After thoroughly mixing the sample by inverting the cylinder 3-4 times, 10ml of the suspension was withdrawn from a depth of 10cm from the water level of the cylinder into a petridish marked 'A' of known initial weight. Two more samples of 10ml each were withdrawn after an interval of 3 minutes 50 seconds and 8 hours 10 minutes into petridishes B and C respectively. The petridishes were oven dried at 105°C. The dried petridishes were weighed and the weights of the fractions A, B and C were computed. The percentage composition of sand, silt and clay in the sediment was calculated using the formula given below.

$$\%\text{coarse silt} = \frac{100\,(A-B) \times 100}{W}$$

$$\%\text{ fine \& medium silt} = \frac{100\,(B-C) \times 100}{W}$$

$$\%\text{ clay} = \frac{100C \times 100}{W}$$

where A, B and C are the weights of the 3 sediment fractions and W is the weight of the sediment taken.

The percentage of sand was calculated by subtracting the sum of the above 3 fractions from 100.

Physico chemical Parameters

Physicochemical parameters such as temperature, pH, conductivity, alkalinity, chlorides and sulphates were estimated in the sediment sample using standard methods (Trivedi *et. al.*, 1987; Saxena, 1987) as outlined below. All the above mentioned parameters except temperature were estimated in the laboratory.

Temperature

The temperature of the sediment, the overlying water and the immediate ambient temperature were recorded directly at the study sites using a mercury thermometer that measured changes upto 0.1°C.

Hydrogen ion Potential (pH)

The pH of the sediment was electrometrically determined using a 'Biocraft Digital pH meter NIG 333' in a 1: 5 soil suspension prepared by mechanically stirring 20g oven dried soil in 100ml of distilled water for 1 hour.

Conductivity

The conductivity of the sediment was determined in 1:5 soil suspension prepared in aerated distilled water using a 'Systronics direct Reading 304' conductivity meter and expressed as uS/µmho. The conductivity at 25°C was calculated as,

$$\text{Conductivity at } 25^{0}\text{C (uS)} = \frac{\text{observed conductance} \times \text{cell constant}}{\text{temperature factor}}$$

Alkalinity

The total alkalinity was determined in 1:5 sediment suspension prepared in aerated distilled water. The suspension thus obtained was filtered and the filtrate was used for the titrimetric analysis of alkalinity. The filtrate measuring 50ml was directly titrated against a strong acid (0.1N HCl) using methyl orange as indicator until the colour changed from yellow to orange red. The total alkalinity was calculated as follows,

$$\text{Total alkalinity (mg/100g)} = \frac{(\text{ml} \times \text{N}) \text{ of HCl} \times 500}{\text{ml of soil solution taken}}$$

Chlorides (Cl)

A 1:5 soil suspension as described above was used for the estimation of chlorides in the sediment. The filtrate measuring 50ml was titrated against 0.02N silver nitrate using potassium chromate as indicator. The titration was continued till a persistent brick red colour appeared. Chlorides were calculated as

$$\% \text{ Chloride} = \frac{(\text{ml} \times \text{N}) \text{ of } AgNO_3 \times 35.5}{\text{ml soil solution} \times 2}$$

Chlorides (mg/100g)= % Chlorides x 1000

Sulphates

The constitution of sulphates in the sediment was estimated from a 1:5 soil suspension by the gravimetric method. For the purpose, the pH of a 50ml aliquot of the clear filtrate was adjusted to 4 by the addition of HCl. The solution was heated to boiling and excess of barium chloride was added dropwise with constant stirring. The contents were then heated at 90^{0}C ion a waterbath for 2hrs 30 minutes. The white precipitate thus obtained was filtered through an ashless filter paper No. 44. The precipitate was washed several times with deionized water so as to free it from chlorides. The washed filtrate was placed in a porcelain crucible and charred at 800^{0}C for one hour in a muffle furnace. The precipitate was cooled in a dessicator and weighed. The percentage of sulphates in the sediment was calculated as per the formula given below.

$$\text{Sulphate (mg/100g)} = \frac{\text{W} \times 411.5 \times 1000}{(\text{ml soil solution} \times 2000)}$$

where, W = weight of the $BaSo_4$ precipitate

Sediment nutrients

Organic carbon and phosphate-phosphorus were estimated adopting procedures described by Trivedi *et. al.* (1987), while nitrate-nitrogen was estimated using the technique described by Saxena (1987) as per the details given below.

Organic Matter

The organic matter was estimated from the organic carbon fraction of the sediment using Walkey and Black Method. 10ml of 1N potassium dichromate and 20ml of concentrated sulphuric acid containing silver sulphate was added to 1g of sediment. After gently swirling the mixture was allowed to stand in an ice bath for 30 minutes before diluting it with 200ml of distilled water. 10ml of 85% phosphoric acid and 1ml of diphenylamine was then added as an indicator to obtain a bluish purple colour. The unutilized potassium dichromate was then titrated against 0.05N ferrous ammonium sulphate. A blank reading was recorded using the same procedure mentioned above but without the addition of a sediment sample. The percentage of organic matter in the sediment sample was calculated from the organic carbon fraction as,

$$\% \text{ Organic carbon} = \frac{(V1 - V2) \times 0.003 \times 100}{W}$$

where V1 = Titration value for the blank

V2 = Titration value for the sample

W = weight of the sediment sample taken

% organic matter = % organic carbon × 1.724

Phosphorus

The available phosphate-phosphorus in the sediment was estimated using the Truogh and Meyer Method. The phosphate phosphorus in the sediment was leeched by treating 1g of oven dried sediment with 200ml of 0.002N sulphuric acid. The concentration of phosphate in the filtrate thus obtained was determined spectrophotmetrically. 0.4ml of ammonium molybdate reagent was added to 10ml of the filtrate followed by 2 drops of stannous chloride solution. The absorbance of the blue colour thus developed was read between 5-12 minutes after the addition of stannous chloride, at 690nm using distilled water as the blank on a spectrophotometer (Systronics 106). A standard curve was prepared using known concentrations of standard phosphate solution in a similar manner. The optical density values obtained for the filtrate were compared with the standard curve and expressed as mg/l. The phosphate phosphorus per gram sediment was calculated as

$$\text{Available phosphorus (mg/l)} = \frac{\text{mg of P/L in soil sample} \times 200}{V}$$

where V = volume of the filtrate used

Nitrogen

The nitrate-nitrogen from the sediment was extracted from the sediment by mechanically stirring 25g of the sediment in 125ml of extraction reagent comprising of copper sulphate and silver sulphate. Then, 0.2g calcium hydroxide and 0.5g magnesium carbonate were added to the mixture. The content of nitrate-nitrogen in the filtrate was then estimated in the filtrate using the brucine method. 2ml sodium chloride was added to 10ml of the filtrate and the contents were placed in a cool water bath followed by the addition of 10ml concentrated sulphuric acid and 0.5ml brucine sulphanilic acid reagent. The contents were then placed in a boiling water bath for 20 minutes. The absorbance of the yellow colour that developed was read at 410nm on a spectrophotometer using distilled water as blank. A standard curve was prepared for various concentrations of the standard nitrate solution. The optical density values obtained for the filtrate were compared with the standard curve and expressed as mg/g of the sediment as follows,

$$NO_3\text{-N (mg/100g)} = \frac{\text{mg/l } NO_2\text{-N in the filtrate} \times V}{1000W}$$

where V = volume of the filtrate used

W = weight of sediment taken

Benthos

Density and Diversity

The sediment samples for studying the diversity and the density of the benthic invertebrates were fixed on the field as described earlier. After 48 hours of fixation the sediment was subjected to sorting under running tap water. Based on the preliminary assessment of seives of mesh size 0.3mm and 0.063mm were used for the macrofauna and meiofauna respectively as against 0.5mm recommended by Holme and McIntyre (1971). The fauna obtained was stored separately based on taxonomic classes in 5% neutralized formaldehyde. The isolated fauna was identified using taxonomic literature (Fauvel, 1932; Edmondson, 1959; Brusca, 1980; Apte, 1998).

Stratification

The variations in the benthic macroinvertebrates in the different strata in the vertical column of the sediment were studied by employing the same method as used for the study of benthic macroinvertebrates. The fauna obtained from each stratum of the sediment was stored separately in plastic vials and identified using appropriate literature. The benthic macroinvertebrates were studied using a binocular stereoscopic Ziess microscope. For estimating the density of the more numerous smaller benthic organisms the Bogrov cell was used.

On a seasonal basis the sediment vegetation and its associated fauna present at the site was scooped from 1m^2 quadrates and brought to the laboratory in polythene bags. In the laboratory the plant material and the fauna was sorted out, cleared of all sediment and stored in 70% alcohol. Both the plant and associated animal species were identified. The sediment algae and the angiosperm species were separated, dried to a uniform weight and weighted to obtain their biomass by dry weight/m^2 of the mud/sandflat.

Avifauna

The density, diversity and the behavioral ecology of the bird species at the six stations were studied as per the procedures detailed below.

Survey

Initial surveys of the avifauna were conducted all along the Mandovi estuary during both high tide and low tide at various times of the day i.e. morning, afternoon and evening. All the mudflats and sandflats along the 3 islands in the estuary and its banks were scanned from a slow moving indigenous dug out canoe with an onboard motor (0.5Hp Honda engine), moving at uniform speed of 10km per hour for probable bird activity. The site at Miramar on the other hand being easily accessible by road the census was carried out on foot. Foot trails were conducted into the dense mangroves not accessible by boat and the bird species therein were listed. The birds sighted were identified using the field guides (Woodcock, 1989; Ali & Ripley, 1983; Sonobe & Usui, 1993; Grewal, 1995; Ali, 1996; Grimett *et. al.* 1998). The morphological characteristics and the behavioral attributes of those species of birds difficult to identify in the field were noted and the identification was carried out using Compact Handbook of Indian Birds by Ali and Ripley (1983). Thus a preliminary baseline checklist of the bird species found at the different study stations were prepared and used for all further census work. The new species of birds occasionally sited during the course of the study were added to the initial list. The feeding and roosting sites of the waterbirds in general and the waders in particular were identified along the mud/sandflats during low tide and the adjoining mangroves during high tide.

The bird census' of all the study stations was carried out at fortnightly intervals. These census trips were conducted preferably at neap tide failing which the low tide with a depth nearest to the neap tide was chosen. A combination of Total Count Method and Transact count method using 8x35x and 12 × 25x binoculars' was employed for the purpose.

The bird census at all the sites was conducted either in the morning from 07 00 hrs to 10 00 hours or in the evening from 15 30 hours to 18 00 hours during the first week and the third week of every month. The census at all sites was carried out within two consecutive days. The census of the bird population inhabiting the mangroves was conducted by walking at uniform speed along the predetermined trails. In the early stages of the work, a census of the mangroves was also conducted from a boat during high tide. Since there was no perceptible change observed between the bird population inhabiting the mangroves at high tide and low tide only the low tide census was maintained so as to obtain a complete census of birds inhabiting the estuarine wetland. To account for the nocturnal use of the mudflats and the mangroves by the waterbirds, separate observations were also carried out well before dawn (02 00-04 30hrs) and after dusk (19 00-24 00 hrs). Observations were also carried out during the entire ebb tide to determine the exposure based movement, if any, of the birds especially the waders to and from the mudflats.

Behavioral studies

The foraging behavior of the waders and the ensuing conflicts and cooperation amongst the waders as well as between the waders and other resident birds was studied with the help of a 60 x 15-45x magnification spotting scope. When two birds either conspecifics or otherwise performed an activity in close positive association it was considered as a cooperation while if the birds were involved in chasing each other away or continuously giving alarm calls it was considered as a conflict.

The foraging in the waders was studied using the following techniques,

Instantaneous Scan

For an hour, at an interval of 5 minutes a complete scan of a single flock of birds numbering not more the 20 individuals was carried out and their activities at that instant were recorded. This was repeated for 10 days so as to obtain at least 120 readings per season.

Focal Animal Sampling

For the purpose, a single bird was observed continuously for 5 minutes followed by a gap of five minutes and the time spent for a particular activity was recorded. Nine such observations were carried out in 1hour 30 minutes per day. Observations were carried out for 15 days.

Focal behavior sampling

The foraging behavior of the waders was studied by this method. A single bird was considered and the time taken by the birds for 10 pecks was recorded. The numbers of successful pecks from among these 10 pecks were also recorded. A peck was considered successful if it was followed by a swallowing action as observed from the movement of the throat muscles. The preferences in the prey type and the prey size in relation to the beak length of the bird were also observed using a combination of the above 3 methods.

During the breeding period, the mangroves along the estuary and its backwaters were extensively surveyed to identify heronry sites, if any. Two heronries were identified and studied. As both the heronries were completely surrounded by water and quickmud all observations were carried out from a distance with the help of a binoculars and spotting scope. One of the heronries, which was located in the mangrove vegetation of the Chorao Island could be assessed only by boat and hence was studied for a continuous period of 6-7 hours starting from 07 00 hours, on the second and fourth week of every month. Twice during the breeding season the number of nests and the number of eggs and hatchlings in each nest were counted by climbing the trees in the nearest vicinity of the heronry. After the desertion of the colony the twigs from the nests were collected and the source plant was identified. The other heronry located along a small creek could be observed with less difficulty from a small park a few meters away from the heronry and was studied for a day at weekly intervals. However, due to total inaccessibility into the heronry invasive observations could not be carried out.

Species Indices

The species diversity, evenness and richness for the populations of benthic macroinvertebrates and the avifauna were calculated using the formulae given below.

Shannon-Wiener Species Diversity Index: (Pielou, 1975)

$$\text{Species Diversity } (H') = \sum_{i=1}^{S} p_i \log p_i$$

where p_i is the proportion of individuals belonging to the ith species and S is the total number of species.

Species Evenness or Equatibility Index : (Pielou, 1975)

$$\text{Species Evenness } (J') = \frac{H'}{\log S}$$

Species Richness Index: (Margalef, 1968)

$$\text{Species Richness (SR)} = \frac{S-1}{\log N}$$

where S is the number of species in the population containing N number of individuals.

The similarity in the avifaunal population between the different sites was calculated as follows:

Sorensons Similarity Coefficient :(Southwood, 1978)

$$\text{Similarity Coefficient (CS)} = \frac{2j}{a+b}$$

where a and b are the number of species at two sites and j is the number of species common to the two sites.

Statistical Methods

The mean and the standard error for most of the data has been computed a

$$\text{Mean} = \frac{\sum_{i=1}^{n} x_i}{N}$$

where x = observation for ith character

N= no of observations taken.

$$\text{Standard deviation} = \frac{\sqrt{\sum (x-x')^2}}{N}$$

$$\text{Standard error} = \frac{\text{standard deviation}}{\sqrt{N}}$$

All data was $\log_{10}$ transformed to meet the requirements of parametric tests. The direct correlation between the parameters was statistically analyzed by calculating the Pearsonian bivariate correlation 'r' using the formula

$$r = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}}$$

The significance of the correlation coefficients obtained was calculated using the t test as

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

The observed 't' value was compared with the critical 't' value obtained for n-2 degrees of freedom at 95% confidence level from the 't distribution table'. Observed 't' values higher than the critical 't' values at $P=0.05$ were considered significant and at $P=0.01$ were considered highly significant.

Unpaired Student T Test:

The variance between the different parameters within the sites during the 2 years of study was compared using unpaired Student T test.

One Way ANOVA

The variations between the various parameters between the six sites were analyzed using One Way ANOVA or F Test.

Kruskal Wallis or χ^2 test:

The seasonal variance between the various parameters was analyzed using the χ^2 test.

Mann Whitney U Test:

The variations in the parameter studied, if any, between the identical seasons of the two years were analyzed using Mann Whitney U Test.

The statistical Analysis were carried out using SPSS (version 6.1.3 for windows)(Einsprunch, 1998).

Chapter 4:
OBSERVATIONS

I Sediment Texture:

The biannual monthly averages of the sediment texture at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar are provided in table 4.1. The variations in the sediment texture on monthly basis at all the study sites are depicted in graphs 4.1 to 4.5 while those on seasonal basis are provided in tables 4.2-4.7.

The sediment texture showed marked variations amongst the sites. The sediment with total sand at Miramar and with 64.97% silt at Chorao, were the two extremes. The sediment of Miramar contained significantly more sand compared to that of other sites (df=137, F=94.08, p=0.00). On the other hand, the percentages of both coarse and fine silt were significantly lower at Diwar (p=0.00, total silt: df=114, F=95.91; coarse silt: df=114, F=37.12 and fine silt: df=114, F=120.01). The six sites could be divided into two statistical clusters depending upon the percentage of clay present in the sediment. The clay content in the cluster comprising of Ribandar and Chorao was significantly higher (df=114, F=22.31, p=0.00) than that in the other cluster comprising of Minor C, Minor D and Diwar. Clay was totally absent at Miramar.

Ribandar: Graph 4.1

The sediment of Ribandar can be described as sandy silt since silt was the largest constituent contributing 58.28%. The silt was made up of 27.67% coarse and 30.61% fine components. Sand and clay constituted 36.30% and 6.42% of the sediment respectively.

The percentage of sand in the sediment of Ribandar ranged from a lowest 12.15% in September to a high of 57.55% in May 1999. However it was exceptionally high in June 2000 (71.8%). On a seasonal basis it was almost constant through all the seasons except in post monsoon when it decreased considerably. Silt, the major component of the sediment comprised largely of fine silt (51.48%) and followed an exactly opposite profile to that of sand. This negative correlation between the two major components was statistically significant ($r=-0.88$, $p<0.01$). Besides sand ($r=-0.73$, $p<0.01$), fine silt also correlated negatively with clay ($r=-0.43$, $p<0.05$) and rainfall ($r=-0.5$, $p<0.05$).

The percentage of clay in the sediment ranged from 3.3% and 2.3% in August to 12.6% in February 2000 and remained fairly constant throughout the year except in summer when it reached a maximum.

Chorao: Graph 4.2

At Chorao also the sediment can be described as sandy silt and contained marginally more silt than that at Ribandar. Fine and coarse silt constituted 36.99% and 27.98% of the sediment respectively. Clay was the least contributing to only 5.53% of the sediment.

The percentage of sand at Chorao ranged from 10.4% in June 2000 to 50.55% in August 1999. On a seasonal basis, sand was highest in monsoon of 1999 and lowest in summer (26.37%) but in the next year the reverse was true. It varied only marginally through the seasons of each year, but significantly between the monsoons of the two years ($u=0$, $p=0.05$). Sand correlated negatively with silt ($r=-0.9$, $p<0.01$) and clay ($r=-0.53$, $p<0.01$).

Silt, comprising largely of the finer component, ranged from 42.25% in March to 80.9% in October. On a seasonal basis, during 1999-2000 silt was highest in post monsoon while in the next year the maxima was recorded in monsoon, a season earlier than the previous year. Silt content varied significantly between the 2 monsoons ($u=0$, $p=0.05$) with fine silt being significantly higher in monsoon of 2000 ($\chi^2=7.64$, df=3, $p=0.05$). Coarse and fine silt correlated significantly with nitrate ($r=0.68$, $p<0.01$) and relative humidity ($r=0.42$, $p<0.05$).

Clay ranged from 2.1% in December/January to 12.05% in April. On a seasonal basis clay followed a similar pattern as that at Ribandar but was significantly lower in winter of 2000-2001 (χ^2=7.51, df=3, p=0.05). Clay correlated positively with the density of benthic macroinvertebrates (r=0.52, p<0.05).

Minor C: Graph 4.3

The sediment of Minor C can be described as silty sand as sand was the dominant component (66.3%). Silt and clay contributed to 30.73% and 2.97% of the sediment respectively.

The percentage of sand ranged from 52.15% in June 1999 to 83.9% in January 1999 and varied significantly between the 2 years. (t=2.23, df=21, p=0.04). Seasonally, in 1999-2000 it was highest during winter but in the subsequent year it was highest in post monsoon, a season earlier than the previous year. Sand correlated negatively with silt (r=-0.96, p<0.01) and clay (r=-0.44, p<0.05).

The percentage of silt, the next major component, ranged from 14% in January 2000 to 46.05% in February 2001 and comprised largely of coarse silt. Silt content was almost uniform through all the seasons except in monsoon of 2000. Only fine silt varied significantly between the two years (t=-2.53, df=21, p=0.02). Both coarse and fine silt correlated significantly with wind {coarse: (r =0.64, p<0.01), fine (r=0.45, p<0.05)}. Coarse silt also correlated positively with humidity (r=0.44, p<0.05) and rainfall (r=0.51, p<0.05).

The clay content ranged from 0.75% in November 1999 to 4.1% in December. Seasonally it was highest in summer of 1999 and winter, a season earlier, during the next year. Clay correlated positively with the nitrates (r=0.43, p<0.05) and phosphates (r=0.43, p<0.05).

Minor D: Graph 4.4

The sediment texture of Minor D was similar to that at Minor C comprising of 68.06% sand, 13.38% silt and 2.31% clay.

Sand in the sediment ranged from 46.6% in August 2000 to 84.45% in March 1999. On a seasonal basis it was comparatively higher in monsoon of 1999. The sand component varied significantly between the two years ($t=2.32$, $df=21$, $p=0.03$) particularly during monsoons ($u=0.0$, $p=0.05$). It correlated negatively with silt ($r=-0.93$, $p<0.01$) and nitrates ($r=-0.51$, $p<0.05$).

Silt, comprising largely of the coarse form, followed a profile almost similar to that at Minor C and ranged from 12.3% in March 1999 to 48.7% in August 2000. Season wise, silt was low in monsoon but varied only minimally through the rest of the seasons. Although silt in general varied significantly between the two years ($t=-2.5$, $df=21$, $p=0.02$), coarse silt varied only between the two monsoons ($u=0.0$, $p=0.05$). Total silt correlated negatively with sand($r=-0.93$, $p<0.01$) while coarse silt correlated significantly with nitrates($r=0.42$, $p<0.05$).

The percentage of clay at Minor D ranged from barely 1.2% in November 1999, to 3.8% in November 2000. Seasonally in 1999-2000, it was maximum in summer, while during the next year it was maximum in winter, a season earlier than that of the previous year. During the second year clay was comparatively high during monsoon also.

Diwar : Graph 4.5

The sediment of Diwar was silty sand as it contained more sand (84.35%) and less silt (13.38%) than that at all the sites mentioned above. However its clay content was similar to that at Minor C and Minor D (2.31%). Silt comprised of almost equal proportion of coarse and fine components.

The percentage of sand ranged from lowest in September-October to highest in February. Seasonwise, it was highest in winter and lowest in post monsoon. Sand correlated negatively with silt ($r=-0.95$, $p<0.01$).

The percentage of silt was least in February 2000 and highest in October-November. On a seasonal basis it was maximum in post monsoon and minimum in winter of both years. Coarse silt correlated significantly with organic carbon ($r=0.48$, $p<0.05$).

Clay oscillated between 0.8% in December 2000 to 5.1% in April 1999. Seasonwise it was maximum in summer (3.67% and 2.77%), followed by those of monsoon (2.35% and 2.69%), post monsoon (1.35% and 2.42%) and was least in winter (1.3% and 1.5%). Clay correlated significantly with rainfall ($r=0.51$, $p<0.05$).

Miramar

The sediment of Miramar all through the year was solely sand with only minute traces of silt.

II Physico chemical parameters

The biannual monthly averages of the physico-chemical parameters at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar are provided in table 4.8. The seasonal variations in the physico-chemical parameters at all the six sites are given in table 4.9-4.14.

Temperature:

The monthly profiles of the ambient temperature, water temperature and sediment temperature at the six sites during the study period are provided in Graph 4.6 a-f.

Ambient temperature:

The biannual average ambient temperature at all the sites except Miramar was almost similar. At Ribandar, Chorao, Minor C and Minor D ranged from a minimum of 21^{0}C in June/July to a maximum of 28^{0}C in March. At Miramar however, it ranged from 22 ^{0}C in January 2000 to 26^{0}C in February 2001. On a seasonal basis at all sites it was lowest in monsoon. This variation was more pronounced at Minor D, being significantly lower during monsoon of 2000 (χ^2=8.05, df=3, p=0.04). The ambient temperature remained fairly stable during the other seasons of both the years.

Water temperature:

Water temperature like ambient temperature showed very little variations through the entire study period. It ranged from 23 ^{0}C in June 2000 to 28^{0}C in February 2001. On a seasonal basis also it followed the same pattern as that of water temperature and was lowest in monsoon. However at Miramar, during 2000-2001, the ambient temperature was lowest in post monsoon. During the same year the water temperature in monsoon was significantly low at Chorao (df=3, χ^2 =8.52, p=0.04), Minor C (χ^2 = 8.22, df=3, p=0.04) and Minor D (χ^2=7.61, df=3, p=0.05).

Sediment Parameters

Temperature:

Sediment temperature of the 6 sites varied only marginally on a biannual basis. At all the sites it closely paralleled the ambient and water temperature. Sitewise details are as shown below.

Ribandar

The sediment temperature ranged from a low of 24^{0}C in December 1999 to a high of 29^{0}C in February 2001. Season wise it was lowest in monsoon (25^{0}C and 25.75^{0}C). It showed only slight variations through the rest of the seasons. However it varied significantly between the 2 years (df=21, t=-2.04, p=0.05). Sediment temperature correlated positively with sunshine ($r=0.45$, $p<0.05$) and water temperature ($r=0.88$, $p<0.01$) and negatively with rainfall ($r=-0.65$, $p<0.01$).

Chorao

Sediment temperature at Chorao ranged from 24^{0}C in June 1999 to 30^{0}C in November 2000. On a seasonal basis the sediment temperature was low in monsoon. In 1999-2000, the temperature was highest in winter (26.33^{0}C). In the next year the temperature reached a maximum a season earlier, in post monsoon. During the rest of the seasons it remained fairly stable. Variations in the sediment temperature were significant only in 2000-2001(df=3, χ^2=9.10, p=0.03). There was a significant positive correlation between sediment temperature, water temperature ($r=0.79$, $p<0.01$) and sunshine ($r=0.44$, $p<0.05$).

Minor C

The temperature ranged from 25^{0}C in November and January 1999, June and July 2000 to 30^{0}C in April 2000. As in the case of Ribandar, here too, the temperature was low in monsoon (25.67^{0}C and 25.5^{0}C) and showed only slight variations between the remaining seasons. During 2000-2001, these seasonal variation were statistically significant (χ^2=9.1, df =3, p=0.03). There was a statistically significant correlation between sediment temperature and water temperature ($r=0.61$, $p<0.01$).

Minor D

Sediment temperature at Minor D followed a similar pattern as that at Minor C and Ribandar. On a seasonal basis, it remained fairly within range through all the seasons except winter when it increased to 28^{0}C. The variations in the sediment temperature were significant only during 2000-2001(χ^2=8.25, df=3, p=0.04). Sediment temperature correlated with ambient temperature (r=0.57, p<0.01), sunshine (r=0.51, p<0.05) and water temperature (r=0.83, p<0.01).

Diwar

The sediment temperature at Diwar followed a similar profile as all the other sites mentioned above but varied significantly between the two years (t=-2.16, df=21, p= 0.04). It ranged from 24^{0}C in July 2000 to 29^{0}C in February 2001. On a seasonal basis, it remained almost uniform through all the seasons of 1999-2000. In the subsequent year it was highest in summer (28.67^{0}C) and dropped steeply during monsoon (25.25^{0}C). Sediment temperature correlated positively with ambient temperature(r=0.5, p<0.05) and water temperature (r=0.85, p<0.01) and negatively with rainfall (r=-0.54, p<0.05).

Miramar

Sediment temperature at Miramar ranged from 24^{0}C in September-October 1999/2000 to 29^{0}C in May 2000. On a seasonal basis during both the years it was lowest in monsoon (25.33^{0}C and 25.5^{0}C) and highest in summer (26.33^{0}C and 27.33^{0}C). The summer high was followed by winter (26^{0}C and 26.67^{0}C). Sediment temperature correlated with ambient temperature (r=0.53, p<0.01) and water temperature (r=0.87, p<0.01).

pH : Graph 4.7

The sediment at all the sites was in alkaline ranges. The sediment of Ribandar was mildly alkaline with a pH of 7.83 while that of Miramar was the fairly alkaline with a pH of 8.76 based on the biannual monthly average. pH of the other sites ranged from 7.97 to 8.34. pH varied significantly between the sites (df=137, F=45.93, p=0.00). pH of Miramar was significantly higher than all other sites while that of Diwar was higher than Ribandar, Chorao, Minor C and Minor D. pH of Minor D was significantly higher than that of Ribandar.

Ribandar

pH was the lowest in June 1999 (7.44) and increased gradually to reach a highest of 8.18 in February. During the next year, although a similar pattern was followed the cyclicity had shifted by approximately 2 months with the pH being minimum in September and maximum in April. Seasonally it remained constant through almost all the seasons except summer of 2000 when it increased sharply to 8.16. In general the pH varied significantly between the 2 years (df=21, t=-3.06, p=0.01) especially during the monsoon (u=0.0, p=0.05). In 1999-2000, pH was significantly higher during winter (df=3, χ^2=9.41, p=0.02) while in the next year it was significantly higher in summer (df=3, χ^2=7.662, p=0.05). pH correlated positively with chlorides (r=0.64, $p<0.01$) and conductivity (r=0.61, $p<0.01$).

Chorao

The sediment of Chorao was mildly alkaline throughout the year with the mean pH of 8.02. It ranged from 8.29 in January-February to 7.39 in March. On a seasonal basis, in the year 1999–2000, pH was low in monsoon and increased steadily through post monsoon to attain a high of 8.16 in winter. During the next year it remained fairly constant but was significantly higher than that of the previous year (t=-2.24, df=21, p=0.05).

Minor C

The average biannual pH of the sediment of Minor C was slightly less alkaline than that of Chorao but more alkaline than that of Ribandar with a value of 7.7. The sediment pH followed a similar pattern as that of Chorao and Ribandar. It ranged from 7.39 in March 1999 to 8.29 in December of the same year. Season wise, pH reached a peak in winter (8.18 and 8.05) but showed no pronounced variation during the other seasons. In 2000-2001, it was also high in early monsoon. pH varied significantly between the 2 monsoons (u=0, p=0.05).

Minor D

The sediment pH averaging 8.07 on a biannual monthly basis was marginally higher than that at Chorao and Minor C. It ranged from a lowest in September-October (7.61 and 7.9) to a highest in May 2000 (8.41). Seasonwise during 1999-2000, it was minimum in monsoon and rose gradually through post monsoon to reach a maximum in winter. During the year, the pH during post monsoon and winter were significantly higher than those of summer and monsoon (χ^2=8.08, df=3, p=0.04). In the next year, the least pH was recorded a season prior to that of the previous year in post monsoon. pH varied significantly between the 2 years (t=-2.18, df=21, p=0.04), especially between monsoons (u=0.0, p=0.05). pH had a significant correlation with clay (r=0.42, $p<0.05$) and coarse silt(r=0.63, $p<0.01$).

Diwar

The biannual monthly average of the pH was 8.34. The sediment pH at Diwar followed a similar pattern as that of Minor D. However, it was more alkaline than all the above sites with the pH ranging from 8.02 in September/October to 8.68 in June/July. The pH was also high in December/ January. On a seasonal basis, pH was highest in winter (8.53 and 8.58). In 1999-2000, it remained fairly uniform through the rest of the seasons while in 2000-2001, it dropped sharply in post monsoon (8.19). pH varied significantly between the 2 years (t=-2.81, df=21, p=0.01) especially between the 2 monsoons(u=0.0, p=0.05). pH showed a statistically significant correlation with fine silt (r=0.47, $p<0.05$).

Miramar

The sediment pH remained higher than that at other sites through most of the study period and ranged from 8. 25 in March 1999 to 9.16 in August. It showed minimal variations through the seasons of the 2 years. pH varied significantly between the years (df=21, t=-5.7, p=0.00) particularly the monsoons (u=0.00, p=0.05). pH correlated significantly with ambient temperature (r=-0.63, p<0.01).

Conductivity: Graph 4.8

The conductivity at all the sites followed a similar seasonal pattern and was low in monsoon but reached a maximum in late winter/early summer. A statistically significant variation was observed in the conductivity of the six sites (df=137, F=56.11, p=0.00), with that of Ribandar being the highest and Miramar the lowest.

Ribandar

The average sediment conductivity on biannual basis at Ribandar was 15.31μmho. It ranged from 7.5μmho in August/September to 22.7μmho in February 2001. A sharp and sudden increase in the conductivity was also observed in May 1999. Conductivity showed a distinct seasonal cyclicity. It was maximum in winter (19.97μmho and 21.2μmho), followed by that of summer (18.73μmho and 18.63 μmho), post monsoon (12.95μmho and 12.9μmho) and monsoon (8.33μmho and 9.97μmho). Conductivity during summer and winter was significantly higher than that during monsoon and post monsoon (df=3, for 1999-2000: χ^2=8.18, p=0.04; for 2000-2001, χ^2=9.15, p=0.03). Conductivity correlated positively with chlorides (r=0.82, p<0.01), clay (r=0.42, p<0.05), temperature (r=0.68, p<0.01) and pH (r=0.61, p<0.01).

Chorao

The sediment conductivity of Chorao remained lower than that of Ribandar all through the year and had a biannual mean of 9.95 μmho. Like Ribandar, here also it was lowest in August/September (5.6μmho) and highest in April (14.6μmho & 15.4 μmho). On a seasonal basis the conductivity was highest in summer (14.1 μmho &13.27μmho), a season later than that at Ribandar. The summer high was followed by the conductivity in winter (10.43 μmho & 11.93μmho). The conductivity during the other 2 seasons varied only marginally. In 2000-2001, conductivity during summer and winter was significantly higher than that observed during monsoon and post monsoon (df=3, χ^2=8.8, p =0.03). Conductivity correlated positively with clay (r=0.50, $p<0.05$), temperature (r=0.50, $p<0.05$) and organic carbon (r=0.54, $p<0.01$) negatively with phosphates (r=-0.43, $p<0.05$) and total alkalinity (r=-0.43, $p<0.05$).

Minor C

The sediment of Minor C had an average conductivity of 6.23μmho on biannual basis. The conductivity was lower than that at Ribandar and Chorao all through the study period. It fluctuated between 3.8 μmho in July 2000 to 11.8 μmho in May. On a seasonal basis, monsoons recorded the least conductivity (4.9 μmho and 4.73 μmho). During 1999-2000, conductivity was maximum in winter (7.93μmho) which continued through the next season, summer of the next year (8.43 μmho). The sediment conductivity varied significantly between the seasons of the two years (df=3; for 1999-2000: χ^2= 8.41, p=0.04; for 2000-2001: χ^2=9.65, df=3, p=0.02). Conductivity correlated positively with chlorides (r=0.85, $p<0.01$), clay (r=0.45, $p<0.05$) and sediment temperature (r=0.46, $p<0.05$).

Minor D

The conductivity of the sediment at Minor D was higher than that of Minor C with a biannual average of 7.17μmho. The monthly conductivity profile of Minor D matched with those of Ribandar and Minor C and ranged from 4.9μmho in August/September to 10.1μmho in December/January. Seasonally, it was maximum in winter (8.9μmho and 9.33μmho) followed by those of summer (7.13 μmho and 8.7μmho), post monsoon (6.85μmho and 6.1μmho) and monsoon (5.17μmho and 5.32 μmho). During both the years sediment conductivity of monsoon was significantly lower than that of the other seasons (df=3; for 1999-2000, χ^2=8.75, p=0.03; for 2000-2001, χ^2=9.03, p=0.03). Conductivity correlated positively with chlorides (r=0.83, p<0.01), nitrate (r=0.52, p<0.05), sediment temperature (r=0.55, p<0.05) and sulphates (r=0.76, p<0.01) and negatively with rainfall (r=-0.69, p<0.01).

Diwar

At Diwar, sediment conductivity on an average was 5.3 μmho on biannual basis and was lower than that at all the 4 sites described above. As in all other sites it was lowest in August (4.9 μmho) but reached a maximum in May (5.8 μmho and 6.4μmho). The conductivity followed a seasonal pattern similar to that at Chorao and was high in summer (5.63 μmho and 5.93 μmho). In 1999-2000, conductivity was least in post monsoon but during the next year the conductivity dropped to a lowest in monsoon, a season prior to that of the previous year. A statistically significant correlation was seen between conductivity and sediment temperature (r=0.46, p<0.05) and total alkalinity (r=0.53, p<0.01).

Miramar

The average conductivity of the Miramar sediment on biannual consideration was 5.13 μmho. Here, the sediment conductivity ranged from 4.9 μmho in

July/August to 5.4 µmho in March/April. The conductivity followed a similar seasonal profile as that at Minor D and was low in monsoon (5.03 µmho and 4.95 µmho) and high in summer (5.5 µmho and 5.27 µmho). In 1999-2000, the sediment conductivity during summer and post monsoon was significantly higher than that of monsoon and winter (df=3, χ^2=7.53, p=0.05) while in 2000-2001 it was also high in summer (df=3, χ^2=8.37, p=0.04). Conductivity correlated significantly with chloride (r=0.49, p<0.05), temperature(r=0.61, p<0.01), organic carbon (r=0.55, p<0.01), and sulphates (r=0.46, p<0.05).

Chlorides: Graph 4.9

Sediment chloride contents were lowest at Miramar and highest at Ribandar. The variations in the chlorides through the 2 years at all the 6 sites coincided greatly with one another. At all the sites chlorides increased sharply during late summer/ early monsoon and decreased during late monsoon/early post monsoon. Chloride concentrations varied significantly between the sites (df=137, F=93.89, p=0.00). At Ribandar chloride content was significantly higher than that at all other sites while at Miramar it was significantly lower. Chloride content at Chorao was higher than that at Minor C, Minor D and Diwar.

Ribandar

The biannual average of the chloride levels in the sediment of Ribandar was 456.58 mg/100g. It ranged from a lowest in August (228.62 mg/100g and 225.62 mg/100g) to a highest in winter of 1999-2000 and continued thus into the next season i.e. summer of 2000. On a seasonal basis, chlorides were minimum in monsoon (268.16 mg/100g and 328.53 mg/100g). The fluctuations through all the other seasons were however not pronounced. In 1999-2000, chlorides during winter were significantly higher than those of the other seasons (df=3, χ^2=8.73, p=0.03), while in 2000-2001, the chloride levels in summer were also significantly high (df=3, χ^2=8.39, p=0.04). Chlorides correlated positively with ambient temperature ($r=0.54$, $p<0.01$), clay ($r=0.43$, $p<0.05$) and pH ($r=0.64$, $p<0.01$).

Chorao

The average chloride concentration recorded at Chorao was 278.09 mg/100g. It ranged from minimum in September (119.28mg/100g and 102.24 mg/100g) to maximum in March/April (636.87mg/100g). The chloride concentration in the sediment followed a distinct seasonal cyclicity. It was highest in summer (382.44 mg/100g and 479.49mg/100g), followed by winter (250.53 mg/100g and 326.37mg/100g), post monsoon (216.91 mg/100g and 181.41 mg/100g) and monsoon (194.54 mg/100g and 174.84 mg/100g). During 2000-2001, chloride content during monsoon and post monsoon were significantly lower than those in summer and winter ($\chi^2 =8.99$, df=3, $p=0.03$). Chlorides correlated positively with clay ($r=0.49$, $p<0.05$), conductivity ($r=0.91, p<0.01$), organic carbon ($r=0.46$, $p<0.05$) and sunshine ($r=0.45$, $p<0.05$).

Minor C

The average chloride concentration in the sediment of Minor C on a biannual basis was 126.97mg/100g and was lower than that at Chorao. At Minor C, it followed a similar pattern as that at Ribandar and Chorao. Like conductivity, the chloride content in the sediment of Minor C also was lower than that at Chorao. It ranged from a lowest in September to a highest in May 2000. On a seasonal basis, chlorides were maximum in winter (188.15mg/100g) of 1999-2000 and continued to be so through the next season, the summer of 2000 (236.02 mg/100g). Chloride levels were minimum in monsoon (55.85 mg/100g and 44.37 mg/100g). The chloride contents in the sediment during both the years were significantly higher in summer and winter (df=3; for 1999-2000: $\chi^2=7.94$, $p=0.05$; for 2000-2001: $\chi^2=10.09$, $p=0.02$). Chlorides had a positive correlation with conductivity ($r=0.85$, $p<0.01$), sediment temperature ($r=0.49$, $p<0.05$) and sunshine ($r=0.71$, $p<0.01$).

Minor D

Chloride content at Minor D was less than that at Chorao and Ribandar, but more than that at Minor C. It had a biannual average of 170.04mg/100g and ranged from 35.5mg/100g in August/September to 250.6mg/100g in April/May. Chlorides also increased sharply in November 1999. On a seasonal basis, chlorides were lowest in monsoon (81.17mg/100g and 89.99mg/100g) and highest in winter (236.79mg/100g and 227.9mg/100g). In 2000-2001 chlorides were significantly higher in summer and winter (χ^2=7.62, df=3, p=0.05). Chlorides correlated positively with nitrates (r=0.5, $p<0.05$) and sediment temperature (r=0.43, $p<0.05$), and negatively with rainfall (r=-0.57, $p<0.05$).

Diwar

The sediment of Diwar had marginally lower chloride levels than those at all the above 4 sites averaging 85.55mg/100g on a biannual basis. Like Minor D it was minimum in June/August and maximum in February/March. On a seasonal basis, like all other sites described earlier chloride levels in monsoon were significantly lower than the rest of the year (df=3, for 1999-2000: χ^2=8.06, p=0.04; for 2000-2001: χ^2=10.27, p=0.02). In 1999-2000, the low monsoon concentration increased gradually through post monsoon and winter. In 1999-2000, chlorides attained a peak value of 159.29mg/100g in winter. It continued to be higher through the next season that was summer of the next year. Chlorides correlated positively with ambient temperature (r=0.63, $p<0.01$) and negatively with rainfall (r=-0.63, $p<0.01$).

Miramar

The average chloride content in the sediment of Miramar on a biannual basis was 82.4mg/100g. The chloride concentrations fluctuated between 51.83mg/100g in August 1999 and 100.11mg/100g in March and December of the same year. Chloride concentrations remained almost uniform through all the 4 seasons of 1999-2000. During the next year chloride levels in winter were significantly lower than those in the rest of the seasons (df=3, χ^2=8.24, p=0.04). There was a statistically significant correlation between chlorides, conductivity (r=0.49, p<0.05) and organic carbon (r=0.58, p<0.01)

Total alkalinity: Graph 4.10

The total alkalinity of all the sites was high in late summer/early monsoon and low in early post monsoon. Total alkalinity at Miramar was significantly lower while that at Ribandar was significantly higher than that at all the other sites (df=137, F=22.05, p=0.00).

Ribandar

The average biannual total alkalinity at Ribandar was 3.72mg/100g. It ranged from 2mg/100g in February to 6.45mg/100g in June. Seasonally it was maximum in monsoon (5.03mg/100g and 5.25mg/100g). In 1999-2000, it was lowest in summer (2.58mg/100g) but during the subsequent year lowest total alkalinity was recorded in winter (3.61mg/100g), a season earlier than the previous year. Total alkalinity correlated positively with rainfall (r=0.56, p<0.05) and negatively with sediment temperature (r=-0.66, p<0.01), fine silt (r=-0.46, p<0.05), conductivity (r=-0.34, p<0.01) and chlorides (r=-0.54, p<0.05).

Chorao

The biannual average total alkalinity of the sediment of Chorao was 2.28 mg/100g. As in Ribandar here also the total alkalinity ranged from 1.67mg/100g in December/January to 4.25mg/100g in June/August. On a seasonal basis, the total alkalinity was maximum during the monsoons (3.58 mg/100g and 2.23 mg/100g). During 1999-2000, total alkalinity decreased steadily through postmonsoon to reach a low of 1.81 mg/100g in winter. During this year the total alkalinity levels in monsoon and post monsoon were significantly higher than those of summer and winter (df=3, χ^2 =8.77, p=0.03). Total alkalinity during summer, post monsoon and winter was fairly uniform. It varied significantly between the two monsoons ($u=0.0$, $p=0.05$). Total alkalinity correlated with sediment temperature ($r=-0.45$, $p<0.05$), pH ($r=-0.48$, $p<0.05$) and conductivity ($r=-0.43$, $p<0.05$).

Minor C

The average total alkalinity at Minor C on a biannual basis was 2.17mg/100g being marginally lower than that at Ribandar. The monthly profile of the total alkalinity at Minor C was similar to that of Ribandar. It was lowest in October/ November and highest in August. On a seasonal basis, total alkalinity was least in post monsoon (1.92 mg/100g and 1.23 mg/100g). In the year 1999-2000, it was highest in monsoon (2.84/100g), but in the subsequent year it attained a peak, a season earlier (2.73mg/100g). Total alkalinity varied significantly on a yearly basis ($t=2.29$, $df=21$, $p=0.03$). Total alkalinity correlated significantly with nitrates ($r=-0.47$, $p<0.05$).

Minor D

The total alkalinity in the sediment of Minor D was higher than that at Minor C and Chorao. The biannual average total alkalinity was 2.37mg/100g. It ranged between 3.5mg/100g in May 1999 and 1.29 mg/100g in February 2001. However, it rose to an exceptional high of 4mg/100g in March-April 1999. Season wise, total alkalinity was minimum in postmonsoon (2.42mg/ 100g and 1.71mg/100g) and varied marginally during the other seasons of 1999-2000. During the next year it increased to a maximum in monsoon (2.37mg/100g). Total alkalinity correlated positively with sand ($r=0.49$, $p<0.05$) and negatively with sediment temperature ($r=-0.42$, $p<0.05$) and silt ($r=0.56$, $p<0.01$).

Diwar

The biannual average total alkalinity of the sediment at Diwar was 1.91mg/ 100g and was lower than that at all other sites. The monthly profile of the total alkalinity at Diwar showed greater similarity with that of Minor D rather than the rest of the sites. It fluctuated between 1.13mg/100g in December and 3mg/100g in June-July. A sharp decrease in the total alkalinity was also observed in August. On a seasonal basis it reached a peak in summer (2.31mg/100g and 2.27mg/100g), a season before the other sites and was low in winter (1.93mg/100g and 1.16mg/100g). Total alkalinity correlated positively with conductivity ($r=0.53$, $p<0.01$).

Miramar

The biannual average total alkalinity at Miramar was 1.3mg/100g. It ranged between a lowest of 0.63 mg/100g in August/September to a highest of 2.6 mg/100g in May. The total alkalinity showed minimal variations through the seasons but for a drop during post monsoon. In the year 2000-2001, based on the total alkalinity 2 seasonal clusters could be formed, one including summer and winter and the other between monsoon and post monsoon The variation between these 2 seasonal clusters was statistically significant ($df=3$, $\chi^2=8.32$, $p=0.04$). Total alkalinity also varied significantly between the 2 years ($df=21$, $t=2.54$, $p=0.02$) especially in terms of monsoon values ($u=0.5$, $p=0.05$).

Sulphates: Graph 4.11

Sulphate concentration throughout the study area was high in late winter and early summer and low in early monsoon particularly in July. Sulphates varied significantly between the sites ($df=137$, $F=45.53$, $p=0.00$). At Miramar they were significantly lower than that at all the other sites while at Diwar they were lower than that at Ribandar, Chorao, Minor C and Minor D. Sulphates at Chorao were significantly higher than that at Minor C and Minor D.

Ribandar

Ribandar sediment contained 264.41mg/100g sulphates based of a biannual monthly average. The levels fluctuated between 112mg/100g in July 2000 and

499.55mg/100g in February/March. On a seasonal basis in 1999-2000, sulphates were maximum in winter (337.12mg/100g) but in the subsequent year maximum sulphate levels were recorded in post monsoon, a season earlier than that of the previous year. Sulphates correlated positively with ambient temperature ($r=0.43$, $p<0.05$) and fine silt ($r=0.41$, $p<0.05$) and negatively with sand ($r=-0.41$, $p<0.05$).

Chorao

Sulphate concentrations in the sediment of Chorao were higher than those at all other sites with a biannual average concentration of 368.79 mg/100g. Like Ribandar here also the levels fluctuated between minimum in July 2000 (146.5mg/100g) and a maximum in September (677mg/100g and 700mg/100g). On a seasonal basis it followed exactly the same pattern as that at Ribandar.

Minor C

The average biannual sulphate concentration at Minor C was 196.90 mg/100g. This was lower than those at the other 2 sites mentioned above. Sulphates ranged from a highest in May 1999 (364mg/100g) to a lowest in November (94.5mg/100g) the same year. Sulphates showed a distinct seasonal cyclicity at Minor C. They were maximum in summer (265.5mg/100g and 301.92mg/100g) and minimum in monsoon (129.5 mg/100g and 135.13 mg/100g) but varied only marginally during the other seasons. In 2000-2001, sulphates during monsoon and post monsoon were significantly lower than those in winter and summer ($df=3$, $\chi^2=9.48$, $p=0.02$). Sulphates correlated positively with chlorides ($r=0.69$, $p<0.01$), conductivity ($r=0.72$, $p<0.01$) and sediment temperature ($r=0.54$, $p<0.01$).

Minor D

Sediments at Minor D contained on an average 173.77mg/100g sulphates, which was marginally less than that at Minor C. It ranged from 67.75mg/100g in July 2000 to 315mg/100g in January the same year. Seasonwise sulphates were high in winter of 1999-2000. It continued to increase and reached a maximum in the next season, namely summer of 2000. Sulphate levels during 2000-2001 were minimum in monsoon, a season later than that in the previous year. Sulphate levels during monsoon and post monsoon were significantly lower than those during summer and winter (df=3; for 1999-2000: χ^2=9.03, p=0.03; for 2000-2001: χ^2=8.65, p=0.03). Sulphates correlated positively with, chlorides (r=0.66, p<0.01), conductivity (r=0.76, p<0.01), sediment temperature (r=0.67, p<0.01), and negatively with rainfall (r=-0.51, p<0.05).

Diwar

The sediment contained 101.71mg/100g of sulphates on a biannual average, which was lower than that at all, the above 4 sites. The monthly sulphate profile at Diwar was similar to that at Minor D. Here also it ranged from a low of 46mg/100g and 58mg/100g in August to a high of 198mg/100g in December/January. On a seasonal basis, it was highest in winter and lowest in monsoon. Sulphate levels varied significantly between the seasons of 2000-2001 (χ^2=7.9, df=3, p=0.05). Sulphates correlated positively with chlorides (r=0.58, p<0.01).

Miramar

The biannual average sulphate content in the sediment of Miramar was 54.67 mg/100g. Sulphate levels in the sediment ranged from barely 2.5 mg/100g in July 2000 to 155.67 mg/100g in December 1999. However, sulphate levels were exceptionally high in March 2000. Seasonally, in 1999-2000, sulphate levels were maximum in winter (86.89 mg/100g) and continued thus into the summer of the next year (106 mg/100g). No major fluctuations were observed during the rest of the seasons. Sulphates and conductivity correlated significantly ($r=0.46$, $p<0.05$).

III Sediment Nutrients:

The biannual monthly averages of the sediment nutrients at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar are provided in table 4.15. The seasonal variations in the sediment nutrients at all the six study sites are provided in tables 4.16-4.21.

Organic Carbon: Graph 4.12

Organic carbon at all the sites followed a similar annual pattern. In general it was high in late summer/early monsoon and low in late winter/early summer. At all sites it increased sharply during April 1999 and decreased almost immediately in the next month. The organic carbon at all the sites was comparatively higher in summer of 1999. The organic carbon content varied significantly between the sites ($df=137$, $F=133.19$, $p=0.00$) with that at Miramar being the least. At Ribandar and Chorao it was significantly higher than that at the other sites. Organic carbon at Minor C and Minor D was significantly higher than that at Diwar.

Ribandar

The sediment contained 3.37% organic carbon on a biannual basis. Except for the high organic carbon in March 1999, it ranged from 2.06% in May to 4.9% in March/April. On a seasonal basis, it was highest in winter but varied only marginally between the other seasons.

Chorao

The biannual average organic carbon at Chorao was 3.17%. Except for the high organic carbon in March 1999, it fluctuated between 2.41% in October

2000 and 3.99% in November 2000. On a seasonal basis it followed the same pattern as that at Ribandar but dropped to a lowest in monsoon (2.88% and 2.64%). Organic carbon correlated positively with conductivity ($r=0.54$, $p<0.05$), and sunshine ($r=0.43$, $p<0.05$) and negatively with phosphate ($r=-0.5$, $p<0.05$) and rainfall ($r=-0.59$, $p<0.05$).

Minor C

The sediment of Minor C contained less organic carbon than that at Chorao and Ribandar averaging 2.07% on a biannual basis. It followed a similar annual cyclicity as that of Chorao and ranged from 1.12% in June to 2.56% in November/December, except for the high organic carbon in March 1999. Seasonwise, in 1999-2000, organic carbon was high in post monsoon. In the subsequent year the maximum organic carbon was recorded a season later in winter. During this year there was a marginal increase in the organic carbon with the advancing seasons. In 2000-2001, organic carbon content in summer and monsoon being near constant were significantly lower than that in post monsoon and winter ($\chi^2=8.33$, df=3, $p=0.04$). The organic carbon content also varied significantly between the 2 monsoons ($u=0$, $p=0.05$). Organic carbon showed a significant correlation with rainfall ($r=-0.6$, $p<0.05$).

Minor D

The sediment at Minor D contained 1.83% organic carbon on the basis of biannual average, which was almost the same as that at Minor C. As at Minor C, except for the high levels in March 1999, organic carbon ranged between 1.13% in June and 2.25% in October. On a seasonal basis, organic carbon reached a lowest level in summer of 2000 but remained fairly uniform through the other seasons.

Diwar

Average organic carbon at Diwar on a biannual basis was 0.96%. Except for the high organic carbon in March 1999, it ranged from barely 0.29% in September 1999 to 2.37% in October 2000. On a seasonal basis, it remained high through post monsoon but varied only marginally between the other seasons. Organic carbon correlated positively with coarse silt ($r=0.48$, $p<0.01$) and nitrate ($r=0.68$, $p<0.01$) and negatively with sand ($r=-0.45$, $p<0.05$)

Miramar

Organic carbon at Miramar averaged to a mere 0.28%. The organic carbon content at Miramar remained constant all through the study period. Seasonally, it was marginally higher during post monsoon. It varied significantly between the 2 monsoons ($u=0.00$, $p=0.05$) and correlated positively with ambient temperature ($r=0.45$, $p<0.05$) and chloride content ($r=0.58$, $p<0.01$).

Nitrates: Graph 4.13

Nitrates varied significantly between the sites ($df=137$, $F=10.44$, $p=0.00$) with that at Ribandar being the highest and that at Miramar being the least. Nitrate concentration at Chorao was significantly higher than that at Diwar. At all the sites they were higher during the second year of study.

Ribandar

The nitrate content in the sediment of Ribandar had a biannual average of 0.42 mg/100g. It ranged from a lowest of 0.3mg/100g in March 1999 to a highest of 0.53 mg/100g in January. Season wise, nitrates were highest in winter (0.46 mg/100g) but varied only slightly during the rest of the seasons. Nitrates correlated significantly with sediment temperature ($r=-0.45$, $p<0.05$).

Chorao

The mean nitrate concentration at Chorao was 0.37mg/100g on a biannual basis. Nitrate levels rose sharply twice annually and ranged between 0.17 mg/100g in October 1999 to 0.47mg/100g in September 1999. On a seasonal basis, nitrate levels were marginally high in winter (0.41 mg/100g) of 1999-2000. During the next year the peak was observed a season earlier, in post monsoon (0.43 mg/100g). Nitrates correlated positively with coarse silt ($r=0.68$, $p< 0.05$) and sediment temperature ($r = 0.42$, $p<0.05$).

Minor C

The sediment of Minor C contained lesser nitrates than the sediment of Chorao at a biannual average of 0.3 mg/100g. It fluctuated between 0.12mg/100g in November 1999 and 0.47mg/100g in April 2000. Seasonally, as at Ribandar, nitrates were highest in winter (0.26mg/100g and 0.42mg/100g) but varied only slightly during the other seasons. Nitrate concentrations in 2000-2001 were significantly higher than those of the previous year ($t=-3.89$, $df=21$, $p=0.00$). Nitrates correlated positively with clay ($r=0.43$, $p<0.05$).

Minor D

The sediment of Minor D contained 0.31mg/100g of nitrates on a biannual basis. Nitrate levels in the sediment of Minor D were similar to that at Minor C and ranged from a lowest of 0.14mg/100g in June 2000 to a highest of 0.44mg/100g in August 2000. Seasonally, in 1999-2000, nitrate levels were highest in post monsoon while in the next year they reached a high in winter a season later than the previous year. During 1999-2000, nitrate content of 0.19mg/100g during monsoons was significantly lower than that during other seasons ($\chi^2=8.5$, $df=3$, $p=0.04$). Nitrates correlated positively with coarse silt ($r=0.42$, $p<0.05$) and sunshine ($r=0.47$, $p<0.05$) and negatively with rainfall ($r=0.55$, $p<0.01$).

Diwar

Nitrates in the Diwar sediment averaged at 0.27mg/100g on a biannual basis. It ranged between 0.1mg/100g in February-March 1999 and 0.36mg/100g in April/May. Season wise, in 1999-2000, nitrates were highest in summer (0.26mg/100g) but in the subsequent year they were high through post monsoon and reached a maximum in winter, a season ~~Ribandar, Chorao, Minor C, Minor D, Diwar and~~ Miramar earlier than that of the previous year. This variation between the seasons of 2000-2001 was statistically significant (χ^2=8.18, df=3, p=0.04). Nitrates also varied significantly between the 2 years (t=-3.97, df=21, p=0.00) particularly the 2 monsoons (u=0.0, p=0.05). Nitrates showed a significant correlation with organic carbon (r=0.68, p<0.01).

Miramar

The biannual average of the nitrate concentration at Miramar was 0.23 mg/100g. It ranged from 0.03 mg/100g in December 1999 to an exceptionally high 0.45 mg/100g in April 2000. Seasonally, except for a low in postmonsoon of 1999-2000 and a high in winter of 2000-2001, nitrates were fairly within range through the seasons. On the whole nitrate concentrations varied significantly between the 2 years (df=21, t=-2.81, p=0.01).

Phosphates: Graph 4.14.

Phosphate levels at all the sites showed two annual peaks one in late summer/ early monsoon and the other in late post monsoon/early winter. Between the sites, phosphate levels were highest at Ribandar and lowest at Miramar. Phosphate concentrations at Ribandar and Chorao varied significantly from those at Minor C, Minor D, Diwar and Miramar (df=137, F=12.49, p=0.00).

Ribandar

Mean biannual phosphate concentration in the sediment of Ribandar was 10.24 mg/100g. On a monthly basis phosphate concentrations at Ribandar fluctuated between 5.03mg/100g in February 2000 and 15.4mg/100g in May 1999. Seasonally, phosphate levels were least in post monsoon (9.2 mg/100g and 7.61 mg/100g) and the highest in monsoon (11.85mg/100g and 11.26 mg/100g)

Chorao

The mudflat sediment of Chorao had a mean biannual phosphate concentration of 9.62mg/100g, which was almost equal to that at Ribandar. A distinct annual cyclicity was observed in the phosphate levels with a lowest in March 2000 (1.6mg/100g) and a highest in July 2000 (15.12mg/100g). In general phosphates during 2000-2001 were significantly higher than during 1999-2000 ($t=-2.6$, $df=21$, $p=0.02$). On a seasonal basis, phosphates were maximum during monsoon (11.7mg/100g and 13.53mg/100g). During the first year of study, the phosphate contents during winter, post-monsoon and summer followed the monsoon high, while in the next year the latter was followed by summer, winter and post-monsoon. Phosphate correlated negatively with organic carbon ($r=-0.5$, $p<0.05$).

Minor C

Phosphate levels at Minor C were lower than those at both Chorao and Ribandar with a biannual mean of 4.88mg/100g. It followed a similar pattern as that at Ribandar oscillating between 1.2mg/100g in October/November and 8.92 mg/100g in January. On a seasonal basis, in 1999-2000, phosphates were highest in monsoons followed by those of winter while in the next year phosphates in winter and monsoon were significantly higher than those of summer and post monsoon ($df=3$, $\chi^2=8.18$, $p=0.04$). Phosphates were low in post monsoon. Phosphates had a statistically significant correlation with clay ($r=0.43$, $p<0.05$).

Minor D

Minor D contained an average 5.33mg/100g of phosphates on a biannual basis. This was marginally higher than that at Minor C. Phosphate levels at Minor D were lower than that at Ribandar and Chorao all through the year except in October 2000, when highest concentration of 12.6mg/100g was recorded. On the other hand the lowest concentration was recorded in March 1999(1.6mg/100g). On a seasonal basis, in 1999-2000, phosphates were maximum in monsoon (7.13mg/100g) and minimum in summer (2.53mg/100g). The levels during the other two seasons remained fairly uniform. In the next year, there was a sharp increase in the phosphates in post monsoon (11.13 mg/100g), a season later than the previous year while those during the rest of the seasons did not show any marked variation. Phosphate levels showed a statistically significant correlation with clay ($r=0.42$, $p<0.05$) and coarse silt ($r=0.62$, $p<0.01$).

Diwar

The biannual average phosphate concentration at Diwar was 5.29mg/100g. Diwar sediment contained almost similar levels of phosphates as that of Minor D. Phosphate levels fluctuated between 1.24mg/100g in February and 11.08 mg/100g in September 2000. As in Minor D, a seasonal cyclicity was observed in the phosphate concentration. It was highest in summer (8.03mg/100g and 8.01mg/100g) followed by that during monsoon (5.7mg/100g and 5.77mg/100g), post monsoon (5.48mg/100g and 4.44mg/100g) and winter (1.54mg/100g and 2.98mg/100g).

Miramar

Average phosphate concentration at Miramar was 4.38mg/100g. The phosphate profile at Miramar followed a similar pattern as that at Diwar ranging from a lowest in February (1.24 mg/100g and 1.26 mg/100g) to a highest in October 2000(8 mg/100g). On a seasonal basis, winter recorded the least phosphate concentration (2.21 mg/100g and 1.7 mg/100g). In 1999-2000, phosphates were maximum in post monsoon, but in the next year it reached a maximum a season earlier i.e. during monsoon. Phosphate levels were the least in winter. Phosphate levels during monsoon and post monsoon of 1999 were significantly higher than those of summer and winter (df=3, χ^2=7.71, p=0.05). Phosphates correlated with sunshine ($r=-0.52$, $p<0.05$) and total alkalinity ($r=-0.46$, $p<0.05$).

IV Benthic Community:

Flora

The seasonal variation in the biomass of the benthic flora during the 2 years of study has been provided in table 4.22. The benthic vegetation of all the sites except Miramar comprised of 2 algal species, *Dicotomosiphon salinas* and *Enteromorpha flexuosa* and a single angiosperm, *Halophila beckerri.* The algal growth was more prolific at Minor C followed by that at Minor D, Ribandar, Diwar and Chorao. On a seasonal basis at all the 5 sites, the floral biomass ranged from almost complete absence during monsoon to a highest in winter/early summer. The extreme fluctuation was recorded at Minor C where it ranged from complete absence in monsoon to a highest of 40g/m^2 in winter of 2000-2001.

Fauna

The community structure of the benthic fauna along with the ranks of dominance at all the six sites is provided in table 4.23. The variations in the biannual cumulative densities of the major groups namely nematodes, polychaetes, crustaceans and molluscs are provided in table 4.24 while their percentage contribution to the benthic community is given in table 4.25. The seasonal variations in the densities of the 4 major groups of benthic invertebrates fauna as well as that of the total soft bodied forms comprising of all the groups except molluscs at the six sites are provided in tables 4.26-4.30.The monthly variations in the density of the dominant benthic invertebrate groups at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar are provided in graphs 4.15-4.20.

The benthic macrofauna of all the 6 sites comprised of 3 major groups namely polychaetes, crustaceans and molluscs while the nematodes constituted the meiofauna of all the sites. The benthic fauna of Minor C was the most diverse and consisted of 53 species while that of Miramar had only 30 species, being the minimum. The benthic fauna of Diwar, Minor D, Ribandar and Chorao comprised of 48, 40, 35 and 31 species respectively.

Nematodes

At all the 6 sites the nematodes constituted a major component of the benthic fauna. Their density was highest at Minor C and lowest at Miramar. Density of nematodes at Minor C varied significantly from that at Miramar, Diwar, Ribandar and Minor D ($df=122$, $F=5.41$, $p=0.00$). However, in terms of percentage of the total population they constituted the largest chunk of the benthic fauna at Ribandar (36.12%) and the least at Miramar (3.41%)

Ribandar

The nematode density at Ribandar fluctuated between 91ind//m^2 in February 2001 to 2,125 ind/m^2 in May 1999. On a seasonal basis, the density was highest in summer but dropped gradually thereafter reaching a low in late postmonsoon/early winter. Nematode density correlated negatively with waterfowl ($r=-0.42$, $p<0.05$) particularly waders($r=-0.42$, $p<0.05$).

Chorao

At Chorao, the nematodes were the second most dominant components of the benthic fauna constituting 33.15% of the total population. Their density during the study period ranged from a complete nonexistence in January 2001 to 2,375 ind/m^2 in March 1999. On a seasonal basis they were comparatively higher in summer. In 1999 there was a sharp decrease in their density during early monsoon which increased gradually thereafter. In the subsequent year the fall was more gradual reaching a minimum in winter. Nematodes correlated positively with mollusc ($r=0.66$, $p<0.01$).

Minor C

Nematodes comprised 27.23% of the benthic fauna at Minor C and ranged from complete nonexistence to 6875 ind/m^2 in April 1999. On a seasonal basis their density was exceptionally high in summer of 1999 but remained almost constant through the rest of the year. During the next year the nematode density decreased sharply in winter.

Minor D

Although nematodes constituted 17.37% of the total benthic population at Minor D their density at the site was lower than that at Minor C and Chorao almost all through the study period. It ranged from total absence in October 2000 to 2545 ind//m^2 in May of the same year. Seasonwise, in 1999, it was lowest in postmonsoon while in the next year it reached a minimum in winter a season later than that during the previous year. The nematode density was high in early monsoon. Nematodes correlated positively with fine silt($r=0.48$, $p<0.05$) and negatively with ambient temperature($r=-0.42$, $p<0.05$).

Diwar

The nematode density at Diwar was lower than that at all the above sites. It constituted only 8.41% of the total population and was 3rd in the order of group dominance. It fluctuated between complete nonexistence in August 2000 to 1,454 ind/m^2 in October 2000. On a seasonal basis it was lowest in late monsoon/early postmonsoon. However, in 2000-2001, their density was significantly higher during post monsoon (df=3, χ^2=8.03, p=0.04).

Miramar

The nematode density ranged from complete absence to 4,091ind/m^2 in May 1999. On a seasonal basis it was exceptionally high in summer 1999 and low during monsoon. It remained almost stable during the rest of the seasons. Nematodes correlated negatively with pH (r=-0.62, p<0.01) and polychaetes (r=-0.77, p<0.01).

Polychaetes

Polychaetes were the most dominant macrofaunal group inhabiting the sediment of all the sites except Miramar. The density of polycheates varied significantly between the sites (df=128, F=11.77, p=0.00). Their density was the highest at Diwar followed closely by that of Minor C while it was lowest at Miramar.

Ribandar

Polychaetes comprised 48.26% of the benthic invertebrate population at Ribandar and ranged from complete absence in October 2000 to 2,545 ind/m^2 in April-May the same year. Seasonally, in 1999-2000, it was lowest in winter and fairly uniform through the rest of the year. During the next year it dropped sharply in monsoon and increased gradually thereafter. The polychaete fauna comprised of 21 species and was largely dominated by nerieds and maldanids. Polycheate population correlated positively with sediment temperature ($r=0.53$, $p<0.05$) and waders ($r=0.66$, $p<0.01$) and negatively with alkalinity ($r=-0.62$, $p<0.01$).

Chorao

Polychaetes constituted 57.43% of the benthic fauna of Chorao and fluctuated between a lowest of 91 ind/m^2 in November 2000 to a highest of 7,182 ind/m^2 in September the same year. On a seasonal basis it remained low in post monsoon. During 1999 it reached to a highest in summer but in the next year the density was highest in monsoon, a season later than that of the previous year. In 2000-2001 the polychaete density was significantly higher in summer and monsoon ($\chi^2=6.7$, df=3, $p=0.08$). A total of 18 polychaete species were encountered at Chorao. In addition to nerieds and maldanids, *Heterospio catalensis* was the other dominant sps.

Minor C

Polychaetes contributed 52.19% of the benthic macroinvertebrate fauna of Minor C and their density was higher than that at the above 2 sites almost all through the study period. The polychaete density ranged from 625 ind/m^2 in September 1999 to 6,091 ind/m^2 in January 2000 and was comparatively higher in 2000-2001. On a seasonal basis, in 1999-2000, it was lowest in monsoon and increased sharply to reach a highest in winter. In the next year there was very little variation between the seasons. The polychaete fauna consisted of a total of 29 species of which nerieds, maldanids, *Ceratoneries coastae* and *Heterospio catalensis* dominated. Polychaete densities correlated positively with nitrate($r=0.45$, $p<0.05$), pH($r=0.6$, $p<0.01$) and waders($r=0.61$, $p<0.01$).

Minor D

Polychaete comprised a highest 69.12% of the benthic community, which was higher than that at all other sites. Polychaetes were totally absent in

September 1999 and reached a highest density of 10,801 ind/m^2 in September 2000. Seasonwise, in 1999-2000, it was highest in summer and lowest in monsoon. During the subsequent year, both the extremes were observed a season later in monsoon and post monsoon respectively. The polychaete community at Minor D was made up of 17 species, of which *Axiothella obockensis, Neries chilkaensis* and *Polydora* sp. dominated. Polychaete densities correlated significantly with coarse silt ($r=0.54$, $p<0.01$) and sand ($r=0.47$, $p<0.05$).

Diwar

Diwar with a 58.64% polychaete component in its benthic community was next only to Minor D. The polychaete density ranged from 625 ind/m^2 in August 2000 to 10,646 ind/m^2 in October the same year. On a seasonal basis however no distinct cyclicity was observed among the polychaetes. In 1999-2000, their density was highest in summer and decreased gradually to reach a lowest in winter. This variation was statistically significant (df=3, x2=8.45, p=0.04). During the next year however it was highest in postmonsoon and low in monsoon. Polycheate density varied significantly between the two monsoons (u=0.0, p=0.05). Of the 23 polychaete species inhabiting the sediment of Diwar sediment, nerieds and ceratonerieds dominated.

Miramar

Polychaetes contributed a meagre 6.67% to the benthic community of Miramar. It fluctuated between a complete nonexistence to a highest 4,545 ind/m^2 in May 1999 and was comparatively higher during 1999-2000. Seasonally, it oscillated from total absence in monsoons to a highest in postmonsoon. Although 13 polychaete species were recorded at Miramar none of them showed clear dominance over the others.

Crustaceans

At all the sites except Miramar the crustaceans occupied a position next only to polychaetes in the macrobenthic community. At Miramar, they were the most dominant constituting 88.52% of the benthic community. The crustacean density at Miramar was significantly higher than that of all other sites (df=111, F=35.69, p=0.00).

Ribandar

Crustaceans constituted 13.56% of the benthic fauna at Ribandar and ranged from complete absence to 705 ind/m^2 in May 2000. The crustacean density remained fairly constant all through 1999-2000. The density observed in 2000-2001 was higher than that of 1999-2000 almost all through the year. On a seasonal basis it was high during summer of 2000 and varied significantly between the 2 monsoons (u=0.0, p=0.05). The crustacean fauna of Ribandar was largely dominated by *Corophium triaenomyx.* Crustaceans correlated significantly with waders ($r=0.43$, $p<0.05$), conductivity($r=0.46$, $p<0.05$) and pH($r=0.6$, $p<0.01$).

Chorao

The crustacean contribution to the benthic fauna of Chorao was a mere 4.29% and was lower than that at all other sites. It ranged from complete nonexistence in January-February 2001 to 625 ind/m^2 in April 1999. On a seasonal basis it was high in summer of 1999 but remained fairly constant thereafter. On the whole crustacean density varied significantly between the years (t=3.13, df=9, p=0.01). Crustacean density correlated with conductivity($r=0.62$, $p<0.05$) and phosphates ($r=0.6$, $p<0.01$).

Minor C

Crustaceans comprised 16.32% of the benthic community at Minor C, which was higher than that at the above two sites. The density ranged from 100 ind/m^2 in June 1999 to 2863 ind/m^2 in February 2001. Seasonally the density remained fairly constant except for a low in post monsoon of 2000. *Corophium triaenonyx* and the estuarine endemic *Apseudes chilkaensis* were the dominant crustaceans.

Minor D

Crustaceans made up 12.1% of the total benthic community and oscillated between total absence to 3,118 ind/m^2 in September 2000. Crustacean density at Minor D was lower than that at Minor C but higher than that at Ribandar. The crustacean density fluctuated sporadically between the seasons of the 2 years. As in Minor C, *Corophium triaenonyx* and *Apseudes chilkaensis* were the dominant crustaceans. Crustaceans correlated positively with humidity ($r=0.53$, $p<0.05$) and negatively with waterfowl($r=-0.62$, $p<0.01$) particularly waders($r=-0.61$, $p<0.01$)

Diwar

At Diwar the crustaceans comprised 27.63% of the benthic community which was higher than that at all the 4 sites mentioned above. Their density ranged from complete nonexistence to an enormous level of 18,545 ind/m^2 in October 2000. On a seasonal basis the density was highest in post monsoon and low in monsoon. However, during the year 1999-2000, their density dropped to an extreme low of 20 during winter. *Gammarus* sp. was the other dominant crustacean at Diwar in addition to *Corophium triaenonyx* and *Apseudes chilkaensis*. Crustaceans correlated positively with coarse silt ($r=0.72$, $p<0.01$), organic carbon ($r=0.74$, $p<0.01$), sediment temperature ($r=0.51$, $p<0.05$) and negatively with sand ($r=-0.43$, $p<0.05$).

Miramar

The density of crustaceans at Miramar ranged from complete nonexistence in March 1999 to a mammoth 34,364 ind/m^2 in November 2000. Extremely large aggregates of mysids were recorded in late monsoon and throughout post monsoon. Crustacean density varied significantly between the 2 years (df=14, t=2.84, p=0.01). Seasonally, it was lowest in summer and highest in post monsoon. Crustacean density was significantly lower in summer (df=3; for 1999-2000: χ^2=7.47, p=0.05 and for 2000-2001: χ^2=7.67, p=0.05). It also varied significantly between the 2 monsoons (u=0.0, p=0.05). *Gastrosoccus* sp., *Dotilla myctroides* and *Emerita holothusii* dominated the crustacean fauna at the site.

Total soft -bodied forms

The total soft-bodied forms are constituted collectively by the nematodes, polychaetes and crustaceans that are supposed to be available to the birds easily. The density of the soft-bodied forms put together varied significantly between the sites (df=135, F=25.21, p=0.00). At Ribandar, Chorao, Minor C and Minor D, their density was highest in late summer and lowest in late post monsoon while at Diwar and Miramar it was highest in postmonsoon but remained fairly constant through the rest of the year. Their density at Minor D varied significantly between monsoons (u=0.00, p=0.05). At Diwar it varied significantly between the two years (df=21, t=-2.18, p=0.04). It was significantly lower in monsoon and winter during 1999-2000 (df=3, x2=7.94, p=0.05) and during monsoon of 2000(df=3, x2=9.35, p=0.02) as compared to the rest of the seasons.

Molluscs

Molluscs formed the smallest component of the benthic invertebrate community at all sites comprising barely 5% of the total density. The molluscan density varied significantly between the sites (df=89, F=11.53, p=0.00). On a comparative basis, molluscan density was maximum at Diwar and minimum at Ribandar. The molluscan fauna at all the sites in the middle and upper reaches of the estuary was dominated by another estuarine endemic, the gastropod *Pontamides cingulatus*. The bivalve *Catelysia opima* was recorded only at Diwar. However at Miramar, bivalves, *Donax faba* and *Donax incarnatus* outnumbered the gastropods. The molluscs occurred sporadically at all the sites and showed no seasonal cyclicity. However, their densities were greatly reduced during the peak monsoons. At Ribandar molluscs correlated with fine silt($r=0.76$, $p<0.01$). At Diwar molluscan density varied significantly between the 2 monsoons ($u=0.0$, $p=0.05$) and correlated significantly with waders ($r=0.55$, $p<0.05$). At Miramar it varied significantly between the 2 years ($t=2.84$, $df=14$, $p=0.01$).

Stratification

The benthic fauna at all the sites showed a distinct stratification. At all the six sites crustaceans were found to inhabit only the top the sediment substrata of 5cm. Polycheates and nematodes on the other hand were most dominant in the upper 10cm but were found sparingly upto a depth of 20cm. At Minor C, polycheates like maldanids, ceratonerieds and nerieds occurred upto a depth of 20cm while at Diwar *Polydora* sp. was also recorded at this depth.

V. Avifauna

Community Structure:

A complete checklist of birds sighted at all the sites during the study along with their resident/habitat status is provided in table 4.31. The avifauna at all the sites comprised largely of waterbirds particularly waders as shown in Table 4.32. The Mandovi estuary as a whole harboured 129 species of birds of which 80 were those of waterbirds. Among the sites Chorao had the best avian diversity with 115 species followed by Diwar with 93 species and Minor C with 81 species. Ribandar and Minor D harboured 73 bird species each while only 34 species were sighted at Miramar. However, Minor C harboured a significantly higher population than Chorao, Minor D and Miramar with a biannual cumulative total of 1,21,493 individuals (df=137, F=4.48, p=0.00). The cumulative biannual bird population of Ribandar, Chorao, Minor D, Diwar and Miramar ranged from 19,493 individuals at Diwar to 53,379 individuals at Chorao. The habitat type and feeding habits of the birds at all the 6 sites have been provided in table 4.33.

Terrestrial Birds

The contribution of terrestrial birds to the avian diversity at Chorao was highest with 59 species followed by that of Diwar with 41 species. On the other hand only 7 species of terrestrial birds were sighted at Miramar. At the other sites, the terrestrial bird species ranged from 11 to 31. In terms of population too, the terrestrial birds dominated at Chorao with 6,214 birds, as compared to that at all the other sites. However, although Chorao and Diwar harboured the best terrestrial bird diversity, its contribution to the avian community in terms of population was a mere 11.64% and 12.86% at Chorao and Diwar respectively. At the rest of the sites, the terrestrial birds constituted less than 9.1% of the cumulative avian population. In general, the terrestrial birds dominating the estuarine mangroves included greenish leaf warbler, *Phylloscopus trichiloides*, Blyth's reed warbler, *Acrocephalus dumetorum*; Indian great reed warbler, *A. stentoreus* ; redwhiskered bulbul, *Pycnonotus jocosus;* black capped kingfisher, *Halcyon pileata*, blue eared kingfisher, *Alcedo meningtin* and collared kingfisher, *Todiramphus chloris*. The 3 species of kingfishers mentioned above were recorded only at Chorao, Minor C, Minor D and Diwar.

Waterbirds

The waterfowl community of all the sites was constituted by both resident as well as migrant birds, the latter far exceeding the former. In general, the waterfowl community of the estuary as a whole comprised of 4 major avian groups namely anatids, ciconids and ardeids, charadrids and larids. Among the 6 sites, Minor C harboured the maximum diversity of waterfowl with 70 species. The high diversity of Minor C was followed by those of Minor D, Chorao, Diwar, Ribandar and Miramar, in that order. In terms of the biannual cumulative population, the waterbirds at Minor C topped the list with 1,19,046 individuals, which was more than twice that at all other sites. The waterbird population of Minor C was significantly higher than that of Minor D and Chorao (df=137, F=4.19, p=0.00). The waterbird population at the rest of the five sites ranged from 58,428 at Chorao to 16,959 birds at Diwar.

Anatids

The anatids or ducks had a limited spatial distribution along the estuary and were restricted to the farthest part of the middle estuary i.e. Chorao, Minor C, Minor D and Diwar. Throughout the two years of study, no anatids were sighted at Ribandar and Miramar. The anatid diversity at the 4 sites in the middle estuary ranged from 3-9 species. In terms of population, it was highest at Minor C followed closely by Chorao. Anatid populations at Minor D and Diwar were almost similar. This group was dominated largely by Northern Pintails, *Anas acuta* (Fig. 4.1) and Northern Shovellers, *Anas clypeata* at all the 4 sites (Fig 4.1). Another noteworthy anatid visiting the estuary was Ferruginous *pochard*, *Athya nyroca*, a globally threatened species recorded at Minor C for a brief period in summer of 2000.

Ciconids and Ardeids

The ciconids and ardeids comprising of long legged wading birds consisted largely of egrets, herons and storks. The ciconids and ardeids were represented by 13-17 species at the sites in the middle estuary. However, their contribution to the avifaunal community of Miramar was rather poor with only 3 species making up a cumulative biannual population of 99 birds. Although Ribandar harboured only 13 species of wading birds, it sustained the largest population of these birds accounting for 9,360 individuals on a biannual cumulative basis. Wading bird densities at Chorao, Minor C, Minor D and

Diwar ranged from 1,529 to 4,180 birds. While the ciconids recorded in the region were migrants all the ardeids were residents, some of which were observed to breed within the estuary. Large egret, *Casmerodius albus*, little egret, *Egretta garzetta*, reef egret, *Egretta gularis* (Fig 4.2), intermediate egret, *Mesophopyx intermedia*, and grey heron, *Ardea grayii* were the dominant wading birds of the estuary, while Asian openbill stork, *Anastomus oscitans*, white necked storks, *Ciconia episcopus* and lesser adjutant storks, *Leptoptilos javanicus* were the migrants.

Larids

The larids comprising of the gulls and terns made a noteworthy contribution to the waterbird community both in terms of population and diversity at almost all the 6 sites. Their diversity ranged from 18 species each at Minor C and Minor D to 10 species each at Ribandar and Miramar. The cumulative biannual population of the gulls and terns was highest at Minor C with 39,573 birds followed by Ribandar with 13,259 birds. At the rest of the sites the larid population ranged from 1,041 to 7,125 birds. The dominant larids recorded at the estuary were brown-headed gulls, *Larus brunnicephalus*; black-headed gulls, *Larus rudibundus*, slender-billed gulls, *Larus genei*; Pallas's gulls, *Larus ichthyaetus*; gull-billed terns, *Gelochelidon nilotica*; whiskered terns, *Chlidonias hybridus*; white-cheeked terns, *Sterna repressa* and river terns, *Sterna aurantia*. Of these, brown-headed gulls (Fig. 4.3) and gull billed terns (Fig. 4.4) were the most dominant. Black bellied tern, *Sterna acuticauda*, a globally threatened species was a passage migrant sighted during the two winters at Minor C, Minor D, Ribandar and Chorao.

Waders

The waders constituted the largest and most diverse chunk of the waterbird community at almost all the sites. The group was largely dominated by 3 families namely charadridae, scolopacidae and glareolidae. The estuary as whole was inhabited by 37 species of waders of which Minor C harboured 29 species. The sites in the middle estuary had a better diversity of waders ranging from 21-29 species. However although their diversity was restricted to only 15 species at Miramar, they constituted 74.97% of the avifaunal community of the site. The biannual cumulative population of waders was the highest at Minor C with 51,419 birds, which was more than twice that at any other sites. This variation was statistically significant (df=137, F=3.6, p=0.00). Their population at the other 5 sites ranged from 7,568 to 22,175 birds on a cumulative biannual basis. Almost all the waders inhabiting the estuary were either long distance or local migrants. Red-wattled lapwings sighted at Ribandar and little ringed plovers sighted sporadically at all the sites were the only exceptions. Ribandar and Chorao were dominated by redshanks, *Tringa totanus* (Fig 4.5); little stints, *Calidris minuta*; curlew sandpipers, *Calidris ferruginea*; ruff, *Philomachus pugnax*; common sandpiper, *Actitis hypoleucos* and small Indian pratincole, *Glareola lactea*. Besides the above mentioned species curlews, *Numenius arquata* (Fig. 4.6); whimbrels, *Numenius phaeopus*; dunlins, *Calidris alpina*; greenshanks, *Tringa nebularia*; marsh sandpipers, *Tringa stagnatilis*; bar tailed godwit, *Limosa lapponica*; black tailed godwits, *Limosa limosa* and broadbill sandpipers, *Calidris falcinellus* were dominant at Minor C, Minor D and Diwar. Lesser sand plovers, *Charadrius mongolus*; greater sand plovers, *Charadrius leschenaultii*, and Kentish plovers, *Charadrius alexandrinus* formed the bulk of the wader population at Miramar.

Habitat Utility

In general most of the waterbirds sighted at the Mandovi estuary used it as a foraging site. Cormorants sighted regularly at Chorao, Minor C, Minor D, used the estuary primarily as a roosting site. Only on 4 occasions during the entire two years of study cormorants were observed to capture fish from the river waters. The dense mangroves in the deeper reaches of the Dr. Salim Ali Bird sanctuary of Chorao were also used as a nesting site by a few cormorants.

Anatids particularly pintails used Minor C exclusively as a foraging site and Chorao, Diwar and Minor D as a resting site. The pintails and shovellers fed actively amongst the *Enteromorpha flexuosa*, *Dicotomosiphon salinas* and *Halophila beckerri* at Minor C during low tide. During high tide large aggregations of anatids with a strength of upto 7,500 were observed idly drifting in the afternoons basking in the afternoon sun on the river surface between the islands towards the furthest part of the estuary. Feeding during high tide was highly restricted and was recorded on two occasions once in December 2000 and another time in February 2001.

Among the ardeids the reef herons, large egrets, intermediate egrets and little egrets used the estuary as a feeding site while the storks used the estuarine mud/sandflats more as a resting site than as feeding site. The herons fed regularly on the fish caught in the nets bordering the sediment-water interface by using the fishing stakes at Chorao and Ribandar as secondary roosts. At Ribandar they were also observed feeding on mudskippers, *Boleopthalmus* sps. Upto 210 herons were sighted in a single sighting at Ribandar when the fishing operations were in progress. However, their occurrence at the other sites was greatly limited. Ciconids on the other hand were observed resting/basking exclusively on the mud/sandflats of Minor D, Minor C, Chorao and Diwar. Asian openbill storks were observed feeding on *Pontamides cingulatus* only once during the entire study period while white necked storks were recorded feeding on the crustaceans entrapped in the sediment surface algae on a couple of occasions. The white-necked storks and lesser adjutant storks used the mangroves of Chorao and Diwar as roosting sites. However, a single pair of lesser adjutants was noted to reside in the mangroves of the Salim Ali Bird sanctuary all through the year.

The larids, like the wading birds, utilized the exposed mud/sandflats as secondary roosts which foraging. Upto 5,071 larids were recorded at Minor C in a single sighting. Minor C, Minor D, Diwar and Chorao were also used as launching pads by the gulls and terns when they resorted to plunge-diving mode of foraging. Whenever available, the larids opportunistically exploited the fish caught between the fishing stakes during the ebbing tide, instead of capturing the fish directly from the river waters.

All the waders from the region utilized the estuarine mudflats as feeding sites as well as nocturnal roosting sites. They were observed feeding extensively during low tide at all the 6 sites. The population of foraging waders was highest at Minor C and Minor D, where the sediment was silty-sand type. Their numbers were comparatively lower at the other sites where the sediment contained more than during low tide at all the 6 sites. The population of foraging waders was highest at Minor C and Minor D, where the sediment was silty-sand type. Their numbers were comparatively lower at the other sites where the sediment contained more than 80% of either sand or silt. Miramar was used as a foraging site by the plovers during the high tides also. Among the waders the larger bodied birds including curlews, whimbrels, ruff, godwits and redshanks showed a marked preference to Minor C, Minor D and Diwar while smaller ones like lesser sand plovers and Kentish plovers preferred Miramar. Almost all the waders used the dense mangroves within the sanctuary cordons of Chorao primarily as a night roost. The lesser sand plovers and Kentish plovers used the sand dune vegetation of Miramar both as a diurnal as well as a nocturnal roost.

Niche Specialization and Resource Partitioning among Waders:

A distinct spatial resource partitioning of food resources was observed among the waders utilizing the estuarine mudflats both between the sites as well as within the sites. The smaller, shorter billed lesser sand plovers and Kentish plovers were found to feed preferentially at Miramar while the larger long billed sandpipers like redshanks, greenshanks, godwits, curlews and whimbrels were observed to forage preferentially at Minor C. Lesser sand plovers, Kentish plovers and little stints also fed extensively at Minor C. Although the waders in general foraged at all the sites in the middle reaches of the estuary, their numbers were significantly higher at Minor C (df=137, F=3.6, p=0.00). The lowest foraging activity of the waders(Fig 4.7) was recorded at Ribandar and Chorao.

At Miramar, the plovers foraged visually both by day and moonlit nights. The sand crab *Dotilla myctroides* accounted for 83% of the successful catches. When feeding on crabs, the foraging flocks of the plovers were restricted to 3-11 birds while the larger part of the flock remained in the drier parts of the sediment above the surfline (Fig. 4.8). During the unavailability/scarcity of the sandcrabs, the plovers in large flocks of up to 80 individuals resorted to tactile foraging along the surfline or in the sediment just above the surfline. At Chorao, Minor C, Minor D, Diwar and Ribandar the plovers fed exclusively at the surfline.

Mixed Species foraging flocks

At Minor C, the waders foraged in mixed species flocks. These flocks comprised both of the visual foragers such as lesser sand plovers, Kentish plovers as well as of tactile foragers like redshanks, greenshanks, curlews, whimbrels and godwits. In these flocks the lesser sand plovers and Kentish plovers were observed to feed exclusively on the wet sediment just above the surfline that was continuously washed by the tide. The plovers at times also resorted to feeding on the sediment surface algae and the organisms trapped therein. The redshanks, greenshanks and the other sandpipers were observed to feed at a distance of atleast 1m away from the surfline on 67% of the occasions and only on 11% of the occasions in the sediment just above the surfline. Godwits, curlews and whimbrels, golden plovers and grey plovers were observed to feed regularly 1-3m away from the surfline. The little stints were observed feeding in discrete conspecific flocks within the limits of mixed species flocks. They fed extensively among the sediment algae on the intertidal sediment. However, the little stints opportunistically foraged amidst the other waders, over the mud/sandflats extending upto 4m upwards from the surfline. All the waders avoided forging in those parts of the mud/sandflats dominated by the anatids particularly Northern Pintails but foraged undisturbed in the regions occupied by gulls.

Diurnal and Nocturnal foraging in waders

The wintering waders used all the six estuarine mud/sandflats for foraging both by day and night. The diurnal seasonal feeding intensity and the feeding success of the Kentish plovers, redshanks and curlews have been provided in table 4.34.

All the 3 species of waders together had a feeding success rate slightly over 60%. Among the 3 species the plovers exhibited the most active feeding averaging 28pecks/min. while the curlews fed on an average at the rate of 3.99 pecks/min. In all of them the feeding activity increased significantly in summer and post-monsoon (One way ANOVA at $p<0.01$, Kentish plovers: $df=59$, $F=4.78$; redshanks $df=55$, $F=8.41$; curlews $df=63$, $F=19.48$). However, in lesser sand plovers a simultaneous significant increase was also observed in the success rate ($df=63$, $F=13.43$, $p<0.01$). But in redshanks the variation in the success rate was close to the limit of significance ($df= 55$, $F=3.32$, $p<0.04$). The variations in the strength of nocturnally foraging flocks of waders at the mudflats/sandflats have been given in table 4.35. Waders used Minor C, Minor D, Chorao, Diwar, Ribandar and Miramar extensively for nocturnal foraging. However, nocturnal foraging was more pronounced at Minor C and Miramar where 100-2,650 waders were recorded to forage on a single moonlit night as against 0-125 at the rest of the sites. At all the sites in the middle estuary, the waders increasingly depended upon the tactile mode of foraging but, at Miramar they adopted visual foraging, feeding largely on the sand crabs, *Ocypoda* sp. The nocturnal foraging success rate for all waders collectively being only 50%, was slightly less than that recorded for diurnal foraging.

Migratory profile of the waterbirds

The seasonal variations in the population of avifauna in general and waterbirds/waders in particular at all the 6 study sites are provided in table 4.36-4.38. The monthly profiles of these groups are provided in graphs 4.21-4.23.

The estuarine mudflats as a whole harboured 78 species of migratory birds of which 70 were waterfowl. Among the migrant waterbirds, charadrids was major group with 34 species. The populations of the waterbirds at all the sites started increasing gradually in late September/early October, with the withdrawal of the southwest monsoon. Initially, small flocks of 40-100 individuals constituted the early arrivals that included redshanks, Kentish plovers, lesser sand plovers, little stints and curlews. The strength of the bird community picked up substantially a month later with the stopovers of passage migrants such as black tailed godwits, bar tailed godwits and slender billed gulls, white-cheeked terns adding to the already steadily increasing population of waterbirds. Large flocks of waders like redshanks, dunlins, marsh sandpipers, curlew sandpipers, small Indian pratincoles and collared pratincoles, numbering on an average 1650 birds per flock descending onto the estuary in early December causing the waterbird population to skyrocket. The population increased consistently during the next couple of months reaching a peak by late January-early February. With the onset of summer, the birds were observed taking sorties/preparatory flights in small flocks. The waterbird population started losing its strength in spurts and starts, as small populations of collared pratincoles, dunlins, sanderlings, broadbilled sandpipers started leaving the estuary in early April. However, other birds such as slenderbilled gulls, golden plovers and grey plovers were observed to alight on the estuarine mudflats during late April. The pintails and shovellers took-off enblock in late April/early May causing the population to plummet sharply in May. The other waders started leaving the estuary in large numbers in early May. By the beginning of June almost all the waders had vacated the estuary. The waterbird population in general and the population of waders in particular plummeted to less than 150 individuals at all the sites in monsoon. During this period only a few residents particularly pond herons, egrets and some residual redshanks and Kentish plovers persisted on the estuarine mudflats. A single pair of lesser adjutants and two pairs of grey herons were also sighted at Chorao, Minor C, Minor D and Diwar during monsoons. Small flocks of redshanks numbering 20-25 individuals were observed to persist along the mud/sandflats even during the monsoons. A reciprocity was observed in the population predominance of residents and migrants at all the sites, which was more pronounced at Minor C, Minor D, Diwar and Miramar. At Ribandar and Chorao, even during monsoon, a small population of 10-125 birds comprising largely of little egrets, cattle egrets, large egrets, pond herons and cormorants was always maintained. The peak populations occurred in February at all the sites. They ranged in strength from 3,255 individuals at Miramar to 21,916 individuals at Minor C.

The population of birds at all the sites during the 2 years of study was significantly higher in winter as compared to the other seasons of the year. The results of Kruskall Wallis One Way ANOVA showing this variation are provided in table 4.39.

Species Indices

Species diversity (H'), species evenness (J') and species richness (SR) at all the 6 sites are provided in table 4.40.

Among the sites species diversity and species richness were the highest at Chorao (H'= 2.71 & SR= 8.23) and least at Miramar (H'=1.80 and SR=2.52). The species diversity at all the sites except Minor D was the best in late summer/early winter. At Minor D however it was highest in post monsoon. The species evenness throughout the study area was at its best in late monsoon/early post monsoon. The species richness on the other hand was highest in late post monsoon/early winter.

The similarity dendrogram of the avifaunal community of the different sites has been given in Fig. 4.9. Depending upon the bird species they harboured, the sites in the middle estuary formed two distinct clusters, one comprising of Ribandar, Chorao and Diwar and the other constituted by Minor C and Minor D. Miramar remained independent from these two clusters.

Statistical Correlation of the avifauna with:

Physico-chemical Parameters of Sediment

The population of avifauna in totality at Minor C, Minor D and Diwar showed a positive correlation with chlorides ($r=0.66$, $p<0.01$; $r=0.69$, $p<0.01$ and $r=0.51$, $p<0.05$) and sulphates ($r=0.67$, $p<0.01$; $r=0.65$, $p<0.01$ and $r=0.67$, $p<0.01$) but a negative correlation with rainfall ($r=-0.79$, $p<0.01$; $r=-0.7$, $p<0.01$ and $r=-0.84$, $p<0.01$). Besides, the avifauna showed a positive correlation with conductivity at Minor C ($r=0.53$, $p<0.05$), Minor D ($r=0.76$, $p<0.01$) and Chorao ($r=0.44$, $p<0.05$). At Ribandar, the avifauna had a positive correlation with pH ($r=0.46$, $p<0.05$) in addition to chloride ($r=0.83$, $p<0.01$) and a negative correlation with alkalinity ($r=-0.59$, $p<0.01$). The avifauna of Chorao also showed a negative correlation with alkalinity ($r=-0.6$, $p<0.01$) besides rainfall

($r=-0.84$, $p<0.01$). Only at Miramar, the avifauna showed a negative correlation with phosphates ($r=-0.64$, $p<0.01$).

Benthic invertebrates

At Ribandar the avifaunal population in general correlated positively with polychaetes($r=0.61$, $p<0.01$), and negatively with nematodes ($r=-0.43$, $p<0.05$). The population also correlated positively with polychaetes at Minor C ($r=0.57$, $p<0.01$) and Diwar ($r=0.58$, $p<0.01$) and with molluscs at Miramar ($r=0.6$, $p<0.01$). The avian population correlated negatively with crustaceans at Minor D ($r=-0.75$, $p<0.01$) and soft bodied benthic fauna at Chorao ($r=-0.53$, $p<0.01$).

Statistical Correlation of the waterbirds with:

Physico-chemical Parameters of Sediment

The population of waterbirds in general correlated positively with chlorides ($r=0.44$, $p<0.05$) and conductivity ($r=0.5$, $p<0.05$) at Chorao but only with chlorides at Diwar ($r=0.54$, $p<0.05$). The population of waterbirds like that of the avifauna in general correlated negatively with rainfall at Chorao ($r= -0.83$, $p<0.01$), Diwar ($r=-0.82$, $p<0.01$), Minor C ($r=-0.73$, $p<0.01$) and Minor D ($r=-0.74$, $p<0.01$).

Benthic Invertebrates

The population of waterbirds in general correlated negatively with soft bodied benthic fauna at Chorao($r=-0.5$, $p<0.05$) and with molluscs at Miramar ($r=0.61$, $p<0.01$).

Statistical Correlation of the waders with:

Physico-chemical Parameters of Sediment

The population of waders in particular at Minor D showed a positive correlation with chlorides ($r=0.65$, $p<0.01$), conductivity ($r=0.74$, $p<0.01$), nitrates ($r=0.55$, $p<0.01$) and sulphates ($r=0.57$, $p<0.01$). These populations exhibited negative correlation's with alkalinity at Ribandar ($r=-0.64$, $p<0.01$) and Chorao ($r=-0.6$, $p<0.01$) but only with phosphates at Miramar($r=-0.61$, $p<0.01$). There existed a positive correlation between the wader population and chlorides ($r=0.65$, $p<0.01$) and sulphates ($r=0.5$, $p<0.01$) at Minor C, with chlorides ($r=0.78$, $p<0.01$) and conductivity at Ribandar ($r=0.71$, $p<0.01$) but only with conductivity at Miramar ($r=0.42$, $p<0.05$).

Benthic invertebrates

The population of waders at Ribandar showed a positive correlation with polychaetes ($r=0.66$, $p<0.01$) and negative correlation with crustaceans ($r=0.43$, $p<0.05$) and nematodes ($r=-0.42$, $p<0.05$). The population at Diwar ($r=0.52$, $p<0.05$) and Minor C ($r=0.61$, $p<0.01$) also showed a positive correlation with polychaetes but that at Minor D showed a negative correlation with crustaceans ($r=-0.61$, $p<0.01$).

Breeding

A number of terrestrial birds including bulbuls and swallows were observed to nest in the mangroves adjoining the mudflats. During 1999, 6 nests of cormorants were sighted in July on 2 Avicennia trees within the sanctuary area of Chorao wherein the incubation was already in progress. One tree had 4 nests while the other had 2. The dried twigs of mangrove plants *Sonneratia apetella* and *Avecennia marina* mainly constituted the nesting material. The nests contained 3-4 eggs each constituting a total of 21 eggs. In the 1^{st} week of August, a total of 18 hatchlings were observed. Of these 14 fledged by the 3^{rd} week of August. During the next year only 3 nests were sighted in June at the same location. However, one of these was destroyed by July. The 2 persisting nests had 4 eggs each. Of the total 8 eggs 6 hatched by the last week of July, but only 3 of them fledged.

Communal Breeding

The Mandovi estuary and its backwaters housed two ardeid heronries during the course of the study, one on a small mudflat in the Ourem creek in the close vicinity of Ribandar and the other within the Dr. Salim Ali Bird Sanctuary at Chorao. Both the heronries were totally surrounded by water during high tide.

Ourem Heronry

The Ourem heronry was a communal nesting site comprising entirely of pond herons and was situated at the edge of Panaji, the capital city of the state. Details of the Ourem heronry and the variations observed during the 2 years of study are provided in table 4.41.

The heronry was located on a 50m long linear stand of mixed mangrove trees of *A. marina* and *R. mucronata* with 60% dense canopy. Except for the few trees at the northern and southern extremities of the stand, all the available trees on the mudflat were used for nesting. The nests were a rough platform mostly of dry twigs collected from a park near by as well a from garbage dumps around the city. All nests were oriented to the east occupying the upper and middle tree canopy. Nest building commenced by the second week of May. Heightwise, nesting was initiated in the middle of the tree canopy.

In June 1999, *R. mucronata* harboured 20 nests while A. marina harboured 38. Within 2 months i.e. by the first week of August, 9 of the nests on *R. mucronata* and 2 of the nests on *A. marina* were destroyed. Hatchlings were observed by the 2nd week of August. The number of chicks in each nest ranged from 1-3 with a total of 84 hatchlings in the heronry. Two of the nests containing hatchlings were destroyed by crows. On the whole 71 chicks were noted to have fledged.

During the subsequent year active nests recorded in the colony were 75, which amount to an increase of 17 nests over that of the previous year. Of these *R. mucronata* harboured 23 nests while the rest were on A. marina. Interestingly, during the year even the extremities of the tree stand were used for nesting. By the last week of August 16 nests had fallen prey to the monsoon vagaries. All the nests along the southern extremity were destroyed but those to the northern limit remained unaffected. Of the 51 nests that survived, 41 were on A. marina.

By the last week of August a total of 108 hatchlings were observed in the colony with 2-3 chicks per nest. However 4 of the nests with nestlings were abandoned before the chicks fledged

During both the years by the 2nd week of September the activity came to an end and the birds left the site.

Chorao Heronry

In 1999 an active heronry was sighted at Chorao, details as regards to the number of nests, hatching success and fledging success are provided in table 4.42.

A stand of mangrove trees of *S. apetella, S. alba* and *A. marina* provided the nesting platforms for the heronry. *R. mucronata*, the only other plant species in the area was not used for nesting. All the trees were located on an 18m long bund, towards the southwestern part of the Chorao Island. Large egrets, cattle egrets and little egrets bred at the site. A total of 12 nests of large egrets, 39 nests of little egrets and 17nests of cattle egrets were sighted in the 3rd week of July. Of the total 68 nests recorded in the heronry, 51 were positioned only on *A. marina*. All the nests were built facing away from the main course of the Mandovi River. But for a single nest of large egret located on Sonneratia all the nests of large egrets and cattle egrets were located on A. marina. However, 5 nests of little egret were situated on Sonneratia. During the course of the breeding period 5 nests of large egrets, 7 of little egrets and 6 nests of cattle egrets were either destroyed by the monsoons or abandoned by the parents.

The large egrets occupied the dense uppermost part of the canopy, little egrets the middle canopy while cattle egrets were positioned on the lower drooping branches. However, 3 nests of the cattle egrets were also observed in the middle strata while a single nest of little egret was situated on the lowermost branch. All the nests were rough hollow platforms of twigs of mangrove plants particularly Aveccenia, Kandelia and Sonneratia. However, the large egrets also used larger twigs of Rhizophora to form the base of the nest.

Hatching had already commenced by the last week of July when the heronry was first sighted. By the first week of August, 21eggs of large egrets, 84 of little egrets and 15 of cattle egrets had hatched. By the 3rd week of August when hatching was almost completed 28, 110 and 20 eggs of large egrets, little egrets and cattle egrets had hatched. Of the total chicks that hatched, only 22 of chicks of large egrets, 69 of little egrets and 10 of cattle egrets survived to the fledgeling stage.

During the next year, although initial attempts of nest building were made by the large egrets at the site they were abandoned in the early stage. Thus, the site was totally abandoned by the birds.

Table 4.1 : The monthly means of the textural components of the sediment at the six study sites on a biannual basis.

Sr.no	Parameters	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1	%Sand	35.30±2.99	29.5±2.37	66.30±2.09	68.06±1.62	84.35±1.29	99.58±0.07
2	%Silt.........Coarse	27.67±1.84	27.98±1.66	18.63±1.68	18.30±1.13	7.62±0.9	00
3	.........Fine	30.60±2.28	36.99±1.92	12.19±0.63	10.96±0.76	5.77±0.5	00
4	.... Total	58.28±3.14	64.97±2.12	30.73±1.99	29.26±1.55	13.38±1.28	00
5	%Clay	6.42±0.51	5.53±0.66	2.97±0.25	2.68±0.2	2.31±0.24	00

Table 4.2: Seasonal variations in the textural components of the sediment at Ribandar from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	%Sand	40.02±8.82	39.58± 10.11	27.55± 10.11	36.75±8.65	35.55±3.98	33.25± 13.65	24±8.37	40.03±4.42
2	%Silt ….Coarse	24.62±4.13	25.35±5.27	24.05±5.27	28.38±8.78	31.52±3.37	32.89±7.33	28.72±1.28	23.25±0.93
3	…….Fine	27.12±6.08	29.27±6.35	43.87±6.35	26.88±4.82	25.02±6.23	28.37±8.39	41.27±8.8	31.75±4.01
4	……..Total	51.73±1.11	54.62± 11.62	67.92± 11.62	55.27±7.08	56.53±3.35	61.26± 14.26	70±7.52	55±4.33
5	Clay	8.25±1.3	5.8±2.045	4.52±2.04	7.98±2.52	7.92±0.63	5.49±1.19	6±0.85	4.97±0.49

Table 4.3: Seasonal variations in the textural components of the sediment at Chorao from summer 1999 to winter 2000/2001.

Sr No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	%Sand	26.37±4.54	40.15±5.32	29.65±6.12	34.53±8.88	32±10.85	18.53±2.78	24.65±9.13	32.2±2.19
2	%Silt... Coarse	33.3±4.04	19.78±1.23	19.91±13.58	25.47±3.54	28.3±4.27	30.75±2.26	35.45±5.46	29.75±2.38
3	.......Fine	32.72±0.97	36.1±5.09	47.36±19.22	34.37±4.12	30.53±4.35	44.5±2.06	35.82±4.19	35.08±1.55
4	.........Total	66.02±4.99	55.88±4.73	67.27±5.64	59.83±6.76	58.83±8.62	75.25±1.76	71.27±9.65	64.83±2.17
5	%Clay	7.62±0.8	3.97±0.87	3.07±0.48	5.63±3.16	9.17±2.38	6.22±1.32	4.07±0.52	2.97±0.07

Table 4.4: Seasonal variations in the textural components of the sediment at Minor C from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	%Sand	69.22±2.19	68.90±8.89	69.25±1.45	75.25±4.43	56.13±0.41	58.71±4.47	70.52±2.98	67.35± 10.01
2	%Silt … Coarse	15.65±3.38	18.25±7.80	20.53±0.85	11.83±2.52	25.00±0.15	24.35±4.12	13.85±0.5	16.68±7.41
3	……….Fine	12.23±1.68	10.68±0.97	8.88±0.22	10.10±1.74	15.53±0.56	13.99±1.78	13.10±2.45	11.62±2.09
4	……..Total	27.22±2.06	28.93±7.89	29.40±0.85	21.93±4.25	40.53±0.55	38.34±4.33	26.95±2.95	28.30±8.94
5	%Clay	3.57±0.29	2.17±0.5	1.35±0.6	2.82±0.64	3.33±0.68	2.95±0.43	2.53±0.02	4.35±1.28

Table 4.5: Seasonal variations in the textural component of the sediment at Minor D from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	%Sand	70.53±8.3	75.97±1.02	72.40±1.60	68.85±2.81	67.53±2.33	62.00±5.83	63.90±0.10	65.35±2.17
2	%Silt ……Coarse	13.43±4.09	11.22±1.72	19.35±0.20	17.95±3.02	21.37±1.69	21.94±3.43	20.13±0.12	20.78±1.92
3	………Fine	12.53±4.41	11.13±2.02	6.70±1.75	10.30±0.22	8.95±0.37	12.91±2.35	13.30±1.15	10.57±0.58
4	………Total	25.97±8.15	22.35±1.30	26.05±1.95	28.25±3.25	30.32±1.7	34.85±5.59	33.42±1.03	31.35±2.04
5	Clay	3.50±0.16	1.68±0.29	1.55±0.35	2.90±0.49	2.15±0.65	3.15±0.39	2.68±1.12	3.30±0.33

Table 4.6 : Seasonal variations in the textural components of the sediment at Diwar from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	%Sand	84.35±1.98	86.4±2.96	79.7±2.70	89.02±2.37	86.32±2.5	82.59±4.56	73.47±3.74	88.4±0.76
2	%Silt	7±0.88	5.43±3.24	13.3±1.47	5.6±0.81	6.03±1.83	8.16±2.85	14.2±2.06	5.12±0.45
	..Coarse								
3	........Fine	5.32±0.98	5.82±0.62	5.65±1.10	4.08±0.63	4.88±0.81	6.56±2.2	9.9±1.75	4.98±0.6
4	........Total	12.32±1.59	11.25±2.73	18.95±2.57	9.68±0.63	10.92±1.95	14.72±4.99	24.1±3.81	10.1±0.4
5	%Clay	3.67±0.9	2.35±0.48	1.35±0.12	1.3±0.10	2.77±0.57	2.69±0.72	2.42±0.01	1.5±0.01

Table 4.7 :Seasonal variations in the textural components of the sediment at Miramar from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	* %Sand	99.43±0.02	99.59±0.02	99.81±0.05	99.58±0.29	99.53±0.13	99.62±0.22	99.38±0.38	99.74±0.05

* The sediment comprised almost entirely of sand but for traces of silt.

Table 4.8 : The monthly means of the physicochemical properties of the sediment at all the study sites on a biannual basis

Sr. No	Physico-chemical Parameters	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1	Temperature (^{0}C)						
	Ambient	25.52±0.36	25.61±0.37	25.57±0.36	25.61±0.35	25.70±0.36	24.35±0.21
2	Water	26.00±0.2	26.13±0.27	26.13±0.26	26.00±0.27	26.13±0.28	25.35±0.21
	Sediment Parameters						
3	Temperature (^{0}C)	26.26±0.26	26.35±0.3	26.35±0.25	26.26±0.27	26.57±0.31	26.04±0.24
4	pH	7.83±0.05	8.02±0.05	7.97±0.05	8.07±0.04	8.34±0.05	8.76±0.05
5	Conductivity (μmho)	15.31±1.07	9.95±0.69	6.23±0.35	7.17±0.35	5.39±0.09	5.13±0.03
6	Chlorides (mg/100g)	456.58±30	278.09± 26.07	126.97±15.17	170.04±15.09	85.55±9.73	82.40±2.25
7	Total alkalinity (mg/100g)	3.72±0.29	2.28±0.14	2.17±0.15	2.37±0.15	1.91±0.14	1.30±0.12
8	Sulphates (mg/100g)	262.42±0.95	368.79± 32.18	196.90±16.14	173.77±14.28	101.71±8.04	54.67±8.83

Table 4.9: Seasonal variations in the physicochemical parameters of the sediment at Ribandar from summer 1999 to winter2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
	Temperature(^{0}C)								
1	........Ambient	26±1.00	25.33±1.33	27±0.00	27±0.00	25.67±.88	23±0.71	26±1.00	25.67±0.67
2	.......Water	26.33±0.33	25.33±0.33	26.5±0.5	25.33±0.33	26.67±.33	25.25±0.63	27±0.00	26.33±0.88
	Sediment Parameters								
3	Temperature(^{0}C)	26.67±0.33	25±0.00	26.5±05	25±0.58	27±.58	25.75±0.75	27.5±0.5	27.33±0.88
4	pH	7.69±0.00	7.49±0.03	7.62±0.03	7.98±0.07	8.16±.01	7.88±0.1	7.76±0.02	7.95±0.07
5	Conductivity (μmho)	18.73±1.9	8.33±0.43	12.95±0.43	19.97±1.74	18.63±1.93	9.97±1.23	12.9±0.8	21.2±0.81
6	Chlorides (mg/100g)	477.59± 54.86	268.16± 1.21	483.19± 1.21	665.15± 38.69	594.51± 20.00	328.53± 55.5	336.27± 13.97	510.71± 51.12
7	Total alkalinity (mg/100g)	2.58±0.16	5.03±2.59	2.92±0.59	3.71±0.38	3.61±0.32	5.25±0.91	3.08±0.24	2.61±0.46
8	Sulphates (mg/100g)	245.17± 19.08	251.33± 8.27	205±34.16	337.12± 101.11	273.96± 109.52	206.08± 49.85	341.32± 35.78	265.28± 43.25

Table 4.10: Seasonal variations in the physicochemical parameters of the sediment at Chorao from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	**Temperature (^{0}C)**								
	Ambient	26±1.00	24.67±0.67	27±0.00	26.67±0.33	26.33±0.66	23±0.7	26±1.00	26.33±0.88
2	Water	26.33±0.33	25.67±0.67	26±0.00	26.67±0.33	26.66±0.33	24.25±0.48	28±1.00	26.33±0.33
	Sediment Parameters								
3	Temperature(^{0}C)	26.33±0.33	25.33±0.33	25±0.00	26.33±0.88	27.67±0.33	25.25±0.48	29.5±0.5	26.33±0.33
4	pH	7.86±0.23	7.56±0.05	8.09±0.15	8.16±0.06	8.05±0.04	8.14±0.1	8.15±0.00	8.17±0.06
5	Conductivity(μmho)	14.1±0.25	6.8±0.7	7.05±0.25	10.43±1.04	13.27±1.99	7.5±1.25	7.55±1.15	11.93±1.13
6	Chlorides (mg/100g)	382.44± 34.76	194.54± 52.19	216.91± 3.2	250.53± 9.54	479.49± 88.17	174.84± 35.35	181.41± 17.44	326.37± 23.88
7	Total alkalinity (mg/100g)	2.07±0.03	3.58±0.41	2.86±0.63	1.81±0.09	1.94±0.14	2.23±0.16	1.88±0.04	1.92±0.21
8	Sulphates (mg/100g)	486.89± 55.27	422± 127.79	336.83± 47.31	321.5± 91.42	369.06± 61.07	343.49± 122.00	404± 170.51	276.08± 24.53

Table 4.11: Seasonal variations in the physicochemical parameters of the sediment of Minor C from summer 1999-winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	**Temperature (^{0}C)**								
	……..Ambient	26.00±1.00	25.33±1.33	27.00±0.00	26.67±0.33	26.00±0.58	23.00±0.71	26.00±1.00	26.00±1.00
2	……..Water	26.33±0:33	25.67±0.67	26.50±0.5	26.33±0.33	27.67±0.66	24.25±0.42	26.50±0.50	26.67±0.67
	Sediment Parameters								
3	Temperature(^{0}C)	26.33±0.33	25.67±0.33	25.50±0.5	26.00±0.58	28.67±0.66	25.50±0.29	27.50±0.50	26.00±0.00
4	pH	7.89±0.17	7.56±0.04	7.90±0.19	8.18±0.08	8.00±0.07	8.12±0.06	7.96±0.05	8.05±0.08
5	Conductivity (μmho)	7.00±032	4.90±0.06	5.15±0.25	7.93±0.35	8.43±1.7	4.73±0.31	5.15±0.05	6.33±0.28
6	Chlorides (mg/100g)	171.58± 25.85	55.85± 10.71	89.11±16.73	188.15± 4.62	236.02± 47.9	44.37±7.98	100.11± 4.27	136.56± 16.12
7	Total alkalinity (mg/100g)	2.38±0.42	2.84±0.51	1.92±.25	2.64±0.39	2.73±0.2	1.93±0.32	1.23±0.15	1.38±0.12
8	Sulphates (mg/100g)	265.50± 61.04	129.50± 16.39	145.75± 51.40	246.33± 30.7	301.92± 43.56	135.13± 11.60	146.25± 3.26	191.50± 7.95

Table 4.12: Seasonal variations in the physicochemical parameters of the sediment at Minor D from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	**Temperature (^{0}C)**								
	........Ambient	26.00±1.00	25.67±1.20	27.00±0.00	27.00±0.00	26.33±0.3	23.00±0.71	25.50±0.50	25.67±0.67
2	........Water	25.33±0.33	26.33±0.33	26.00±0.00	26.67±0.33	28.00±0.00	24.25±0.48	26.00±0.00	26.00±1.00
	Sediment Parameters								
3	Temperature(^{0}C)	26.00±0.58	26.00±0.57	25.50±0.50	26.67±0.67	28.00±0.50	24.75±0.25	26.50±0.50	27.00±1.00
4	pH	7.96±0.06	7.75±0.07	8.11±0.02	8.16±0.08	8.15±0.13	8.23±0.06	8.06±0.17	8.09±0.01
5	Conductivity(µmho)	7.13±0.55	5.17±0.18	6.85±1.15	8.90±0.3	8.70±0.37	5.32±0.12	6.10±0.50	9.33±0.43
6	Chlorides (mg/100g)	213.74± 14.28	81.17±22.93	218.59± 77.53	236.79± 9.76	200.68± 39.48	89.99± 12.94	116.44± 3.55	227.90± 6.14
7	Total alkalinity (mg/100g)	2.83±0.97	2.77±0.43	2.42±0.08	2.73±0.07	2.18±0.34	2.37±0.22	1.71±0.04	1.73±0.28
8	Sulphates (mg/100g)	181.33± 0.82	128.17± 22.55	91.50±4.51	267.06± 25.22	243.67± 24.21	98.69± 22.46	168.63± 16.92	207.00± 24.14

Table 4.13: Seasonal variations in the physicochemical parameters of the sediment of Diwar from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
	Temperature (^{0}C)								
1	Ambient	26±1.00	5.33±1.33	27±0.00	26.33±0.33	26.33±0.33	23.25±0.85	26±1.00	26.67±0.88
2	Water	26.33±0.33	25.33±0.33	26±0.00	25.67±0.33	27.67±0.33	24.5±0.64	27±1.00	27.33±0.88
	Sediment Parameters								
3	Temperature(^{0}C)	26.67±0.33	26±0.00	26±0.00	25±0.58	28.67±0.33	25.25±0.34	28±1.00	27.67±0.88
4	pH	8.08±004	8.11±0.07	8.15±0.09	8.53±0.04	8.41±0.02	8.53±0.08	8.19±0.12	8.58±0.07
5	Conductivity(μmho)	5.63±0.09	5.07±0.17	4.95±0.04	5.43±0.18	5.93±0.26	5.2±0.27	5.6±0.6	5.3±0.15
6	Chlorides (mg/100g)	127.83±20.44	35.08±4.88	77.39±24.38	159.29± 10.26	114.78± 12.45	34.18±4.77	65.81±4.06	77.86±0.04
7	Total alkalinity (mg/100g)	2.31±0.22	2.32±0.58	1.66±0.27	1.93±0.45	2.27±0.29	1.73±0.44	1.84±0.5	3.99±1.16
8	Sulphates (mg/100g)	92.77±14.75	69.5±15.8	85.62±11.95	148.39± 30.99	108.87± 14.48	65.92±3.42	113.58± 19.97	139.54± 21.24

Table 4.14: Seasonal variations in the physicochemical parameters of the sediment of Miramar from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	**Temperature(^{0}C)**								
	....Ambient	25.67±0.33	23.67±0.33	24.50±0.50	23.67±0.88	24.67±0.33	24.00±0.41	23.50±0.5	25.00±0.58
2	.....Water	25.67±0.67	25.00±0.57	25.50±0.50	25.33±0.33	26.33±.033	25.00±0.41	24.00±1.00	25.67±0.67
	Sediment Parameters								
3	Temperature(^{0}C)	26.33±0.88	25.33±0.67	26.00±0.00	26.00±0.0	27.33±.088	25.50±0.28	25.00±1.00	26.67±0.67
4	pH	8.38±0.07	8.47±0.06	8.66±0.15	8.73±0.03	8.89±0.08	9.03±0.96	9.01±0.01	8.85±0.08
5	Conductivity(μmho)	5.40±0.00	5.03±0.09	5.20±0.00	5.07±0.03	5.27±0.03	4.95±0.02	5.15±0.05	5.03±0.06
6	Chlorides (mg/100g)	93.43±5.91	68.63±9.27	81.89±8.3	86.21±6.98	88.35±1.44	83.95±1.6	81.35±0.41	74.31±3.29
7	Total alkalinity (mg/100g)	1.76±0.43	1.72±0.48	0.83±0.00	1.79±0.03	1.33±0.19	0.74±0.04	0.75±0.00	1.30±.0.28
8	Sulphates (mg/100g)	55.67±7.73	41.17±8.95	57.25±8.77	86.89± 27.48	106.00± 45.75	35.12± 16.62	35.50±3.51	20.73± 10.82

Table 4.15 : The monthly means of the sediment nutrients at the six study sites on a biannual basis.

Sr.no	Parameters	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1	% Organic carbon	3.37±0.25	3.17±0.14	2.07±0.21	1.83±0.13	0.96±0.13	0.28±0.12
2	Phosphates (mg/100g)	10.24±0.56	9.62±0.79	4.88±0.41	5.33±0.54	5.29±0.63	4.38±0.43
3	Nitrates (mg/100g)	0.42±0.01	0.37±0.01	0.30±0.02	0.31±0.02	0.27±0.02	0.23±0.02

Table 4.16: Seasonal variations in the sediment nutrients at Ribandar from summer 1999 to winter 2000/2001.

Sr. No	Physicochemical Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	5.17±1.88	3.16±0.02	3.22±0.02	3.25±0.14	2.77±0.32	3.06±0.05	2.95±0.15	3.29±0.11
2	Phosphates (mg/100g)	11.73±1.87	11.85±0.41	9.2±0.41	9.58±2.31	9.2±1.92	11.26±1.17	7.61±0.46	9.96±1.46
3	Nitrates (mg/100g)	0.34±0.02	0.43±0.01	0.42±0.01	0.46±0.01	0.39±0.00	0.44±0.01	0.41±0.01	0.46±0.03

Table 4.17: Seasonal variations in the sediment nutrients at Chorao from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	4.21±0.72	2.88±0.1	3.02±0.13	3.17±0.21	3.1±0.31	2.64±0.08	3.19±0.88	3.29±0.09
2	Phosphates (mg/100g)	3.13±0.9	11.7±1.76	7.02±2.51	8.39±1.41	10.73±0.97	13.53±0.54	9.87±1.69	10.5±2.23
3	Nitrates (mg/100g)	0.34±0.01	0.34±0.06	0.28±0.11	0.41±0.01	0.41±0.03	0.39±0.01	0.43±0.03	0.37±0.01

Table 4.18: Seasonal variations in the sediment nutrients at Minor C from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	3.32±1.51	1.41±0.10	2.38±0.03	1.77±0.3	1.64±0.23	1.76±0.08	2.15±0.17	2.41±0.15
2	Phosphates (mg/100g)	3.63±0.71	5.77±0.18	3.60±2.41	4.90±1.11	3.73±0.75	6.12±0.07	2.28±0.28	7.31±1.01
3	Nitrates (mg/100g)	0.22±0.04	0.20±0.04	0.16±0.04	0.26±0.01	0.37±0.08	0.32±0.07	0.39±0.06	0.42±0.03

Table 4.19: Seasonal variations in the sediment nutrients at Minor D from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	2.65±0.82	1.34±0.21	1.94±0.00	1.49±0.11	1.50±0.03	1.78±0.23	2.25±0.30	1.87±0.17
2	Phosphates (mg/100g)	2.53±0.48	7.13±1.31	5.30±0.30	5.68±0.28	4.98±0.74	4.65±1.24	11.13±1.47	3.39±0.45
3	Nitrates (mg/100g)	0.34±0.03	0.19±0.01	0.34±0.05	0.26±0.02	0.32±0.05	0.27±0.06	0.34±0.03	0.43±0.00

Table 4.20: Seasonal variations in the sediment nutrients at Diwar from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	1.58±0.77	0.49±0.1	0.95±0.02	0.56±0.14	0.86±0.1	0.84±0.21	1.86±0.51	0.88±0.02
2	Phosphates (mg/100g)	8.03±0.47	5.7±1.37	5.48±0.22	1.54±0.12	8.01±0.9	5.77±1.95	4.44±2.85	2.98±1.38
3	Nitrates (mg/100g)	0.26±0.06	0.16±0.05	0.25±0.02	0.14±0.04	0.29±0.05	0.31±0.01	0.4±0.01	0.4±0.01

Table 4.21 :Seasonal variations in the sediment nutrients at Miramar from summer 1999 to winter 2000/2001.

Sr. No	Parameters	Summer	Monsoon	Post monsoon	Winter	Summer	Monsoon	Post monsoon	Winter
		1999-2000				2000-2001			
1	% Organic carbon	1.45±0.64	0.06±0.01	0.15±0.05	0.13±0.03	0.10±0.02	0.12±0.00	0.11±0.00	0.08±0.01
2	Phosphates (mg/100g)	3.17±0.33	6.23±0.78	6.86±1.14	2.21±0.97	5.06±0.45	5.86±0.41	4.24±1.76	1.70±0.33
3	Nitrates (mg/100g)	0.22±0.01	0.23±0.02	0.10±0.04	0.11±0.05	0.28±0.09	0.26±0.03	0.25±0.00	0.34±0.02

Table 4.22: Seasonal variations in the biomass of benthic flora (g/m^2) at the six study sites in the Mandovi estuary.

Seasons	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	14.7	8.9	24.5	19.0	23.0	0.00
Monsoon	0.5	0.00	0.00	0.8	0.00	0.00
Post Monsoon	2.1	0.00	8.5	10.4	12.9	0.00
Winter	21.8	9.7	36.3	21.9	23.6	0.00
2000-2001						
Summer	24.3	7.0	30.8	25.0	20.5	0.00
Monsoon	0.0	0.00	2.0	0.5	4.9	0.00
Post Monsoon	0.0	0.00	12.0	15.0	12.5	0.00
Winter	15.0	14.0	40.0	35.2	27.0	0.00

Table 4.23: The checklist of the benthic macroinvertebrates found in the sediment of all the six sites and their ranks of dominance based on their biannual cumulative densities.

Sr. No.	Group/ Species	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
	Mieofauna						
1	Nematodes	1	1	1	2	6	3
	Macrofauna						
	Polychaetes						
2	*Maldane* sp.	3	1	3	-	5	12
3	*Axiothella obockensis*	-	-	10	1		
4	*Ceratoneries costae*	7	6	6	7	4	9
5	*Ceratoneries flagelliceps*	9	13	20	13	9	17
6	*Neries kauderni*	8	8	9	8	7	20
7	*Neries chilkaensis*	-	-	15	3	2	-
8	*Neries* sp.	4	3	2	-	1	7
9	*Lumbrineries* sp.	18	-	-	11	-	18
10	*Lumbriconeries polydesma*	21	9	11	-	12	-
11	*Lumbriconeries simplex*	13	15	25	-	-	-
12	*Perineries nuntia*	19	-	7	15	14	20
13	*Platyneries* sp.	-	-	31	-	25	-

.........contd/-

Sr. No.	Group/ Species	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
14	*Dendroneries aestuarina*	20	15	28	14	24	-
15	*Glycera alba*	17	7	23	20	18	-
16	*Glycera longipinnis*	-	-	26	-	20	-
17	*Nepthys polybranchia*	11	12	14	10	13	10
18	*Polydora* sp.	6	5	6	4	8	4
19	*Heterospio catalensis*	5	4	16	6	20	5
20	*Lyscastis indicus*	20	17	27	23	26	-
21	*Cirratulus* sp.	14	19	18	12	28	-
22	*Phyllodoce* sp.	23	16	21	19	19	-
23	*Polynoe* sp.	-	-	24	18	20	16
24	*Laonome* sp.	16	17	20	13	17	-
25	*Prionospio polybranchiata*	15	20	32	-	28	-
26	*Prionospio tridentata*	13	-	33	-	-	-
27	*Caulleriella* sp.	-	-	27	-	-	-
28	*Gonaida incerta*	-	-	31	-	-	-
29	*Heteromastus filiformes*	-	-	36	-	-	-
30	*Pista* sp.	-	-	30	-	-	-
31	*Sylla* sp.	15	-	-	-	28	-

………contd/-

Sr. No.	Group/ Species	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
32	*Odontosylla* sp.	-	-	-	-	-	19
33	*Tomopteries* sp.	-	20	-	-	-	19
34	*Diopatra neapolitana*	-	-	-	-	22	-
	Crustaceans						
35	*Cyclops* sp.	24	20	29	-	27	14
36	*Paracyclops* sp.	-	-	36	26	29	-
37	*Ligia* sp.	-	19	20	16	21	19
38	*Calanus* sp.	-	-	-	-	26	19
39	*Gammarus* sp.	18	10	13	9	3	14
40	*Corophium triaenonyx*	2	14	4	5	2	6
41	*Apseudes chilkensis*	-	-	5	8	3	-
42	*Brachionus* sp.	-	-	39	-	30	-
43	*Metapenaeus* sp.	10	19	34	22	23	-
44	Chiromnomous larva	20	-	34	15	28	-
45	*Harpacticoid copepod*	-	-	37	30	-	-
46	Ghost shrimp	19	-	-	26	-	-
47	*Gastrosoccus* sp.	-	-	-	-	-	1
48	*Pontogoneia* sp.	-	-	-	24	-	-

.........contd/-

Sr. No.	Group/ Species	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
49	*Squilla* sp.	-	-	37	-	-	-
50	*Insect larva*	-	-	-	-	20	-
51	*Coleoptera*	17	-	35	26	31	-
52	*Balanus amphitrite*	-	-	35	26	24	-
53	*Grapsus* sp.	21	21	22	27	28	-
54	*Sesarma* sp.	18	22	40	28	29	-
55	*Scylla* sp.	-	-	-	26	-	-
56	*Emerita holothusi*	-	-	-	-	-	2
57	*Matuta lunaris*	-	-	-	-	-	21
58	*Ocypoda ceratopthalma*	-	-	-	-	-	19
59	*Dotilla myctiroides*	-	-	-	-	-	2
60	Medusa	-	-	38	-	-	-
	Molluscs						
61	*Pontamides cingulatus*	13	16	8	17	11	-
62	*Natica* sp.	-	17	19	29	30	-
63	*N. zigzag*	-	-	36	30	30	-

.........contd/-

Sr. No.	Group/ Species	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
64	*Olivia nebulosa*	-	19	20	25	-	21
65	*Trochus* sp.	-	-	-	-	20	-
66	*Turitella* sp.	-	-	-	-	-	19
67	*Sunnetta effosa*	-	18	-	-	-	-
68	*Meretrix casta*	12	11	17	21	10	13
69	*M. ovum*	-	16	12	22	15	-
70	*Arca symmetrica*	-	-	35	-	-	-
71	*Cardium* sp.	-	-	40	29	25	15
72	*Crassostrea edulis*	23	-	-	-	28	-
73	*Perna viridis*	22	-	-	-	-	-
74	*Catelysia opima*	-	-	-	-	16	-
75	*Donax incarnatus*	-	-	-	-	-	8
76	*Donax faba*	-	-	-	-	-	11

Table 4.24: The variation in the biannual cumulative densities of total benthic macroinvertebrates and their major constituents at the six study sites.

	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
Nematodes-SBF	14417	19034	42028	16342	12008	9353
Polychaetes-SBF	19266	32979	81469	65038	83719	18274
Crustaceans-SBF	5414	2464	25196	11387	39441	242527
Molluscs	726	2483	5627	1573	7599	3812
Total Soft Bodied Forms(SBF)	39191	54932	148693	92517	135168	270154
Total BMI	39917	57415	154320	94090	142767	273966

Table 4.25: Variations in densities of the 4 major benthic macroinvertebrate groups in terms of percentage composition at the six study sites.

	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
Nematodes	36.12	33.15	27.23	17.37	8.41	3.41
Polychaetes	48.26	57.43	52.19	69.12	58.64	6.67
Crustaceans	13.26	4.29	16.32	12.10	27.63	88.52
Molluscs	1.82	4.32	3.65	1.67	5.32	1.39

Table 4.26: Seasonal fluctuations in the density of nematodes (individuals/m^2) at all the six sites from March 1999 to February 2001.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	978±581	1750±292	5083±1174	375±125	555±133	1515±909
Monsoon	551±88	583±213	2130±747	792±364	351±177	212±94
Post Monsoon	188±83	875±376	2750±752	375±3	107±36	495±369
Winter	244±67	792±209	2280±990	795±496	862±204	303±155
2000-2001						
Summer	1031±349	848±339	737±316	981±784	692±167	394±248
Monsoon	812±379	750±23	985±436	1045±191	210±102	0
Post Monsoon	766±16	955±137	895±425	727±7	949±136	91±0
Winter	284±176	152±80	333±66	376±116	313±28	303±61

Table 4.27: Seasonal fluctuations in the density of polychaetes (individuals/m^2) at all the six sites from March 1999 to February 2001.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	1026±301	2125±391	655±333	2458±856	3628±552	1939±961
Monsoon	542±209	750±308	542±273	1250±617	1483±506	848±264
Post Monsoon	1125±125	375±125	2875±1630	3775±0	2654±517	2273±452
Winter	416±237	1383±380	5292±864	1227±172	1323±428	607±243
2000-2001						
Summer	1667±698	1909±525	4501±1880	3516±2567	4110±623	667±280
Monsoon	255±60	3455±937	4013±839	5269±2261	2344±737	0
Post Monsoon	677±63	136±46	3988±17	1228±7	7694±278	182±0
Winter	1231±303	788±471	4354±794	2867±1841	5792±651	394±212

Table 4.28: Seasonal fluctuations in the density of crustaceans(individuals/m^2) at all the six sites from March 1999 to February 2001.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	121±6	458±83	1263±557	42±42	1244±86	1122±559
Monsoon	44±26	42±30	1004±430	417±417	370±179	8675±2147
Post Monsoon	222±6	63±36	1250±414	63±1	1612±1607	21636±2976
Winter	143±107	95±55	1456±716	152±80	20±20	9928±2098
2000-2001						
Summer	560±94	33±19	937±500	909±229	1653±272	5009±153
Monsoon	178±33	61±30	831±320	1348±609	281±251	10488±1255
Post Monsoon	268±178	91±91	560±44	370±4	7932±5095	31137±3237
Winter	374±88	30±30	1423±730	191±49	1023±692	6942±2920

Table 4.29: Seasonal fluctuations in the density of the total soft bodied forms which include nematodes, polychaetes and crustaceans(individuals/m^2), at all the six sites from March 1999 to February 2001.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	2130±878	4333±137	2754±680	2833±981	5427±400	4576±2431
Monsoon	1139±158	1375±42	3629±2210	2458±42	2204±755	9736±1811
Post Monsoon	1539±68	1313±84	6875±177	4213±2	4368±1131	24404±2487
Winter	81±303	2270±109	9028±1383	2174±538	2204±321	10837±1742
2000-2001						
Summer	3260±289	2942±61	6133±1630	5364±3526	6455±780	6070±665
Monsoon	1248±430	4242±76	5829±910	7662±2529	2883±808	10488±3237
Post Monsoon	1717±128	1182±10	5443±626	2325±3	22323±8347	31410±2683
Winter	1890±568	970±30	939±488	3434±1880	7128±1299	7640±456

Table 4.30: Seasonal fluctuations in the density of molluscs (individuals/m^2) at all the six sites from March 1999 to February 2001.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	102±53	915±108	225±173	8±8	311±85	114±8
Monsoon	34±34	733±42	237±137	75±75	121±63	89±15
Post Monsoon	0	313±95	325±46	38±0	623±196	105±15
Winter	71±37	371±125	239±31	18±10	473±242	173±65
2000-2001						
Summer	33±33	989±61	250±141	87±74	433±57	250±104
Monsoon	1±1	1845±146	333±143	116±18	342±38	46±58
Post Monsoon	0	0	146±20	87±0	238±187	249±57
Winter	0	518±61	268±36	99±54	238±124	348±55

Table 4.31: A systematic list of the birds with their migrant/habitat status and abundance based on the biannual cumulative population at the six study sites.

Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar (1-40)	Chorao (1-51)	Minor C (1-46)	Minor D (1-50)	Diwar (1-34)	Miramar (1-22)	
	Pelecaniformes/ Phalacrocoracidae								
1	*Phalacocorax niger*	Little cormorant	25	26	30	29	20	-	R/A-D/P
2	*P. fuscicollis*	Indian shag	-	51	-	-	33	-	R/A-D/P
3	*P. carbo*	Great cormorant	-	48	-	49	33	-	R/A-D/P
	Ciconiiformes/ Ardeidae								
4	*Egretta garzetta*	Little egret	7	13	23	10	11	20	R/A-Wa/P
5	*E. gularis*	Western reef-egret	16	29	43	27	22	-	R/A-Wa/P
6	*Ardea cinerea*	Grey heron	39	43	38	38	30	-	R/A-Wa/P
7	*A. purpurea*	Purple heron	-	51	46	50	32	-	R/A-Wa/P
8	*Casmerodius albus*	Large egret	13	14	22	15	8	-	R/A-Wa/P
9	*Mesophoyx intermedia*	Median egret	16	19	19	14	12	-	R/A-Wa/P
10	*Bubulcus ibis*	Cattle egret	19	18	-	-	23	18	R/A-Wa/P
11	*Ardeola grayii*	Indian pond-heron	11	27	32	23	29	18	R/A-Wa/P
12	*Butorides strictus*	Little green-heron	35	40	-	-	-	-	R/A-Wa/P
13	*Nycticorax nycticorax*	Black-crowned night-heron	32	46	45	47	27	-	R/A-Wa/P
14	*Ixobrychus minutus*	Little Bittern	-	48	46	-	-	-	LM/A-Wa/P
15	*I. cinnamomeus*	Chestnut bittern	39	47	44	43	31	-	R/A-Wa/P
16	*Dupetor flavicollis*	Black bittern	40	47	45	-	-	-	LM/A-Wa/P
	Ciconiidae								
17	*#Anatomosus oscitans*	Asian Openbill-Stork	-	41	45	40	28	-	LM/A-Wa/B
18	*Ciconia episcopus*	White-necked stork	-	31	34	34	29	-	LM/A-Wa/B
19	*Ciconia ciconia*	European white stork	-	-	-	-	34	-	M/A-Wa/B
20	*#Leptoptilus dubius*	Lesser Adjutant-stork	-	40	37	-	26	-	LM/A-Wa/B
	Threskiornithidae								
21	*Plegadis falcinellus*	Glossy ibis	36	-	43	42	33	-	M/A-Wa/Pl

Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
22	*#Threskiornis melanocephalus*	Oriental white ibis	-	-	42	-	31	-	LM/A-Wa/Pl
23	*#Pseudibis papillosa*	Black ibis	40	-	46	45	-	-	LM/A-Wa/Pl
	Anseriformes/ Anatidae								
24	*Dendrocygna javanica*	Lesser whistling-duck	-	-	27	-	27	-	LM/A-S/Pl
25	*Anas strepera*	Gadwall	-	-	46				M/A-S/Pl
26	*A. penelope*	Eurasian Wigeon	-	-	46	50	-	-	M/A-S/Pl
27	*A. platyrhynchos*	Mallard	-	-	45	50	-	-	M/A-S/Pl
28	*A. poecilorhyncha*	Spot-bill duck	-	-	36	39	-	-	LM/A-S/Pl
29	*A. clypeata*	Northern Shoveller	-	9	25	-	14	-	M/A-S/Pl
30	*A. acuta*	Northern Pintail	-	1	1	1	1	-	M/A-S/Pl
31	*A. querquedula*	Garganey	-	-	10	-	24	-	M/A-S/Pl
32	*#Aythya nyroca*	Ferruginous Pochard	-	46	44	46	-	-	M/A-S/Pl
	Falconiformes/ Accipitridae								
33	*Milvus migrans*	Blach Kite	30	39	38	36	26	17	R/T-R/C
34	*Haliaster indus*	Brahminy Kite	30	39	38	32	26	16	R/T-R/C
35	*Haliaeetus leucogaster*	White-bellied Sea-Eagle	34	42	39	36	29	20	R/T-R/C
36	*#Haliaeetus leucoryphus*	Pallas's Fish-Eagle	-	-	-	49	34	-	R/T-R/C
37	*Circus aeruginosus*	Western Marsh-Harrier	35	41	-	44	24	-	M/T-R/C
38	*Accipiter badius*	Shikra	-	51	-	-	-	-	R/T-R/C
	Pandionidae								
39	*Pandion haliaetus*	Osprey	-	-	-	-	34	-	M/T-R/C
	Falconidae								
40	*Falco peregrinus*	Peregrine Falcon	-	-	-	-	31	-	R/T-R/C
	Gruiformes/ Rallidae								
41	*Amaurornis phoenicurus*	White-breasted Waterhen	-	44	-	-	-	-	R/A-W/I
	Charadriiformes/ Rostratulidae								
42	*Rostratula benghalensis*	Greater Painted-Snipe	-	43	-	-	-	-	M/A-W/B
	Haematopodidae								

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Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
43	*Haematopus ostralegus*	Eurasian Oystercatcher	41	-	-	-	-	-	M/A-W/B
	Charadriidae								
44	*Pluvialis fulva*	Pacific Golden-Plover	-	21	34	25	19	-	M/A-W/B
45	*P. squatarola*	Grey plover	-	44	28	35	30	-	M/A-W/B
46	*Charadrius dubius*	Little Ringed Plover	16	16	7	21	13	5	M/A-W/B
47	*C. alexandrinus*	Kentish Plover	5	5	5	2	5	2	LM/A-W/B
48	*C. mongolus*	Lesser Sand Plover	4	3	2	4	2	1	M/A-W/B
49	*C. leschenaultii*	Greater Sand Plover	-	-	11	-	6	9	M/A-W/B
50	*Vanellus vanellus*	Red-wattled Lapwing	37	44	-	-	-	15	R/A-W/B
	Scolopacidae								
51	*Gallinago stenura*	Pintail Snipe	-	49	-	-	33	-	M/A-W/B
52	*G. gallinago*	Common Snipe	-	49	46	-	34	-	M/A-W/B
53	*Limosa limosa*	Black-tailed Godwit	-	-	43	43	33	-	M/A-W/B
54	*L. lapponica*	Bar-tailed Godwit	-	-	35	47	33	-	M/A-W/B
54	*Numenius phaeopus*	Whimbrel	4	33	36	22	24	-	M/A-W/B
56	*Numenius arquata*	Eurasian Curlew	34	21	33	19	20	-	M/A-W/B
57	*Tringa erythropus*	Spotted Redshank	30	32	41	41	-	-	M/A-W/B
58	*T. totanus*	Common Redshank	1	4	3	3	3	18	M/A-W/B
59	*T. stagnatilis*	Marsh Sandpiper	24	20	30	20	21	13	M/A-W/B
60	*T. nebularia*	Common Greenshank	12	-	18	11	16	21	M/A-W/B
61	*T. ochropus*	Green Sandpiper	40	46	29	18	-	13	M/A-W/B
62	*T. glareola*	Wood Sandpiper	29	33	40	33	29	14	M/A-W/B
63	*Xenus cinereus*	Terek Sandpiper	-	46	46	48	-	18	M/A-W/B
64	*Actitis hypoleucos*	Common Sandpiper	22	22	27	16	17	14	M/A-W/B
65	*Calidris canutus*	Red Knot	41	5	46	-	-	-	M/A-W/B
66	*C. alba*	Sanderling	-	-	-	5	7	11	M/A-W/B
67	*C. minuta*	Little Stint	8	2	8	-	6	-	M/A-W/B
68	*C. temminckii*	Temminck's Stint	20	26	24	-	-	-	M/A-W/B
69	*C. alpina*	Dunlin	21	-	29	-	9	-	M/A-W/B
70	*C. ferruginea*	Curlew Sandpiper	38	45	42	48	-	-	M/A-W/B
71	*Limicola falcinellus*	Broad-billed Sandpiper	-	-	45	50	-	-	M/A-W/B
72	*Philomachus pugnax*	Ruff	10	24	29	17	-	-	M/A-W/B

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Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
	Recurvirostridae								
73	*Himantopus himantopus*	Black-winged Stilt	32	-	-	-	24	-	LM/A-W/B
74	*Recurvirostra avosetta*	Pied Avocet	-	-	-	49	34	-	M/A-W/B
	Burhinidae								
75	*Burhinus oedicnemus*	Stone-Curlew	-	50	46	49	-	-	LM/A-W/B
76	*Esacus recurvirostris*	Great Stone-Plover	-	51	-	-	-	-	LM/A-W/B
	Glareolidae								
77	*Glareola pratincola*	Collared Pratincole	-	-	45	-	-	20	M /A-W/B
78	*G. lactea*	Small Pratincole	6	-	15	-	-	7	LM/A-W/B
	Laridae								
79	*Larus marinus*	Great Black-backed gull	-	-	14	-	-	-	M/A-D/P
80	*L. fuscus*	Lesser Black-backed gull	-	-	44	-	-	-	M/A-D/P
81	*L. ichthyaetus*	Pallas's Gull	23	-	-	-	27	12	M/A-D/P
82	*L. argentatus*	Herring gull	-	-	-	-	-	16	M/A-D/P
83	*L. brunnicephalus*	Brown-headed Gull	2	6	7	6	17	4	M/A-D/P
84	*L. rudibundus*	Black-headed Gull	11	10	12	13	-	6	M/A-D/P
85	*L. genei*	Slender-billed Gull	-	-	33	24	-	-	M/A-D/P
86	*Gelochelidon nilotica*	Gull-billed Tern	9	8	6	9	10	3	M/A-D/P
87	*Sterna caspia*	Caspian Tern	-	49	42	-	-	22	LM/A-D/P
88	*S. aurantia*	River Tern	27	30	29	30	25	19	LM/A-D/P
89	*S. bengalensis*	Lesser Crested Tern	-	29	28	28	-	18	LM/A-D/P
90	*S. hirundo*	Common Tern	-	-	16	12	-	-	M/A-D/P
91	*S. albifrons*	Little tern	-	-	43	37	-	-	LM/A-D/P
92	*S. repressa*	White-cheeked Tern	-	-	4	-	-	-	LM/A-D/P
93	*#S. acuticauda*	Black-bellied Tern	-	-	46	-	33	-	LM/A-D/P
94	*Chliconias hybridus*	Whiskered tern	13	23	9	26	15	-	M/A-D/P
	Rynchopidae								
95	*#Rynchops albicollis*	Indian Skimmer	-	-	-	-	-	22	LM/A-D/P
	Columbiformes/ Columbidae								
96	*Columba livia*	Blue Rock Pigeon	29	51	-	50	-	-	R/T/F
97	*Streptopelia senegalensis*	Little Brown Dove	39	44	-	-	-	-	R/T/F

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Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
98	*S. chinensis*	Spotted Dove	31	45	-	50	31	-	R/T/F
	Cuculiformes/ Cuculidae								
99	*Eudynamys scolopacea*	Asian Koel	40	49	-	49	34	-	R/T/I
	Apodiformes/Apodidae								
100	*Apus affinus*	House swift	17	46	-	-	-	-	R/T/I
	Coraciiformes/ Alcedinidae								
101	*Alcedo atthis*	Small Blue Kingfisher	29	39	39	33	23	-	R/T/I
102	*A. meninting*	Blue-eared Kingfisher	-	39	-	42	-	-	R/T/I
103	*Halcyon capensis*	Stork-billed Kingfisher	38	47	-	-	33	-	R/T/I
104	*H. smyrnensis*	White-breasted Kingfisher	29	33	40	31	28	20	R/T/I
105	*H. pileata*	Black-capped Kingfisher	37	45	45	40	33	-	R/T/I
106	*Todiramphus chloris*	Collared Kingfisher	-	37	-	38	-	-	R/T/I
107	*Ceryle rudis*	Lesser Pied Kingfisher	37	43	-	48	33	-	R/T/I
	Meropidae								
108	*Merops orientalis*	Small Bee-eater	30	27	-	-	33	-	R/T/I
109	*M. persicus*	Blue-cheeked Bee-eater	-	49	-	-	-	-	R/T/I
110	*M. philippinus*	Blue-tailed Bee-eater	40	36	-	45	-	-	R/T/I
	Coraciidae								
111	*Coracias garrulus*	European roller	-	51	-	-	-	-	R/T/I
112	*C. benghalensis*	Indian Roller	39	49	-	-	33	-	R/T/I
	Passeriformes/ Hirundinidae								
113	*Hirundo rustica*	Common Swallow	-	43	-	-	18	-	R/T/I
114	*H. smithii*	Wire-tailed Swallow	15	15	21	8	5	10	R/T/I
115	*H. daurica*	Red-rumped Swallow	14	12	13	7	4	8	R/T/I
	Motacillidae								
116	*Motacilla maderaspatensis*	Large Pied Wagtail	40	45	44	45	32	-	R/T/I

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Sr. No	Order/Family/Species	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
117	*M. flava*	Yellow Wagtail	-	44	-	45		-	M/T/I
118	*Anthus rufulus*	Paddyfield Pipit	-	35	-	-	33	-	R/T/I
	Campephagidae								
119	*Coracina macei*	Large Cuckoo-Shrike	-	50	-	-	33	-	R/T/I
120	*C. melanoptera*	Black-headed Cuckoo-Shrike	-	45	-	-		-	R/T/I
	Pycnonotidae								
121	*Pycnonotus jocosus*	Red-whiskered Bulbul	28	37	-	-	33	-	R/T/F
122	*P. cafer*	Red-vented Bulbul	27	38	-	-	32	-	R/T/F
123	*P. luteolus*	White-browed Bulbul	38	38	-	-	31	-	R/T/F
	Laniidae								
124	*Lanius cristatus*	Brown Shrike	40	46	-	46	33	-	M/T/I
125	*L. schach*	Rufous-backed Shrike	38	49	-	-	33	-	R/T/I
	Turdinae								
126	*Copsychus saularis*	Oriental Magpie-Robin	38	50	-	-	33	-	R/T/I
127	*Phoenicurus ochriros*	Black Redstart	-	51	-	-	-	-	M/T/I
128	*Saxicola torquata*	Common Stonechat	-	11	-	-	-	-	M/T/I
129	*Oenanthe desertii*	Desert Wheatear	-	48	-	-	-	-	M/T/I
130	*O. isabellina*	Isabelline Wheatear	-	51	-	-	-	-	M/T/I
	Timaliinae								
131	*Pellorneum ruficeps*	Spotted Babbler	-	-	-	-	34	-	R/T/I
	Sylviinae								
132	*Prinia socialis*	Ashy Prinia	-	32	-	-	31	-	R/T/I
133	*Acrocephalus agricola*	Paddyfield Warbler	-	22	-	-		-	R/T/I
134	*A. dumetorum*	Blyth's Reed-Warbler	26	29	-	-		-	R/T/I
135	*A. stentoreus*	Indian Great Reed-Warbler	33	34	-	-	33	-	R/T/I
136	*A. aedon*	Thick-billed Warbler	-	47	-	-	33	-	M/T/I
137	*Hippolais caligata*	Booted Warbler	-	46	-	-	33	-	M/T/I
138	*Orthotomus sutorius*	Common Tailorbird	-	50	-	-			R/T/I

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Sr. No	*Order/Family/Species*	Common Name	Ranks of Dominance						Migrant Status, Habit/Habitat, Feeding Habit
			Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar	
139	*Phylloscopus trochiloides*	Greenish Leaf-Warbler	35	7	-	-	30	-	M/T/I
	Muscicapinae								
140	*Ficedula parva*	Red-throated Flycatcher	-	25	-	-	33	-	M/T/I
	Dicaeidae								
141	*Dicaeum erythrorynchos*	Tickell's Flowerpecker	-	-	-	-	32	-	R /T/I
142	*Rhipidura albicollis*	White-throated Fantail-Flycatcher	-	25	-	-	-	-	R/T/I
143	*R. aureola*	White-browed Fantail-Flycatcher	-	44	-	-	-	-	R/T/I
	Estrildidae								
144	*Lonchura striata*	White-rumped munia	-	37	3-1	-	27	-	R/T/I
	Sturnidae								
145	*Acridotheres fuscus*	Jungle myna	18	23	-	-	27	19	R/T/I
	Oriolidae								
146	*Oriolus oriolus*	Eurasian Golden Oiole	-	43	-	-	25	-	R/T/I
147	*O. xanthornus*	Black-headed Oriole	-	41	-	-	-	-	R/T/I
	Dicruridae							-	
148	*Dicrurus macrocercus*	Black Drongo	38	46	-	45	32	-	R/T/I
149	*D. caerulescens*	White-bellied Drongo	-	43	-	-	-	-	R/T/I
150	*D. paradiseus*	Greater Racket-tailed Drongo	-	51	-	-	-	-	R/T/I
	Corvidae								
151	*Dendrocitta vagabunda*	Indian Treepie	-	45	-	-	34	-	R/T/I

Note:

= denotes a globally threatened or near threatened species (Collar, *et al*, 1994).

Migratory Status: R= Resident M= Migrant LM= Local migrant

Habitat: A-D= Aquatic divers A-Wa= Aquatic wading birds A-W= Aquatic waders T-R=Terrestrial Raptors T=Terrestrial

Feeding type: **P=Piscivores** **B= Benthivores** **Pl=Planktivores** **C= Carnovores** I= Insectivores F=Frugivores

Table 4.32: The results of the correlation test (r values) showing the correlations between the avifauna, waterbirds and waders at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar.

Sr. No	Parameters	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1	Avifauna and waterbirds	0.99**	0.99**	0.99**	0.98**	0.99**	0.99**
2	Avifauna and waders	0.98**	0.93**	0.96**	0.93**	0.87**	0.99**
3	Waterbirds and waders	0.98**	0.95**	0.96**	0.96**	0.93**	0.99**

** indicates statistical significance at $p<0.01$.

Table 4.33: The biannual cumulative distribution of the bird community at the six sites with special reference to their habitat type and feeding habit. The numbers in parenthesis indicate the number of species constituting the respective population.

	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
Total	33,399 (73)	53,379 (115)	1,21,493 (81)	34,897 (73)	19,463 (93)	29,577 (34)
Terrestrial	3,040 (31)	6,214 (59)	2,447 (11)	2,665 (21)	2,504 (41)	1,508 (7)
Aqautic	30,359 (42)	47,165 (56)	1,19,046 (70)	32,232 (52)	16,959 (52)	28,069 (27)
Wading Birds	9,360 (13)	4,180 (16)	2,234 (17)	1,680 (13)	1,529 (16)	99(3)
Waders/Benthivores	18,505 (21)	17,171 (27)	51,419 (29)	18,742 (23)	7,568 (22)	22,175 (15)
Divers/Skimmers	13,259 (11)	7,125 (12)	39,573 (18)	2,350 (18)	1,041 (14)	5,481 (10)
Dabblers/Swimmers/ Herbivores	00	18,689 (3)	25,887 (9)	7,796 (5)	7,226 (4)	00
Piscivores	22,480 (16)	9,467 (26)	41,807 (35)	40,330 (31)	2,560 (30)	5,580 (13)
Carnivores	321 (4)	146 (4)	146 (4)	125 (5)	143 (7)	135 (3)

Table 4.34: The seasonal variations in the rates of feeding (pecks/minute) and the rates of success in Kentish plovers, redshanks and curlews.

Seasons	Kentish Plovers		Redshanks		Curlew	
	Pecks/min.	**% success**	**Pecks/min.**	**% success**	**Pecks/min.**	**% success**
Summer	35.54±1.32	62.27	18.92±1.58	62.80	4.96±0.48	70.56
Monsoon			Waders absent.			
Post Monsoon	29.8±2.31	61.24	15.60±1.85	69.87	4.80±0.54	56.25
Winter	18.85±1.45	61.01	8.40±1.1	63.09	2.20±0.38	81.82

Table 4.35: The seasonal variations in the nocturnally foraging population of waders at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	75±21	58±13	798±78	52±38	148±43	442±22
Monsoon	No trips undertaken due to violent weather					
Post monsoon	00	85±4	425±9	28±25	15±15	113±15
Winter	79±12	164±32	1573±180	73±4	250±121	795±234
2000-2001						
Summer	100±11	102±45	2945±213	195±37	815±234	1715±589
Monsoon	No trips undertaken due to violent weather					
Post monsoon	12±6	00	968±12	2±2	40±34	168±65
Winter	87±13	93±80	2650±315	25±19	669±123	1548±496

Table 4.36: Seasonal profile of the avifaunal population at the 6 sites under study on a biannual cumulative basis.

Season	**Ribandar**	**Chorao**	**Minor C**	**Minor D**	**Diwar**	**Miramar**
1999-2000						
Summer	553-1580	481-1048	1658-3390	334-990	205-359	535-1043
Monsoon	320-566	135-607	109-608	73-210	108-318	84-100
Post Monsoon	881-1467	1022-1382	3823-4545	334-439	431-478	691-849
Winter	2817-3348	2167-5802	4166-10351	1055-2105	784-868	1843-3040
2000-2001						
Summer	914-2168	607-3604	2375-6738	475-611	235-856	603-2188
Monsoon	195-544	154-454	147-1160	114-23	80-393	55-300
Post monsoon	1001-1248	1010-2483	2558-8763	434-1608	635-1045	1843-2208
Winter	2689-3651	3761-11928	11423-21916	3041-102223	1966-5475	2706-3255

Table 4.37: Seasonal profile of the population of waterfowl the 6 sites under study on a biannual cumulative basis.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	418-1490	367-943	1547-3321	224-896	74-236	487-1002
Monsoon	210-467	85-294	43-537	7-117	29-237	33-70
Post Monsoon	749-1323	613-1146	3767-4477	266-363	344-388	653-794
Winter	2691-3177	1748-5381	3935-10149	954-1983	661-737	1777-2994
2000-2001						
Summer	754-2022	414-3349	2314-6570	205-492	196-704	542-2090
Monsoon	115-398	39-199	85-1067	75-124	25-325	17-233
Post monsoon	790-993	756-2087	2456-8663	299-1535	537-892	1755-2113
Winter	2592-3550	3272-11453	11302-21818	2907-10105	1844-5342	2598-3148

Table 4.38: Seasonal profile of the population of waders the 6 sites under study in the form of biannual cumulative number.

Season	Ribandar	Chorao	Minor C	Minor D	Diwar	Miramar
1999-2000						
Summer	130-778	242-861	1475-3212	52-331	72-90	243-643
Monsoon	38-242	25-218	6-464	9-99	0-188	10-52
Post Monsoon	502-878	472-960	3714-4340	195-198	210-270	554-680
Winter	1606-2100	1453-1869	3649-6385	562-1617	298-361	1381-2339
2000-2001						
Summer	426-1186	284-1248	2240-4750	171-285	128-522	454-1636
Monsoon	36-170	10-163	45-1040	66-113	0-248	5-226
Post monsoon	433-732	691-1911	2424-8106	128-1114	454-795	1564-1901
Winter	1794-1642	2297-2993	10012-13518	2265-4790	761-1034	2109-2523

Table 4.39: The results of the Kruskall Wallis nonparametric ANOVA showing the significant variations in the population of the avifauna, waterbirds and waders at the six study sites on a seasonal basis.

	Years	df	Avifauna χ^2	Avifauna P	Waterbirds χ^2	Waterbirds P	Waders χ^2	Waders P
Ribandar	1999-2000	3	8.06	0.04	8.06	0.04	8.48	0.04
	2000-2001	3	9.76	0.02	9.75	0.02	9.76	0.02
Chorao	1999-2000	3	8.48	0.04	8.80	0.03	8.80	0.03
	2000-2001	3	9.69	0.02	9.76	0.02	9.13	0.03
Minor C	1999-2000	3	9.03	0.03	9.03	0.03	8.80	0.03
	2000-2001	3	9.75	0.02	9.76	0.02	9.76	0.02
Minor D	1999-2000	3	8.90	0.03	8.72	0.03	8.19	0.04
	2000-2001	3	9.69	0.02	9.76	0.02	9.69	0.02
Diwar	1999-2000	3	8.92	0.03	8.32	0.04	8.32	0.04
	2000-2001	3	9.16	0.03	9.40	0.02	9.01	0.03
Miramar	1999-2000	3	8.80	0.03	8.80	0.03	8.80	0.03
	2000-2001	3	9.95	0.02	9.95	0.02	9.95	0.02

Table 4.40: Species indices of the avifauna of the 6 sites throughout the study period (1999-2001).

Site/Index	Summer	Monsoon	Post Monsoon	Winter	Summer	Monsoon	Post Monsoon	Winter
	1999-2000				2000-2001			
Ribandar								
H'	2.81	2.54	2.67	2.73	2.75	2.57	2.72	2.68
J'	0.73	0.74	0.71	0.71	0.8	0.78	0.71	0.7
SR	6.62	4.95	5.95	5.66	5.76	4.41	6.54	5.74
Chorao								
H'	3.03	2.84	2.94	2.18	2.7	3.13	2.77	2.05
J'	0.74	0.76	0.7	0.52	0.67	0.82	0.65	0.48
SR	8.63	7.49	9.32	7.7	7.52	8.38	9.41	7.89
Minor C								
H'	1.97	2.31	1.18	2.46	1.33	2.25	2.27	2.32
J'	0.56	0.74	0.32	0.63	0.57	0.7	0.61	0.58
SR	4.21	4.06	4.56	5.45	4.26	3.93	4.94	5.61
Minor D								
H'	2.4	1.98	2.6	2.15	2.1	2.11	2.37	2.13
J'	0.69	0.66	0.75	0.6	0.66	0.72	0.66	0.57
SR	4.91	3.88	5.04	4.74	3.74	3.52	5.17	4.71
Diwar								
H'	2.75	2.59	2.79	2.68	2.48	2.01	2.42	2.00
J'	0.79	0.68	0.76	0.72	0.74	0.68	0.60	0.51
SR	6.32	3.78	6.05	5.9	4.52	3.83	5.51	5.85
Miramar								
H'	1.61	2.16	2.08	1.94	1.49	1.68	1.67	1.86
J'	0.53	0.84	0.71	0.61	0.53	0.71	0.57	0.59
SR	3.1	2.73	2.56	2.92	2.18	2.08	2.3	2.75

Table 4.41: The biannual variations in the number of nests and the fledging success in the Ourem heronry.

Year	No of nests			No. of Chicks/nest	Total no. of chicks hatched	Fledging success (%)
	Avicennia	Rhizophora	Total			
1999	35	11	46	1-3	84	84.52
2000	41	18	59	2-3	108	79.63

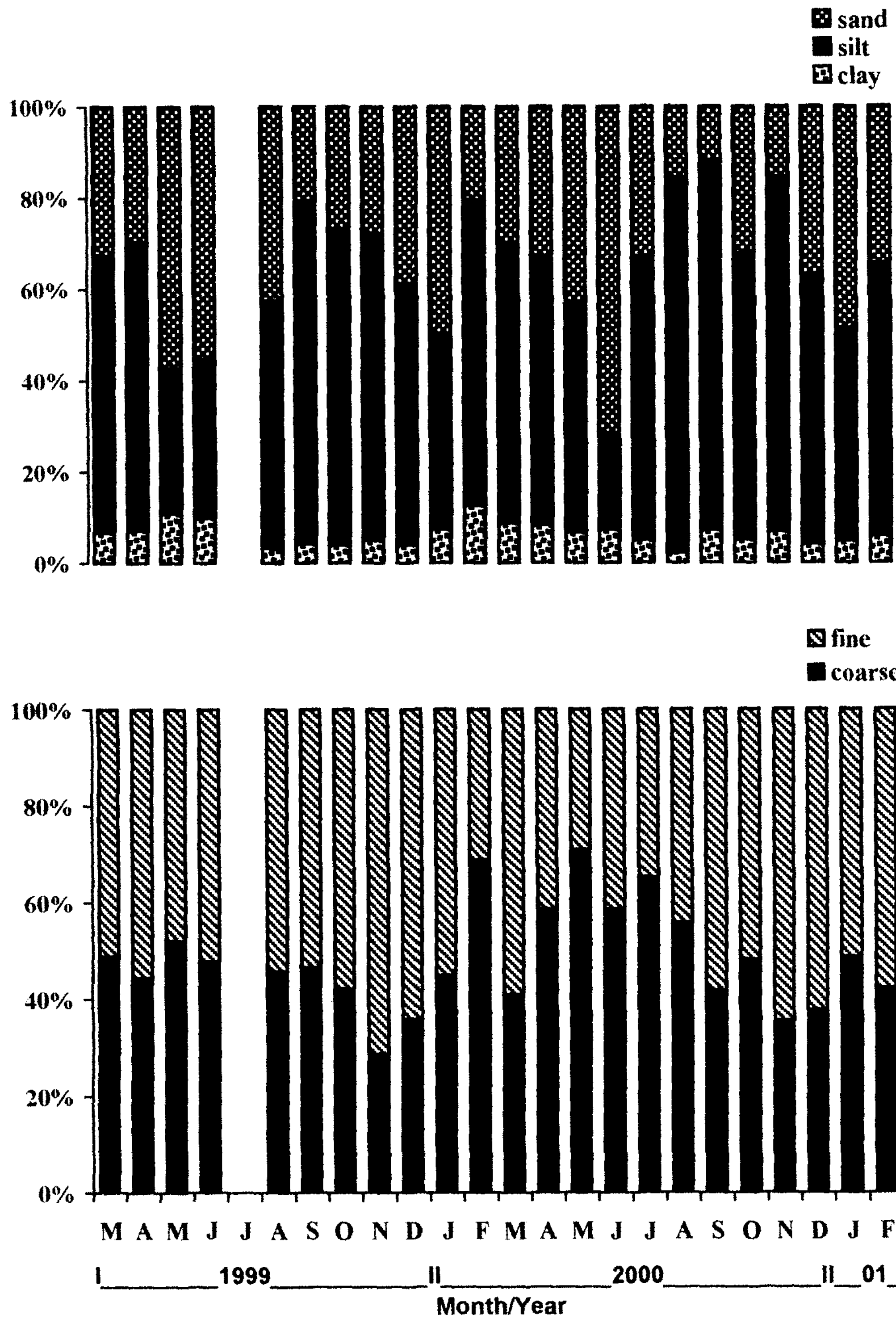
Table 4.42: The utility, hatching and fledging successes of the 3 ardeid species utilizing Chorao heronry.

Sr. No	Species	No. of nests			No. of Eggs/nest	Total no. of Eggs	Hatching success (%)	Fledging success (%)
		Avicennia	Sonneratia	Total				
1	Large egret	11	1	12	1-3	28	89.29	88.00
2	Little egret	34	5	39	2-4	109	89.91	70.41
3	Cattle egret	17	0	17	2-3	35	77.14	37.03

Graph 4.1

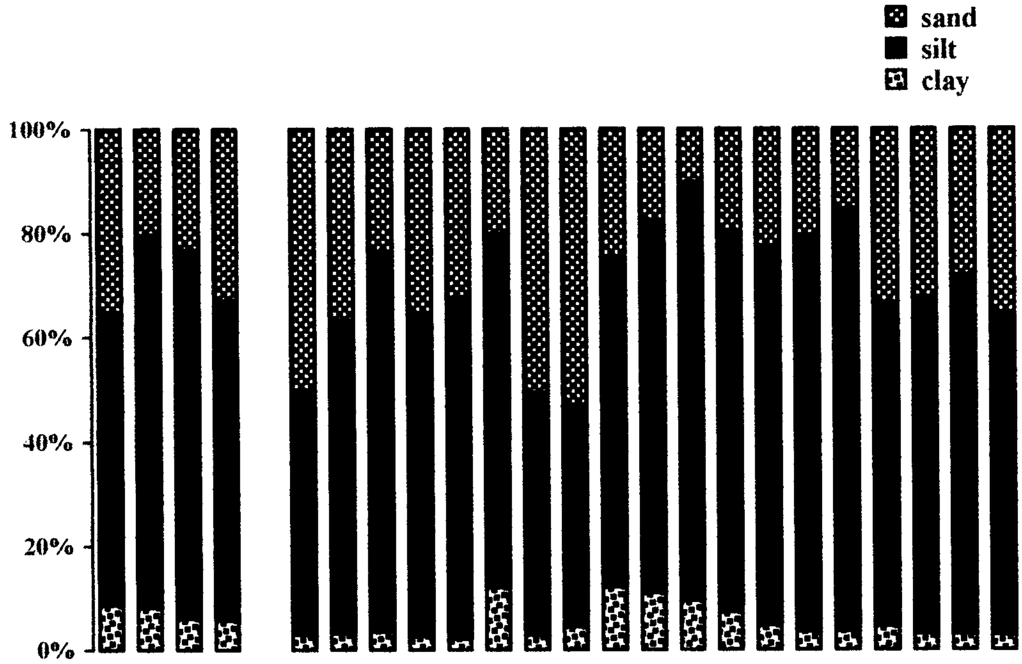
Monthly variations in the composition of the sediment at the 6 study stations.

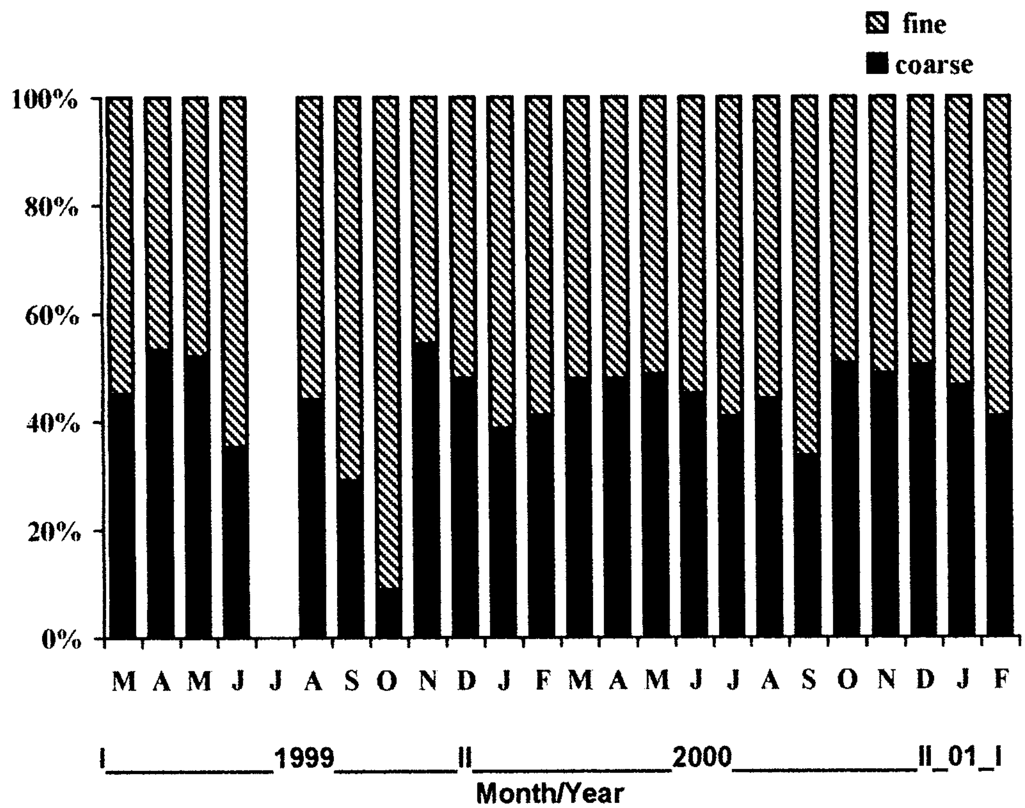
Ribandar



GRAPH 4.2

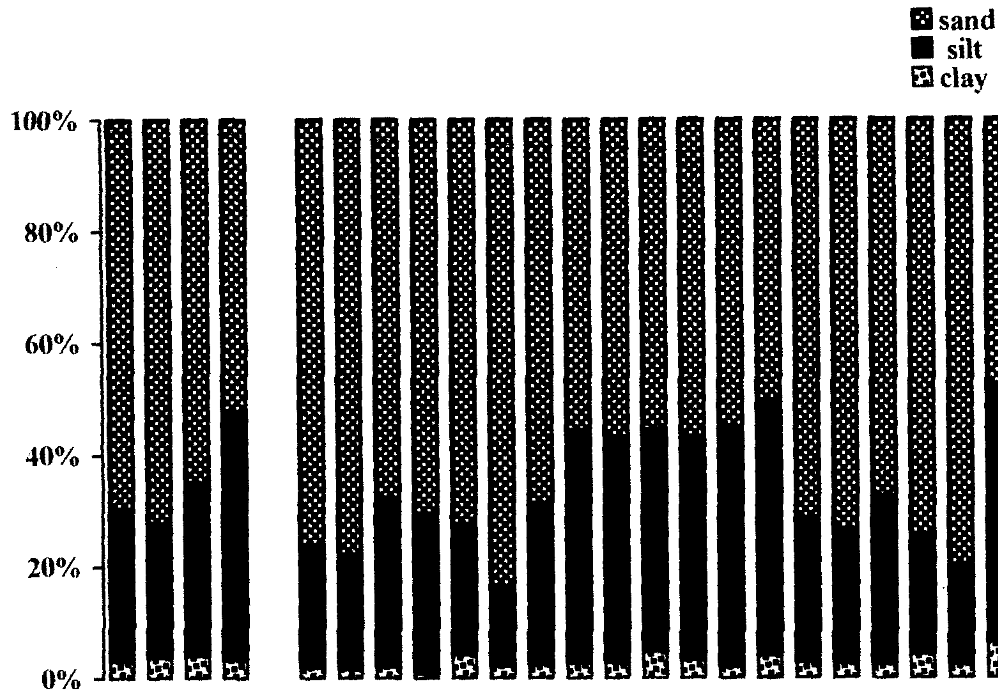
CHORAO

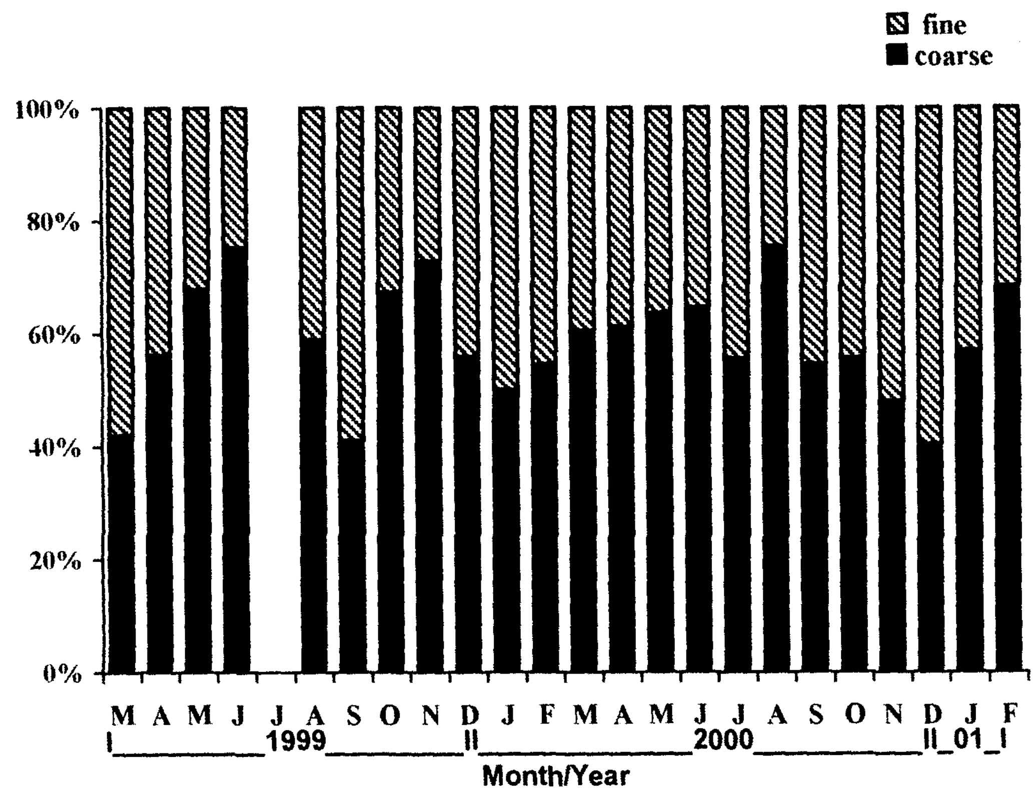




Graph 4.3

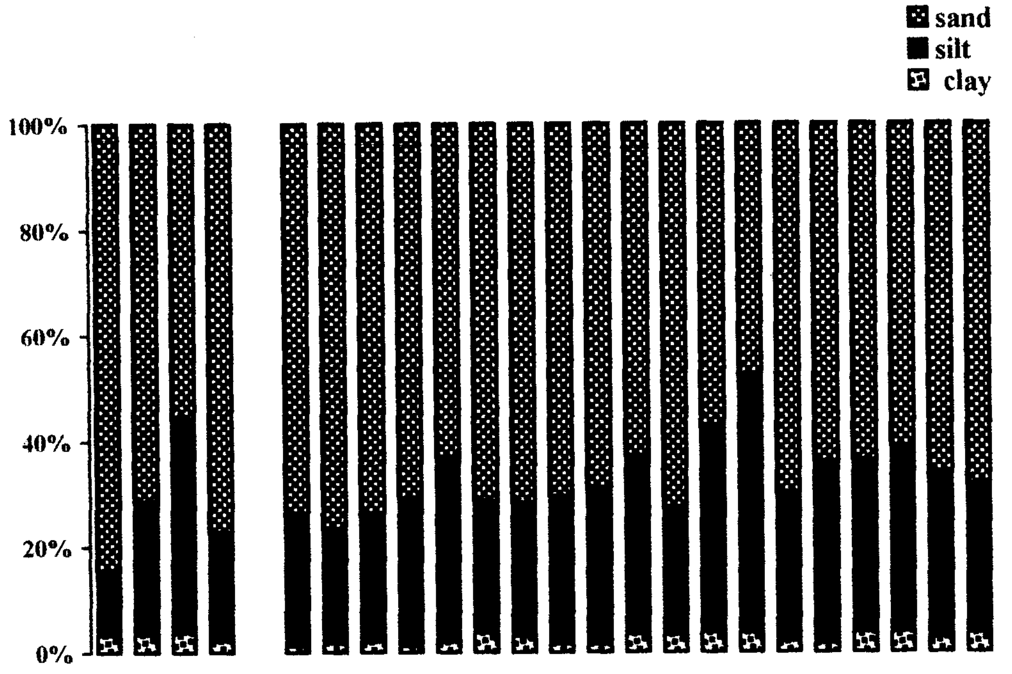
Minor C

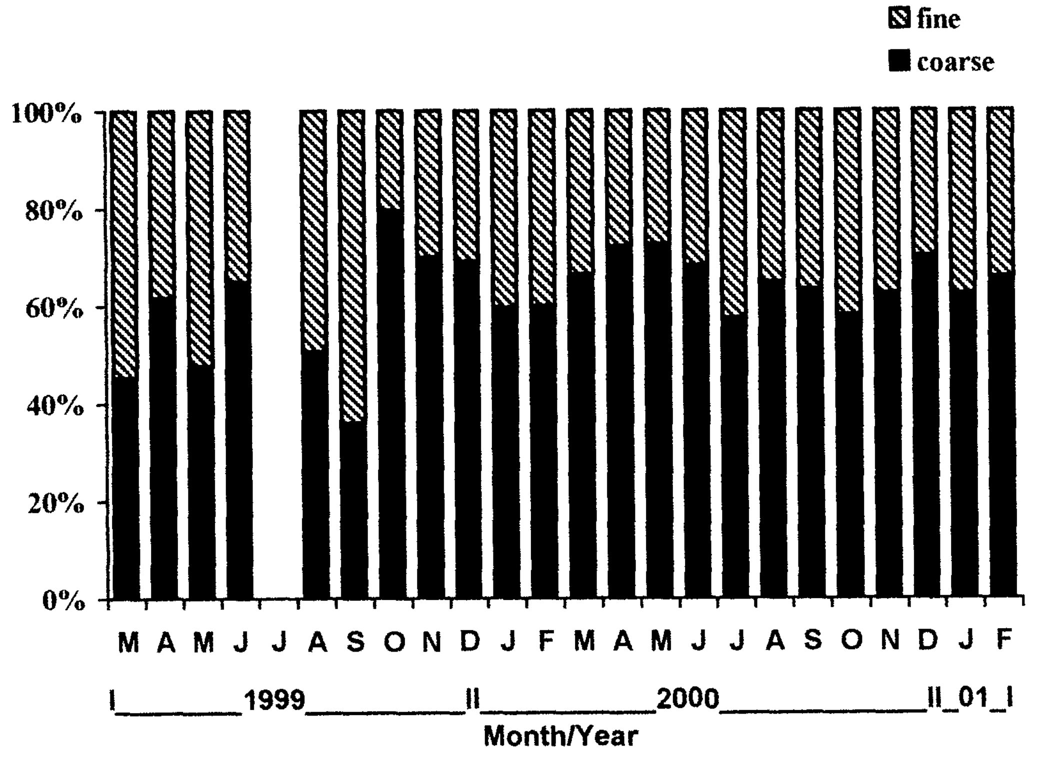




Graph 4.4

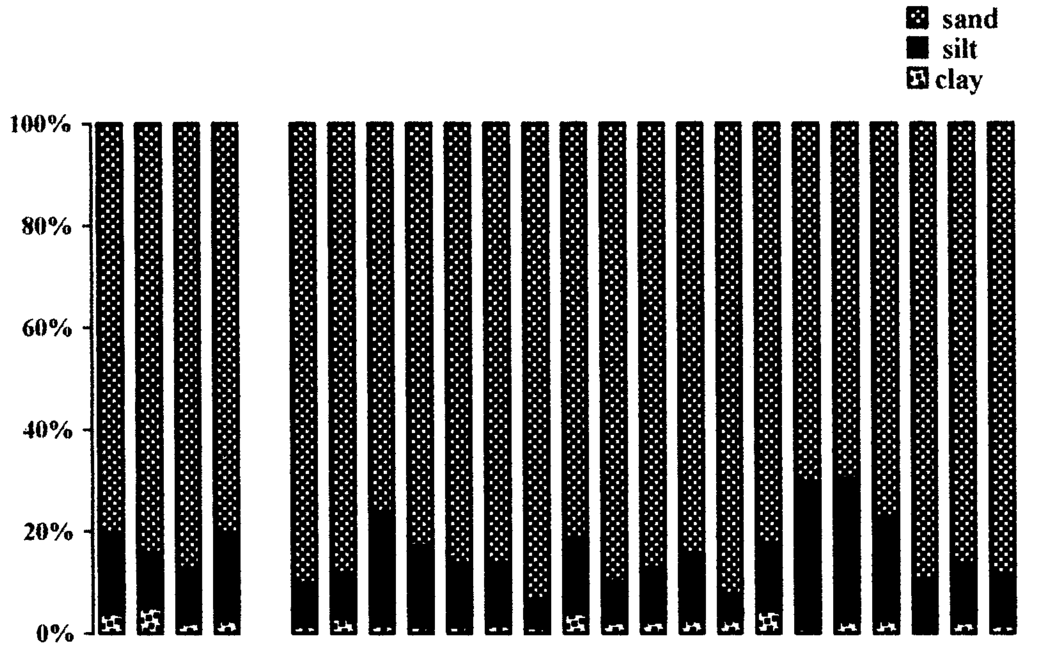
Minor D

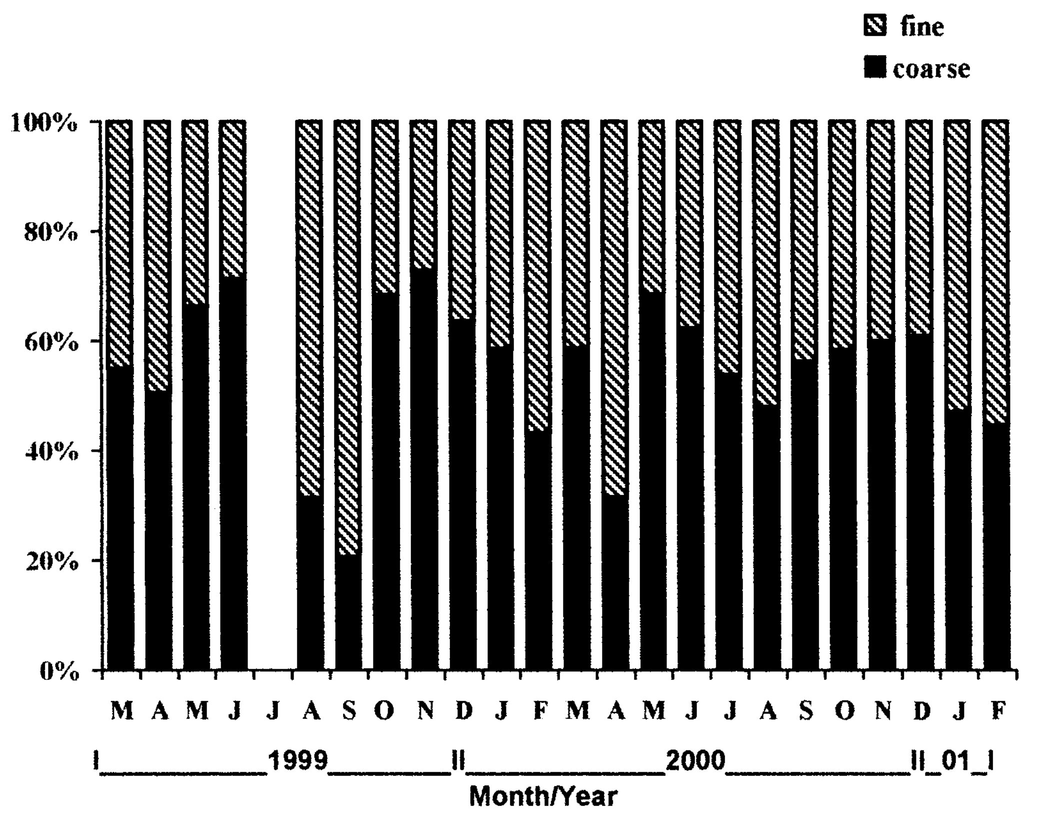




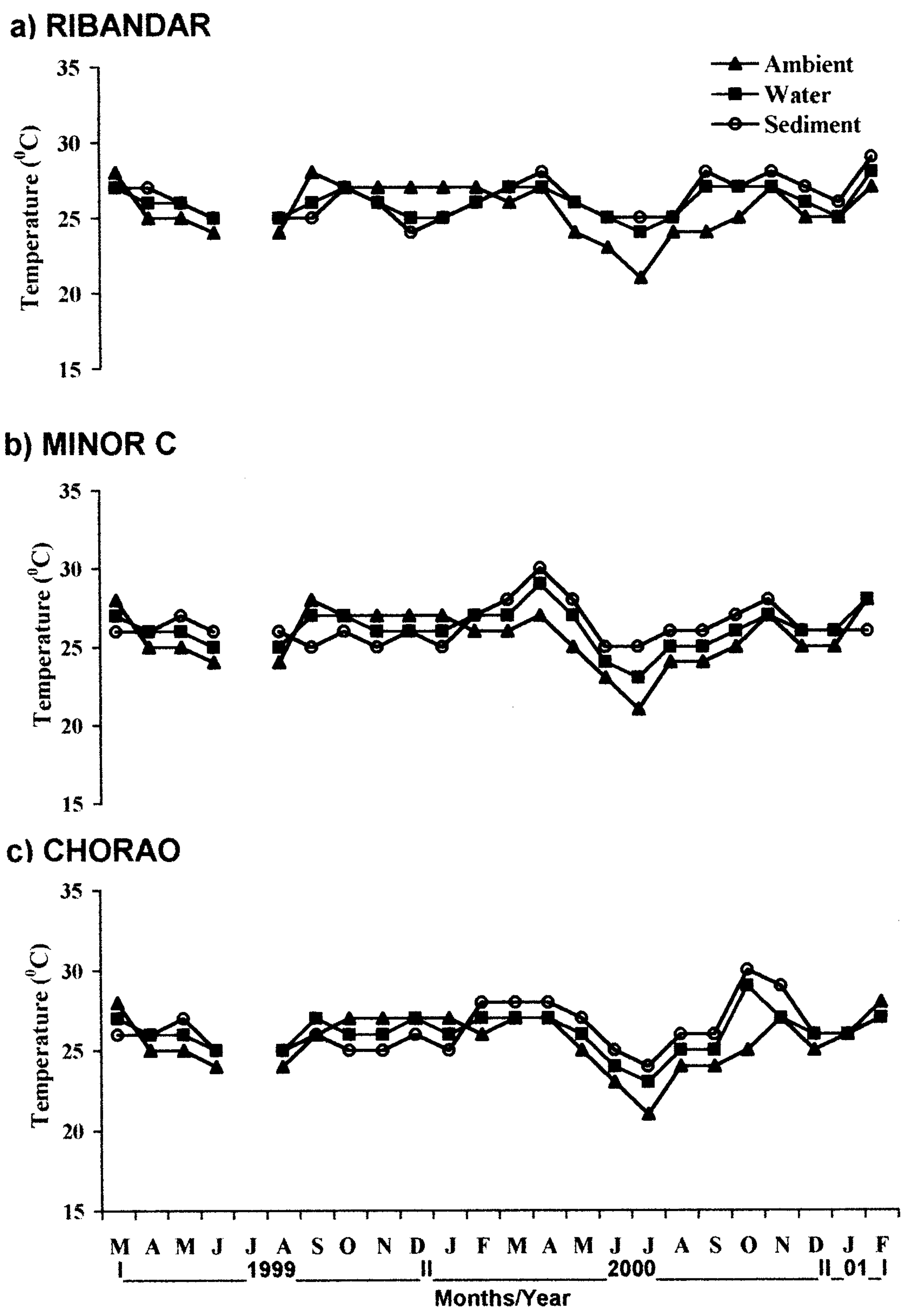
Graph 4.5

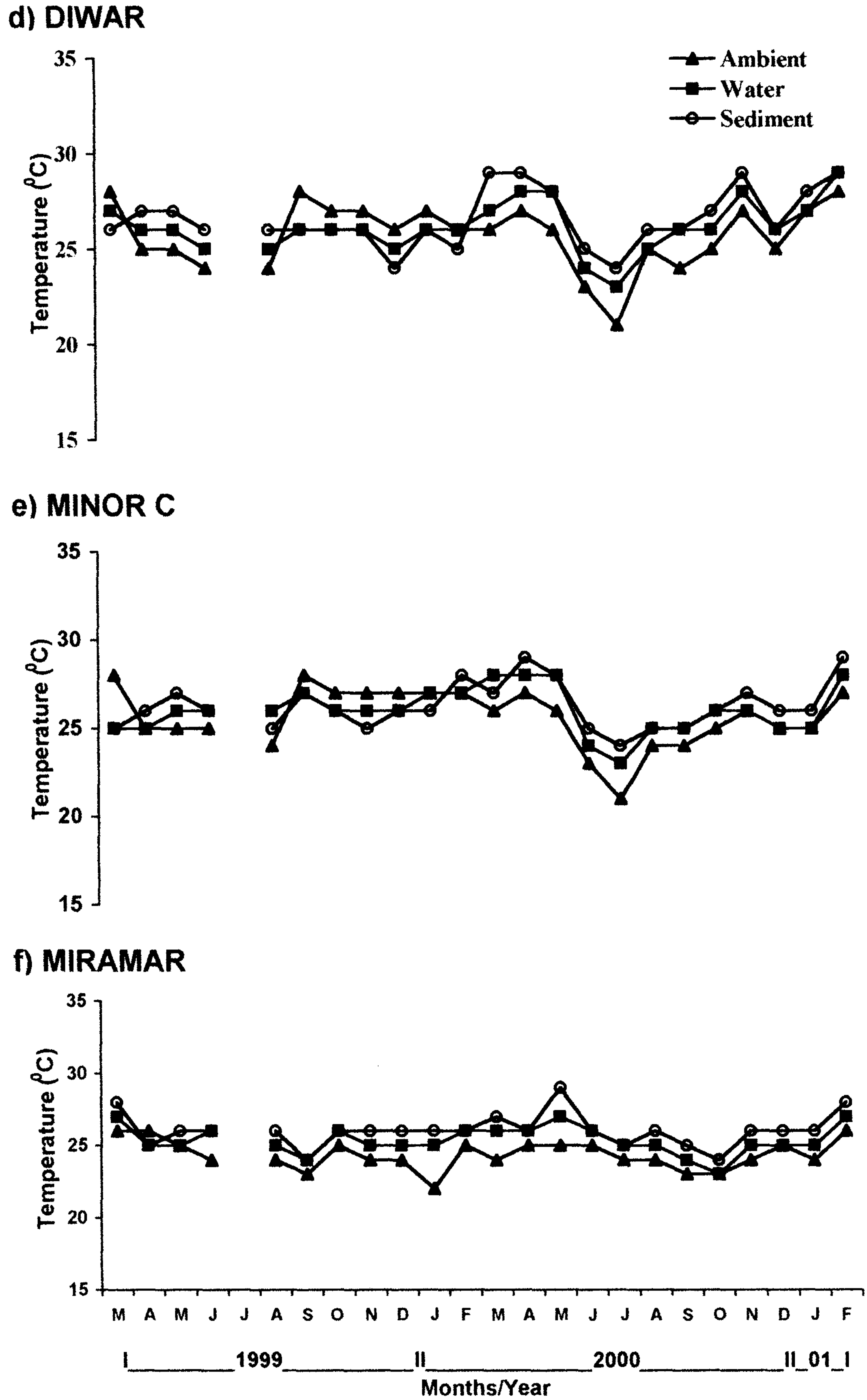
Diwar





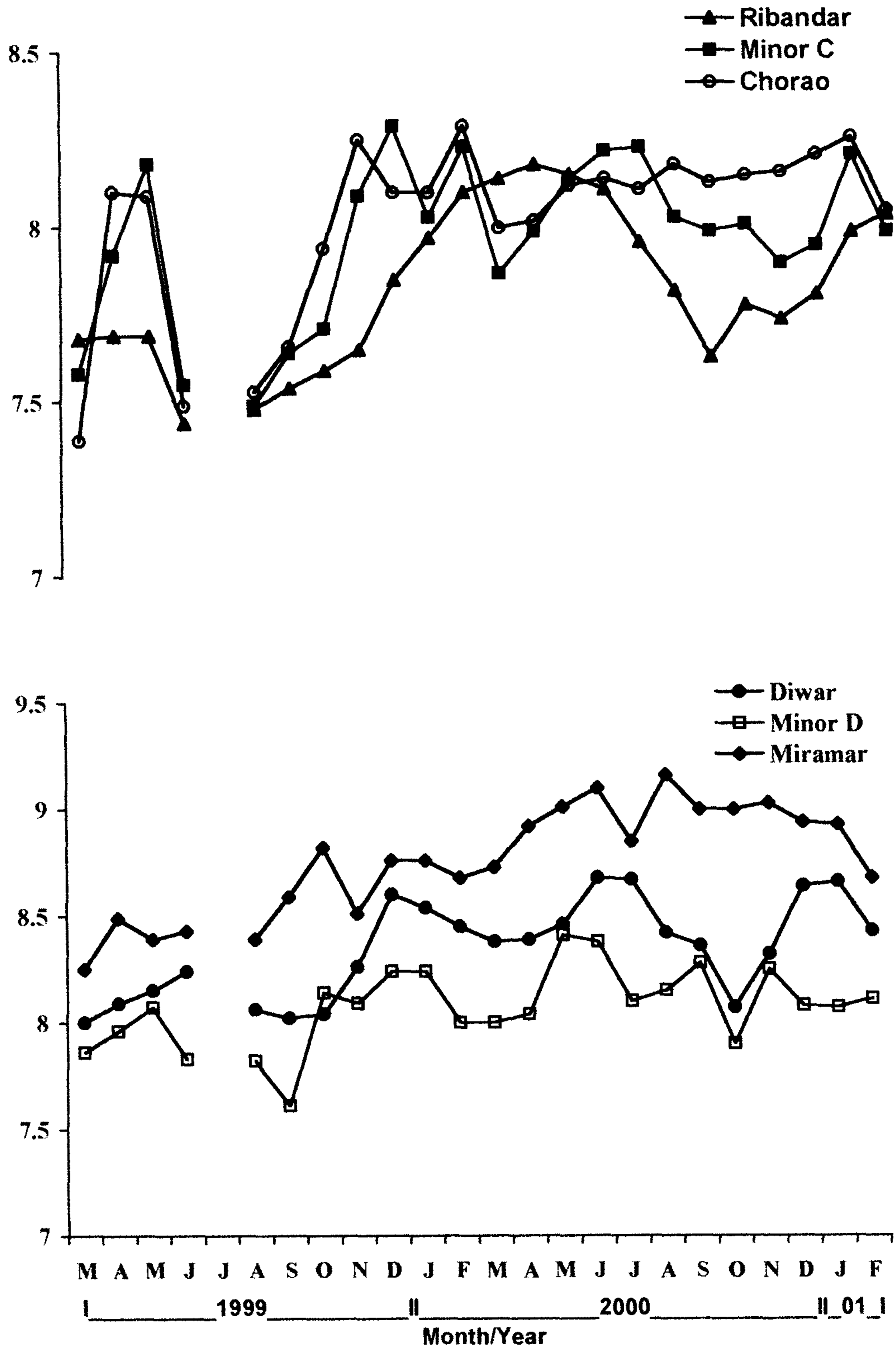
Graph 4.6 :
Monthly variations in the ambient, water and temperature at the six sites under study.




d) DIWAR
Ambient
Water
Sediment
Temperature (°C)
35
30
25
20
15
e) MINOR C
Temperature (°C)
35
30
25
20
15
f) MIRAMAR
Temperature (°C)
35
30
25
20
15
M A M J J A S O N D J F M A M J J A S O N D J F
I_______1999_______II_______2000_______II_01_I
Months/Year

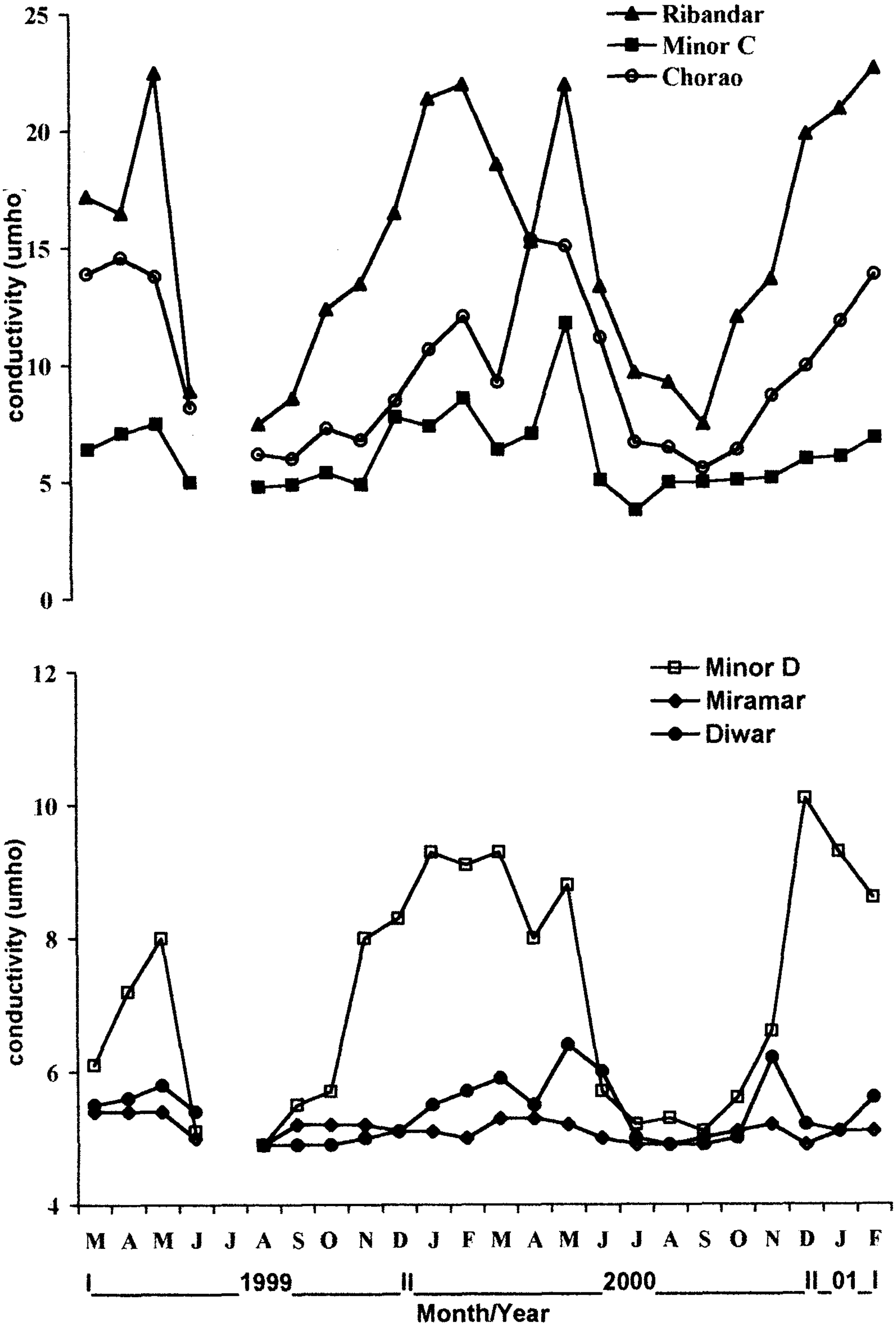
Graph 4.7 :

Monthly profile of the pH of the sediment at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar.



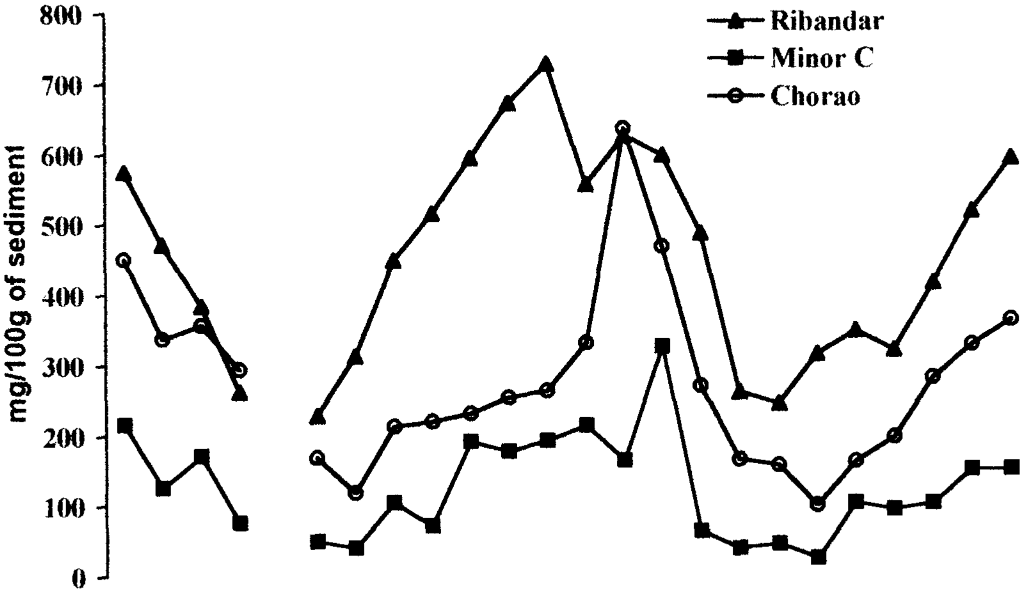
Graph 4.8 :

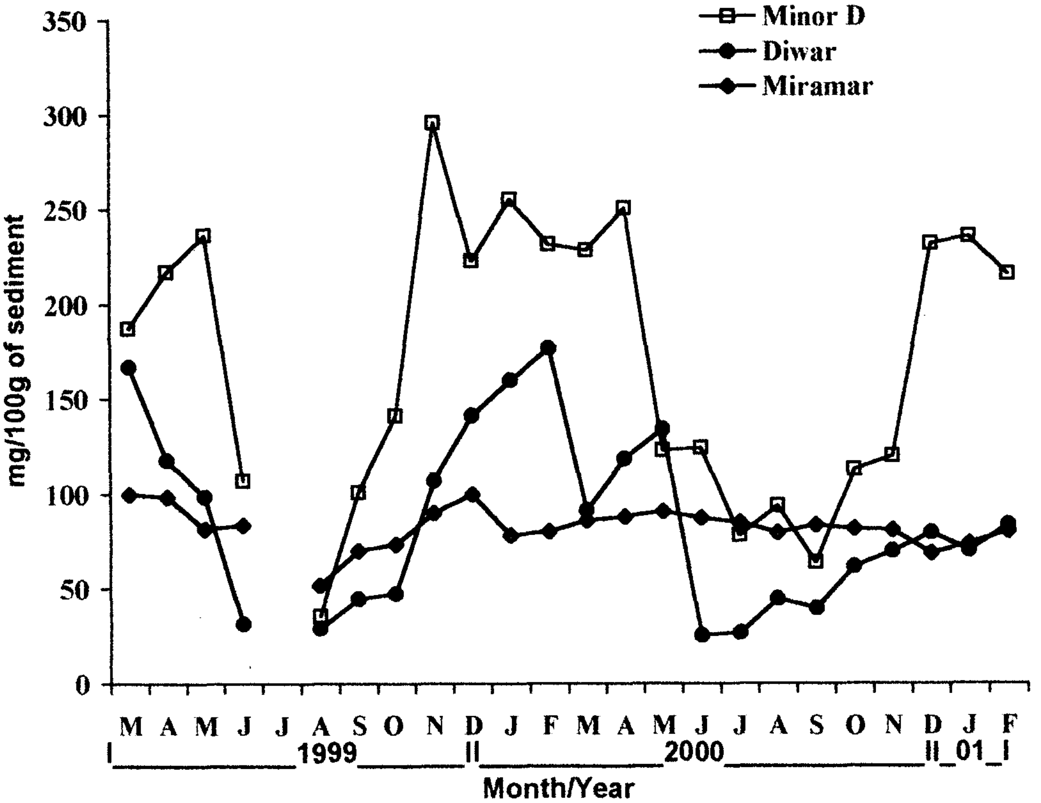
Variations in the sediment conductivity at Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar through the 2 years of study (1999-2001).



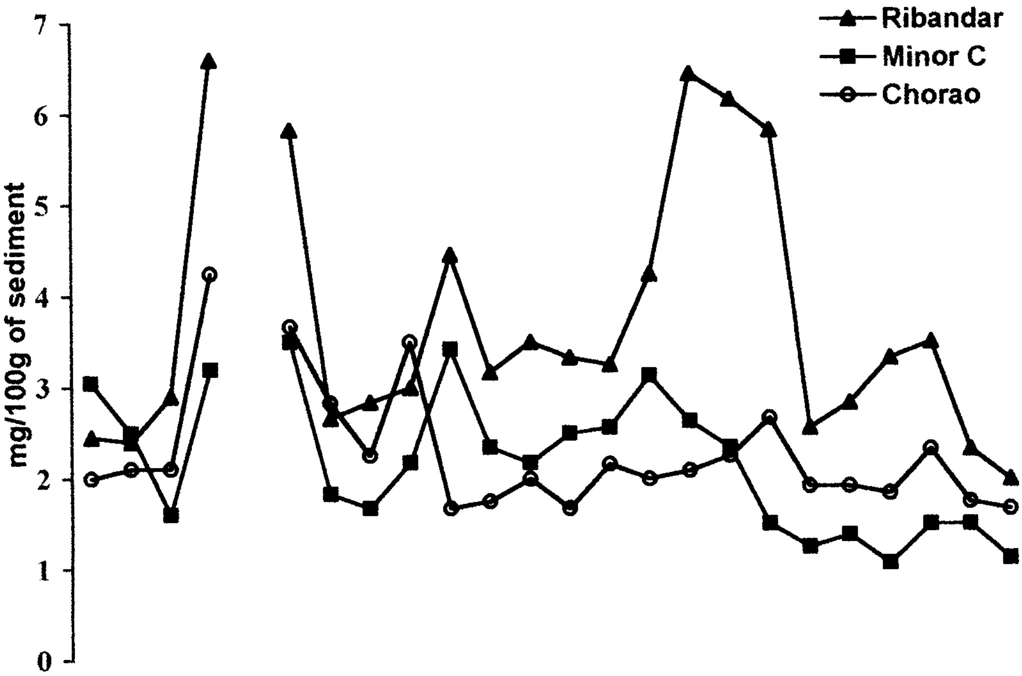
Graph 4.9

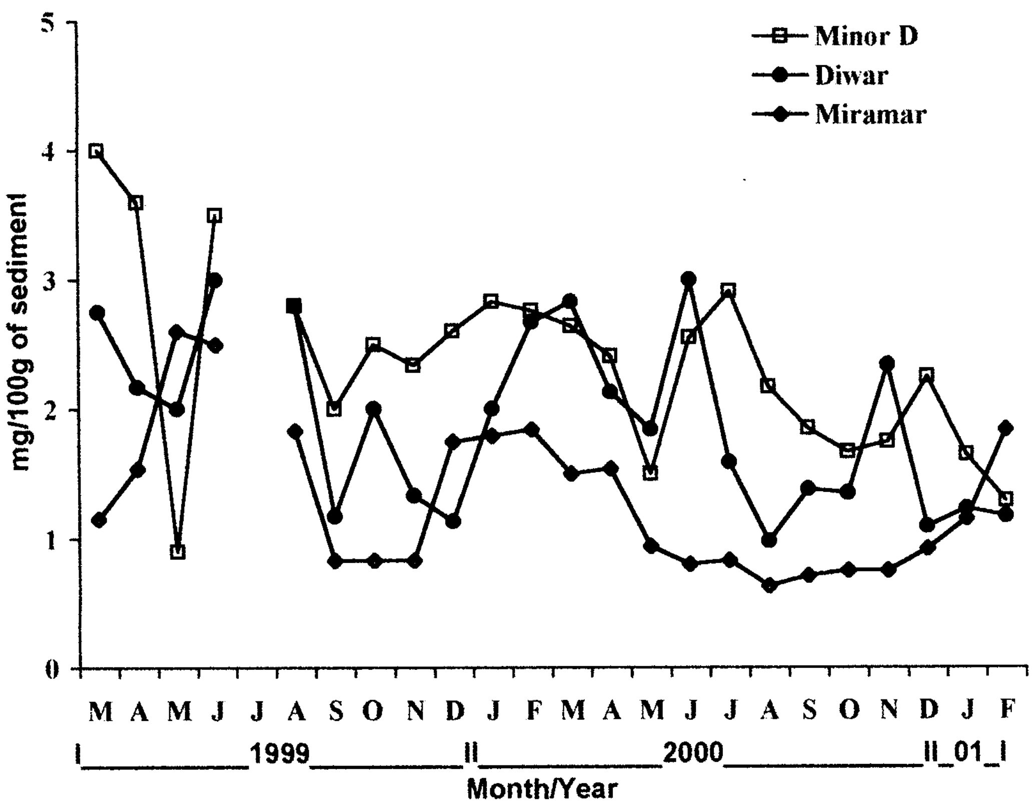
Monthly variations in the sediment chlorides at the six sites under study.





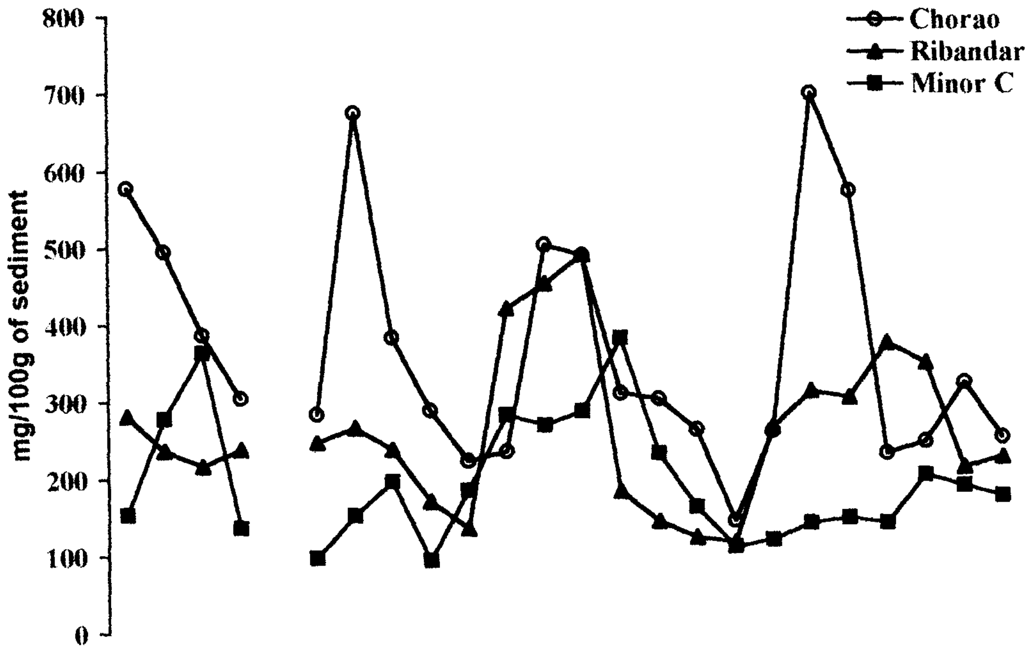
Graph 4.10 :
Monthly variations in the total alkalinity of the sediment at the six sites under study.

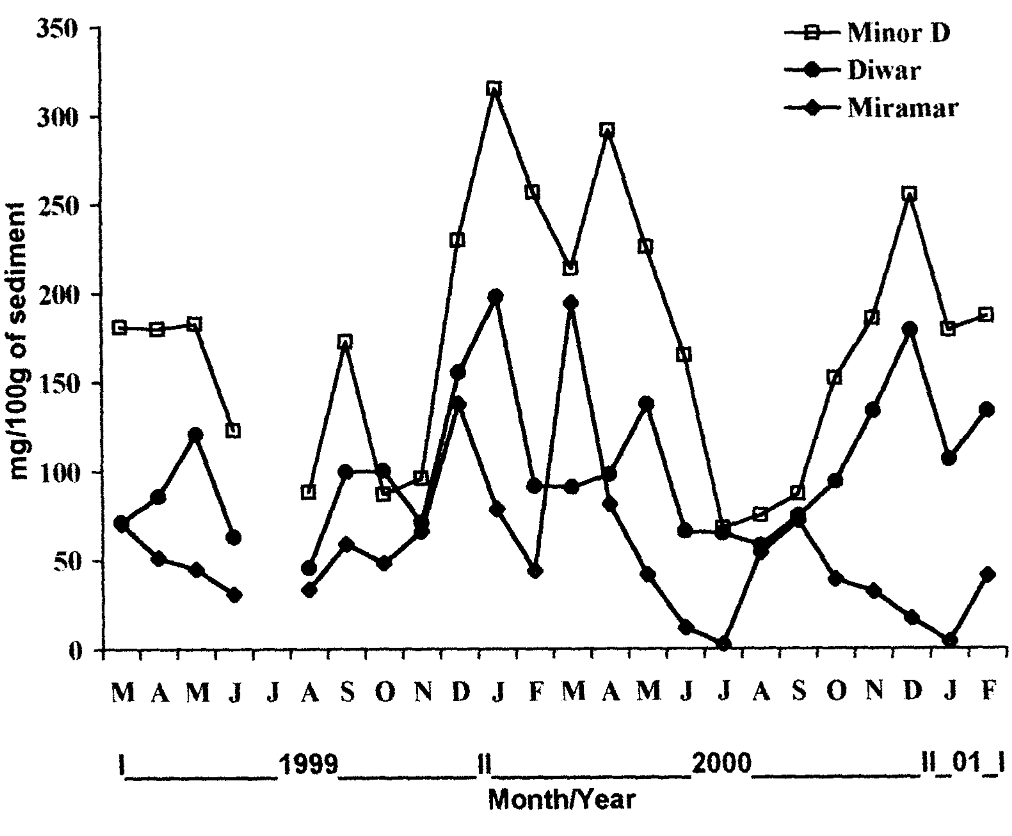




Graph 4.11:

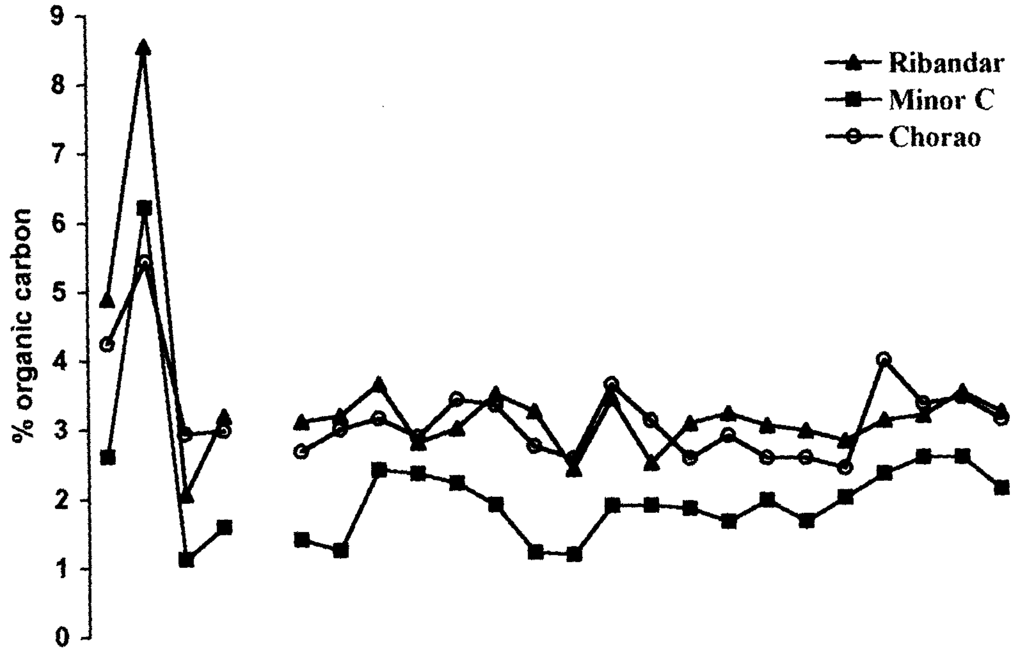
Monthly variations in the sulphate concentration of the sediment at the six sites under study.

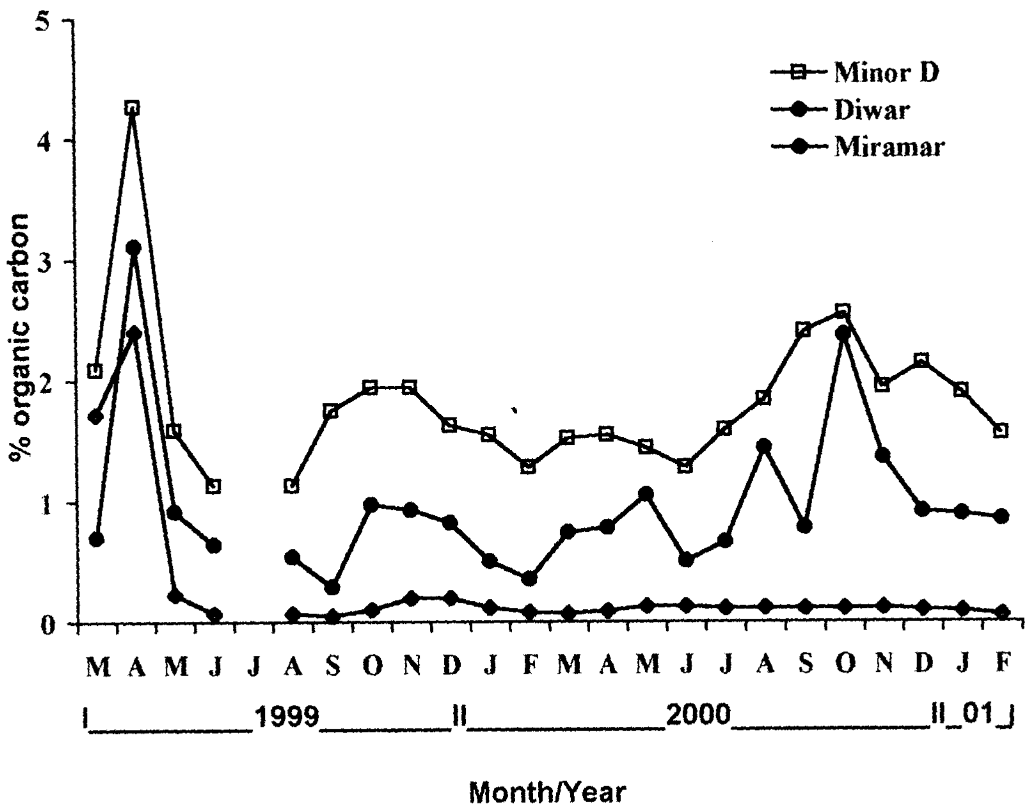




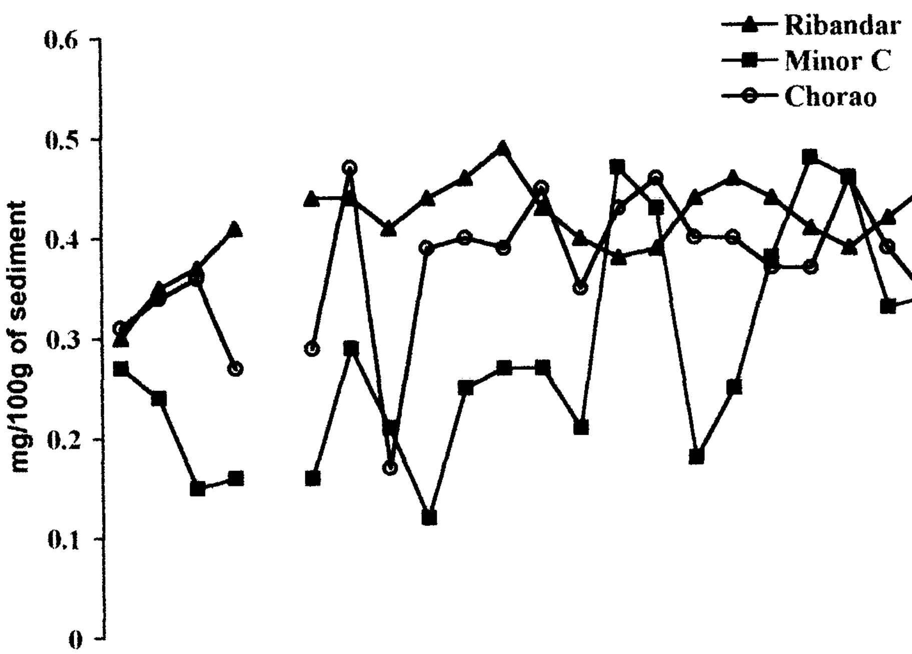
Graph 4.12:

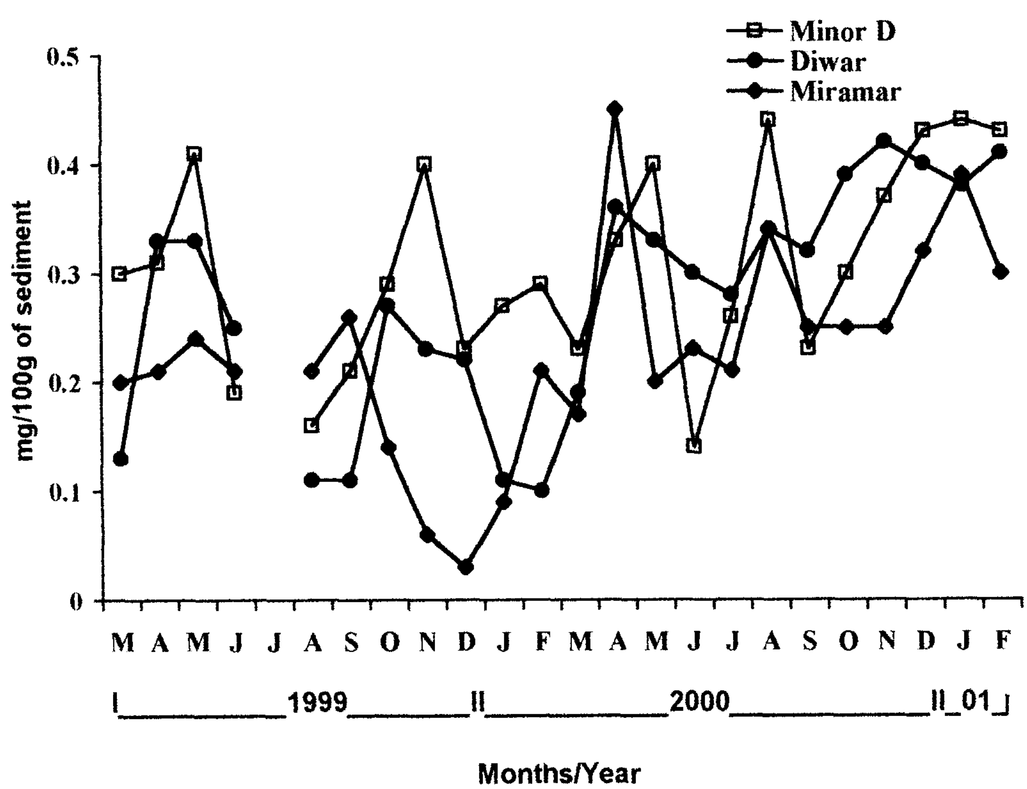
Monthly variations in the percentage of organic carbon present in the sediment of the six sites under study.





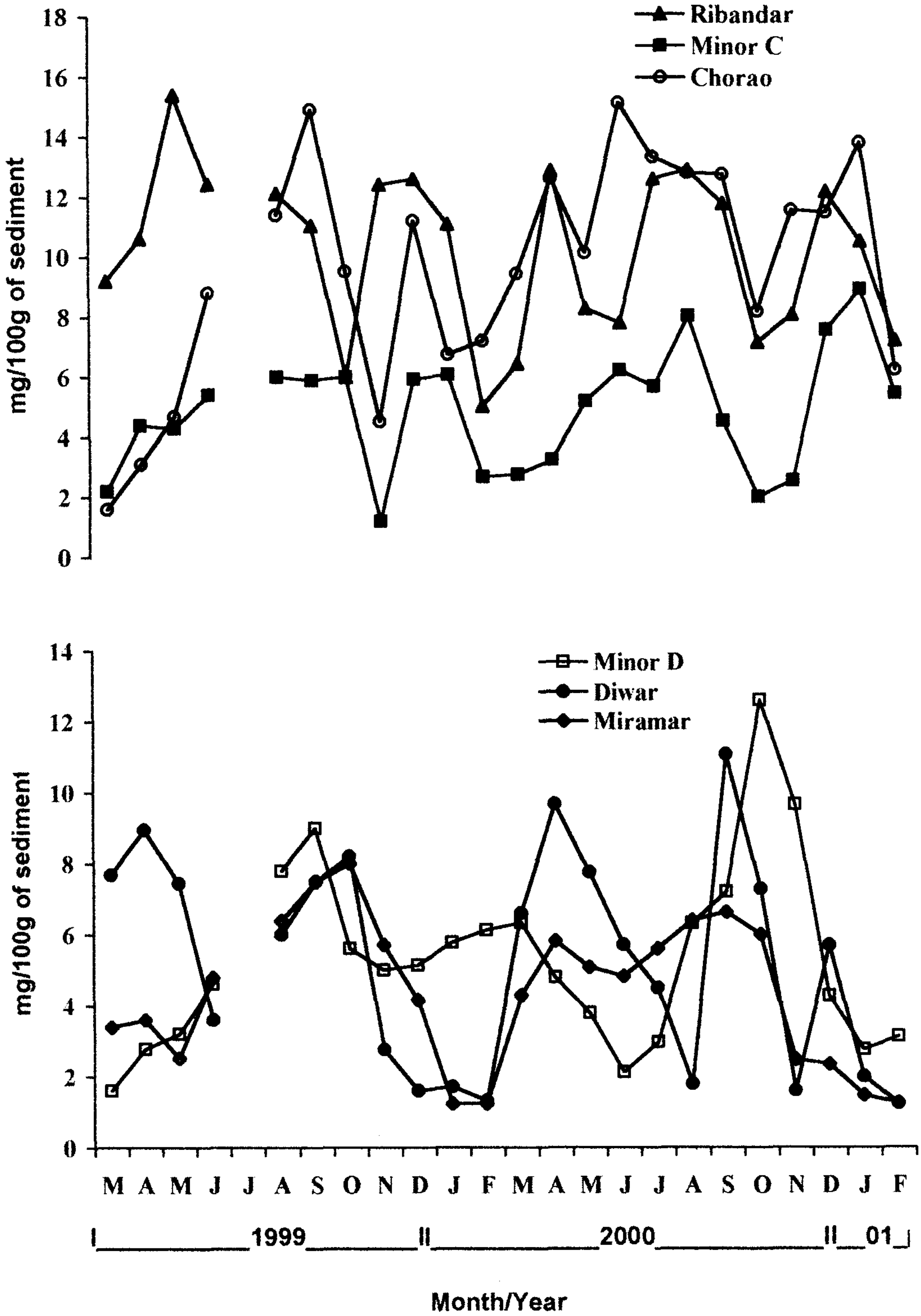
Graph 4.13:
Monthly variations in the nitrate content in the sediment of the six sites under study.





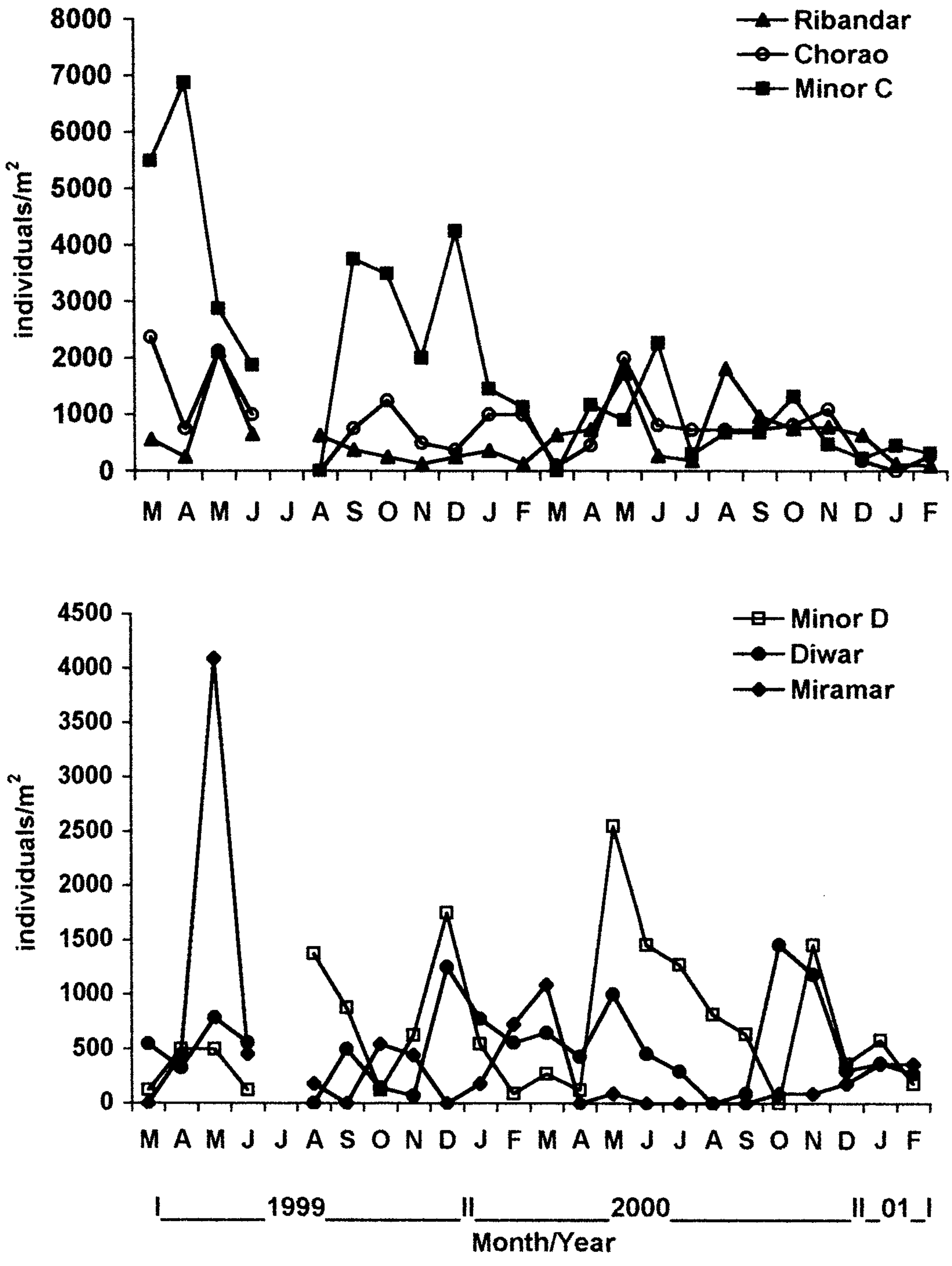
Graph 4.14:

Monthly variations in the phosphate content in the sediment of the six sites under study.

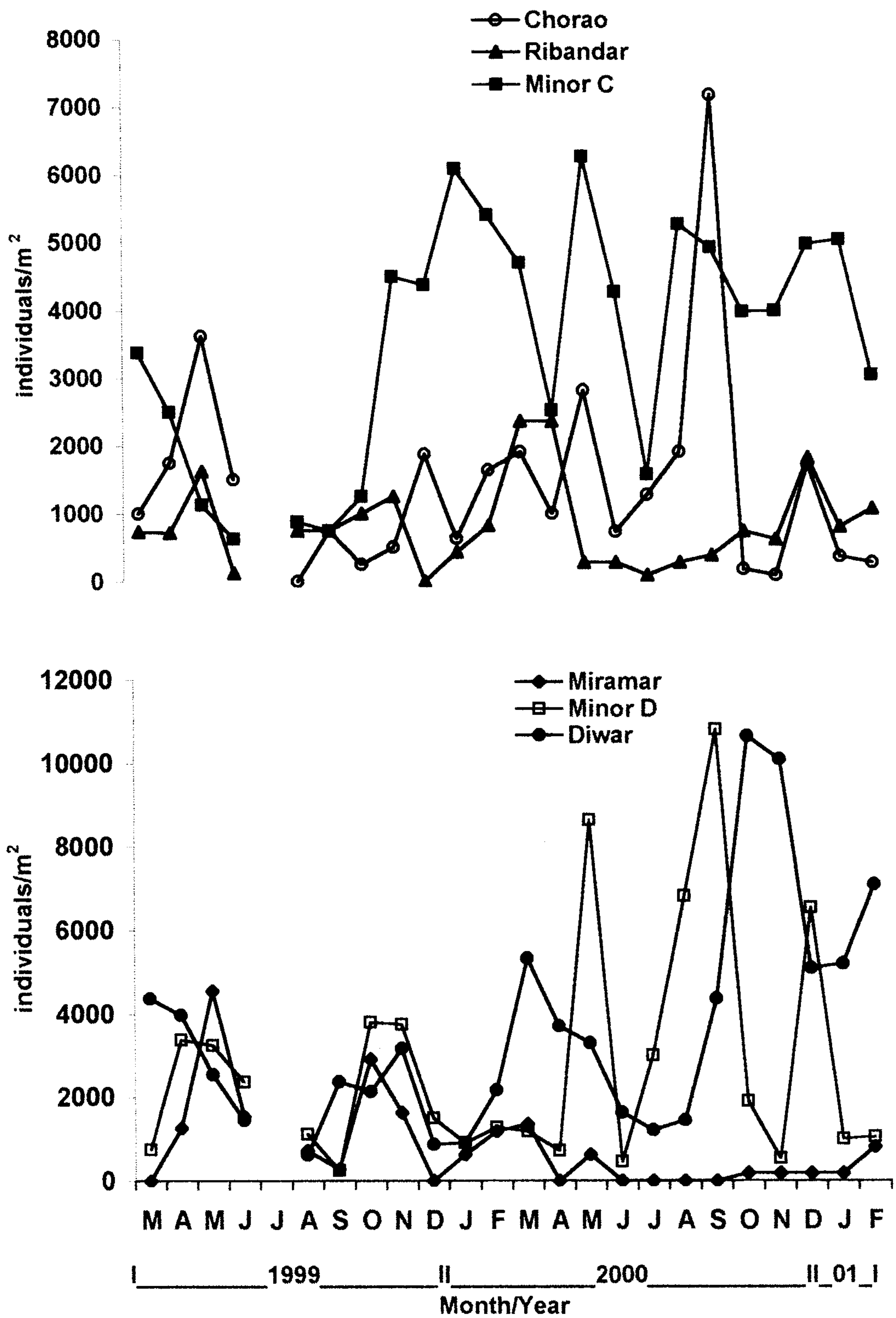


Graph 4.15:

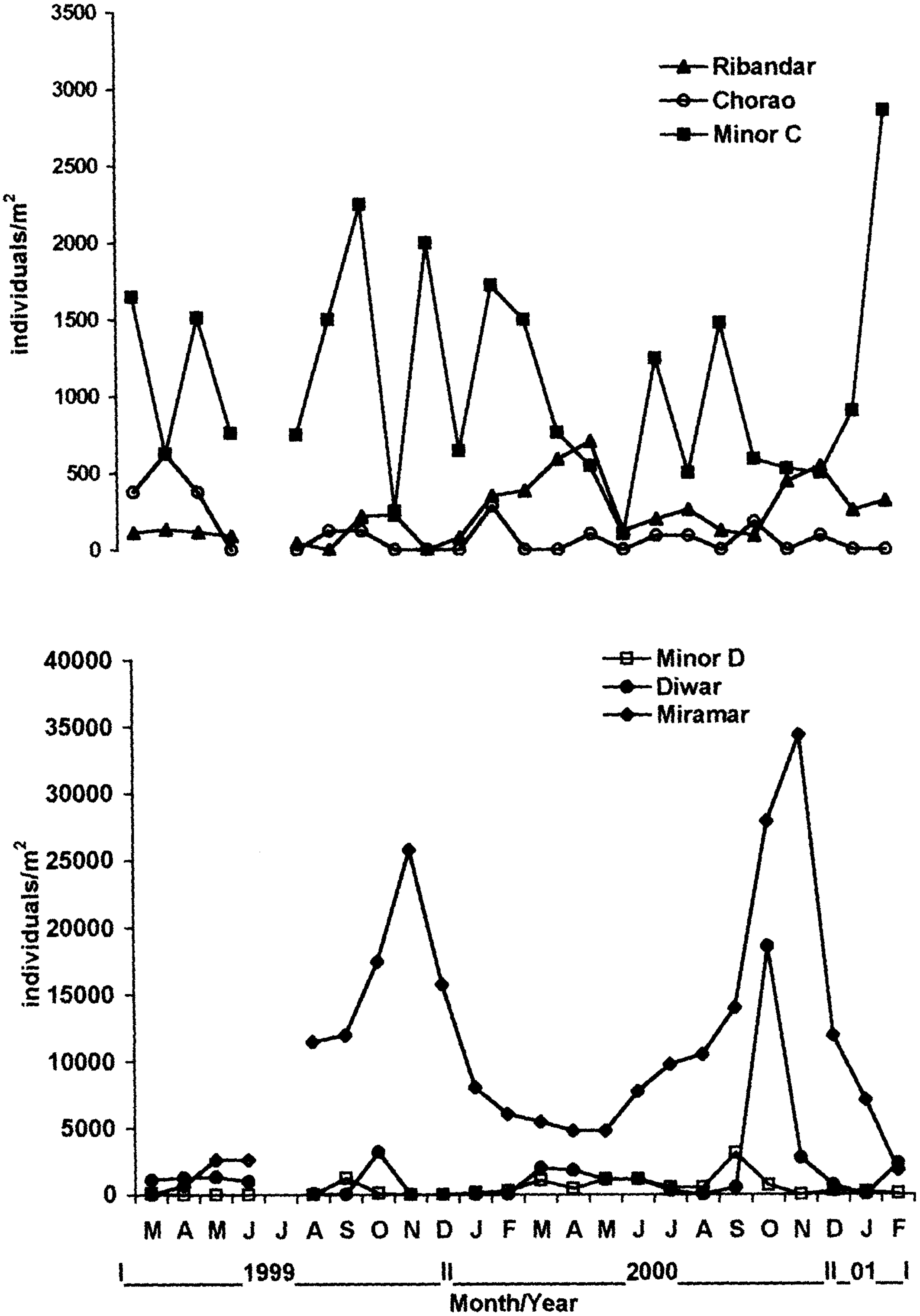
Monthly variations in the density of the nematodes at the six study sites.



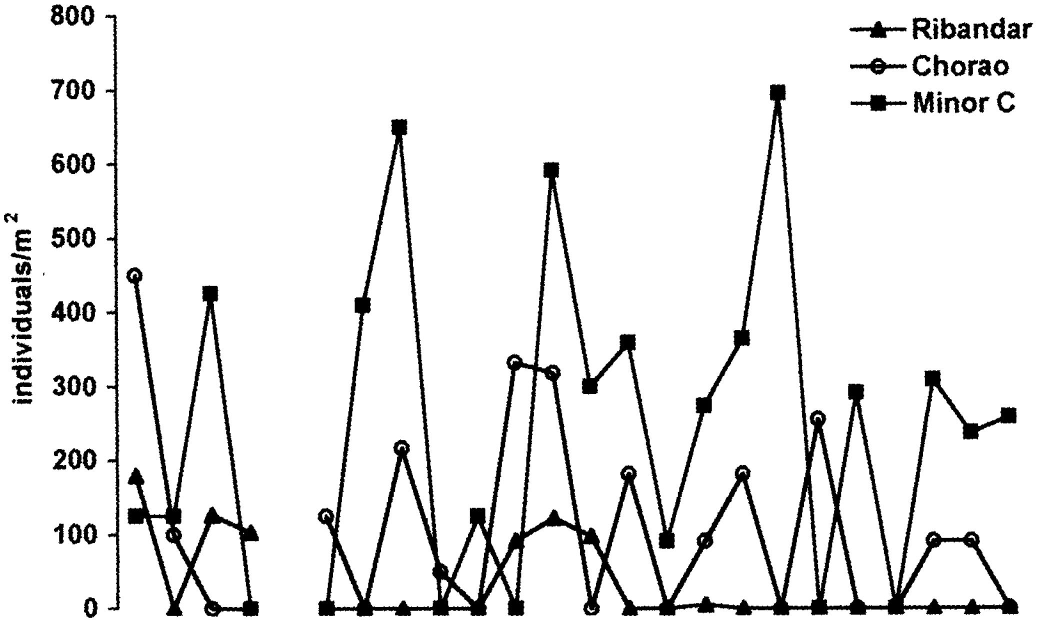
Graph 4.16:
Monthly variations in the density of polychaetes at the six study sites.

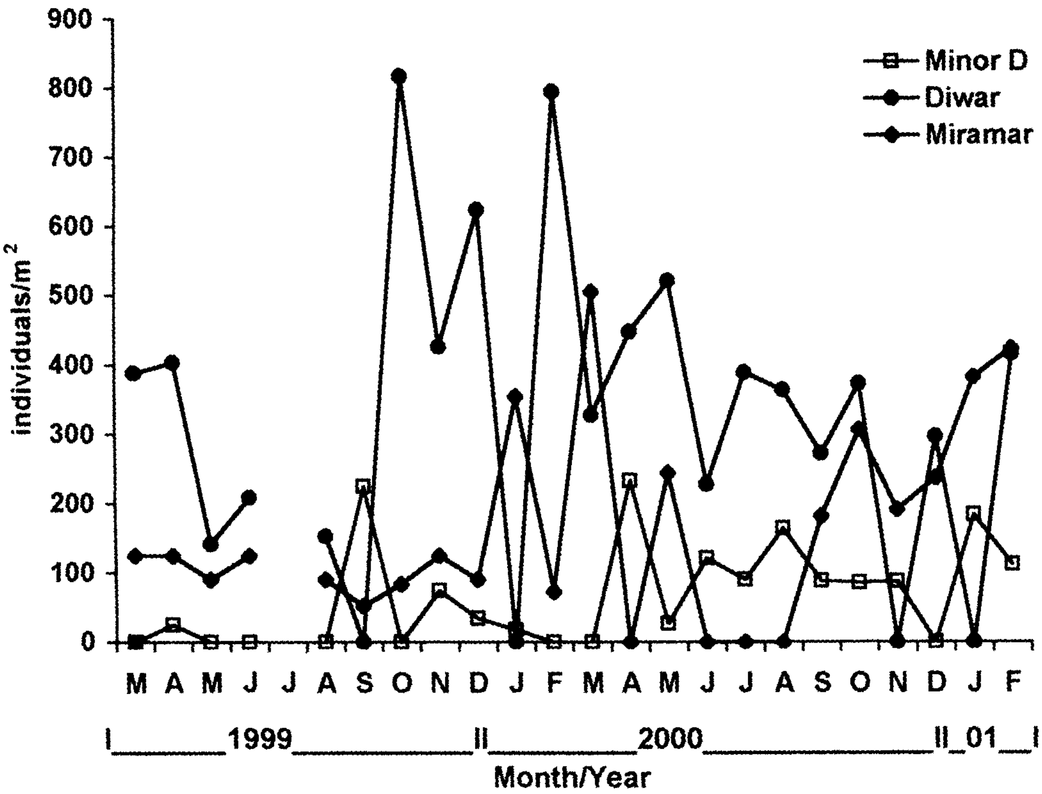


Graph 4.17:
Monthly variations in the density of crustaceans at the six study sites.

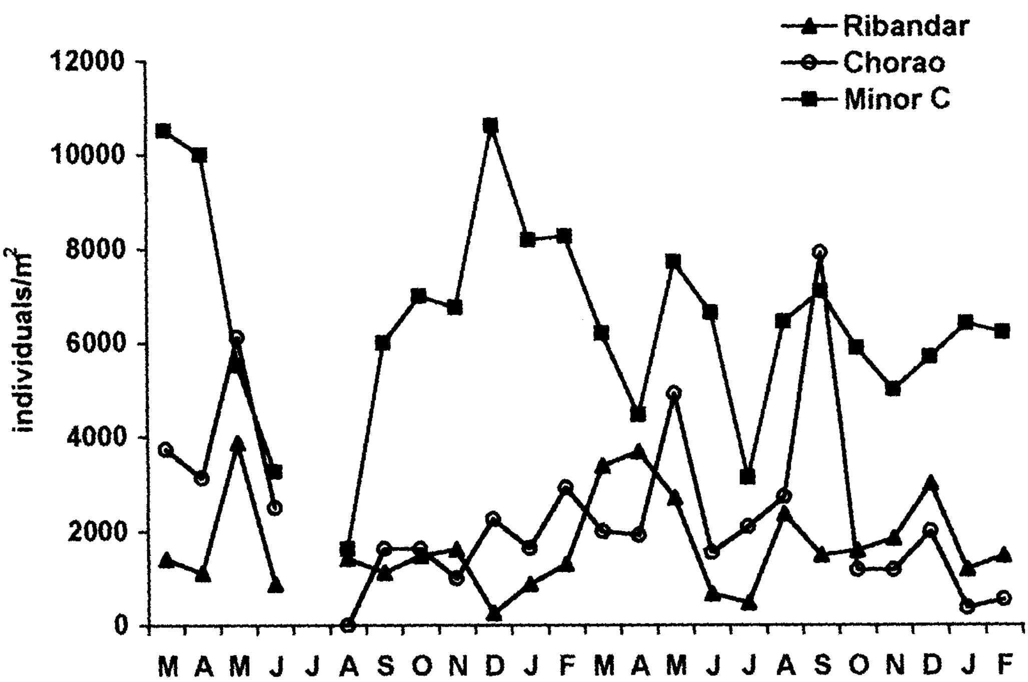


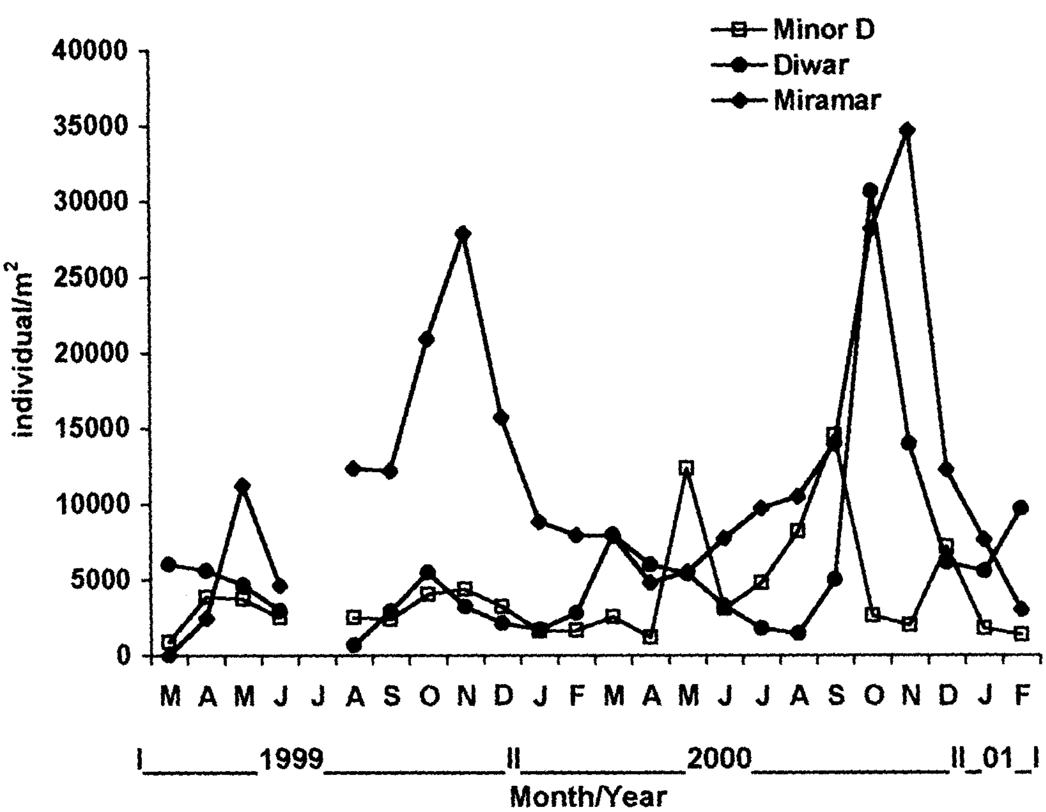
Graph 4.18:
Monthly variations in the density of molluscs at the six study sites.





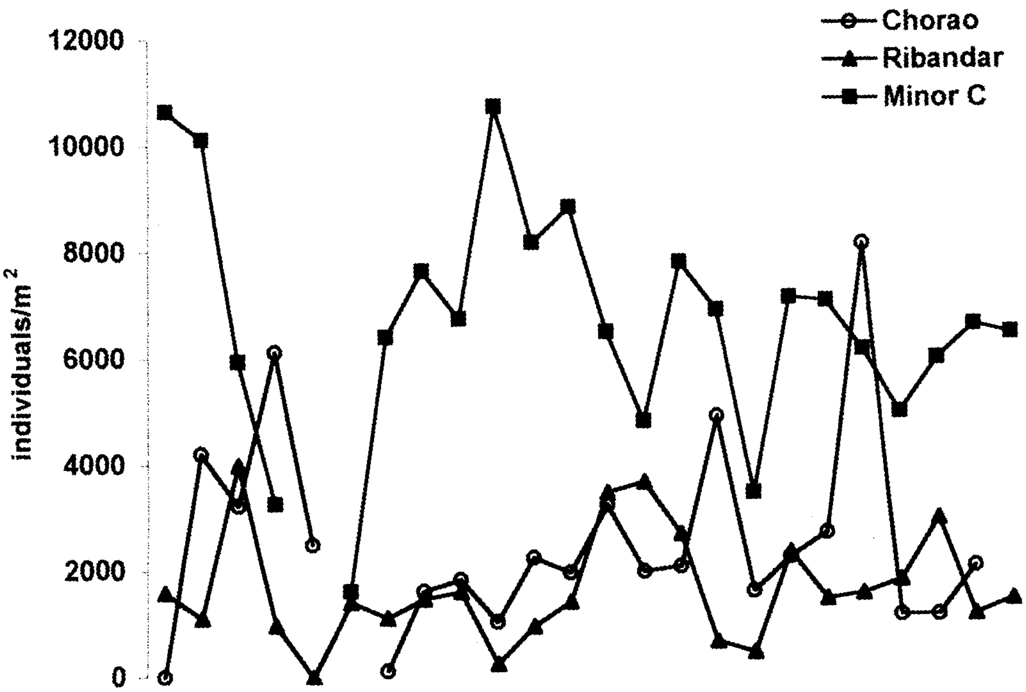
Graph 4.19:
Monthly variations in the density of the soft bodied benthic macroinvertebrates at the six study sites.

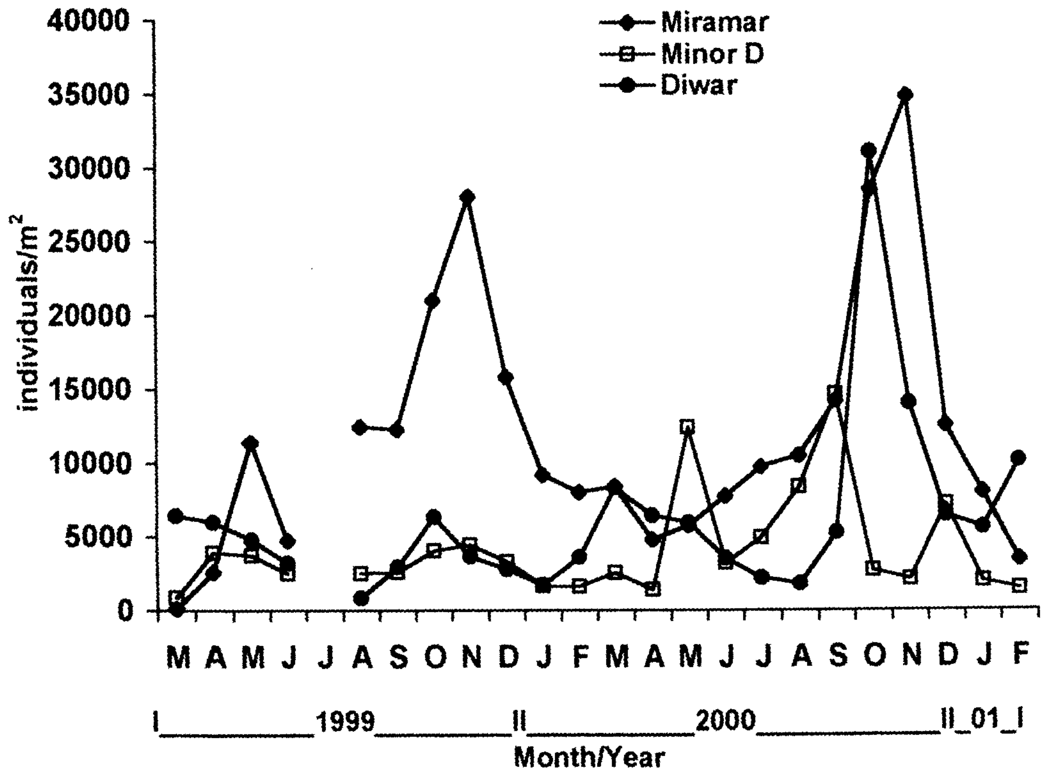




Graph 4.20:

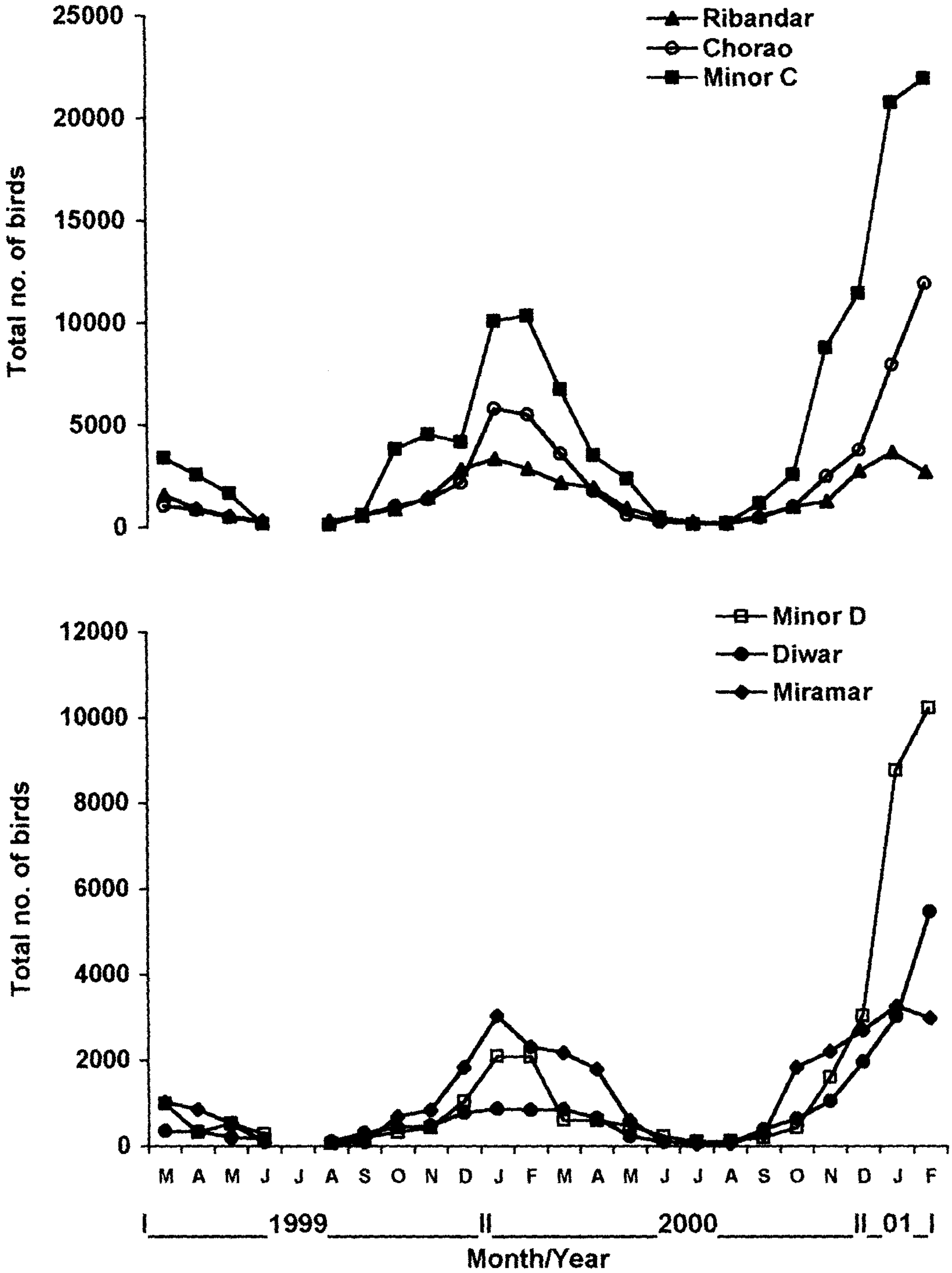
Monthly variations in the density of the total benthic macroinvertebrate fauna at the six study sites.





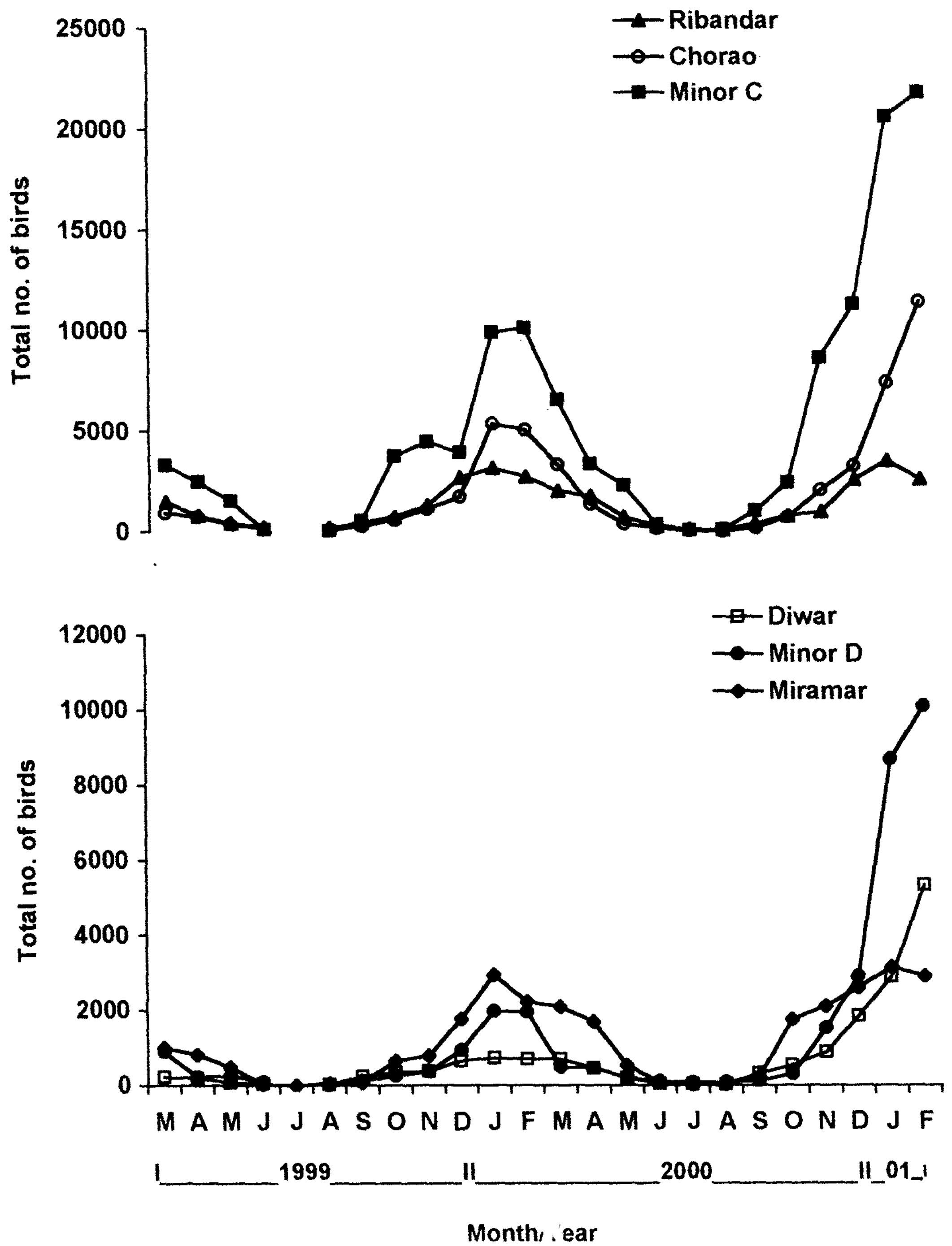
Graph 4.21:

Monthly profile of the population of the avifauna at the six study sites.



Graph 4.22:

Monthly profile of the population of the waterbirds at the six study sites.



Graph 4.23:

Monthly profile of the population of the waders at the six study sites.

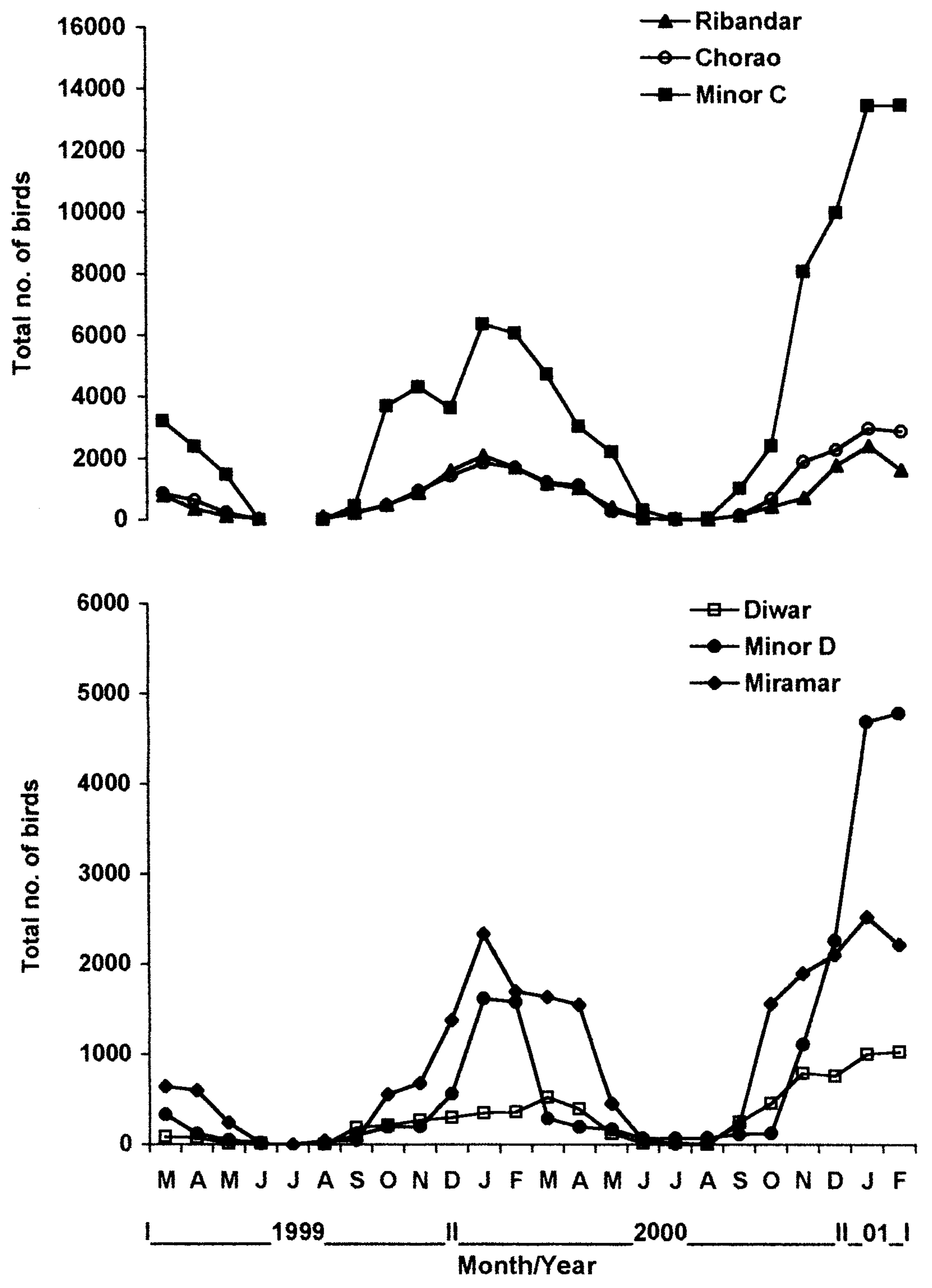


Fig 4.1: Large flocks of Northern Pintails, *Anas acuta*, seen wintering in the estuary. A single flock as seen in this picture at Minor C may be comprised of upto 7000 birds.

Fig. 4.2: The resident ardeids, little egret, *Egretta garzetta* and western reef egret, *E. gularis*, seen feeding in the waters along the Minor C sandflat.

FIG:4·1

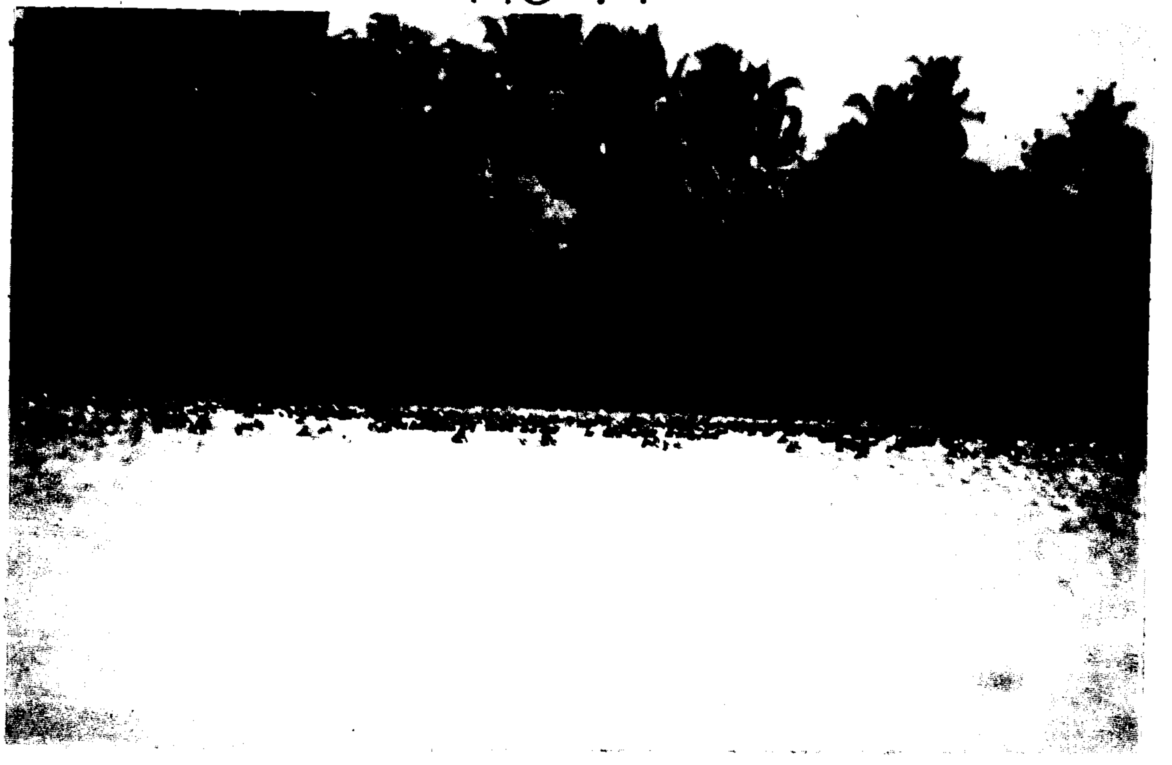


FIG:4·2

Fig 4.3: A few brown headed gulls, *Larus brunnicephalus*, the most dominant amongst gulls in the region, seen perched on the remains of a collapsed bridge near Ribandar. The winter plumage characterized by the brown ear coverts can be noted.

Fig. 4.4: A flock of gull billed terns, *Gelochelidon nilotica*, seen idling on the Minor D mudflat and along with a single large egret, *Casmerodius albus*. A stand of *Rhizophora mucronata* can be seen in the background.

FIG:4·3

FIG:4.4

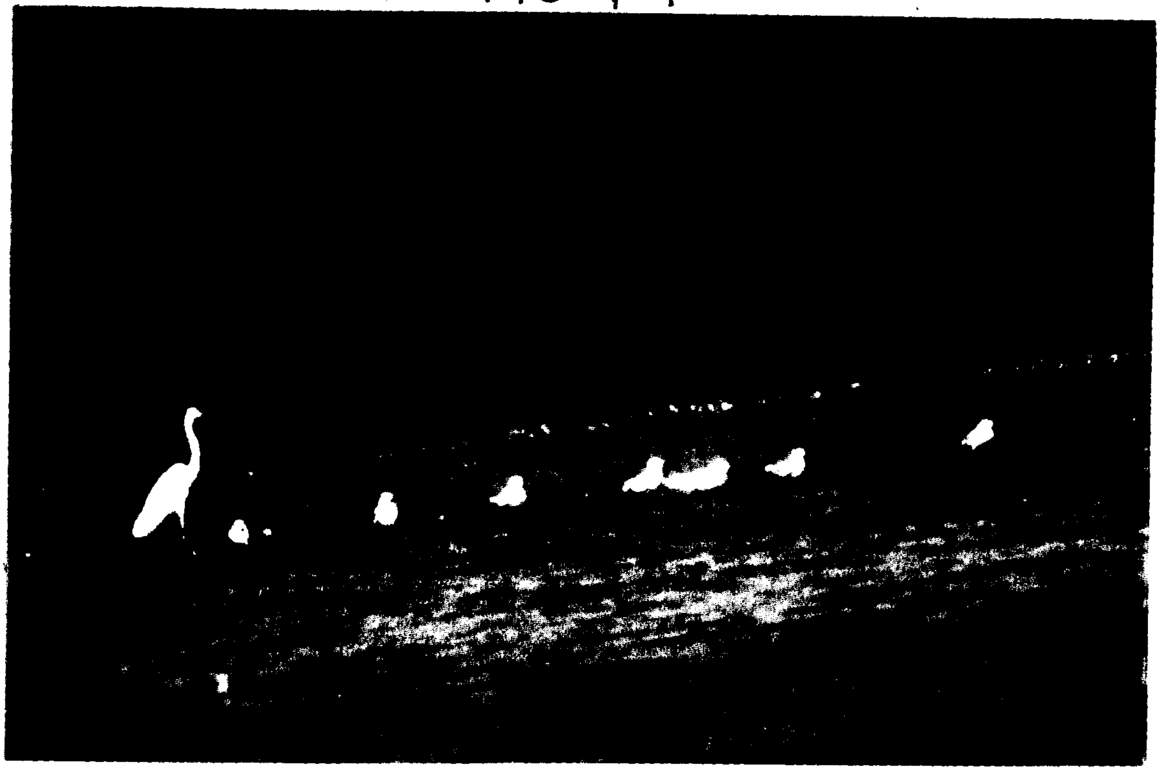


Fig 4.5: A small flock of redshanks, *Tringa totanus*, the most dominant waders visiting the estuary are seen perched on a few dried mangrove twigs in the Dr. Salim Ali Bird Sanctuary at Chorao.

Fig 4.6: A pair of Eurasian curlews, *Numenius arquata*, seen actively foraging in the exposed mudflat of Minor C.

FIG: 4·5

FIG: 4·6

Fig 4.7: A pair of lesser sand plovers, *Charadrius mongolus,* seen foraging on the Chorao mudflat amidst the gastropod *Pontamides cingulatus*.

Fig 4.8: Large flocks of Kentish plovers, *Charadrius alexandrinus*, seen in the intertidal region at Miramar. Only small flocks of the plovers fed at a time while the others remained above the surfline or in the intertidal region.

FIG: 4.7

FIG: 4.8

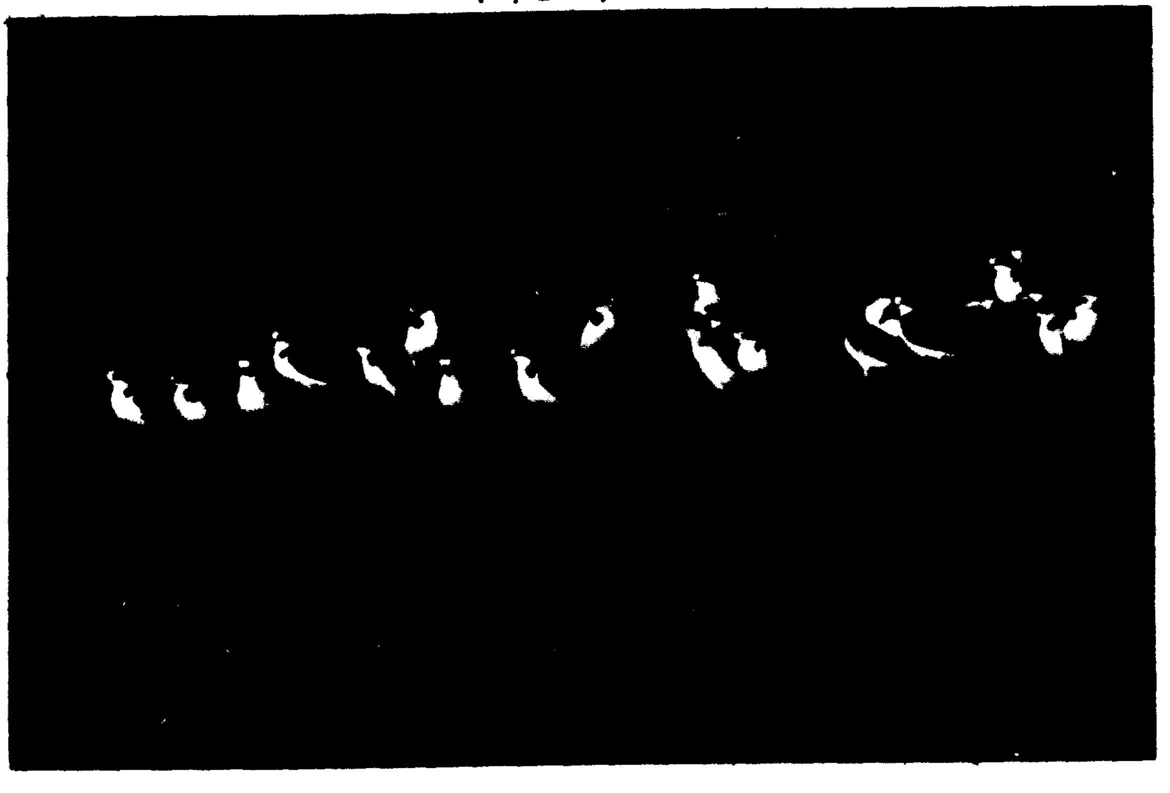
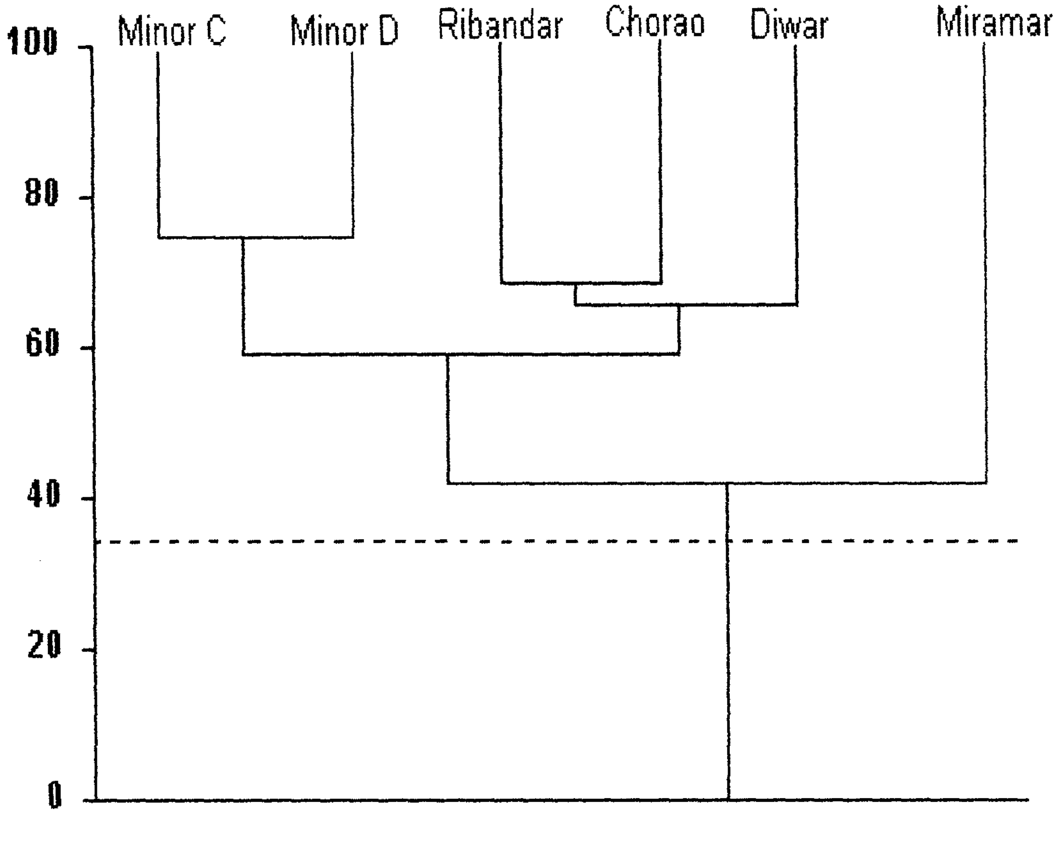


Fig 4.9:
The similarity dendrogram showing the similarity in the avifaunal community of Ribandar, Chorao, Minor C, Minor D, Diwar and Miramar.



Chapter 5:
DISCUSSION

Sediment texture

The sediment texture largely dependent on the relative proportions of 3 of its inert/inactive components, sand, silt and clay naturally is moulded by the interplay of prevailing physical forces such as tidal waves, currents and biotic or abiotic turbations. In the course of present study except for totally sandy sediment of Miramar, a broad dichotomy in the nature of sediment existed at rest of the sites. The sediment at Ribandar and Chorao fell in the category of sandy silt with the predominance of silt, while that at Minor C, Minor D and Diwar was silty sand with the predominance of sand. In the estuarine belts the transport of particles by tidal currents are known to play a crucial role in determining the nature of sediment (Murty *et al.*, 1976). At Ribandar and Chorao which lie in the middle reaches of the estuary, either interrupting projections of ferry boat jetties or extensive mangroves, decelerating the intensity of the tidal currents have further led to increased accretion of sediment along the river edge. This facilitates the settling down of the finer sediment particles of autochthonous as well as allochtonous origin to the river-bed thereby increasing the silt and clay content. Further, the small quantities of organic waste entering these two sites from the adjoining backwaters must be another factor responsible for the higher silt content in their sediment. Although Minor C, Minor D and Diwar were situated not very far from Chorao and Ribandar, unlike the latter contained less silt and clay in their sediment. The continuous ore transporting barge movement through the deeper mid course of the river close to these sites probably produced sufficient currents to dislodge and wash away the lighter sediment particles i.e. clay and silt resulting in a higher percentage of sand in their sediment. The detrivory by the fairly dense population of polychaetes (Leppanen, 1995) at these sites might probably be further reducing the already low silt content therein. Reid (1961) stated that near the mouth of the estuary where predominating forces of the sea build spits, the substrate is conspicuously sandy. Miramar, which lies towards the mouth of the estuary where wave action is high, exemplifies this phenomenon.

The percentage of silt at all the sites was high during post monsoon-early winter and late summer-early monsoon. This can be attributed to the relatively tranquil conditions of the overlying waters resulting in increased sedimentation of the suspended finer particles onto the sediment surface during the seasons.

Temperature

The ambient temperature of all the 6 sites under study varied only marginally between the sites although they are situated within different reaches of the 'mixed' Mandovi estuary. The entire estuary is positioned along a linear course and all the six sites are located within a distance of about 17km from each other. Further, all the sites except Miramar had vegetation comprising of mangroves restricted only to the upper reaches of the mud/sandflats thereby exposing them to the tidal influence. Miramar on the other hand was an open beach with no vegetation in the intertidal region. Hence, all the 6 sites within the estuary had a similar ambience and consequently fairly constant ambient temperatures. Nevertheless, the ambient temperature fluctuated to a tune of 7^0C through the year with temperatures being particularly low in July. The formation of a low-pressure zone over the area as a result of the southwest monsoon coupled with increased wind speed and lesser sunshine together must have contributed to the sharp fall in the ambient temperature during July. This was particularly true in the year 2000, when the region received 2537.9mm of the expected 3000mm rainfall within a very short span of time extending from late June to early July. The temperature oscillations limited to a narrower range at Miramar could be due to its position at the mouth of the estuary. It may be noted that Boaden and Seed (1985) opined that temperature fluctuations are less pronounced near to and at the mouth of the estuary.

Water temperature at all the six sites closely followed the general profile of the ambient temperature with a variation of barely 1^0C. Air temperature is known to greatly influence the temperature of the surface waters (Efford, 1967; Setty *et.*

al., 1984). At all the sites since only a minimal quantity of surface water washed the tidal flat during low tide, led to a decrease in the depth of the water column overlying the mud/sandflat. The continuous mixing of the surface waters owing to the tidal waves might have also facilitated maintenance of the water temperature almost at par with the ambient temperature. A drop in the water temperature by 5^0C during monsoons can thus be explained as a result of a parallel decrease in the ambient temperature during the season. Goswani (1982), while studying the distribution of copepods in the Mandovi-Zuari estuarine complex also noticed a similar seasonal relationship between water temperature and ambient temperature of the shallow coastal zones.

The sediment temperature at all the sites followed a broadly similar pattern as that of ambient temperature and water temperature. The temperature observed at all the sites was at par with that recorded by Ingole and Parulekar (1998) at Siridao in the neighbouring Zuari estuary. The sediment of all the 6 sites remained either partially or totally exposed during low tide. As such the sediment-water-air interface was greatly increased. Wherever the water did persist, the water column was greatly reduced thereby making the sediment directly susceptible to changes in the ambience.

pH

Qasim and Sengupta (1981) opined that during monsoon the Mandovi estuary becomes freshwater dominated owing to heavy precipitation and land runoff, which in turn alters its physical and chemical properties. The pH of the sediment at all the six study sites throughout the study was mildly alkaline within a narrow range of 7.5 to 8.5. However, the alkalinity at Chorao and Ribandar was very mild, almost close to the neutrality, while that at Miramar was the highest, pH being beyond 8.25. The continuous addition of humic and fulvic acids due to the breakdown of organic matter in the form of algae/ mangrove litter must have been the causative factors reducing alkalinity at the former sites. However, at Miramar, which lies towards the mouth of the estuary, a lesser inflow of fresh water and a greater incursion of saline water (Parulekar and Dwivedi, 1974) must be responsible for a significantly higher pH of the sediment. At all the sites pH was least during monsoons. The increased inflow of the freshwater into the estuary, an increased monsoon precipitation and a consequent resupension of the surface sediment into the overlying water must have collectively contributed to a decrease in the pH of all the sites during monsoon. The high temperature and sunshine along with increased evaporation from late winter to summer on the other hand collectively might have contributed to the significantly high pH during this period. A fairly narrow range of oscillations in pH without any drastic/peak changes all through the estuary indicates that none of the five sites in the middle estuary served as a sink for highly alkaline/ acidic waste of either domestic/ industrial origin.

Conductivity

The quantum of trapped ions within the interstitial water imparts the conductivity to the sediment (Nyabakken, 1988) which in turn is influenced by the conductivity of the overlying water, air temperature and precipitation (Ingole & Parulekar, 1998). The quantity of clay present in the sediment is also known to have a direct bearing on the number of ions trapped in it (Vuori, 1995; Parsons and Wilson, 1997). The significantly higher sediment conductivity at Ribandar and Chorao could probably be because of the higher percentage of clay content. Extrapolation of the same logic explains as to why the sediment of Miramar with no clay at all had the least conductivity. The higher temperatures in addition to the autochtonous input of ions into the sediment resulting from the death and decay of plant and animal matter settling to the bottom contributes to the higher conductivity during summer. The drop in the conductivity at all the six sites during late monsoon that continued through post monsoon coincided with a decrease in the temperatures and an increase in precipitation. The rapid wash down of these nutrient ions during monsoon and postmonsoon explains the lower conductivity during that period.

Chlorides

The greater influence of the sea on estuarine sediments considerably alters the physical characteristics of the estuary (Reid 1961, Reseck 1988). Chloride content in the sediment is also dependent on the chlorides in the interstitial water, which in turn is influenced by the tidal invasions of the saline water. Saline incursion during high tide occurs at all the six sites considered for this study (Parulekar, 1973). Hence, understandably the chloride levels in the sediment of all the sites were fairly high. Amongst the sites studied, chloride levels of the sediment were significantly higher at Ribandar and Chorao and lower at Diwar. This could probably be because the sediment of Ribandar and Chorao with greater clay content remained waterlogged for longer period while that of Diwar with higher sand content retained only minimal interstitial water and subsequently smaller amounts of chlorides. This is further augmented by the statistically positive correlation of chlorides with clay, sunshine and temperature. In general, at almost all the sites, chloride levels were significantly high in late winter/early summer and low in monsoon. Teal (1991) opined that clear tranquil waters, higher temperatures and longer days during summer improve conditions for autotrophic activity. The increased autotrophic production and the resultant prolific growth of surface algae concomitant with the death and decay of the underlying algal mat is probably another factor responsible for the increased chloride content in the sediment during late winter and early summer at most of the sites. In monsoon however, increased downstream flow of the river flushes a large amount of the estuarine contents into the sea and hence is probably responsible for the lower chloride levels during monsoon and post monsoon. A similar phenomenon was also reported for the estuary under study by Untawale *et. al.*, way back in 1973. The conversion of the 'well-mixed' estuary into a 'stratified' estuary in monsoon (De

Sousa and Sengupta, 1986) could be yet another reason for the low chloride content during that season.

Alkalinity

Alkalinity is a reflection of the presence or absence of negatively charged ions (Trivedi and Gurdeep Raj, 1992) which further reflects the oxic or reduced condition of the substrate. A reduced state/higher alkalinity is a characteristic feature of intertidal sediments (Ingole and Parulekar, 1998). During the course of this study a significant correlation between total alkalinity and clay content of sediment was noticed, which seems to reflect upon the sediment texture having an influence on its alkalinity. In this background, the higher clay content of the sediment at Ribandar and Chorao must have been successful in holding water long after the ebb tide, in turn enriching the sediment with a larger quantity of negative ions resulting in higher alkalinity. This must have been further augmented by the respiration and other metabolic activities of the sediment fauna as well as the death and decay of the sediment vegetation at these sites. Obviously, the high content of sand coupled with lesser benthic fauna and complete absence of surface algae at Miramar must have collectively contributed to its significantly lower alkalinity. Total alkalinity at all the sites was comparatively higher in summer. The higher temperatures and increased daylength in summer, resulting in rapid evaporation of interstitial water from the mudflats, concentrating the negative ions must have contributed to the increased alkalinity of the sediment during the season. With the onset of monsoon, as a result of increased river flow and episodic flooding, the movement of silt and sand on the riverbed increases turbidity (Hart, 1985). Such mixing of the lighter sediment components with the bottom water releases a considerable load of ions from the sediment into the overlying waters resulting in a subsequent decrease in the total alkalinity. It is pertinent to note in the context that the seasonal flooding is reported to be a major ecological event in terms of ion release in the flood plains of the Pongola river (Heeg *et. al.*, 1980).

Sulphates

The sulphates in the sediment remain bound to clay and hence their desorption and leaching from it is known to help replenish the sediment sulphur pool (Das, 1995). Therefore the significantly high sulphate levels in the sediment of Chorao and Ribandar is understandable in view of the high clay content as the stores compared to those of other sites. On the other hand the incorporation of sulphates into proteins by sediment algae is considered to be an important phenomenon responsible to reduce their levels in the sediment (Odum, 1971). Hence, higher incidence of sediment algae and the lower concentration of clay in the sediment at the remaining study sites must have collectively contributed to the lower sulphate levels although the sites were in the close vicinity of Chorao. By the same token, a complete absence of clay at Miramar explains the low concentration of sulphates in its sediment. A similar concentration of sulphates in the sediment as that recorded in the present study was reported from the Mandovi estuary in 1981 (Qasim and Sengupta). This rather stable concentration of sulphates over a period of 20 years goes a long way to imply that pollution in the estuary, if at all present, is still under control as sulphur levels are known to indicate the pollution status of the locales. In general, at all the 6 sites the sulphate content remained fairly high in early winter. The increased mixing of the sediment with the overlying waters containing sulphates of terrigenous origin accumulating in the sediment through late post monsoon and early winter, must have further enhanced the sulphate pool in the sediment during this period. Brinkmann and Santos (1974) in the course of his study of the hydrogen sulphate emmission from the Amazonian floodplain lakes showed that continuous disturbances cause leeching of sulphates from the sediment into the overlying waters. Therefore, the turbulence in the surface sediment due to continuous disturbances owing to the movement of ore transporting barges close to Diwar explains the low sulphate concentration at the site.

Sediment Nutrients

Organic Carbon

The nutrient status of the sediment depends upon the amount of organic matter laid down into it (Wilson *et. al.*, 1993) which in turn depends on the disturbances in the overlying waters (Mortimer *et. al.*, 1998). The sediment of Ribandar and Chorao contained the highest percentage of organic carbon while that at Miramar contained the least. The input of organic matter resulting from the biological oxidation of plant and animal matter from the adjoining mangrove forests at Chorao and backwaters at Ribandar probably played an important role in increasing the organic carbon in the sediment. Clay in particular has been recorded to have a greater affinity to organic carbon which also serves as a store for organic carbon that is generated in the overlying waters (Oades, 1989; Nelson *et. al.*, 1990; Algarswamy 1991; Agarwal *et. al.*, 1993). The significant correlation's observed between organic carbon and the fine grain sediment particles during the present study are in accordance with these generalizations. Benthic detritivores particularly nematodes and polychaetes play an important role in depleting the organic carbon from the sediment by their extensive foraging and bioturbation, resultant of their vertical burrowing and horizontal scavenging movements (Mc Call, 1979; Cheng, 1995). Thus, the concentration of organic carbon in the sediment is under the cohesive control of a multitude of factors. The comparatively higher percentage of silt and lower density of detritivore benthic fauna at Ribandar and Chorao together with the minimal currents explain the higher percentage of organic carbon in the sediment. A comparatively lower clay content and a more densely populated polychaete and nematode fauna at Minor C, Minor D and Diwar and the complete absence of clay and sparsity of polychaetes at Miramar must have collectively contributed to the lower percentage of organic carbon at these sites. Organic carbon at all the sites was significantly high in summer and winter. During summer and winter, longer days and clear waters increase primary production such that the rate of organic carbon production far exceeds the rate of its decomposition This results in an accumulation of organic carbon in the sediment, accounting for its higher percentage during summer and winter. The abnormally high percentage of organic carbon in April 1999, at all the sites was probably a result of the pruning of mangrove plants and the dumping of the foliage along the upper reaches of the estuary as well as the organically rich residual matter let off from the shrimp farms located upstream along the river's course.

According to Folger (1969), organic carbon levels greater than 5% are charecteristic of a polluted estuary. During the present study the percentage of organic carbon at all the sites was well within the normal limits ranging from 0.28% to 3.37 %. However, the steep increase in the percentage organic carbon at Chorao in summer 1999 dropped drastically during the succeeding season restoring normalcy without pushing the site in the pollution range.

Phosphates

Phosphate-phosphorus in the sediment was significantly high at Chorao and Ribandar and lowest at Miramar. Sediment acts as a reservoir of phosphate-phosphorus (Shankaranarayanan and Punampannayil, 1979). The replenishment of phosphates into the sediment by adsorption at the sediment-water interface (Pomeroy *et. al.*, 1965) depends upon the clay content of the sediment (Jitts 1959; Hartner 1968; Li *et. al.*, 1972; Golterman, 1973; Nduku 1976; Egborge 1981). Phosphorus retention in the sediment has been reported to be best at pH 4 and least at pH 10 (Rajagopal and Reddy 1984). Thus, it is evident why Ribandar and Chorao, the sites with a higher percentage of clay and lesser pH have the highest phosphate-phosphorous reserves while Miramar, the site with the highest pH and no clay at all had the least phosphate-phosphorous concentration. The higher incidence of sediment flora that utilise phosphates during photosynthesis could be yet another reason for the lower phosphate levels at Minor C as compared to Minor D and Diwar. At all the sites phosphorous levels were high in monsoon. This is probably because of a large amount of colloidal soil humates and other humic substances in the form of fertilisers getting washed down into the estuary and settling on the bed.

Nitrates

The sediments of Ribandar and Chorao had relatively higher concentrations of nitrates while that of Miramar had the least. Intertidal mudflats are known to serve as sinks for nitrate-nitrogen (Mortimer *et. al.*, 1998, Uncles *et. al.*, 1998), the concentration of which, is positively influenced by organic matter (Barnes and Owens, 1998) and clay (Nasnolkar *et. al.,* 1996). Ridd (1996) was of the opinion that the burrows of crabs and other organisms in a mangrove swamp form a labyrinth of interconnected tubes which possibly provide an extremely efficient pathway for the transfer of nutrients from the water along the swamp bed. Thus, it is self explanatory as to why the sediment of Ribandar and Chorao with a higher silt and clay content than other sites had a higher concentration of nitrate-nitrogen while that of Miramar with only traces of silt and practically no clay had the least. The adsorption of nitrates into the sediment is said to depend upon 3 factors namely soil properties, its vegetation and the climate (Holmes *et. al.*, 1980; Teal 1991). The comparatively lower silt and clay content at Minor C and the utilisation of nitrates by the sediment algae during autotrophic production might have collectively contributed to their lower content in the sediment at Minor C, as compared to Minor D and Diwar. At all the sites the nitrate levels were relatively higher in winter. The large amounts of nitrate -nitrogen entering the estuary through monsoon wash-down must be remaining suspended in a colloidal form within the water column owing to turbulence (Oldam and Larery, 1999). It probably settled to the bottom only after cessation of turbulence in winter.

Benthos

Flora

The physical nature of the sediment and the transparency of the overlying water column are the most important factors that influence the sediment biota (Ngan, 1979). The sediment of all the sites except Miramar harboured varying amounts of sediment vegetation. Heavy sediments, less prone to displacement during wind and turbulence are said to provide a better habitat for sediment flora particularly algae (Ngan and Price, 1980). Another decisive factor affecting the sediment flora is the availability of nutrients in the surface sediment. Underwood and Jernakoff (1981) showed that regular grazing by the intertidal gastropod *Siphonaria denticulata* enhances the growth and proliferation of surface algae at New South Wales. A similar hypothesis to this regard was proposed by Paine almost a decade and a half earlier in the year 1966. All this reasoning put together explains the presence of the sediment flora in the mud/sandflats of the middle estuary and the absence of the same at Miramar. The higher incidence of *Enteromorpha flexuosa* and *Halophila beckerri* at Minor C can thus be attributed to the following 3 reasons 1) higher content of sand and silt but lower levels of clay in the sediment 2) higher concentration of nutrients 3) presence of large populations of herbivorous amphipods like *Corophium triaenonyx, Apseudes chilkensis*, and birds particularly Northern Pintails which fed on the sediment surface algae.

Haukos and Smith (1996), emphasized the role of sediment flora in improving benthic diversity. Thus, it is not surprising that the greater incidence of sediment flora at Minor C as compared to other sites, also supported the maximum number of benthic macroinvertebrates. The extensive vegetative mat formed by the intermingling of *Enteromorpha flexuosa, Dicotomosiphon* *salinas* and *Halophila beckerri* formed on the sediment surface probably provided diverse niches for a large number of benthic communities besides providing them with the adequate nutritional requirements.

Fauna

Suresh *et al.* (1992), opined that the maximum benthic density and diversity occurred in sandy sediments. During the present study however it was observed that silty-sands of Minor C, Minor D and Diwar harboured better benthic invertebrates both in terms of density and diversity rather than the sandy sediment of Miramar. This can be attributed to the appropriate abiotic environment provided by the sediment therein, with a right combination of silt and sand. This in turn must be possible due to the enhanced productivity of the sediment, owing to the higher nutrient potential of the silt and the increased provision of varied niches by the silty sand. The sediments of Minor C and Minor D were subject to less turbulence as the sites were located in the upper reaches of the estuary which in turn provided stable habitat for the surface dwellers. Relatively good drainage of these sediments owing to the presence of sand prevented the water from stagnating in the burrows of the burrowing forms.

The role of sediment texture as the decisive factor controlling benthic communities has been well documented (Parulekar, 1973; Parulekar and Dwivedi, 1974; Harkantra, 1975; Harkantra, 1982; Ramchandra *et. al.*, 1984; Ansari *et. al.,* 1986b; Jones *et. al.,* 1986, Vizakat, 1991; Prabhu *et. al.*, 1993). Studies in the past have shown that benthic polychaetes prefer muddy sediment rather than sandy and clayey type (Reish, 1963; Reish, 1979; Harkantra and Parulekar, 1981). The direct influence of sediment organic matter on benthic invertebrates particularly polychaetes has also been widely reported (Ansari and Gauns, 1996). During the present study also a strong positive correlation was observed between the density of benthic macroinvertebrates particularly polychaetes and the organic carbon content of the sediment at Minor C, Minor D and Diwar. The highest diversity and density of benthic forms especially polychaetes at Minor C can be attributed to its relatively softer sediment, probably facilitating the burrowing ability of polychaetes and nematodes. The higher content of sand and comparatively lesser organic carbon in the sediment of Minor D and Diwar as compared to that of Minor C must be responsible for the smaller populations of benthic invertebrates particularly polychaetes at these sites. On the other hand, at Chorao and Ribandar the high organic matter did not sustain a high density and diversity of benthic macroinvertebrate. The most succinct reason for this unusual phenomenon could be the higher percentage of clay, creating anoxic and unstable substrate conditions at these sites.

Silty sediments have been shown to sustain flourishing populations of deposit feeders (Peterson, 1979; Ansari and Parulekar, 1998). Therefore, the presence of maldanids, nerieds and spionids in good numbers in the sediment of Minor C, Minor D and Diwar is only but natural in view of the detritivore feeding habit of the groups and the good amount of silt in the sediment at the sites. On the other hand the poor representation of these polychaete population at Miramar is also obvious in view of near total lack of silt in its sandy sediment. However, the occurrence of carnivorous polychaetes like *Glycera alba* at all the six sites under study amounts to indicate that their raptorial needs are met at all the sites.

Among the sites, Miramar harboured a significantly largest and most diverse crustacean community while it was very sparse at Ribandar and Chorao. The greater dominance of crustaceans at Miramar and Diwar can be attributed to the higher percentage of sand in the sediment of these 2 sites. Crustaceans, being filter feeders used Diwar and Miramar more extensively as compared to other sites probably owing to the clear waters facilitating filter feeding. The occurrence of the sand crab *Dotilla myctroides* on the surface of the sandy sediment of Miramar can also be explained by its filter feeding mode of foraging in addition to the totally sandy sediment of Miramar facilitating easy locomotion. The exceptionally high population of mysids encountered at Miramar during monsoons could be due to reproduction of the groups coinciding with the season (Achutancutty and Nair 1982; Pechenik, 1987). Finer interstitial spaces and compact configuration imparted to the sediment by the larger sand component, as encountered at Miramar is presumed to be facilitative for smaller and slender fauna (Rodrigues *et. al.*, 1982). Further, limited agility of minute bodied truly aquatic mysids in the sediment-water interface leading to their large aggregations getting stranded in the surf zone cannot be ruled out. On the other hand the considerable amount of clay present in the sediment of Ribandar and Chorao probably interfering with filter feeding of crustaceans led to their lesser representation at these sites. The sporadically encountered fairly dense population of *C. triaenonyx, A. chilkensis* at Minor C, Minor D, Diwar, Ribandar and Chorao may be due to the presence of extensive surface vegetation with which these amphipods are closely associated.

Molluscs in general have been reported to prefer sandy sediments because of their filter-feeding mode of foraging. Ramchandra *et. al.* (1984), observed that among the molluscs gastropods prefer sandy sediments containing some quantity of mud in it, while bivalves prefer increasingly sandy sediments. During the present study also, gastropods particularly *Pontamides cingulatus* were found to inhabit Diwar, Minor D, Minor C, Chorao and Ribandar, the sites with varying amounts of silt in the sediment. On the other hand the density of bivalves was the highest at Miramar followed only by Diwar, the sites with increased sand content.

At all the six sites the density of benthic macroinvertebrates showed extremely wide oscillations through the study period. Similar wide oscillations in polychaete densities were reported earlier in the macrobenthic fauna in the near shore sediment off Gangolli (Prabhu *et. al.,* 1993), another site down south, along the West Coast of India. The high density of all the benthic invertebrate groups during late summer and early monsoon and during late post monsoon/early winter was probably because of the higher organic matter in the sediment, an after effect of increased productivity of the overlying waters. The increase in the surface algae provides substantial detritus for the benthic detritivores during this period. The sharp drop in the populations of all the four major groups of benthic macroinvertebrates during the peak monsoon may be a consequence of an unstable substratum and diminishing food supplies owing to rapid currents and riverine wash down. The conversion of the otherwise 'well-mixed' estuary into a 'stratified' type thereby changing the physico-chemical nature of the substratum could be yet another reason for the decrease in the density of the sediment biota during monsoons.

The use of benthic organisms particularly polychaetes and nematodes as indicators of a polluted environment have been elucidated by many biologists (Bryan *et. al.,* 1985; Adams, 1987; Bryan and Gibbs, 1987; Foster *et. al.,* 1987; Bryan and Langston, 1992; Bendell-Young *et. al.*, 2000). Benthic detritivores have been considered highly effective as pollution indicators because these organisms are expected to be the most responsive to changes in their substratum, the place where pollutants accumulate (Reish, 1979; Brown *et. al.*, 2000). Increase in the density of a few sturdy species at the cost of the others or succession by some new species not existing in a region before the onset of a polluted state are believed to be tell-tale signs of pollution (Jhingran *et. al.,* 1989). In the late seventies, 3 schools of benthic study, simultaneously inferred that polychaetes tend to be the first macro- benthic forms to inhabit the stressed region of a pollution gradient (Gray, 1976; Pearson and Rosenberg, 1976; James and Gibson, 1980). Ansari *et. al.* (1986 a), showed a positive corelation between the density of benthic macro-invertebrates and the concentration of organic nutrient occuring out of trawler washings and dumping of fish waste. However Rodrigues *et. al.* (1982) observed a decrease in the benthic polychaete density when the concentration of organic carbon exceeded 4%. Interestingly, as mentioned earlier, organic carbon levels only above 5% indicate pollution as such none of the sites studied qualified as polluted. Hence utmost caution need be excersised while ascribing the pollution status to any waterbody/ wetland based merely on the presence or absence of the 'indicator species'. At this instance it is pertinent to note that the densities of all benthic forms including the 'indicator species' are regulated by a delicate interplay of biotic and abiotic factors (Ramchandra *et. al.* 1984; Vodopich and Cowell, 1984). It need also be noted that presently the very concept of indicator species has come under storm (Saiz Salinas and Zubillaga, 1997)

Avifauna

According to the globally accepted definition as adopted at the Ramsar Convention (1971) wetlands are "areas of marsh, fen or peat, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh brackish or salt including marine water, depth of which at low low tides does not exceed 6 m". Since the presence of shallow water is an important prerequisite of wetland, tropical estuarine mudflats have been ascribed the status of wetlands playing an important role towards the maintainence of the rich biodiversity of the region (Parish, 1987). All the 6 sites covered under the present study fall in the category of wetlands in the tropical Mandovi Estuary. Estuaries have been described as ecotones between freshwater and marine habitat (Day, 1981) while wetlands have been defined as lands of transition between terrestrial and aquatic systems wherein the land is covered by shallow water (Cowardin *et al.*, 1979). Therefore, these unique estuarine wetlands at the confluence of 3 types of ecosystems naturally harbour organisms belonging to varied habitats. In view of the above facts and presence of dense mangroves fringing the Mandovi estuarine mud/sandflats it is not surprising that almost all the sites harboured atleast some terrestrial bird fauna. Vijayan (1986) while reviewing the subject categorized wetland birds as completely dependent on wetlands, less dependent and opportunistic users. The few terrestrial birds sighted at most of the sites studied can be relegated to the second category. Oswin (1999) recorded 64 species of terrestrial birds at the Muthupet mangrove forests while Jayson (2001) encountered 31 species in the Mangalavanam mangroves of Kerala. During the present study also, the number of terrestrial bird species sighted ranged from 11 at Minor C to 59 at Chorao. Both Chorao and Diwar had dense mangroves and were in the close vicinity of inhabitation. Hence the more extensive canopy provided by the mangrove vegetation and the alternative food source in the form of orchards and floral gardens at near quarters probably paved way for a better diversity of terrestrial birds therein. On the other hand Minor C and Minor D were situated in the middle of the river totally isolated from habitation, Ribandar had very limited mangrove vegetation and Miramar was an open beach, which explains the lesser terrestrial bird fauna at these sites. Although the diversity of terrestrial birds was relatively high in regions with denser and more expansive mangroves, in terms of population it was well below 25% at all the sites. This indicates that the population density of terrestrial birds in a wetland depends largely on the proximity of habitation/deciduous forests, which provide the birds with essential food resources.

Tropical estuarine wetlands with a rich invertebrate fauna have been reported to serve as ideal habitats for a large number of resident as well as migrant waterbirds (Moreira, 1997). The migrant shorebirds in particular use these invertebrate rich regions as foraging grounds (Taylor *et. al.,* 1993) besides using them as stopover points during migration (Davis and Smith, 1998). Although the above statements are based on studies conducted in Europe, America and the fareast, it is natural that the tropical wetlands of the Mandovi estuary could also harbour substantially high populations of waterbirds. This was particularly true of Minor C which harboured a biannual cumulative total population of 1,19, 046 waterbirds belonging to 70 taxa.

Feeding is one of the major activities of wintering waterfowl (Fasola and Biddau, 1997, Hurtado *et. al.*, 1997). The type and rate of food intake in aquatic birds is known to vary with prey availability (Solis *et. al,* 1996), time of the day (McNeil *et. al.,* 1995), migratory status (Halse *et. al.,* 1996) and age (McKilligan, 1990). Accordingly non breeding waterfowl due to their low energy requirements are reported to feed mainly on aquatic plants while the breeding waterfowl, young ones and the birds preparing to migrate feed largely on a protein rich invertebrate diet owing to their high energy requirements (Swanson *et. al.*, 1979; Tamisier and Boudouresque, 1994). Many avian biologists have shown a direct correlation between different species of migrant shorebirds and their invertebrate prey (Goss Custard, 1980; Zwarts *et. al.,* 1990; Mercier and McNiel, 1994; Thibault and McNeil, 1995; Botto *et. al.,* 1998; Beukema *et. al.,* 2000). During the present study also a significant positive correlation was observed between the waders and the soft bodied benthic forms. Since the usage of the estuary by waders feeding on molluscs was almost negligible, no correlation was observed between the wintering birds and molluscs. Further, extremely high population of waders at Minor C could be a direct reflection of the higher density of benthic invertebrates at the site. Goss Custard (1977) reported that at The Wash, redshanks, preferentially consumed large sized polychaetes, *Neries diversicolor* and *Nepthys hombergii* in a bid to minimise foraging costs. Recently, Yates *et .al.* (2000), inferred that the amphipod *Corophium volutator* was the preferred prey of redshanks. Therefore, occurrence of maximum redshanks at Minor C as compared to other sites would be owing to the higher density of preferred food items such as *Corophium triaenonyx, Nepthys polybranchia*, and *Neries* sp. at the location.

Substrate quality greatly influences prey availability to the waterbirds. Besides regulating the primary productivity (Anderson and Smith, 2000) and benthic resources (Sanders, 2000) it also interferes with the prey searching ability of benthivorous waders (Blackwell *et. al.*, 1998). Johnstone and Norris (2000) showed that the increased silt in the sediment adversely affected the probing ability of oystercatchers in South Wales. In this background, the higher silt and clay content in the sediment of Ribandar and Chorao might be responsible for the comparatively lesser number of waders particularly the sandpipers foraging at the sites. The fine sediment particles probably clogged the tactile receptors located on the bills of these shorebirds thereby affecting their tactile sensory ability. The little stints however successfully exploited all the sites. The little stints fed largely on the smaller crustaceans, *C. triaenonyx* and *A. chilkensis* that got trapped in the luxuriant mat of the sediment surface vegetation and were hence unaffected by the sediment texture.

Bill morphology plays a decisive role in ascertaining the type of prey available to the birds (Paszkowski and Moermond, 1984; Durrell, 2000). Although varying proportions of invertebrate biomass may occur below a depth of 5cm, is relatively inaccessible to most waders with smaller bills who forage by probing the superficial subsurface (Kaljeta, 1994). Minor C, Minor D and Diwar harboured a considerably larger population of sandpipers while the plovers showed a marked preference for Miramar. The large foraging flocks of sandpipers at Minor C, Minor D and Diwar can thus be attributed to a combination of silt and sand in the sediment, the latter being higher than the former, thereby affording better penetrability to the larger and longer bills of these birds and the occurrence of their polychaetes prey upto a depth of 20cm.

The foraging waders of Minor C adopted foraging in 'mixed species flocks'. Mixed flock foraging in waders was also observed by Master *et. al.* (1993). The probable reason for the formation of mixed species foraging aggregations is the improved foraging benefits derived by the birds (Erwin *et. al.,* 1985) which is probably true at Minor C. Another reason for such feeding associations could be the lesser expenditure by the individual birds towards defense and vigilance in a place like Minor C, wherein exposed sandflats with fewer mangroves render the foraging waders an easy prey for raptors. Hence, the benefits accrued by the waders constituting these mixed species aggregations at Minor C were multifaceted and can be summed up as follows, 1) increased foraging success resulting from prey beating 2) reduced energy expenditure during foraging and 3) better protection from raptorial predators. Avian biologist in the past opined that such aggregations are typical of sites with high prey availability (Kushlan, 1978 and Cezilly *et. al.,* 1990). Thus, it would be but appropriate to state that the higher density and diversity of benthic invertebrate prey at Minor C was conducive to the formation of such aggregations. At this juncture it need be noted that even in mixed species foraging flocks, the wader species that were least benefited from such an association continued to opportunistically feed in solitary patches within the association thereby simultaneously deriving benefits from the association as well. Hence, large 'single species' foraging flocks of little stints feeding along the surfline and those of curlews and whimbrels along the higher reaches of the sandflat were not uncommon. At this point it must be noted that while little stints feed largely on crustaceans the curlews and whimbrels probe for polychaete worms in the deeper substratum. In the process these waders, with diagonally opposite prey preferences have been successful in partitioning their resources with minimum interspecific conflict. This complex and intricate association between the foraging waders at Minor C also goes a long way to explain the better wader species diversity of the mudflat.

Nocturnal foraging has been well documented among waders particularly amongst long billed shorebirds (Rompre and McNeil, 1996a; McNeil and Silva, 1996; McNeil and Rodriguez, 1996). Rompre and McNeil (1996b) opined that the need to supplement an inadequate daytime energy intake is reflected in nocturnal foraging. During the present study also the waders particularly the plovers and redshanks were found foraging extensively during the night with almost the same intensity as that during the day. This can be attributed to the tidal fluctuations limiting the availability of food resources at all the sites to only a few hours during the day. Nocturnal foraging in waders has also been observed by some avian ecologists in the past (Robert *et. al.*, 1989; McNeil and Rodriguez, 1996; Rompre and McNeil, 1996 a&b).

The waterbird population of Miramar comprised almost entirely of shorebirds such as lesser sand plovers and Kentish plovers. Both the species are visual feeders but have also been reported to feed opportunistically by probing in the upper substratum (Morrier and McNeil, 1991). Thibault and McNeil (1994) opined that visual foragers feed in large aggregations thereby reducing energy expenditure and increasing foraging benefits. At Miramar also the plovers were observed to feed in fairly large flocks, preferentially on the sand crab, *Dotilla myctroides* in the intertidal region. However, being opportunistic feeders, they resorted to feed on mysids along the surf line as also on those stranded in the top 5cms of the sediment in the absence/scarsity of the sand crabs. The increased visibility of invertebrate prey in the lighter coloured sediment of Miramar as compared to the darker sediment containing a greater quantity of clay and silt at other sites, could have contributed to the higher incidence of visual foragers at the site.

Burger (1991) reported that the presence of people on intertidal beaches adversely affected the foraging activity of piping plovers. He later reported that the plovers overcome this by shifting habitats (Burger, 1994). In the present study it was observed that although the Miramar attracts large number of tourist during most part of the year, no conflict occured between the plovers and humans. This could be probably because the plovers may have over the years, learnt to adapt well to the presence of people. Yet another reason for the persistent occurrence of plovers on the beach could be the easier availability of abundant invertebrate prey, *Dotilla myctroides* on the sediment surface, affording a greater benefit at a lesser cost.

Large flocks of Northern Pintails, *Anas acuta*, were sighted at Minor C, Minor D and Diwar during their winter stay in the state. Interestingly these ducks were found to feed exclusively at Minor C. Walia (2000), during the course of her study at the Carambolim Lake of Goa also encountered a sizeable population of these ducks in the lake during winter. She attributed the increased utility of the lake by these ducks to the 'availability of ample food in the form of extensive hydrophytic vegetation' in the lake. DuBowy (1988) was of the opinion that most congeneric anatids feed primarily on aquatic invertebrates, seeds and vegetation. Similar views were also put forth by other wetland biologists and bird ecologists (Poysa, 1987; Gaston, 1992; Krapu *et. al.*, 1997; Hamilton, 2000). Mayhew and Houston (1999) inferred that the continuous grazing by wigeons at Solway Estuary in Southwest Scotland, elevated vegetative food quality. On account of this, they concluded that birds return to these sites of increased food value at regular intervals. The greater incidence of sediment algae, coupled with a high density of aquatic amphipods *C. triaenonyx* and *A. chilkensis* go a long way to explain the greater site affinity/fidelity to Minor C of the ducks. The better growth of the sediment surface algae at Minor C during winter together with the restrictive foraging area available due to tides could explain the continuous feeding activity of the birds.

Resting is the other of the two prominent activities of migrant birds on their wintering grounds (Hepp, 1982). Feeding and resting among anseriforms are mutually inclusive activities and hence most anatids use the same site for both these activities. As already mentioned earlier, these two activities in the Mandovi estuary were mutually exclusive with the pintails restricting their feeding to Minor C and resting to the neighbouring mudflats of Minor D, Chorao and Diwar. The better abundance of invertebrate prey as well as the higher incidence of sediment algae at Minor C must have favoured the greater use of the site for foraging.

Disparity in the sex ratio of anatids has been globally reported (Johnsgaard and Buss, 1956; Alexander, 1983). Many intriguing explanations have been proposed to explain this disparity. Oring and Lack (1982) attributed this phenomenon to a male dominated sexual aggression while Hepp and Hair (1984) laid stress on delayed pairing. Still others were of the opinion that this imbalance was because the smaller sized females move to warmer locales further south to overcome the cold (Owen and Dix, 1986; Alford and Bol en, 1997). Walia (2000), during the course of her work on the ecological aspects of the Carambolim Lake of Goa also observed a female biased disparity among the anatids. Although a similar observation was also made among the Pintails wintering at Chorao, Minor C, Minor D and Diwar, during the year 2000-2001, the ratio had shifted in favour of the males. Such a perplexing inconsistency can only be explained by the harsh northern winters of that year. This had probably pushed the male population normally wintering in the Koeladeo National Park (Bhupatty *et. al.*, 1997), further south to escape the harsh conditions. The intersexual, intraspecific aggression as a result of increased population may have forced the females further down south. A long-term study of the bird migration coupled with a survey of its distribution within the state will go a long way in creating intellectual inroads into understanding of the causes for such a disparity.

Gulls and terns formed a major component of the waterbird population at all the six sites. These divers forage by 'plunge-diving' on the fish available in the deeper waters of the estuary. However, at times they also resort to feed at the fishing stakes laid along the river's course as well as on the discarded fish drifting inshore from the nearby Malim jetty. In the absence of rocky substrate as perching sites, the birds use the mud/sandflats in the middle and upper reaches of the estuary as launching pads during their fishing sorties. Unlike the other sites, at Miramar the gulls were sighted only during the morning hours when fishing activity along the beach was pronounced.

Ribandar unlike all other sites studied, played host to a large number of piscivores, most of which were wading birds. Many wading birds particularly the larger herons have been shown to selectively capture larger fish (Kushlan, 1979; Willard, 1977). For the efficient capture of large fish the water level of the foraging premise acts as a decisive factor (Maheswaran and Rehmani, 2001). The small rivulets and creeks dotting the Ribandar mudflat provided an ideal fishing environment to large egrets, little egrets and reef herons. The continuous fishing activity at this site using stake seines also served as an easy source of food resources for the egrets and herons. The smaller pond herons on the other hand, fed largely on the marsh crab *Grapsus* sp. commonly found in the exposed mudflat of Ribandar. Such a resource segregation is in accordance with the opinion that within an aggregation, food is apparently apportioned by a combination of 2 predominant types of niche specificity, behavioral interaction resulting in both resource segregation (small birds-small fish) and spatial segregation (large birds-deep waters) (Kushlan, 1976).

The eminence of the Mandovi estuary is all the more heightened as it played host to 2 colonial heronries one at Chorao and the other at Ourem, close to Ribandar. The Ourem heronry is especially worth a mention as it is a traditional one. The only other heronry in the state was reported by Walia and Shanbhag (1996) from the industrial premises of Syngenta India limited. Colonial breeding is known to occur commonly among waterbirds and more so in ardieds (Krebs, 1978). The formation of nesting colonies by herons amidst wetlands is not uncommon (Marion, 1989). Studies in the past have shown that vegetation cover, tree height and food availability to the parents and the young are the deterministic factors which govern nest site selection by birds (Hill, 1988; Buckley and Buckley, 1982; Butler, 1993). The dense canopy of interspersed mangrove plants comprising of *Aviccenia marina* and *Sonneratia alba* at Chorao and while that comprising of *A. marina* and *Rhizophora mucronata* at Ourem provided the necessary nesting platforms for the birds. In addition, the twigs from the dried mangrove plants also provided the nesting material. Secondly, both Chorao and Ourem are totally surrounded by wetlands and hence food availability is never a limiting factor. The paddy fields in the near vicinity served as supplementary foraging sites for the breeding birds. Besides, both these sites being situated in the middle of flowing waters and dense mangrove vegetation accessibility is highly restricted thereby ensuring protection to the birds from predators.

Subramanya (1996) in a review on the literature on heronries in India elucidated that 26 species of waterbirds actively breed in colonies, prominent among them being little egrets, pond herons, cattle egrets and cormorants to name a few. At Chorao, the large egrets were also observed to breed together with the little egrets and the cattle egrets. Interestingly at Chorao, the little cormorants did not form a part of the colony but were nesting in isolation some distance away from the egrets. Contrary to this, the heronry at Ourem comprised entirely of pond herons. Burger (1978) developed classification of heronries based on their vegetative coverage. Subsequently, Singh *et. al.* (1988) and his coworkers modified this classification by incorporating four new characteristics to suit the Indian context. On the basis on this broad classification, they also described 36 subtypes by ascribing a combination of different abbreviations, formulated by the combination of the first 2 alphabets drawn from alternative choices of characteristics. The basic characters and alternative choices considered for the purpose were,

1) Location of the heronry
   i) Associated with human habitation (A) ii) Free from human habitation (F)
2) Physiognomy of the heronry
   i) Compact (C) ii) Loose (L)
3) Type of vegetation serving as nesting platform
   i) Reeds and Bushes (R) ii) trees (T)
4) Nature of vegetation
   i) Homogenous i.e comprising of a single plant species (Ho)
   ii) Heterogeneous I.e with more than one plant species (He)
5) Composition of breeding species
   i) Mixed where 2 or more species breed regularly (M)
   ii) Pure comprising of a single species of breeding birds (P)

based on this criteria, the heronry at Chorao can be broadly classified as FCTHeM type while that at Ourem can be described as ACTHeP type.

Fasola and Alleri (1992) proposed that nesting herons align and stratify themselves vertically in direct relation of their body length with larger species occupying higher levels. This was dependent mainly on arrival times and the aggressive dominance of larger species. At Chorao also such stratification was evident with the tallest species, large egret, occupying the higher regions of the canopy and the cattle egrets occupying the lowest position. At both the heronries *A. marina* was supposedly chosen over the other plants as nest building commenced on this species. At this juncture it may be noted that the more profuse branching in *A. marina* and the numerous lenticels on the surface of the stem probably enhance anchorage of the nests.

Nest site selection among birds is supposed to depend upon the reproductive success of conspecifics breeding in the area. Brown *et. al.* (2000), reported that colony choice in cliff swallows depends upon the reproductive success of the conspecifics in the colony during the previous breeding season. A similar learning and perception might have been exercised by the waterbirds during nest site selection. The unutilisation of the heronry site of Chorao during the year 2000-2001 could hence be a result of the increased damage incurred upon the eggs and nestlings by the crab-hunting boys. Contrary to this, the almost complete inaccessibility of the Ourem colony saw the colony growing with time.

As on date, breeding activity of lesser adjutant stork has been largely confined to Assam and the northeast region of the country. Though the bird was once recorded to bred as far south as Kerala (Baker, 1935), no other such sighting has been reported in recent years. Therefore, it would be interesting to learn if the attempts made by a lone pair of resident lesser adjutant storks at Chorao along with the initial attempts made by a few grey herons will bear fruit. An important reason for the nesting failure of these larger birds could probably be their dismally small resident population that fails to satisfy the threshold level. So far none of the 2 species has been reported to breed successfully in Goa.

The avian species diversity of Minor C, Minor D, Diwar and Miramar was the highest in late postmonsoon/early winter. This period also coincides with increased autotrophic activity as well as an increase in the benthic invertebrate prey of the waders. With the subsistence of the monsoons the initial migrants including the plovers and redshanks start making their appearance in as early as in October. During this period comparatively larger flocks of passage migrants like godwits and slenderbilled terns and Terek sandpipers use these sites as stopovers to replenish their depleted energy reserves. All these factors are collectively responsible for the higher diversity at Minor C, Minor D, Diwar and Miramar during late post-monsoon/early winter. On the other hand both Ribandar and Chorao harboured more species of resident birds rather than migrants. The presence of colonial nesting activity close to these sites in addition to a greater resident bird population results in the species diversity at these 2 sites being higher during monsoon.

Preference ranking provides a new refinement to the criteria on which the conservation value of an estuary, for waterbirds might be assessed. The most commonly used criterion is the so-called 1% level (Fuller and Langslow, 1986). An estuary is considered nationally or internationally important it regularly supports more than 1% of the national or international population of a species (Moser, 1988). Consequently, an estuary like the Mandovi estuary harbouring more than 5% of the pintail population wintering in the country and more than 1% of the country's redshank population demands due importance. Although a an initial beginning has already been made by notifying a part of the Chorao island within the estuary as a bird sanctuary, it is of utmost importance that the main foraging ground, Minor C, of the birds roosting within the sanctuary be safeguarded from human interference.

Most of the work/literature available on the birds of the region right from the first/ever report (Grubh and Ali, 1976; Saha and Dasgupta, 1992; Lainer 1999 a&b) was more in the category of annotated checklists. Further till recently but for a sketchy and intermittent waterfowl census (Perennou *et. al.*, 1994; Lopez and Mundkur, 1997) information of the wetlands and waterbirds of the region was practically nonexistence. The work from this laboratory (Walia, 2000), was successful in plugging the lacunae and happened to be the first ever ecological work on the freshwater wetlands and the waterfowl from the region. Thus, there still existed an unbridged gap in the ecological outlook on the estuarine wetlands, some of the important ecosystems of the coastal state of Goa and the waterfowl inhabiting them. The present study was undertaken to analyze the temporal and spatial profile in the diversity and ecology of avifauna of the wetlands in the Mandovi-Zuari estuarine complex, one of which supported the only bird sanctuary of the state. The study was aimed at providing comprehensive information about the interactions of the waterbirds with the conspecifics, interspecifics as well as with their immediate environment. Yet another aim of the study was to provide baseline data on the avifauna of the Mandovi estuary particularly the Chorao Island, indispensable for the effective management and conservation of the bird habitats already buckling under demophoric pressures.

The study was carried at 6 mud/sandflats, Chorao, Minor C, Minor D, Diwar, Ribandar in the middle reaches and Miramar in the lower estuary. Minor C and Minor D are the two banks of Chorao Minor, an uninhabited accretion island situated between Chorao and Diwar. The Chorao Island harbours the Dr. Salim Ali Bird sanctuary notified in the year 1988. Miramar, on the other hand, is an open beach situated towards the mouth of the estuary. All the sites were exposed either totally or partially for 3-4 hours during normal low tide and for approximately 4-5 hours during the neap tide. All the sites except Miramar were fringed with varying degrees of mangrove vegetation. The vegetation of

Miramar however was confined to sand dune plants *Ipomea biloba*, and *Spinifex* sp.

The study was coincident over a period of 2 years extending from March 1999 to February 2000. The ecological work carried out during the present study included the analysis of the physico-chemical parameters like texture, temperature, pH, conductivity, chlorides, alkalinity and sulphates and nutrients such as organic carbon, phosphate-phosphorous and nitrate-nitrogen of the sediment. It also covered the analysis of the density, diversity and seasonal profiles of the benthos and avifauna. The complex interactions of the waterbirds, particularly the waders with conspecifics, interspecifics and the ecosystem as a whole also formed an integral part of the study. The outlines of the findings in general emanating out of the study and the reasoning for the recorded dispositions are as under.

Sediment Parameters:

1. The sediment texture of the 6 study sites can be categorized into 3 types, sandy silt comprising of 51.73% to 75.25% silt, at Chorao and Ribandar, silty sand containing 56.13-89.02% sand at Minor C, Minor D and Diwar and sandy sediment at Miramar containing predominantly sand with only traces of silt. The high silt at Chorao and Ribandar was a result of the autochtonous input from mangrove litter at the former and allochtonous input from the neighbouring village at the latter. Sediment textural components of all the sites showed a seasonal cyclicity with an increase in silt in late postmonsoon-early winter and sand in monsoon.
2. The sediment pH of all the sites was mildly alkaline within a range of 7.83 to 8.76 but did not attain extremely alkaline/acidic levels at any time of the year. At all the sites it dropped sharply during monsoons owing to incessant precipitation during the period.

3. Sediment conductivity, chlorides, alkalinity, sulphates as well as the sediment nutrients like organic carbon, phosphate-phosphorus, nitrate-nitrogen, showed texture based intersite variations and were high at Ribandar and Chorao and least at Miramar. All these parameters showed a broad seasonal cyclicity with a high in summer and low in monsoon. Interestingly, the sediment sulphate levels encountered during the present study were in the same range as those reported 20 years back for the same estuary.
4. The sediment pH positioned well within the range of mild alkalinity, very often close to the limit of neutrality; the organic carbon levels of the sediment never exceeding 4% limit and no perceptible changes in the sulphate levels from those reported 20 years earlier augur well to proclaim that the estuarine belt under study is not yet confronted with overt pollution.

Benthos:

1. Sediment surface flora comprised of 2 algal species, *Enteromorpha flexuosa* and *Dicotomosiphon salinas* and a single angiosperm species *Halophila beckerri*. The flora showed a distribution related to texture of the sediment from complete non-existence at Miramar to $40g/m^2$ in dry weight at Minor C.
2. The benthic fauna of all the sites comprised broadly of 75 invertebrate species belonging to 4 major groups. Nematodes constituted the meiofauna while 34 species of polychaetes, 25 species of crustaceans and 16 species of molluscs made up the macrofauna.
3. The benthic fauna exhibited a texture dependent spatial and temporal distribution. The polychaetes were best represented in the silty sand of Minor C where in maldanids, nerieds, ceratonerieds and spionids dominated. While the sandy sediment of Miramar was dominated by the crustaceans such as *Gastrosoccus* sp. and *Dotilla* sp. and bivalves particularly donacids.

4. The benthic invertebrates showed a vertical stratification at all sites. They were most abundant in the top 5 cm of the substratum but decreased progressively with increase in depth. In the extremely anoxic sediment of Chorao and Ribandar they were almost totally absent below the depth of 10cm.
5. None of the sites in the mid-estuarine belt of Mandovi showed any degree of overt pollution in terms of physicochemical charecteristics or the nutrient levels of the sediment, although nematodes and nerieds were predominant fauna. Therefore, it amounts to the increased need to excercise care and caution before labelling any site with a pollution status based only on the 'indicator species concept'.

Avifauna:

1. The estuary as a whole supported 151 species of birds that included 87 species of waterfowl. Among the 6 sites, Chorao harboured the best avian diversity, with 115 species of birds. But in terms of population it was next only to Minor C, which harboured 1,21,493 birds on the basis of biannual cumulative total.
2. Although the terrestrial bird fauna was best represented at Chorao and Diwar with 59 and 41 species respectively, it contributed a meagre 23.08% and 12.86% of the total bird population at the respective sites.
3. As compared to all other sites, Minor C had the highest density and diversity of waterbirds, particularly waders. The site harboured 70 species of waterbirds that included 29 species of waders.
4. Large flocks of lesser sand plovers and Kentish plovers reaching upto 700 individuals used Miramar not only as a foraging ground but also as a roosting site.
5. Almost 80% of the avifauna at the Mandovi estuary consisted of migrant waterbirds. The dominant waterbirds wintering in the estuary were adjutant storks, white necked storks, pintails, shovellers, slenderbilled gulls, Pallas's

gulls and black bellied tern while the migrant waders included godwits, curlew sandpipers, broad billed sandpipers, Terek sandpipers, little stints, redshanks, golden plovers, Kentish plovers, large sand plovers and lesser sand plovers.

6. An efficient food/resource partitioning was observed amongst the waders utilizing the estuary with sandpipers foraging preferentially on the benthic polychaetes in the silty sediment of Minor C, Minor D and Diwar and plovers feeding on the mysids and decapods in the sandy sediment of Miramar. Variations in the feeding habits and prey accessibility owing to differential bill morphology and sediment type could have lead to such a complex seggregatory phenomenon.
7. The waders at Minor C resorted to 'mixed species flock foraging' as an effective method of food resource partitioning which can be attributed to the more diverse macrobenthic fauna available at the site and the larger open areas affording better vigilance.
8. Large flocks of pintails with over 7000 individuals per flock were recorded actively feeding on the sediment surface algae and entrapped crustaceans *Corophium triaenonyx* and *Apseudes chilkensis* at Minor C. Besides, the ducks used Chorao, Minor D and Diwar as a secondary roost.
9. The Mandovi estuary harboured two heronries; a traditional pure pond heron heronry at Ourem and a mixed heronry catering the breeding requirements of large egrets, little egrets and cattle egrets within the Chorao bird sanctuary. Unfortunately, the latter, was deserted in the second year probably owing to increased human disturbances. However, there were no signs of its re-establishment so far in and around the region, despite the fact that it was also known to be a traditional heronry.

Conclusions and Recommendations:

1) The mudflats of the Mandovi estuary squirming with a variety of benthic life are rich repositories of biodiversity. However, since the present work was centered around studying the avifauna of the estuary and not the biodiversity *per se* some of the smaller benthic forms might have missed enumeration. Hence a combination of more than one technique may have to be employed for complete assessment of the biodiversty of the estuarine mudflats/ sandflats.
2) The large flocks of migrant pintail ducks observed to utilize the Mandovi estuary during the course of the present work confirms the speculation that large number of northern pintails wintering in the Carambolim lake of the state must be using the Mandovi estuary during some part of their stay in the region.
3) The mangroves forests of the Chorao Island particularly the Dr. Salim Ali Bird sanctuary continues to serve as an ideal resting/roosting site for a large number of both residents as well as migrant waterbirds particularly waders. But, in the absence of earlier reference data on the avifauna of the sanctuary, little can be said about any change in its status. In this context the extensive avifaunal data generated by the present study spanning over a period of 2 years will serve as the baseline data for all further avifaunal studies in the region.
4) The hands-off conservation presently practiced at the Chorao bird sanctuary can do little to improve the habitat status of the sanctuary. The extremely overcrowded growth of mangroves within the sanctuary has resulted in disruption of the intervening watercourses. The water thus stagnated has resulted in highly anoxic conditions of the sediment, unconducive for the growth and survival of the larger benthic forms. Further, the overpopulous mangroves must be adversely affecting the visibility range and hence vigilance of the waterbirds. Therefore, a systematic and planned rarefaction, pruning and the clearance of

intermittent mangrove strips from the marsh will go a long way in improving the quality of the sanctuary. The movement of powered motor boats/hovercrafts very close to the sanctuary should also be limited as this might be causing substantial disturbances to the alert birds.

5) Food is the single most important requirement of migratory birds. Although the Chorao island serves as an ideal roosting site for wintering birds, it is the neighbouring mudflats/sandflats like Minor C that provides the essential proteinaceous diet for the benthivorous waterbirds particularly the waders. Hence, all out efforts are required to conserve and protect the uninhabited tiny island close to Chorao as well as the other mudflats/sandflats in the near vicinity.
6) The dependence of large flocks of lesser sand plovers and Kentish plovers on Miramar, a beach of tourist importance, both for feeding and roosting throughout their stay in the state cannot be taken for granted. In an era of unscrupulous growth of tourism and increasing encroachment of the shoreline, care should be taken to see that the sand dune vegetation, the lifeline of the plovers be maintained undisturbed along the beach.
7) With adventure tourism being a major source of the nation's foreign revenue the estuary can be used scrupulously and sparingly to enhance nature tourism in the state. However all such advances need be done with a load of conscience and caution, so as not to disfigure this pristine ecosystem or upset its delicate balance. Only thus can this unique and indispensable treasury of nature be sustained for posterity.

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* = not refered to in original.