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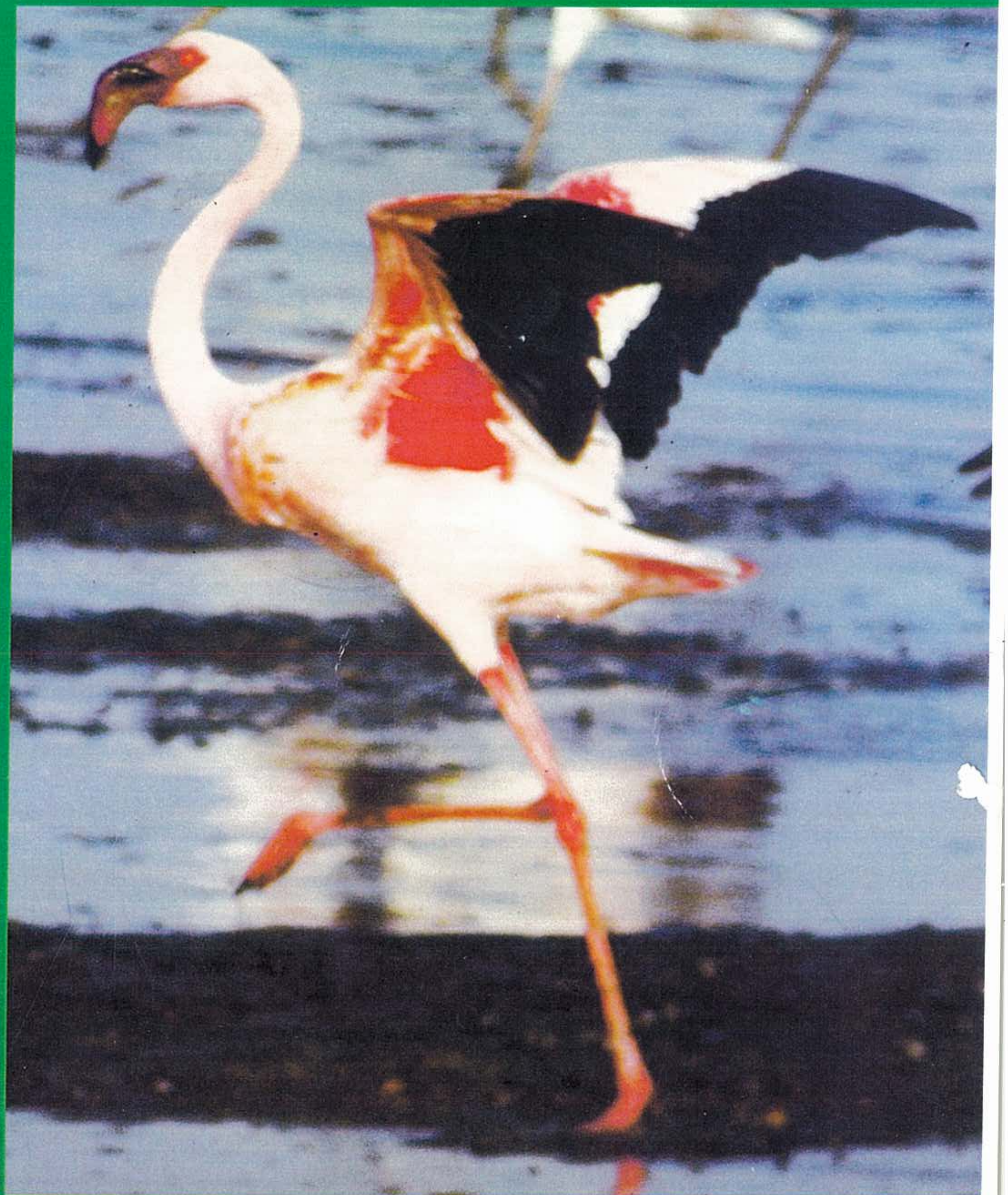
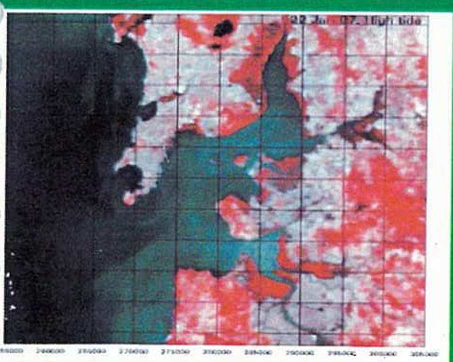
MUMBAI TRANS HARBOUR LINK (MTHL) PROJECT: STUDY OF FLAMINGOS AND MIGRATORY BIRDS

20.

Final Report





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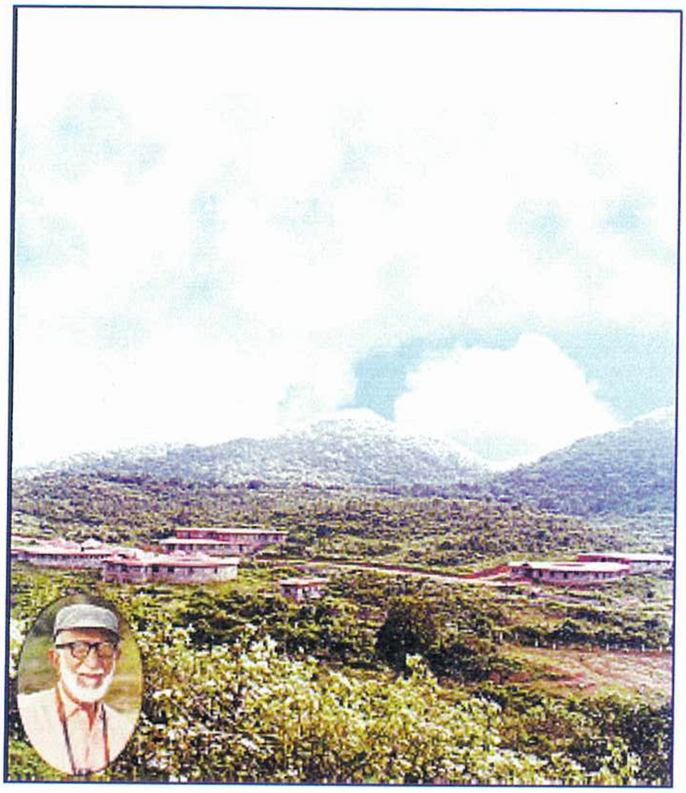

One of the cherished dreams of late Dr. Sálim Ali, the father figure of Indian Ornithology, was to have a national centre to perpetuate studies in Ornithology and Natural History. Thanks to the ceaseless efforts of the Bombay Natural History Society (BNHS), the country's oldest NGO, his dream came true in 1990 when the Ministry of Environment and Forests (MoEF), Government of India came forward to support such a centre. The centre was befittingly named after Dr. Sálim Ali, in appreciation of his monumental contribution to Ornithology as Sálim Ali Centre for Ornithology and Natural History (SACON).

The Centre was set up with a mission to "Help conserve India's biodiversity and its sustainable use through research, education and people's participation with birds at its centre stage", SACON focuses on the following broad areas:

- ❖ Conservation of endangered birds
- ❖ Impact of anthropogenic activities on the biodiversity
- ❖ Environmental contamination
- ❖ Tropical rain forest ecosystem conservation
- ❖ Conservation and sustainable use of wetland resources
- ❖ Environmental Impact Assessment, and
- ❖ Nature Education

Citation

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SUMMARY AND RECOMMENDATIONS

The Maharashtra State Road Development Corporation (MSRDC) has proposed the Mumbai Trans Harbour Link (MTHL), mainly passing over the Thane Creek connecting Sewri and Nhava in Mumbai. The Sewri-Mahul mudflats (1000 ha) have been identified as an Important Bird Area (IBA) since this area harbours a large population (>15000) of the Lesser Flamingo *Pheonicopterus minor*, a globally near threatened species, and thousands of smaller waders. Hence, a project has been commissioned by MSRDC to study the population of birds with emphasis on the flamingos, their behavior and the quality of the habitat, which will help take necessary mitigatory steps for the protection of the birds and the area. A mandatory EIA clearance has already been obtained by MSRDC from the Ministry of Environment and Forests, Government of India. This study is a follow up measure and a proactive approach on the part of MSRDC to internalize environmental concerns into the project.

The study encompassed three major components, namely 1) bird studies (population, distribution, habitat use and behaviour of flamingos), 2) habitat evaluation including mapping (classification and quantification of habitats and delineation of inter-tidal zone and sediment load) using modern spatial technology tools such as remote sensing and GIS and 3) Water quality, levels of contaminants in water, sediment and fishes, and noise. Studies were conducted in the mudflats of Sewri - Mahul region and Nhava between August 2006 and October 2008 following standard methods. Summary of the findings and recommendations are given below.

I. Population and distribution of birds in Nhava and Sewri-Mahul region along the Thane Creek

1. Total abundance of birds

Total abundance of birds in the Sewri-Mahul region was much higher than in Nhava, >53000 birds of 54 species in 2008 in the former and only >2000 of 26 species in the latter. These numbers were slightly higher than in 2007.

2. Population and distribution of the flamingos

The Lesser Flamingo started arriving the area during December 2006 in small numbers and increased slowly in March, and in large numbers in April 2007 reaching the peak of about 11000 -12000 birds in May 2007. They started leaving the area in June with a few juveniles remaining in June-July 2007. During 2007-2008, they arrived early and the population increased during January to March 2008 and reached the peak of about 14000-15000 birds in April 2008. Accordingly, their departure was mainly in May 2008, earlier than in the previous year, with very few juveniles remaining in June 2008.

Only a few Greater Flamingos were recorded during November 2007 to January 2008. But, subsequently, they reached the peak of about 340 birds in February and most of them left in March 2008 along with the juveniles.

Distribution pattern was similar in both the years, using more of Mahul- Sewri region and low density towards Retibhandar. Roosting and / or resting during high tides were near Tata Power and Tata jetty.

Disturbance was caused by the ship repair activities at Sewri and tourists going closer to the flamingos by boat. The local people catching crabs did not cause much disturbance. Small construction works by Tata Power caused slight disturbance, but the birds got adjusted and went back to the area after the construction was over. This shows their adjustable nature with local movements as recorded elsewhere in the world.

3. Food availability for the flamingos: plankton and benthos in the Sewri-Mahul region

Total mean biomass of plankton was high in this area, especially during winter and summer which correlated positively with the population of the Lesser Flamingo as they feed mainly on these. The Myxophyceae including three species of *Spirulina*, the favoured food of the Lesser Flamingo was higher in winter and summer, again correlating with the abundance of the Lesser Flamingo.

Total abundance of benthos was comparatively less and it went down from winter to summer and monsoon, which might be the reason for fewer number of the Greater Flamingos in this area and their departure at the beginning of summer.

The abundance of plankton and benthos also needs to be studied in other mudflat areas which could be used by the Flamingos if they are disturbed in the Sewri-Mahul region during the construction period.

II. Assessment of habitats through Remote Sensing & GIS

Area of interest was marked along the coast of the Thane Creek and habitats were classified and quantified belonging to mangrove (dense and open), mudflats, waterbody, area with tree cover, and built-up area; 12.6% area out of 301sq.km is mudflats and 16.5% mangrove.

The distribution of flamingos and the proposed bridge are overlaid on the satellite imagery and the output maps are given. The bridge passes over the flamingo areas in the Sewri-Mahul region. The new areas of sightings of the flamingos in 2007-08 are also marked on the imagery. It is interesting to see that they used mudflats near and below Vashi bridge and the salt pans near Uran and JNPT and mudflats of Zasai.

The inter-tidal zone and sediment load in the Sewri-Mahul region was analyzed using satellite data, *viz.* TERRA and AQUA MODIS (3bands) of 2007 which showed the areas of high sediment load corresponded with the areas used by the flamingos in huge flocks.

Similar analyses of the satellite imageries of the Thane Creek are needed to examine the suitable habitats for the flamingos all along the coast of the Thane Creek and especially those areas used by the flamingos in 2008. Areas suitable for mangrove restoration also could be identified using remote sensing data.

III. Environmental Contamination

1. Physico-chemical properties of water

Dissolved oxygen levels were less, indicating greater input of industrial and domestic wastes. Mahul recorded very high turbidity, while COD was high in Sewri, followed by Mahul. Nhava had the highest total alkalinity, and oil and grease. Mahul also had levels of oil and grease higher than the prescribed limit.

The high concentration of phosphate, sulphate and nitrate may be due to surface run off. This might help better growth of plankton and algae.

Total organic carbon levels of the sediments in all three regions were lower than levels reported elsewhere as contaminated.

2. Heavy metal contamination

Heavy metal contamination in water, sediment and fish samples from the study locations showed that high levels were of iron, nickel and copper in the sediment in Sewri, and chromium and cadmium in Mahul because of effluents from industry, domestic sewage and ship repair. These would create toxicity to the biota on a long-term exposure.

3. Levels of Pesticides, PCBs and PAHs

Among the various isomers of HCHs, α-HCH appeared to be higher than the other isomers. *a*-HCH showed least contribution to the total HCH. High concentration of HCH was recorded in fishes of Nhava and Mahul followed by Sewri. Among the metabolites of DDT, the *p,p'*-DDT showed major contribution to the total DDT followed by DDD and DDE.

Significantly higher loads of organochlorine pesticides were recorded in water and sediment in Mahul. Comparatively higher concentrations of β- and α-HCH were also recorded in all the species of fishes. The average concentration of total HCH in fish samples of the present study is two to three folds higher than the permissible limit prescribed for fish products by FAO/WHO.

Among the three study sites, the total polychlorinated biphenyls (PCBs) in sediment of Mahul and Sewri were higher than the sediment quality guideline values. Total PCB residues in fishes also exceeded the US EPA's human health screening values. This indicates increased health risk to local fish consumers.

Polycyclic aromatic hydrocarbons (PAHs) concentration in sediment and fishes exceeded the sediment guideline values suggested by various agencies. It is to be noted that higher concentrations of total PAHs found in sediment and fishes are demonstrated to be carcinogenic and mutagenic. The overall concentration of organochlorine pesticides, PCBs and PAHs in Mahul samples were comparatively higher than Sewri and Nhava; this may exert ill effects on the resident organisms over a period of time.

4. Noise levels

Among the three locations, namely Sewri, Mahul and Nhava, Sewri had higher noise levels ranging from 71 to 79dB followed by Nhava (68 to 75bB). The minimum noise was recorded at Mahul region (52-64dB). The flamingos' feeding ground recorded maximum of 60dB of noise which is considered to be normal.

RECOMMENDATIONS

- Flamingos have moved away from the Sewri Port area probably because of the increased activity of ship repair. This also creates pollution. Hence this needs to be shifted.
- Tourism has to be regulated and managed in an eco-friendly way to avoid disturbance to the birds.
- Also, education and awareness programmes for different target groups including students and local communities have to be organized.
- Ensure no or minimum disturbance to the flamingos in the feeding and resting areas. Construction activities in this area may be restricted to the season when flamingos are not here (or not in larger flocks).
- Contamination by PCBs, oil and grease, and PAHs is above the prescribed limits and hence of great concern. Necessary action may be taken with the concerned authorities.
- Mangrove restoration programmes may be undertaken in suitable areas. These areas also need to be identified.
- Further studies are needed on the flamingoes and their habitat: examination of flamingo habitats in other areas and possible disturbances to them. Since the flamingos have the habit of moving between sites, multiple foraging sites should be available. Hence, monitoring and protection of all the mudflats in the Thane Creek are important.
- Long-term monitoring and detailed studies during the construction work of MTHL.
- To improve our knowledge of flamingos and ensure their protection, monitoring populations at regional scales at the breeding and non-breeding sites, and international cooperation are crucial.

Chapter -1

GENERAL INTRODUCTION & STUDY AREA

INTRODUCTION

The Maharashtra State Road Development Corporation (MSRDC) has proposed a project Mumbai Trans Harbour Link (MTHL) between Mumbai island (Greater Mumbai) and the mainland Mumbai (Navi Mumbai). Several development initiatives have been planned for making Navi Mumbai as a satellite city to Mumbai. Since the traffic and communication facilities at present are inadequate and with the expected steep rise as a result of the development in the coming years, the Maharashtra Government has found the construction of MTHL (road and rail link) essential. Studies have been conducted since 1970s to find a feasible solution and finally the proposal was approved by the State and Central Governments in 2004. The MTHL will be of 22 km connecting Mumbai with Navi Mumbai across the Thane Creek mainly passing over the sea (Thane Creek) and a stretch of about 5 km over the land and 9 km on the intertidal zone at Sewri and Nhava-Sheva ends.

The link passing over the mudflats area at the Sewri end is of major concern for the environment as the Mahul - Sewri mudflats (1000 ha) have been identified as an Important Bird Area (IBA) by the Indian Bird Conservation Network through Bombay Natural History Society and BirdLife International as it qualifies for three IBA criteria, namely supporting globally threatened species (A1), ≥ 1% population of a congregatory waterbird species (A4i) and ≥ 20,000 waterbirds (A4iii). Since 1994, the flamingo population in Sewri Bay has been increasing and in 2003 the numbers were reported to be around 17,000 with about 15,000 Lesser Flamingo *Pheonicopterus minor* (Islam and Rahmani 2004). This species is a near threatened species under the IUCN Category (Lesser Flamingo *Phoeniconaias minor*; BirdLife International 2008). globally critically endangered species, namely White-rumped (White-backed) Vulture *Gyps bengalensis* and Long-billed Vulture *Gyps indicus*, endangered Spotted (Nordmann's) Greenshank *Tringa guttifer* and, vulnerable Eastern Imperial Eagle *Aquila heliaca* and Greater Spotted Eagle *Aquila clanga* and another near threatened species Black-headed (White) Ibis *Threskiornis melanocephalus* are also reported from this area (Islam and Rahmani 2004). This area is polluted with the wastes, both industrial and domestic, discharged into the creek through several inlets. However, the area has been still supporting a large population of birds including the small waders and the flamingos. It is imperative that the development programmes be implemented without affecting the biodiversity of the area and proper mitigatory measures are taken to safeguard the environment. This necessitates a study of the area and the major populations of species, especially the large population of the globally near threatened Lesser Flamingo. Hence, a study was commissioned by MSRDC in 2006 to look at the population of birds with emphasis on the Flamingos, their population, distribution and behavior, and the quality of the habitat, which will help in taking necessary steps for the protection of the birds and the area.

Knowledge of population size is not only of intrinsic biological interest but is also fundamental to the application of conservation planning and action (Kershaw and Cranswick 2003). For better understanding of the Flamingos and their habitats a strong seasonal data is required on their arrival and their numbers during more seasons. Food availability is the crucial factor for determining the number of birds in an area. Lesser Flamingo is reported to feed mainly on plankton, algae, diatoms, invertebrates, seeds of aquatic plants, grit and organic mud (Ali and Ripley 1987, Parasharya and Tere 2006). Competition for space and resources is considered an important determinant of population size and it is also important that how much suitable area is available in a particular region (Rehfisch *et al.*, 2003). Besides the usual physico-chemical nature of water and sediment, analysis of the contaminants in the habitat including residues of pesticides, toxic (heavy) metals and toxic congeners of polychlorinated biphenyles (PCBs) and polycyclic aromatic hydrocarbons (PAHs) is required to understand the relationship between the contaminants in the habitat and their probable impact on the birds.

Hence, the present study encompassed three major subcomponents, namely 1) bird studies, 2) habitat evaluation including mapping (classification and quantification) and distribution of flamingos using modern spatial technology tools such as Remote sensing and GIS, and 3) water quality and levels of contaminants in water, sediment (soil), fish, and noise levels. This report contains the findings of the two years (2006 - 2008) with the different aspects of the study in different chapters.

LITERATURE REVIEW

Flamingos Distribution

Shorebird populations worldwide are in a perilous state, with 48% of the 200 populations with known trends in decline (International Wader Study Group, 2003). These declines are troubling because shorebirds are likely to be important indicators of wetland health on a global scale (Thomas *et al.*, 2006)

Flamingos are among the birds best adapted to seasonal wetlands (marshes, salt pans, brackish lakes) characterized by an irregular hydrological cycle. Flamingos occupy these highly productive wetlands, conducting erratic movements to seek inundated areas where they are opportunistic feeders when conditions are favorable (Rendon-Martos *et al.*, 2000).

The Lesser Flamingo is an itinerant species adapted to respond to changes in local environmental conditions by moving, and thus depends on a network of suitable sites. Although the most numerous of the world's flamingos, it is classified "Near Threatened", nearly qualifying as threatened under criteria A3c: A population size reduction of 30%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer (up to a maximum of 100 years), based on a decline in area of occupancy, extent of occurrence and/or quality of habitat (Childress *et al.*, 2007).

The distribution of animals is usually thought to be restricted by the occurrence of good feeding areas, with predators and disease organisms determining the quality of such areas in addition to resource abundance (Newton, 1998). However, many animals use feeding areas for only part of the day and at other times relies on alternative areas to roost and loaf. In tidal areas shorebirds have to leave their intertidal feeding areas for high tide roosts. Shorebirds are particular in their choice of such roosts (Piersma *et al.*, 1993; Luı´s *et al.*, 2001; Rogers, 2003), preferring accessible sites where birds are safe and not thermally stressed. Accessibility is a function of the distance from the feeding grounds. Safety is a function of the risk of predator attack, perhaps in combination with human disturbance (Rosa *et al.*, 2006). Thermal stress, either because of wind and cold induced rises in maintenance costs (Wiersma and Piersma, 1994) or excessive heat load (Battley *et al.*, 2003), is a function of the geomorphological features of a place, and may also be influenced by human disturbance (Rogers *et al.*, 2006).

The Lesser Flamingo is regularly seen in 29 countries from West Africa, across sub-Saharan Africa and along the SW Asian coast to South Asia, and occurs as a vagrant in 26 additional countries (BirdLife International 2008). However, its global population is concentrated in just 10 primary range states and confirmed regular breeding is confined to only five sites in four of these countries (Childress *et al.*, 2007).

In the High Andes wetlands of Argentina, Bolivia, Chile, and Peru, three flamingo species were present namely James (*Phoenicoparrusjamesi*), Andean (*P. andinus*), and Chilean, (*Phoenicopterus chilensis*) (Masciti 1998). Flamingo population abundance was related to habitat variables such as lake depth, water composition, plankton, and submergent vegetation. Deep lakes with macrophytes and dense zooplankton habitats the Chilean Flamingo and more diverse waterbird communities were recorded. The Andean Flamingo occurred in almost every lake at High Andes but in low numbers. Overall, shallow lakes sustained great numbers of flamingos, but changes in lake size did not explain abundance variations (Caziani and Derlindati, 2000).

Six flamingo species were found of which Lesser Flamingo was found in four separate populations (Table 1.1). Although it is assumed that some interchanges probably occur between the populations, the largest population was estimated to be between 1.5 and 2.5 million individuals on the alkaline-saline lakes of the Great Rift Valley in East Africa. Smaller populations occur in different places with an estimate approximately 390,000 birds of north-western India, between 55,000 and 65,000 birds in southern Africa, and between 15,000 and 25,000 birds in West Africa. Declines have been suggested for much of Africa, but are difficult to clarify due to wide scale movement within the continent. Increasing numbers of vagrant Lesser Flamingos are sighted each year in the Middle East and the Mediterranean region (Childress *et al.*, 2007).

Earlier observations and censuses indicated considerable nomadic or migratory movement of the Lesser Flamingos in East Africa among different lakes (Akeley, 1912; Ridley and Percy, 1953; Jenkin, 1957; Brown, 1959; Brown, 1975; Pennycuick and Bartho- lomew, 1973; Vareschi 1978). At certain times, large, dense flocks congregate at lakes such as Nakuru and Bogoria and on the breeding areas of Magadi and Natron; at other times, these sites only support relatively fewer birds (Tuite, 2000).

Table1.1. Flamingo population and range in the world (Childress *et al.*, 2007).

	Greater Flamingo	Caribbean Flamingo	Chilean Flamingo	Lesser Flamingo	Andean Flamingo	James's Flamingo
Range estimate (km^2)*	100,000 - 1,000,000	300,000	2,940,000	331,000	189,000	274,000
Population estimate*	545,000 - 682,000	257,000 - 332,000	200,000	2 - 3 mil	34,000	100,000
Population trend*	–	–	↓	↓	↓	↓
IUCN Red List	LC	LC	NT	NT	VU	NT

- Sources: Wetlands International (2004) & BirdLife International (2008)

Africa's Lesser Flamingos are found in the East African Rift Valley lakes in Ethiopia, Uganda, Kenya, and Tanzania and the populations varied between 1.5 and 5 million birds (Brown, 1975; Kahl, 1975; Tuite, 1979; Rose and Scott, 1997). There population fluctuation was mainly due to the difficulty in assessing huge concentrations of flamingos on relatively inaccessible lakes.

In Kenya two flamingo species namely the Lesser Flamingo (*Phoeniconaias minor*) and Greater Flamingo (*Phoenicopterus ruber roseus*) were present. Flamingos in Kenya are part of the East African population, which mainly breeds at Lake Natron in Tanzania (Nasirwa, 2000). Lesser flamingos were the most abundant species, constituting 92% of the total in Kenya, while Greater Flamingos were only 2% (Simmons, 2000). The population trend showed a general decline in the number of flamingos (Lewis and Pomeroy, 1989) and the main threats were breeding failure, predation of young, drying of lakes and resultant hyper-alkalinity, soda mining, and other human developments resulting in disturbance, as well as pollution caused by sewage and heavy metal effluents from industries and diseases mainly tuberculosis (Grootenhuis, 1995; Nasirwa, 2000). Movements of Flamingo in Kenya were not well understood, but those of the Lesser Flamingos were mainly based on the changes in the abundance of the blue-green algae *Spirulina platensis* (Nasirwa, 2000).

Long distance flight movement of flamingos was observed at night (Rooth 1965, Berry 1975, Johnson 1983) and the flight velocity of flamingos was estimated at 50-60 km/ hr (Pocy, 1926; Rooth, 1965; Berry, 1975; Brown, 1975), and the average distance potentially covered in one night was 480-640 km (Brown, 1975).

Flamingos are the most important migratory bird in Indian coastal wetlands and are physiologically adapted to utilize shallow saltwater areas and lagoons (Ali and Ripley, 1987). In India, two flamingos are present, namely the Lesser and Greater flamingos (Ali and Ripley, 1987; Grimmett *et al.*, 1998; Kazmierzack, 2000; Jadhav and Parasharya, 2004). Flamingos are the most important migratory bird in Indian coastal wetlands of Gujarat, Rajasthan, Maharashtra and the western Gangetic plain and Chilka Lake, Orissa (Ali and Ripley, 1987). Johnson (1983) reported the puddle feeding behavior of flamingos in Koonthankulam, Tamil Nadu. Manakadan (1995) studied the impact of salt works on the population of the Greater Flamingo in Great Vedaranyam swamp, Point Calimere sanctuary and Sumathi *et al.* (2007, 2008) studied the population changes in the same area.

Flamingos Feeding

Lesser Flamingo depends primarily on shallow saline/alkaline lakes, pans, wetlands and coastal areas. In all regions, the birds breed on large shallow saline lakes and pans in areas that are inaccessible to terrestrial predators. Lesser Flamingos in East Africa and southern Africa feed primarily on microscopic cyanobacteria and benthic diatoms. Diets in West Africa and South and southwest Asia are not well known but in South Asia include diatoms from the surface of tidal mud in Sewree Bay near Mumbai for part of each year (Childress *et al.*, 2007).

Brown *et al.* (1973) found that food abundance was not an important factor in flamingo movements, but Tuite (1979) found there was a correlation between flamingo density and algal blooms. Flamingos can excrete excess salt through salt glands in their nostrils, and they can manage their body heat by curling their leg from the water (www.wkonline.com). Flamingos wade in shallow marshy areas and filter feed by stamping their webbed feet to stir up food from the bottom. They sweep their heads from side to side on the bottom with their bills hanging upside-down and facing backward in the water to capture prey. Their fringed tongue lamellae filter out food, and water is passed back out of the bill. Gut content analysis of this species indicate that blue-green and red algae, diatoms, larval and adult forms of small insects, crustaceans, molluscs, and small fishes make up the main diet of flamingos (Ramesh and Ramachandran, 2005).

Flamingos use shallow wetlands in which variations in water levels are very dynamic (Rendón-Martos, 1996; Baldassarre and Arengo, 2000). These variations may occur both within as well as between years, and this may affect food availability. This in turn may affect the quality and/or quantity of food received by chicks, which may translate to differences in body condition of those chicks. Because nutrients may influence blood chemistry, some blood parameters may be used to assess the nutritional condition of individuals (Perry *et al.*, 1989; Amat *et al.*, 2007).

It is also well known that an important component of the diet of the Lesser Flamingo was the filamentous blue- green algae, *Spirulina* (Jenkin, 1957; Vareschi, 1978). From crop content analysis, Jenkin (1957) also reported that Lesser Flamingos ate benthic diatoms. However, there were no time series data on the distribution of flamingos in relation to the abundance and availability of these algal food resources (Tuite, 2000). He also found a correlation of the Lesser Flamingo with planktonic blue-green algae *Spirulina*, and benthic diatoms. Two distinct patterns of population distribution were observed, clumped and dispersed. The clumped distribution occurred when a high density bloom of *Spirulina* was available at one or more of the larger lakes in South Africa. Productivity models showed that the carrying capacity of *Spirulina* when present at 1 of these larger lakes was sufficient to support more than the entire population of Lesser Flamingos at one site. However, the standing crop density of *Spirulina* could fluctuate significantly over short time periods. When *Spirulina* density fell below a certain threshold, Lesser Flamingos could not obtain enough food to meet their energy requirements. *Spirulina* blooms were not widely available, and Lesser Flamingos were forced to change their diet to benthic diatoms when none of the larger lakes supported a high standing crop density of *Spirulina* (Tuite 2000).

Flamingos foraged in groups within coastal wetlands of the Yucatan Peninsula, Mexico and are regionally aggregated among sites, thus responding to variation in habitat availability and quality at different spatial scales. Therefore, food abundance and availability are likely factors determining flamingo movements and distribution according to Arengo and Baldassarre (1995).Wading birds use diverse strategies to exploit food sources and to cope with seasonal habitat fluctuations, and these strategies shape their foraging tactics, movement patterns, and breeding-site selection (Kushlan, 1986). The location of feeding sites and success of foraging depends on both past and present surface water conditions that influence the distribution, demography, and availability of prey species (Kushlan, 1986; Powell, 1987). With such a variable environment, the advantages to feeding in a group are the increased ability to find available food and decreased searching time, which appears to occur for flamingos in Yucatan (Arengo and Baldassarre, 1995).

Hydrological factors such as tidal inputs, groundwater discharges of fresh water, and major habitat perturbations such as hurricanes create a food base that acts like a shifting mosaic along the entire coastal wetland complex to flamingos in Yucatan, Mexico (Arengo and Baldassarre, 1999). American Flamingos in Yucatan, their population, social, and movement characteristics were shared with a number of nomadic species using highly variable habitats. White Ibises (*Eudocimus albus*) in the United States are known to exploit food resources that are highly unpredictable at large spatial and temporal scales, and they exhibit interregional shifts when feeding opportunities become degraded (Frederick *et al.*, 1996). A similar pattern of fluctuating conditions of wetlands and American flamingo use has been observed in coastal Venezuela (Guzman, 1986).

Arengo and Baldassarre (1999) found that hydrological conditions make the planktons unavailable to flamingos, whereby they were forced to use other sites in Coastal Wetlands of Yucatan, Mexico. Similar type of habitat use shift was documented in 1993 (Arengo and Baldassarre, 1995). Alternative sites were not necessarily lower quality sites, because flamingos chose to use them even when food availability was low. In Ria Lagartos Lagoon it was reported that flamingos rarely (Espino-Barros and Baldassarre, 1989). In Coastal Wetlands of Yucatan, Mexico, Arengo and Baldassarre (1999) found that seasonal variability in habitat availability was the major management implications because the maintenance of a stable flamingo population depends on the availability of multiple foraging sites that may not actively be in use at any given time. Fledgling body condition was influenced by water levels in the Camargue, which are very variable from year to year (Cxzilly *et al.*, 1994).

All five species of flamingos regularly feed in large flocks (Baldassarre *et al.*, 2000). Potential costs associated with feeding in groups include competition and interference with other group members. Among the benefits of group foraging, individuals can gather information about food sources from the group (Ward and Zahavi, 1973), or individuals can use the presence of others to locate favorable feeding sites ("local enhancement;" Krebs, 1978). Foraging in groups also may decrease per capita search time in patches, decrease the probability of individual predation, flush prey items, improve efficiency of catching prey, or exclude competing species (Bertram, 1978). The hydrological dynamics of the coastal wetlands are highly influenced by cyclical events (floods, tides, seasonal weather) and large natural disturbances and both types of processes can alter food abundance and availability (Robertson and Frederick, 1994). Hence, food was patchily distributed and foraging flamingos must choose patches at both local and regional scales (Arengo and Baldassarre, 1995, 1999). As a result of this, flamingo use of wetland areas changes throughout the year and from year to year (Arengo and Baldassarre, 1999, 2002).

In Yucatin Peninsula also the local level site changes for foraging in non-breeding American Flamingos were based on patchily distributed invertebrates and plant foods (seeds of widgeongrass [*Ruppia maritima*] and tubercles and oogonia of muskgrass [*Chara fibrosa*]; Schmitz *et al.*, 1990), and groups within a site appear to be distributed as predicted by the ideal free model (Arengo and Baldassarre, 1995). In wading birds, foraging efficiency may be increased by local enhancement (Erwin, 1985) because foraging groups advertise the presence of food. Because flamingos used different foraging behaviors to exploit invertebrate and plant-dominated patches, flamingo flocks may also provide information about food type in the patch.

Nonetheless, individuals in groups appear to receive payoffs by selecting patches of different food quality (plant vs. invertebrate), and potentially by reacting to feeding behavior and flock size of conspecifics as a cue to such quality (Arengo and Baldassarre, 2002).

Foraging behavior of flamingos has markedly increased from early summer to autumn (Studer-Thiersch, 2000). Their differences in foraging behavior were probably due to differences in quality and quantity of the plankton supply. The flamingos either forage in widely scattered groups or are concentrated within a few square meters (Studer-Thiersch, 1974). Flamingos feed at the bottom in winter and spring, when plankton production is low and foraging in the shallow pools largely reduced (Johnson, 1989; Studer-Thiersch, 2000).

The greater flamingo is a large, filter-feeding wading bird foraging in open bodies of water (Allen, 1956; Zweers *et al.*, 1995). Foraging occurs both day and night in this species. As tactile foragers, flamingos are not constrained to adapt prey capture tactics to the amount of light available during foraging. Flamingos commonly filter food underwater with a scything action of the head (Cramp and Simmons, 1977). While underwater, detection of predators or any sources of disturbance is not possible. The head is held upright above water between feeding bouts, thus allowing vigilance. Vigilance and feeding are therefore clearly delineated and incompatible activities.

Because of its large size, the greater flamingo has few or no natural enemies (Cramp and Simmons, 1977; del Hoyo *et al.*, 1992; Ce´zilly *et al.*, 1996). Nevertheless, flamingos are sensitive to human disturbance (e.g. by boats or walkers; Galicia and Baldassarre, 1997; Arengo and Baldassare, 2000). In open bodies of water with no obstacles to visual detection, human disturbance is not like a stalking predation threat, and the war-of-attrition argument is not expected to favour randomness in vigilance patterns. Detection of human disturbance should be achieved best by regular scanning of the surroundings. Upon detection, flamingos can then choose to stay or leave the area, depending on the distance between the source of disturbance and themselves (Beauchamp, 2006).

The Greater Flamingo (*Phoenicopterus ruber roseus*) breeds irregularly in salt lakes, marshes, and salt pans in Spain, France, Tunisia, and Sardinia, and breeds regularly in salt pans in the Camargue (southern France), and at the temporary lake of Fuente de Piedra Lake (Fuente de Piedra, southern Spain; Rose and Scott, 1994; Rendon-Martos and Johnson, 1996). Successful mass breeding is possible only in optimal conditions of water levels and biological productivity both around the breeding site and at alternative foraging areas (Rendon-Martos *et al.*, 1991; Cezilly *et al.*, 1995; Rend6n-Martos, 1996). The foraging range of flamingos between breeding colonies and alternative foraging areas has been documented by several authors (Rooth, 1965; Brown, 1975; Rendon-Martos, *et al.*, 1991; Rendon-Martos and Johnson, 1996; Johnson, 1997).

For Greater Flamingos, Camargue is recognized as a high-quality breeding site with high-quality individuals (those in good condition) within the Mediterranean region (Nager *et al.*, 1996). Green *et al.*, (1989) found that differences between partners in the proportion of individuals observed in two different wintering sites Tunisia and Spain. Greenwood & Harvey (1982) reported that Juvenile flamingos disperse widely from their natal site after their independence. In Greater Flamingos fledgling body condition is affected by environmental conditions (water levels), and because tarsus length in fledglings is variable from year to year (Johnson, unpublished data and tarsus length may also partly reflect growth conditions. Barbraud *et al.* (2003) found that body condition can affect dispersal patterns of young Greater Flamingos that disperse over long distances, and support the hypothesis of good body condition as a critical prerequisite to dispersal. Juvenile flamingos moving to Tunisia must fly 800-850 km over water to reach feeding areas. Although flamingos fly in formation (Johnson, 1989), which may reduce energy expenditure (Weimerskirch *et al.*, 2001) during sea-crossing, they seldom rest on the sea, and they need greater energy reserves than birds dispersing to Spain, which have several stopover sites available along their route (Green *et al.*, 1989). Individuals in relatively poor condition which attempt to cross the Mediterranean Sea are probably at greater risk, and may rather stay within the natal area, resulting in relatively low dispersal rates at intermediate or low levels of body condition.

Barbraud *et al.*, (2003) identified some proximate factors to explain the relationship between body condition and dispersal in juvenile Greater Flamingos. Young flamingos are faithful to their first wintering site and both natal and breeding dispersal rates were low in the Camargue flamingos population (Nager *et al.*, 1996). Flamingos disperse in order to spend the winter in safer winter grounds to avoid unfavorable climatic conditions in the breeding ground, which is considerable for a long-lived species (Lebreton *et al.*, 1992).

Intraspecific competition may be an ultimate cause of dispersal, with age-related behavioural dominance as part of the mechanism responsible for dispersal of juveniles. A tyrannical distribution of flamingos has been shown to occur in breeding colonies, with younger individuals displaced to lower-quality nesting colonies (Rendon *et al.*, 2001). A similar pattern of settlement of individuals may also occur after the breeding season and during winter and would explain the dispersal of juveniles in Camargue flamingos (Barbraud *et al.*, 2003). In the closely related American Flamingo *P ruber ruber*, Schmitz and Baldassare (1992) found that juveniles lost more encounters than adults in aggressive interactions during foraging among non-breeders.

The effect of body condition on susceptibility of flamingos to predation was studied in Austria with relevance to wild populations (King, 2000). Mycobacteriosis (tuberculosis) was almost certainly responsible for >30,000 Lesser Flamingo deaths in Kenya during a 6-month period in 1993-94 (Kock *et al.*, 1999). Analyses of mortality at the Wetland and Wildfowl Trust in

Slimbridge suggested that flamingos had a natural immunity to tuberculosis as found by Brown and Pickering (1992). Infection by mycobacteria, causing avian tuberculosis, and poisoning by heavy metals and pesticides have been thought to be major contributors to the observed deaths in Kenyan Lakes (Kairu, 1996; Nelson *et al.*, 1998; Kock *et al.*, 1999). More recently, however, poisoning from cyanotoxins was found to contribute to the observed deaths in the Kenyan volcanic lakes (Krienitz *et al.*, 2003). (Lugomela *et al.*, 2006).1986-87 study in Celestun reported that non-breeding flamingos spent 45-56% of their time feeding, followed by 18% preening, and 12% resting. Following hurricane Gilbert in 1988 found that feeding time increased to near 90%. Food items available to flamingos were gastropods (40%), muskgrass (Chara spp.) bulbils (26%), crustaceans (11%), and chironomids (10%); food was distributed in patches. Flamingos initially concentrated where food was most abundant, but dispersed to other areas as they depleted food resources.

Flamingos used the high-salinity ponds year-round and the low-salinity ponds during wet seasons (Baldassarre and Arengo, 2000). Feeding (28.7-46.4%), preening (14.8-29.7%), and resting (8.8-19.3%) were the major activities of adults during each month. Immature spent most of their time feeding (57.2-68.5%) and <1% of their time in activities associated with breeding in Caribbean Flamingos (*Phoenicopterus ruber ruber*), in Yucatan, Mexico in 1987 (Espino-Barros and Baldassarre, 1989). Adult activity varied somewhat among habitat types, with feeding being an important activity in man-made ponds associated with commercial salt operations.Feeding time was higher and aggression was much lower than observed in foraging flocks of American Flamingos (Schmitz and Baldassarre 1992). Time spent in courtship activity by adults increased from October (0.2%) to peak in February (21%); courtship activity of immatures was <1% during all months. Time spent in any other activity usually was <10% for both age classes. They also found that habitat conditions in the estuary did not appear threatened, however, the potential for disturbance exists as increasing numbers of tourists are guided up river to view flamingos.

Flamingos in Zoo

Flamingos were kept in the zoos worldwide (King, 2000). Keeping flamingos in zoos has a long tradition and appears to be easy. Flamingos may reach a very old age in zoos, and since the late 1950s they have bred successfully in an increasing number of institutions (Studer-Thiersch, 2000). Flamingos are usually highly colonial breeders, there are examples of flamingos breeding in group sizes similar to captive colonies, in the Galapagos (Sprunt, 1975), Turkey (Kirwan, 1991), and Italy (Albanese *et al.*, 1997). Many captive flamingos maintain long-term pair bonds (Shannon, 1985; Stevens *et al.*, 1992; King, 1994), whereas Greater Flamingos in the much larger Camargue breeding population rarely do so (Cezilly and Johnson, 1995).The Basle Zoo in Switzerland was among the first zoos to breed flamingos, and since 1958 they have raised a variable number of chicks nearly every year. However, observations on the causes of egg losses in the settling breeding colony of

Greater Flamingos (*Phoenicopterus ruber roseus*) at the Basle Zoo in the late 1980s revealed that >50% of the eggs laid were abandoned in the very first days after laying due to high aggression and low breeding motivation. The replacement of eggs was common, and a few females subsequently laid up to 6 eggs. Although several chicks were reared every year, the breeding of the flamingos was regarded as unsatisfactory. Because other zoos appeared to have similar problems, the high amount of egg loss was interpreted as a husbandry problem (Studer-Thiersch, 2000). Long-term studies of mate selection and extra-pair copulations on flamingos were undertaken in some zoos, including Basle Zoo (since 1959), Rotterdam Zoo in The Netherlands (since 1992), and San Antonio Zoo in Texas, USA (since 1981).

The effect of increased social stimulation through augmentation of the population size has been observed in zoos (e.g., Pickering *et al.*, 1992; Stevens and Pickett, 1994), and a study of the relationship between colony size, group display, and reproductive success was undertaken at Dallas Zoo in Dallas., Texas, USA (King, 2000). Captive flamingo pairs alternate incubation and chick-care duties more than their wild counterparts. Incubation shifts in the Greater and Caribbean Flamingo were observed by Cezilly (1993). However, nest-building, incubation, parental and defense behaviors, and division of labor were similar between captive and wild flamingos (Cezilly *et al.*, 1995).

Impact of disturbances on Flamingos and their habitats

Tourism / recreation: The effect of motorized tour boats on the behavior of non-breeding American flamingos (*Phoenicopterus ruber ruber*) in the Celestuin Estuary, Mexico, from November 1994 to February 1995 was studied by comparing activity budgets between flocks of flamingos disturbed and undisturbed by tour boats. Disturbance reduced feeding time from 40% before disturbance to 24% after while alert behavior increased by 400%. Tour boats averaged 13 per day and caused a disturbance 75% of the time or 3.3 hours per day. Potential loss of feeding time for individuals was estimated at 13% but is likely much higher on days with excessive numbers of tourboats (Galicia and Baldarasse 1997). Flamingos returned to normal feeding rates (40%) within 20 minutes after disturbance. Most tourists (52%) were from Mexico, followed by Germany (14%) and, 88% of Mexican visitors were willing to pay an entrance fee to the Celestuin Reserve. Childress *et al.*, (2007) recommended that conservation efforts should focus on education of tourboat operators to reduce disturbance to flamingos, education of tourists through a visitor's center and brochures produced in Spanish and English, and expanded involvement of local people.

The impact of recreational activities in the Pampaa's wetlands in Argentina showed that recreational activities on transitional areas has only instantaneous effects on water birds because they return to that area in absence of disturbance (Cardoni *et al.*, 2008).

Altered hydrology and/or water quality: The ecology of the Lesser Flamingo is highly specialized (Childress *et al.* 2007). Its diet is limited to microscopic cyanobacteria and benthic diatoms that occur only in saline/alkaline lakes, salt pans and coastal lagoons, and the species is known to breed in only five locations throughout its vast range from Ethiopia to South Africa and from West Africa to India. The species is not only dependent on a specialised habitat, but because it is adapted to respond to changes in environmental conditions by moving among sites regularly, it is dependent on a network of such sites. The growth of cyanobacteria and diatoms in the costal mudflats was influenced by water chemistry. Wet mud surface is support to growth of diatoms. Several hours each day when the surface of the water is sufficiently calm it enables the flamingos to feed or otherwise are unable to are confined to the limited areas of wet mud.

The Lesser Flamingo is sensitive to changes in water levels and quality. Cyanobacteria, its primary food, require a certain range of salinity to reproduce in sufficient quantities to feed large numbers of Lesser Flamingos. Changes in the abundance of cyanobacteria can have a substantial effect on the Lesser Flamingo population at a site. Water levels are also critical to successful breeding. If the level is too high, the birds are unable to build their nests. If it is too low, terrestrial predators are able to reach the nests and destroy the breeding attempt. If the water level drops prematurely after the eggs are laid, but before the chicks are ambulatory, terrestrial predators are able to reach the colony and destroy the breeding attempt by feeding on the eggs and chicks.

Changes in water and salinity levels can occur either from natural causes (*e.g.* from flooding due to heavy rainfall or evaporation due to prolonged drought), or from man-made causes including increased flooding and sedimentation due to deforestation, over-grazing or an increase in arable farming on steep slopes in the catchment, or reduced inflows and water levels due to drainage of land for agricultural or roads, buildings and other infrastructure, creation of dams and reservoirs, canalisation of rivers, diversion of rivers, abstraction from feeder streams and rivers for irrigation and drinking water, and reforestation.

Extraction of salt and soda ash: The saline lakes and pans traditionally have been important sources of salt for human use. Extraction methods vary from small local evaporation projects to large commercial operations run by international corporations often requiring their own power plants, roads and employee villages. While the flamingos can live with most small local projects, the large commercial operations can have devastating effects, depending on their size, location, methods and hours of operation.

Invasive plants: Invasive fresh-water plants, particularly *Typha* in West Africa and macrophytes elsewhere may reduce the shallow littoral area available for Lesser Flamingo feeding. In the lower Senegal delta, both Greater and Lesser Flamingos are found in 'non-saline lakes. These lakes are linked to an estuarine hydrology, so their salt levels fluctuate. The water in these lakes is essentially brackish, sometimes fairly fresh, sometimes fairly salty depending on rains, tides etc. However, dams and canalisation have reduced the inflow of salt water to many areas, so many of the lakes have become more fresh water than brackish or saline. This has resulted in a massive growth of *Typha*. More recently, some counter-balance hydrological improvements have been initiated, which have resulted in some measure of restoration of former hydrological systems. However, the *Typha*, once established, is difficult to eradicate, and cannot simply be removed by periodical flooding with salty water.

Building roads, buildings and other infrastructure: The disturbance caused by the building of roads, buildings and other infrastructure projects near a Lesser Flamingo feeding or breeding site, and the resulting long-term increase in human activity in the area may cause the abandonment of the site. Githaiga (1995) stated that flamingo conservation is difficult due to their spontaneous and unpredictable movements.

Habitat Mapping

Kondratyev *et al.* (1994) studied the application of remote sensing techniques to comprehensive monitoring of inland water ecosystems. Spatio-temporal changes in the Mediterranean wetland of Northern Greece were studied by using remote sensing and GIS (Papastergiadou *et al.*, 2008). Malthus and Mumby (2003) reviewed the use of remote sensing on the coastal zone management. Zoran and Anderson (2006) studied the use of mutlitemporal and multi spectral satellite data for change detection analysis of the Romanian Black Sea coastal zone. Miller and McKee (2004) studied the concentrations of total suspended matters in coastal waters by using MODIS Terra 250m imagery. Eenie creek road Noosa environmental Project reported a road in Eenie Creek over the Noosa Fish Habitat Area and Koala and other fauna corridors. The process has been accepted as a best practice model for future infrastructure projects having environmental impacts in sensitive environments having higher order conservation values, and requiring approval from state agencies (Eenie creek road Noosa environmental Project). Nayak and Bahuguna (2001) studied the application of remote sensing data on the changes in the mangroves and other coastal vegetation of India. Jagtap *et al.* (2001) assessed the coastal wetland resources of central west coast India by using Landsat data and Nayak (2002) used the satellite data in coastal mapping of India. Wetland mapping was done in India by Space Application Cnetre (SAC 1998) and Prasad *et al.*, (2004).

Sasamal *et al.*, (2007) studied the pollution in the coastal waters of the Mumbai by analyzing the spectral signature with high resolution IRS-L3 data at the sewage discharge points in the Thane creek. The sewage distribution pattern was studied with reference to local tide on 21 February 2002 and 29 October 2002. The sewage plumes were identified off the discharge points in Thane Creek, Mumbai and spread areas were estimated indicating relatively high concentration of pollutants in the inner creek. Jha *et al.*, (1999) studied the accumulation of mercury and nickel in Thane Creek, using 210Pb dating technique.

Environmental Contamination

Pollution of the feeding lakes, pans and coastal areas may cause large scale illness and death. Large-scale die-offs, each involving tens of thousands of Lesser Flamingos and attributed variously to pollution by industrial heavy metals and pesticides, have occurred on feeding lakes in Kenya and Tanzania. Pollution due to pesticides and industrial heavy metals is a problem also in Botswana.

Organic contaminants

OCPs are of concern because of their high bioaccumulation potential and harmful biological effects (Tanabe, 1991; Tanabe *et al.*, 1994). The mobility characteristic has resulted in their detection even in remote areas of the Polar Artic (Iwata *et al.*, 1994, Stern *et al.*, 1997) and Antarctic regions (Focardi *et al.*, 1991; Ockenden *et al.*, 2001). Recently, many new broad spectrum pesticides have been developed. However organochlorine pesticides continue to be the potential group of chemicals used in control of agricultural pests and vectors of diseases like malaria (David *et al.*, 2003). Extensive use of organochlorine pesticides to protect the crops in agricultural fields has resulted in serious health hazards to the non-target aquatic organisms mainly fish, which is directly affected by the pesticides due to residue accumulation in their body (Hazarika, 2003).

Production of pesticides started in India during 1952 with the establishment of BHC production plant near Culcutta. India is now the second largest manufacturer of pesticides in Asia after China and ranks twelfth globally (Saiyed *et al.*, 1999). Polychlorinated biphenyls are a mixture of chlorinated biphenyl congeners (CBs) that differ in the amount of chlorine attached to the biphenyl molecule. Toxicity of PCBs has been related to the position of the chlorine on the biphenyl molecule. Chlorinated Biphenyls (CBs) having no or only one chlorine in the ortho positions are responsible for the most acute toxicity (Poland and Knutson, 1982; Hoffman *et al.*, 1998). It is also characterized that the PCB congeners, namely 201, 209, 172/192, 194 and 195 have greatest bioaccumulation factors (Falandysz *et al.*, 2003).The most abundant PCBs in the environmental samples analyzed are PCBs nos.138 and 153. Congeners with low chlorination grade are more readily metabolized and eliminated than highly chlorinated congeners (Schulte and Acker, 1974).

The *mono*-ortho substituted PCB congeners such as 105, 118, 123, and 167 are thought to have high toxicological and biochemical activities, but somewhat less potent properties (Safe, 1985; Tanabe *et al.*, 1987). Although the most toxic congeners, namely 77, 126, and 169 are present in very small amounts in most industrial PCB mixtures (Albro *et al.*, 1981), these coplanar congeners along with their less toxic mono or ortho- substituted analogs, among 105, 118, 156, 157, 167, and 189 are even considered as a greater threat to terrestrial and marine mammals than polychlorinated dibenzodioxins and dibenzofurans.

The levels of *p,p'*-DDT in the fish muscle tissue depend on the contamination of the aquatic environment and also on the mode of feeding of the fish as well as on the size weight and length and reproductive status of the individual. Britto *et al.*, (2002) stated that the major organochlorine residues involved in water pollution is Lindane, the gamma isomer of BHC. It is one of the most widely used OC insecticides in controlling crop pests. Regarding the alicyclic family, beta HCH has been reported as the most persistent isomer (ECO/OPS/OMS, 1995).

While the Council of the European Communities (1980) suggested the limit for HCH in natural water (3μg/l) and reported the maximum permissible limit for γHCH (4 μg/l) and DDT in drinking water (1 μg/l). The concentration of total DDT in marine fishes of Hong Kong markets ranged between 2.30ng/g and 1018ng/g and the higher concentration is recorded in *Snubnose pompano* (Cheung *et al.*, 2007). It has been reported that carnivorous fishes normally contain the highest lipid content as they are the top consumers in the food chain and will accumulate more POPs such as DDT due to its lipophilic nature, though factors such as size, age and species will also affect the rates of their bioaccumulation (UNEP, 2002).

Dickman and Leung (1998) estimated that a person in Hong Kong consumes fish or shellfish four or more times a week averaging about 164.4 g/day, which is higher than the fish consumption rate of 142.2 g/day, set by USEPA (2000). The maximum permissible value of DDT in fishery products set by China's National Environmental Protection Agency (NEPA) is 1000 ng/g wet weight based on 23 g/day of fish consumption rate. Picer *et al.*, (1991) reported total DDT in the coastal water of Adriatic Sea with the concentration ranging from 0.1 ppb to 93.9 ppb, whereas, the total PCB concentration ranged between 0.5 ppb and 294.0 ppb. Total PCB concentration of the inter - tidal sandflat Sediments from Manukau ranged from 0.20 ng/g to 2.08 ng/g and the total DDT concentration 0.07 ng/g to 21.93 ng/g. Lindane varied from 0.03ng/g to 0.50 ng/g, where Heptachlor epoxide and Dieldrin measured not detectable value to 0.06 ng/g and 0.05 ng/g to 0.41 ng/g respectively (Holland *et al.*, 1993).

Manirakiza *et al.*, (2002) studied seven species of fishes in Lake Tanganyika, Burundi, Africa and reported the maximum concentration of PCBs in *Baulengerochromis microlepis* (153:34.7 ppb) followed by *Oreochromis niloticus* and *Lates stappersii*. PCBs were detected in all fish species analyzed at levels higher than those of *p,p'* DDE, the most abundant OCP residue in Guanabara Bay fish (Sarkar *et al.*, 2002).

Yamaguchi *et al.*, (2003) reported the mean PCB concentrations to be 3.32 ppb, 1.83 ppb 1.85 ppb, 36.6 ppb, and 64.2 ppb dry weight in Roach, Perch, Pike, Dace and Eel respectively. Kannan *et al.*, (1992), reported mean PCB concentrations (wet weight) of 3.5 ppb and 330 ppb in fishes and prawns collected from different locations in India.

PCB concentration in mudflat sediments from the inner Thames Estuary averaged at 14 μg/kg with a maximum value of 120 μg/kg at Grays, located in close proximity to Tilbury docks. Hartmann *et al.*, (2004) reported a maximum of 1760 of PCB, in Narragansett Bay surface sediments. The PCB levels in 43% of the samples exceeded the effects range medium (ERM) guideline of 180ng/g, indicating possible adverse biological effects at the stations (Long *et al.*, 1995).

It is also reported that the total PAHs levels above 1 ppm is regarded as heavy contamination. This could be due to the pyrogenic and petrogenic origin, coming from the inflows of the rivers crossing industrial areas, oil and gasoline spills from boating operations.

Presence of organochlorine chemicals have been reported in various biota including fishes and birds. Fish uptake OCPs and PCBs rapidly from water, and depending on the species and habitat, also from the sediment or food to different degrees. Fish exhibit a low metabolism for OC and they concentrate the pollutants in their tissues directly through the diet, as well as from water (Muir *et al.*, 1990).

A study conducted by Rajendran (2005) in the coastal waters of Bay of Bengal reported the concentration of total PCB to range between 1.93 ppt and 4.46 ppt and total DDT between 0.13 ppt and 0.44 ppt. In sediment the concentration of total PCB and total DDT ranged from 19.9 pg/g to 6570 pg/g and 0.04 pg/g to 0.8 pg/g respectively. Sarkar and Sen Gupta (1990) reported the total DDT, γHCH and dieldrine concentration to range from 15.81 ng/l to 444 ng/l, 0.26 ng/g to 9.4 ng/g and not detectable value to 50.98 ng/l respectively in central West Coastal waters of India.

Sarkar *et al.*, (1997) reported the concentration of total DDT, total HCH and dieldrin in sediments of both Offshore and Estuaries of West Coast of India. They ranged from 1.47 ng/g to 25.17 ng/g, 0.85 ng/g to 7.87 ng/g and 0.70 ng/g to 3.33 ng/g in Weat coast estuaries and 1.14ng/g to 17.59 ng/g , 0.10 ng/g to 6.20 ng/g and 0.20 ng/g to 1.41 ng/g in Offshore sediment respectively. In the East Coast of India the total DDT of marine sediment ranged from 0.02 ng/g to 0.78 ng/g and dieldrine 0.05ng/g to 0.51 ng/g (Sarkar and Sen Gupta, 1991). A study conducted by Sarkar *et al.*, (1989) reported varying levels of chlorinated pesticide residues in marine sediments of Bay of Bengal; total DDT ranged between 0.02 μg/g and 0.78 μg/g and aldrin and dieldrin from 0.02 μg/g to 0.53ug/g and 0.05 μg/g to 0.51 μg/g respectively.

Study done by Kole *et al.*, (2001) reported the presence of endosulfan and hexachlorocyclohexane residues in market fish samples in Calcutta. The results showed that more than 50 % of 235 samples analyzed during 1993-94 to 1997-98 were contaminated with endosulfan residues in the range of 0.01 to 1.41 ug/g. About 16 % of the samples were above the maximum residue limit (MRL) of endosulfan (0.2 ug/g) prescribed by FAO/WHO for meat on fat basis. More than 80% of 157 samples tested positive for HCH residues in the overall range of 0.01 to 9.72 ug/g. The extent of contamination was, therefore, much higher by HCH than that of endosuflan. The majority of the contaminated samples were in the range of 0.21 to 2.00 ug/g of HCH residues.

The presence of varying levels of cyclodine insecticide residues were reported in Varanasi during South West monsoon and North West monsoon (Singh *et al.*, 2006). About 83% of the South West monsoon samples showed the presence of Aldrin.While the percentage occurence of dieldrin, heptachlor, Heptachlor epoxide and γ-chlordane were 8.3, 25, 29 and 54% respectively. A monitoring study by Singh and Gupta (2002) between 1997 and 2000 reported the presence of pesticide residues in different sources of drinking water of Jaipur, India. Kumari *et al.*, (1996) reported total HCH and total DDT in Soils and pond water of Haryana, Indi; the values of total HCH ranged from 0.048μg/g to 0.162 μg/g and 2.2 μg/g to 9.0 μg/g respectively. Total DDT concentration varied from below detectable level to 0.045 μg/g in soil samples and below detectable level to 2.7 μg/g in pond water.

Nair *et al.*, (1996) studied the DDT and HCH load in mothers and their infants in Delhi, India. Of all the levels of HCH isomers in breast milk, beta HCH was the most persistent isomer and is eliminated more slowly than the gamma isomers from the body (ECO/OPS/OMS, 1995). Karunagaran *et al.*, (1994) reported HCH and *p,p'*-DDE residues in eight species of edible fish comprising carnivorous, herbivorous and planktivoruos collected from landing centers of Kanniyakumari. Total HCH concentration ranged between 4.2 ng/g in *Sardinella longiceps* and 23.1 ng/g in *Scomberomorus guttatus*. The lowest concentration of *p,p'*-DDE was recorded in *Scomberomourus guttatus* (0.11 ng/g) and the highest (2.2 ng/g) in *Nemipterus japonicus.* The residual concentrations in fishes were well below the tolerance levels prescribed for fish products in India (DDT, 7 ug/g) (Anonymous, 1995), FAO/WHO, (HCH 0.2 - 0.5 ug/g and DDT 2.5 ug/g) and USFDA (DDT 5 ug/g).

Jayanthi (2004) reported the organochlorine pesticide residues in ten species of fishes caught at Cochin and Rameshwaram coast, and sold in Coimbatore, Tamil Nadu, India. A total of 389 fishes analyzed showed varying levels of residues of HCH, DDT, endosulfan and dieldrin. Among the ten species compartively high concentrations of pesticide residues were recorded in *Sardinella longiceps, Carangoides malabaricus, Chlorophthalmus agassizi, Saurida tumbil* and *Rastrelliger kanagurta.* Only four species of fishes showed monthly variation in residue levels and there was no significant correlation between the body size and residue levels in the tissue. About 22% of the fishes exceeded the Maximum Residue Limits (MRL) of total HCH prescribed by FAO/WHO for fish products. The calculated dietary intake of total HCH through consumption of the above referred species also exceeded the maximum ADI limits prescribed for human consumption.

Pandit *et al.*, (2006) carried out a study of Multi-compartment monitoring of residue levels of organochlorine pesticides in coastal marine environment of Mumbai. The concentration of total HCHs and total DDT in seawater varied from 0.16 to 15.92ng/l and 3.01 to 33.21ng/l respectively. Among HCH isomers, γ-HCH contributed almost 55% to the total HCH. The concentration of total HCHs and total DDT in different marine species varied from 0.87 ng/g to 33.73 ng/g and 0.38 to 34.1 ng/g respectively.

In India studies on fish (Kannan *et al.*, 1995), birds (Muralidharan, 1993) and soil (Singh, 2001) have provided information on the contamination status of persistent organochlorine pesticide residues in environment. Although a large number of studies are carried out on coastal ecosystem all over the world (Sericano *et al.*, 1995; Tanabe *et al.*, 2000), studies in India are limited.

Inorganic contaminants

Aquatic organisms can only survive within a particular temperature range. If the temperature goes too far above or below the tolerance range for a given species, its ability to survive may be compromised. Unnatural changes in water temperature impact directly the biota through loss of supporting habitat by changing the solubility of oxygen and calcium carbonate in water or by influencing the extent to which metal contaminants and other toxicants are assimilated by physiological processes (Luoma, 1983; Elder, 1988). Discharges of cooling waters from power plants and municipal or industrial effluent are sources of thermal pollution in the coastal zone.

Desirable pH for aquatic organisms is 6.5 to 8.5. Deviation from this range may indicate the entry of acidic or basic effluent (Gawas *et al.*, 2006). Aquatic organisms are very sensitive to pH. Most are severely stressed if pH drops below 5.5 and very few are able to survive when pH falls below 5.0. Moreover, as pH drops, certain toxic minerals such as aluminum, lead, and mercury, which are normally insoluble and relatively harmless, can turn lethal to fish and other organisms (Masters, 1991).

Turbidity is a measure of water clarity. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles. Turbidity results from coloured dissolved organic matter and suspended particulate matter in the water column. Degree of turbidity and changes in turbidity levels in the coastal and estuarine waters are an indicator for the state of environment. Algal blooms are often indicative of excessive loads of nutrients and can be an important cause of turbidity in eutrophicated systems. Increased turbidity will result in reduction of light available for photosynthesis (Duarte, 1995). Unnaturally high turbidity levels can lead to reduction in production and diversity of species.

Dissolved oxygen is one of the most important factors for existence of an aquatic organism in a water body. Dissolved oxygen concentrations reflect equilibrium between oxygen producing processes (e.g photosynthesis) and oxygen consuming process (e.g. aerobic respiration, nitrification, chemical oxidation etc.). It is of prime importance in natural waters both as regular of metabolic process of biotic community and indicators of aquatic health. The DO levels in natural waters depend on physical, chemical and biological activities of a water body. Alteration in the DO levels will affect the aquatic organisms adversely.

Chemical oxygen demand is the amount of oxygen required to carry out oxidation of organic waste by using strong oxidizing agent, whereas biochemical oxygen demand is the amount of oxygen required by microorganisms to degrade organic waste anaerobically (Gawas *et al.*, 2006). Panigrahy *et al.*, (1999) documented dissolved oxygen in Orissa to vary from 5.90 to 8.70 mg/l in surface water and 5.23 to 8.37 mg/l in bottom waters. In general, dissolved oxygen is recorded higher in surface waters, decreasing with increasing depth. The higher concentration at the surface water may be due to the phytoplankton and higher solubility of oxygen in low salinity water. The low values of dissolved oxygen in bottom water are due to high salinity and consumption of oxygen due to decomposition of organic matter and respiration of the bottom fauna. Jegadeesan (1986) stated that the low oxygen content of water near the bottom perhaps may be due to the rapid oxidation of organic matter in the sediment and the slow diffusion of dissolved gases. pH of surface water varied from 7.52 to 8.19. There was a slight decrease in pH with increasing depth which may be attributed to an increase in CO_2 due to photosynthesis in the upper layers leading to the production of organic matter followed by its oxidation resulting in nutrient release.

Nitrates and phosphates in sewage fertilise sea water, leading to increase in the growth of phytoplankton in the sea. This acts as a food for minute animals which in their turn end up as food for fish, birds and large sea animals. The excessive nutrients lead to prolific breeding of the minute plants near the sea shore leading to eutrophication. This algal bloom prevents the sunlight from reaching deep in the sea. As a result, photosynthesis is either reduced or stopped, leading to decrease in the oxygen content. As a result, fish which requires about 3 mg of dissolved oxygen per litre of water, and other animals begin to die (Sharma, 2005).

Although phosphorous is essential for phytoplankton growth, it is a potential pollutant if it is found in higher concentrations (Saad, 1973 a). The concentration of NO_3-N and PO_4 in the water at Flic en Flac, Mauritius ranged from <0.1 to 0.2 mg/l and <0.01-0.06 mg/l respectively. The higher level of phosphate may be attributed to the intrusion of sewage as evidenced by lower salinity and pH at the stations in that part of Lagoon (Chineah *et al.*, 2001). Phosphates are also the most important limiting factor responsible for eutrophication of water (Wetzel 1983). Presence of synthetic detergents which are known to contain 30% organic poly phosphate may also be a reason for eutrophication.

Oil spills continue to pollute marine environment and pose big threat to our marine and coastal ecosystems. Oil prevents the transfer of oxygen into water and thus has harmful effects on aquatic life. Hydrocarbons even at low concentration may be ingested and then accumulated in marine plant tissues. Inland oil spills cause damage on their seepage into the soil and their vapours pollute the atmosphere and man (Gunasekaran and Mutunayagam, 2003). While oil films inhibit photosynthesis and formation of oxygen, the growth of plankton gets reduced. All aquatic animals depend, either directly or indirectly, on plankton, which is the basis of the trophic chain. However plankton can grow only when the solar radiation penetrates.

The level of the organic carbon in the sediments is reported to be a reliable index of nutrient regeneration and the productivity of water body. Metal ions present in atmosphere and soil also enter the marine system through precipitation and run off. They exhibit an enormous range if chemical reactions are closely related to the biogeochemical cycle in the marine environment. With rapid industrialization in our country, the risk of discharge of heavy metals, both toxic and non-toxic to the marine system is gradually increasing (Sengupta *et al.*, 1980).

Anilakumary (2001) conducted a study on sediment characteristics of Poonthura Estuary and observed that the low organic carbon content in the beach was during post monsoon period which can be ascribed to the sandy nature of the substratum which allows better percolation. The high values during premonsoon were ascribed to the heavy sewage discharges and the absorption of organic matter by the finer fractions of the sediment. Mixing of sewage is one of the principal sources of organic pollution in estuaries. In most unpolluted estuaries organic carbon content of the bottom sediment is < 5 % whereas in areas where organic pollutants are high, organic carbon level often exceeds 5 % (Alagarswamy, 1991).

The accumulation of metals in sediment could pose problems because such metals may act as a source of contamination when the physio-chemical characters of the environment are changed (Chen and Jiao, 2007). Metal ions present in atmosphere and soil also enter the marine system through precipitation and run off. With rapid industrialization in our country, the risk of discharge of heavy metals, both toxic and non-toxic to the marine system is gradually increasing (Sengupta *et al.*, 1980).

Joseph *et al*, (2003) observed trace metal concentration in sediment and water column of Cuddalore during southwest monsoon. During the monsoon, in water the concentrations of Cu (0.7 ppm), Ni (1.2 ppm), Zn (3.0 ppm), and Fe (31 ppm) were less when compared with post monsoon concentrations. (Cu-1.0 ppm; Ni-1.6 ppm; Zn -7.2 ppm and Fe -67.0 ppm). Concentration of trace metals in sediment during southwest monsoon (Cu-8.0 ppm; Cd-1.7 ppm; Ni-22.8 ppm; Zn -31.3 ppm and Fe-11.6 ppm) was less than post monsoon concentrations (Cu-93.4 ppm; Cd-1.2 ppm; Ni -33.7 ppm; Zn -919.3 ppm and Fe- 912.8 ppm).

Ship-breaking industries provide scrap steel for foundries and for a variety of reuse to local industry. This industry is the biggest source of heavy metal pollution to the marine environment. In addition, waste oils and other waste products are also discharged directly into the inter-tidal area on the beach (Sharma, 2005). Marine sediment is widely believed to act as a filter for many metals passing from terrestrial to the marine setting (Schubel and Kennedy, 1984; Tam and Wong, 2000; Yu *et al.*, 2000 and Morillo *et al.*, 2004) and to accumulate some metals within marine water bodies.

Meitei *et al.* (2006) reported phosphate in the waters of river Purna to be 0.96 mg/L to 1.9 mg/L at upstream, 1.9 mg/L to 1.2 mg/L at midstream and 2 mg/L to 2.3 mg/L at downstream. Maximum concentration of phosphates was recorded in summer and minimum in winter. Mishra *et al*, (1993) documented the dissolved oxygen concentration (3.3-5.6 ml l^{-1}) to have irregular pattern. Perceptible upstream increase in DO was noticed during monsoon season. Higher DO values were obtained once during July-August, which could be attributed to freshwater influx. Generally low DO values were noticed from March-June and this could be related to high salinity and high temperature. Higher concentrations of nitrate and silicate were noticed during monsoon (July-Sept.) while lower concentrations were observed during Feb-May. The level of phosphate was high in July at all the stations. This may be attributed to entry of phosphate through surface runoff during early parts of the monsoon seasons.

Swami *et al.*, (2000) observed the water quality status of Bombay harbour and reported the concentrations of NO_2-N, NO_3-N, NH_4-N and PO_4-P to be near critical levels. Concentrations of DO were normal. Since a good amount of water is readily and regularly removed from the basin, the vibrant water movements contributed towards the maintenance of the normal DO despite heavy loading of the organic matter. Further, it also provided a quick dispersion and high terminal dilution of the same as the bay water move into the open sea. The temperature varied from 22.8^0 C in January to 32^0 C in May. The pH values were found to be generally lower in basin waters when compared to those in harbour waters. The nitrate values varied from 0.43 to 50.66 μg-at.l^{-1}. Widely varying and high values noted in this study was attributed to the varying quantities of the waste discharged in the basin waters. The phosphate values recorded in harbour and the basin varied from 0.27 μg-at.l^{-1} to 7.19 μg-at.l^{-1} and 1.56 to 9.79 μg-at.l^{-1}, respectively. PO4-P was significantly in high concentration in the basin waters. Average concentration of 2.95 μg-at.l^{-1} was found to be approximating 3.5 μg-at.l^{-1} representing critical limit of the element in seawater.

Nayak *et al*, (2004) reported that the pH of Chilika lake was alkaline. High pH was found where larger amount of weeds are present. The photosynthesis of weeds may cause the lake water into slightly higher alkaline wherever they are present (SubbaRao *et al.*, 1981). Lower Dissolved Oxygen values reported, may be due to anthropogenic activities in and around Balugaon ghat area, whereas higher Dissolved Oxygen found in stations where more weeds are present may be due to photosynthetic activities. The higher nutrients were due to the land drainage brought out by river systems through which the inland soil and agricultural fertilizers were washed out and added to lake water.

Gouda and Panigrahy (1995) conducted a study in the Rushikulya Estuary in Orissa. Spatio-temporal distribution in surface water concentrations of NO_3^- –

N ranged from 0.37-18.48 μg-at. l^{-1} in 1988 and 0.04-22.27 μg-at. l^{-1} in 1989. Surface water PO_4^{3-} varied from 0.09-1.86 and 0.05-3.30 μg-at. l^{-1} during 1988 and 1989 respectively. Rapid increase of NO_3^- – N contents during the monsoon season suggests that freshwater discharge act as the primary source of NO_3^- – N into the estuary. This also endorses that the chief source of NO_3^- – N into the estuary is land runoff. The lower values of NO_3^- – N both during premonsoon (Feb-Jan) and post monsoon seasons show that the input of NO_3^- – N from the sea is low. The levels of PO_4^{3-}–P began increasing from July/September. High PO_4^{3-}–P contents during monsoon season together with strong negative correlation ($P \leq 0.01$) between salinity and PO_4^{3-}–P suggest that land runoff serves as the main source of phosphorous for the estuary.

Padma and Periakali (1999) conducted a study on physicochemical and geochemical studies on Pulicat Lake and reported that in the pre-monsoon period the pH ranged from 8.7 to 9.1 and in the post-monsoon period it ranged from 8.1 to 8.5. The reduction of pH in the post-monsoon period is due to the input of fresh water from river Kalangi. Three time increases in alkalinity during the post-monsoon period is due to the input of fresh water and dissolution of $CaCo_3$ from the sediments which increases the carbonate and bicarbonate ions concentrations in the water column.

Satpathy (1996) observed and reported the distribution, behaviour and seasonal variation of nutrients in coastal waters of Kalpakkam. High values (7-10 mg/l) of D.O were found during Northeast monsoon during which the salinity was minimum. Nutrients (Nitrate, Phosphate, Nitrite and Silicate) showed high values during monsoon period and low values during summer period. The large scale discharge from land runoff during Northeast monsoon might have contributed to the observed increase in nutrients during this period. Nutrients entrapped in the bottom sediments might have also been released to this water due to turbulence during the monsoon thereby enhancing nutrient content. The low nutrient levels observed in summer could probably be attributed to the utilization of nutrients by phytoplanktons as phytoplankton production reaches a maximum during summer at Kalpakkam (Sargunam, 1994).

Mahapatro and Padhy (2002) observed significant variations of nutrients in different seasons. The average nitrate and phosphate values were 3.85 μg at-l^{-1} and 0.83 μg at-l^{-1} respectively. Heavy rain and consequent land drainage cause high values during monsoon. Low concentrations of nitrate observed during premonsoon months which could be due to rapid utilization of nitrate by phytoplankton. Nair and Ramachandran (2002) reported that rainfall during monsoon results in heavy river discharge and transportation of sediments leading to increase in phosphate level. The presence of phosphate in an estuary can be taken as an index of potential fertility of the ecosystem as a whole (Redfield, 1934). High planktonic production leaves behind large amount of dead planktonic matter due to grazing by zooplankton. As this dead matter sinks to bottom, it gets oxidized and on settling its decomposition releases organic carbon into the sediment and part of which is then diffused in to the overlying water. The phosphate concentration ranged from 0.46 to 6.74 $mg.g^{-1}$ during monsoon and increased from 3.65 to 6.79 $mg.g^{-1}$ in post monsoon.

Sultana and Rao (1998) documented the bioaccumulation patterns of Cu and Cd in different organs of Grey mullet *Mugil cephalus,* a detritus feeder living in contaminated waters of the Vishakapatnam harbor, India. They observed high copper (25.17±5.13 ppm) in liver and cadmium (2.79±0.51 ppm) in kidney tissues. Krishnamurti and Nair (1999) documented the concentration of metals in fishes from Thane and Bassein creeks of Bombay, India.

Mathew (2004) conducted a study on heavy metal contamination in thirteen species of commercially important marine fishes available at Coimbatore market, supplied from Cochin and Rameshwaram coastal area of Kerala and Tamil Nadu respectively. The study revealed that on an average, the levels of metals such as copper, lead, zinc, cadmium and chromium were 0.62± 0.12, 1.65± 0.06, 7.40± 0.9, 0.07± 0.04 & 1.33± 0.08 ppm wet weight respectively. Al-Mohanna (1994) examined heavy metal concentration in five species of fishes and recorded lead and copper concentration to be higher in the liver (Pb - 27.03 ppm; Cu – 5.56 ppm) and kidney (Pb - 7.77 ppm; Cu – 1.66 ppm) than the concentrations recorded in muscle (Pb -1.73 ppm Cu - 0.57 ppm) and gills (Pb- 6.35 ppm; Cu - 0.92) of *Scarus strongylocephalus* collected from the Red Sea Coast, (Jizan), Saudi Arabia. The cadmium values ranged between 0.16 ppm and 2.53 ppm in muscles with the maximum in *Caranx melanphygus* and minimum in *Lethrinus lentjan.* Zinc levels in muscle tissues ranged between 2.7 ppm and 10.91 ppm with the maximum in *Lutjanus johni.* Thus, it has been proved that metal accumulation is more in gill, kidney and liver and this could be probably due to the presence of more binding sites and physiological role.

Jayakumar (2007) revealed that metal contamination in fishes collected from Cochin and Rameshwaram coast during different seasons in 2005-06 varied among species. Among the metals studied, Zn levels were very high in all the species. *Sardiella longiceps,* a plankton feeder recorded the maximum levels of Zn, Cu, Cr and Cd. The planktivorous diet and surface dwelling could be the two important factors for high accumulation in this species. Further, the levels of Zn and Cu recorded in muscle tissue could be treated as background levels as it matches with the earlier reports. It is understood that the significant variation in metal contamination among species could be due to inter-species differences, habit and habitat features. On an average, *Rastrelliger kanagurta* recorded the maximum concentrations of Cu (1.90+0.16 ppm) followed by *Nemipterus japonicus* (1.71+0.13 ppm). *S.longiceps* scored highest mean levels of Cd (0.12+0.02 ppm) and Zn (30.19+2.97 ppm).

STUDY AREA

Sewri

The Sewri Bay is situated just off the wide mouth of Thane Creek, along the northern periphery of Mumbai's eastern harbor. Sewri-Mahul region (19° 01'

00″ N, 72° 52′ 60″ E) has mudflats stretching from 'Reti Bhandar' area (where sand is transported from large boats to the land employing innumerable cranes) through Sewri Port and Sewri Fort areas extending to the Mahul region and finally merging with the Trombay region. This entire stretch of mudflats is flanked by mangroves on one side and the Mahul region holds an extensive cover of mangroves. The Sewri - Mahul mudflats have a surface area of about 4 sq km while the Mahul area has an extensive cover of mangroves. The Mahul rivulet, highly polluted with wastes from Vadala, drains directly into this area. Indian coast is continuously being threatened by effluent discharges from metropolis and industrial town. This gives rise to immense environmental problems leading to deterioration of water quality. There are many major industrial and port-related establishments located overlooking the Bay which include Tata Power Plant, Mumbai Port Trust (MbPT) Jetty, Bhabha Atomic Research Centre (BARC), Bharat Petroleum Corporation Ltd (BPCL), Aegis Logistics, Oil & Natural Gas Commission (ONGC), and Hindustan Petroleum Corporation Ltd. (HPCL). Mumbai is one of the major cities in India, which has great diversity of industries. The coastal region of Mumbai receives industrial discharges up to 230 million liters per day (MLD) and domestic wastes of around 2200 MLD of which 1800 MLD are untreated (Zingde and Govindan 2000).The geographical location and the altitude of the study locations are given in the Table 1.1 and marked on a map (Fig.1.1 & 1.2).

Nhava and other locations in the Thane Creek

Nhava in Navi Mumbai is located towards the eastern side of Sewri in the mainland. Shivaji Nagar is the nearest village closest to the site where the proposed MTHL Bridge will be meeting the mainland. Nhava harbours a vast stretch of inland shores fringed by a narrow strip of dense mangroves, open mangroves and mudflats. Other areas along that coast such as Uran, JNPT, Zasai and Vasi also had mudflats and saltpans which were reported to have occasional sightings of a few flamingos and hence were also surveyed periodically.

Survey locations outside Thane Creek

Bhigwan wetland (Co-ordinates – 18°14′ N, 74°44′ E) also known as Ujjani is a very large and well-known wetland site. It is situated 100 km from Pune on the Pune - Solapur highway (Fig. 1.3). This wetland harbours flamingos and was reported to have some problems during the construction of the highway, which passes closer to one end of the wetland. Hence, this area was also surveyed to understand the flamingo population.

Table 1.2. GPS readings of relevant locations in the study area.

Location	Coordinates	Altitude
Sewri Port	N 18 59′ 40.1″& E 72 51′ 45.1″	*c.* 3.5 MSL
Sewri Fort	N 19 00′ 03.4″ & E 72 51′ 40.6″	*c.* 13.8 MSL
Reti Bhandar	N 18 59′ 23.9″ & E 73 51′ 28.1″	*c.* 3.7 MSL
Nhava (Kher Kalouri)	N 18 58′ 20.8″ & E 73 00′ 22.1″	*c.* 4.0 MSL
Zasai village	N 18 55.′ 28″ & E 73 00′ 58″	*c.* 4.0 MSL
Vashi mudflats	N 19.03′.43.2″ & E 72.59′.02.8″	*c.* 3.7 MSL
Uran	N18.54′.53.7″ & E 72.58.26.9	*c.* 3.5 MSL

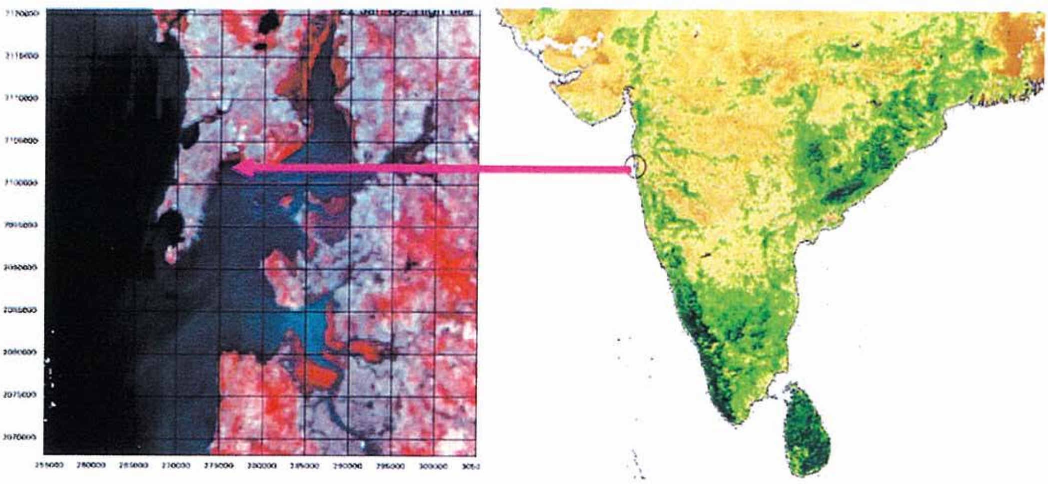


Figure 1.1. Study area showing Thane creek (MODIS data).

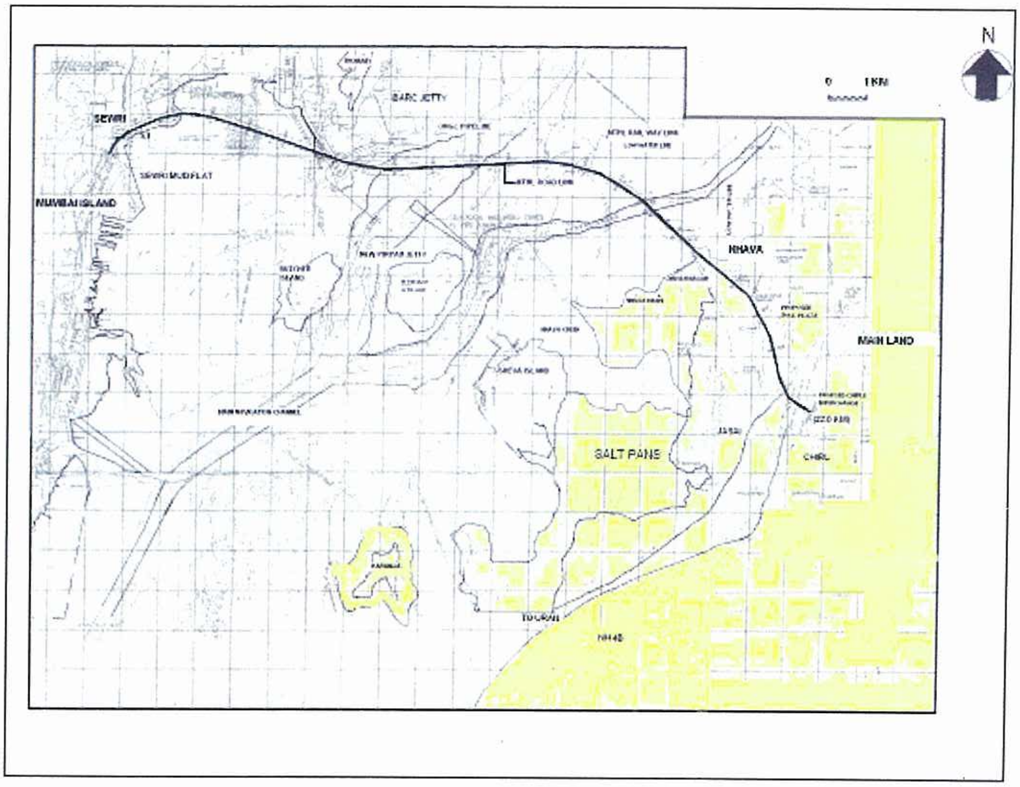


Figure 1.2. The study area showing the proposed bridge from Sewri to Nhava.

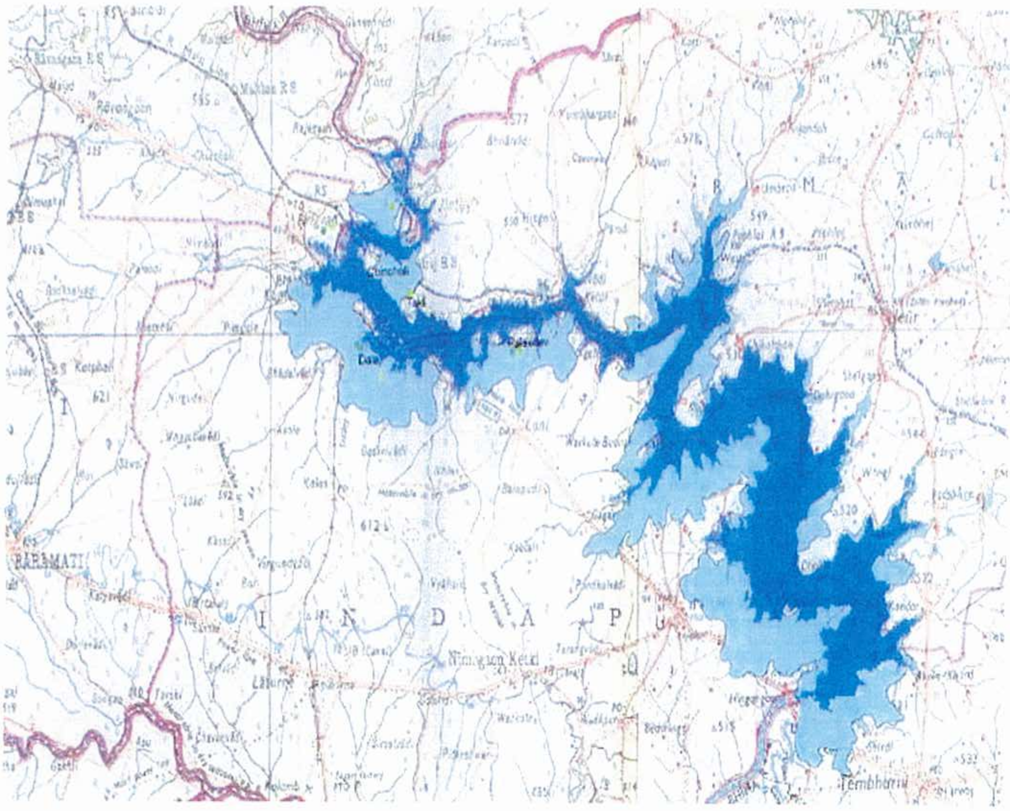


Figure 1.3. Bhigwan wetland.

Chapter 2

BIRD STUDIES

INTRODUCTION

Wetland birds form the most acceptable and internationally recognized wetland indicators (Weller, 1999). Diverse groups of waterfowl utilize different but more specific habitats (Baldassare and Bolen, 2000). Even among the ducks there are diving ducks using open water with submerged vegetation, dabbling ducks using shallow water with sparse vegetation while the grazing birds preferring more emergent vegetation (Vijayan, 1991). The wading birds, such as egrets and storks use that portion of the wetlands where the height of their tarsus suits the depth. Thus a wetland bird community would indicate the habitat diversity and health of the ecosystem (Weller, 1999). Apart from the scientific basis that it offers, wetland birds are so magnificient that they attract attention of a large number of people across the country (Vijayan, 1991).

Several studies have used the presence and abundance of some important groups of animals and plants for assigning conservation status to prioritise them (Singh and Taneja, 2000; Singh *et al.*, 2000). The Ramsar Criteria on birds were used to prioritize the inland wetlands of India for conservation (Vijayan *et al.*, 2004). BirdLife International has used some criteria on birds to identify important areas for conservation of birds and their habitats in different regions/countries and thus help conservation of biodiversity. In India also such a programme in collaboration with the BirLife Partner, the Bombay Natural History Society, has brought out the Important Bird Areas (Islam and Rahmani 2004) and the Mahul-Sewri mudflats in Mumbai is one among them. As this area is supposed to be disturbed by the construction of the proposed bridge, Mumbai trans harbour link (MTHL), it was found necessary that a study on the birds of this region, especially the flamingos should be taken up with emphasis on their population and habitat use.

Flamingos are wading birds adapted to use a variety of wetlands freshwater, brackish and coastal habitats with erratic movements to utilize favourable sites (Rendon-Martos *et al.*, 2000). Shorebirds are reported to show declining trends and hence of concern. They are also indicators of wetland health (Thomas *et al.*, 2006). Many large water birds are edging very close to extinction through the disturbance or conversion of their habitats, as well as intense hunting pressure in most areas and as a result about 20% of threatened bird species are found in the wetlands in Asia compared to about 10% globally (BirdLife International 2008).Two species of flamingos, namely the Greater and Lesser, reported from India, inhabit the coastal areas of Sewri-Mahul region. The Lesser Falmingo is a globally near threatened species based on a decline in area of occupancy, extent of occurrence and/or quality of habitat (BirdLife International, 2001, 2008; Childress *et al.*, 2007, 2008) and hence required special attention.

METHODS

Abundance of Flamingos and other birds

Flamingos and shorebirds were counted from two vantage points - Sewri Port and Remadevi Tekdi (in front of Tata Power) in the Sewri-Mahul region. Shorebirds were also surveyed along an approximately 1.5 km intertidal stretch at Nhava (Shivaji Nagar). During 2007-08 flamingos were reported from a few sites on the Navi Mumbai side and the coastal mudflats and salt pans were surveyed for the flamingos and other birds. The study areas are explained in Chapter 1. The following equipments were used for this study:

1. Spotting Scope (Nikon Field Scope ED 82)
2. withNikon 24/30 X Digi scoping & 25-75 X MC II Zoom Eyepieces
3. SLR Digital Camera (Nikon D70) with AF-S DX Zoom - Nikore ED Lens and Camera Attatchment FSA-L1
4. Binoculars (Nikon Monarch 10 x 42 DCF)

Identification of the birds was done with the help of books of Ali and Ripley (1987) and Grimmett *et al.*, (1998).

Studies were conducted in this region between August 2006 and September 2008, concentrating more in the Sewri - Mahul region as it was occupied by the Flamingos, whereas Nhava mudflats recorded many common smaller waders, but neither in such larger congregations nor by the flamingos. A preliminary survey in the study area was conducted observing birds during September 2006 for ten days as trial for finalizing the methods. Intensive studies were started from October 2006 and continued up to August 2008 with a small gap of October to December 2007.

The mudflats in the Sewri–Mahul region was divided into four blocks/sections namely Retibhandar (Section RB), Colgate Area (Section C), Mahul (Section M) and Remadevi (Section RD) as shown in Fig. 2.1. Existing landmarks were used for delineating blocks or compartments and additionally poles were fixed at known intervals. Total counts of birds were carried out by sample counting and estimation in these sections in different days. Counts of flamingos were made during both high and low tides from suitable vantage points in the Sewri - Mahul region. The number of flamingos was estimated by total count method (Bibby *et al.*, 1992) almost accurately counting individuals in a segment of a flock and then estimating the number of birds in each of the subsequent segments of similar length for the whole flock. Photographic counts were also used along with total counts to get a rather accurate figure. Photographs that were taken by Digi-scoping were used in estimation of flamingos as well as shorebirds in the Sewri – Mahul region with some modification from those of other flamingo studies (Woodworth *et al.*, 1997; Tourenq *et al.*, 2001). At least two counts were done monthly in each section and also in the Nhava region. Mean of the bird numbers in all the sections were calculated to get average monthly abundance.

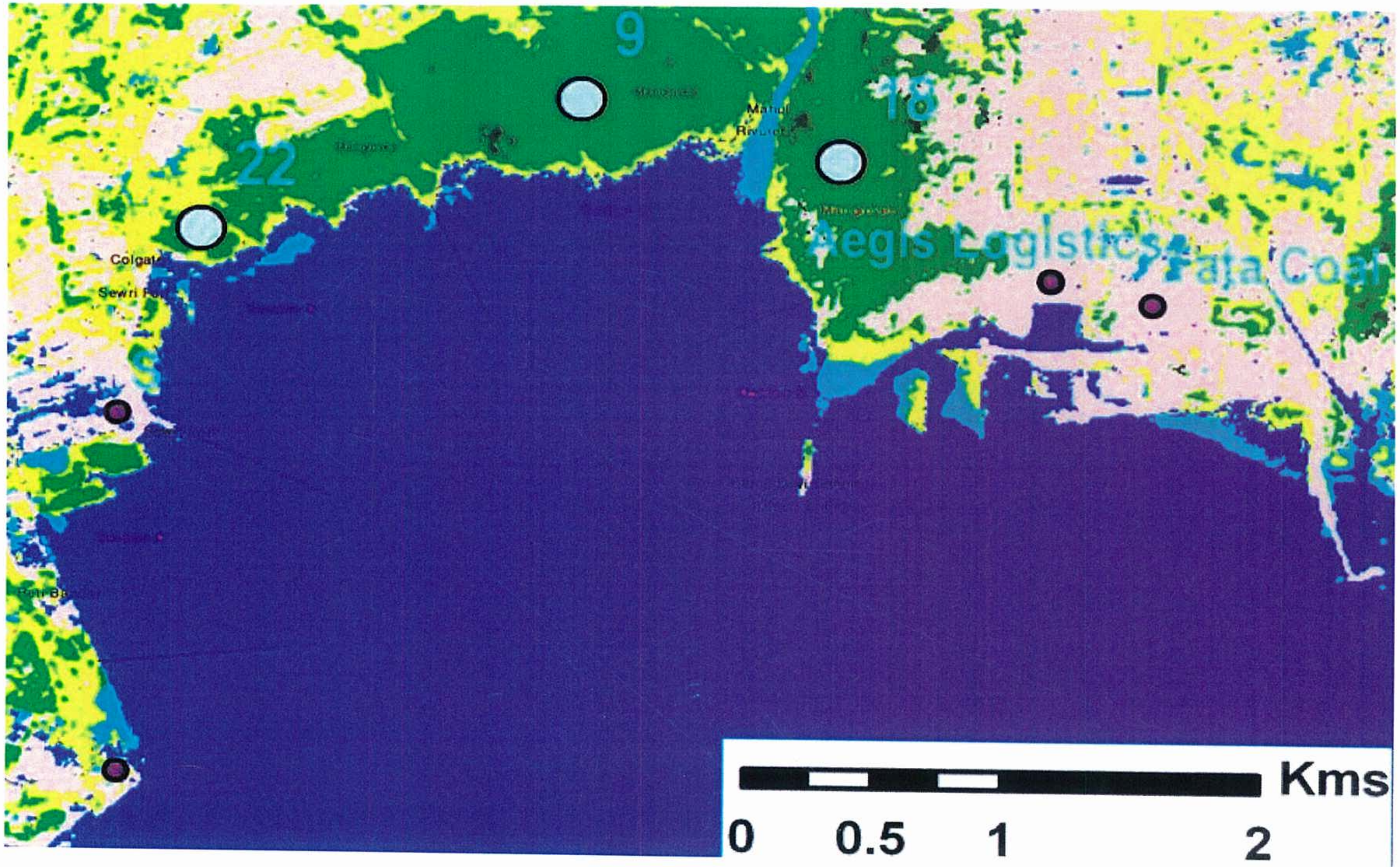


Figure 2.1. Delineation of the study area in the Sewri-Mahul region into different sections

During the population counts of flamingo, composition of the flocks was also recorded with the number of adults and juveniles/sub-adults of the two species of flamingos, namely the Lesser Flamingo *Phoenicopterus minor* and Greater Flamingo *Phoenicopterus ruber*. Sample flocks were selected, counted the number of adults and juveniles/sub-adults and their proportion was calculated.

Data were also collected on the ecology and behavior of the flamingos and, environmental quality of the habitat.

Scan Sampling (Population activity patterns)

Scan sampling (Altman, 1974) was used to measure the activity pattern of the Lesser Flamingo. Sampling proceeded from one end of a flock to the middle, by moving the spotting scope progressively in the same direction to prevent sampling the same individuals twice. The limited field of view of the spotting scope and the number of birds within that view served as a random sample (Schmitz and Baldassarre, 1992). In this way, behaviour of randomly selected ten individuals that were in the centre of the focus of the spotting scope was scanned at every 5 minutes intervals.

Activities were categorized as feeding (Rooth, 1965) (stamp feeding and walk feeding: Simmons, 1996) resting, flying (flying undisturbed, flying because of people or boats within 50 m; Staine and Burger, 1994), walking, preening, comfort, courtship, aggression, (Schmitz and Baldassarre, 1992) alert and standing (Simmons, 1996, Espino-Barross and Baldassarre, 1989). Scan sampling was conducted at different times of the day and across a wide range of tide heights and tidal elevations in all months during the study (Maron & Myers, 1985).

Evaluation of the habitat of the Flamingo

Water quality

Water Samples were collected from Flamingo feeding and non-feeding areas (although it was difficult to differentiate such areas as these birds changed the sites mainly depending on the water depth and, analyses were done as explained under chapter 5 on water quality and contamination.

Abundance of invertebrates

The phytoplankton, zooplankton and benthos in the different zones of the Sewri-Mahul region were investigated during the monsoon, summer and winter of 2007-08. The composition, distribution, abundance and diversity of plankton and benthos from the different stations in the eight zones of the mudflat are presented. Data were used to calculate macro-invertebrate abundance from the Lesser Flamingo feeding and non-feeding areas (Colwell 1993; Staine and Burger, 1994).

Abundance of plankton

The study region in the Sewri-Mahul mudflat was divided into four sections (as explained for bird counts) from which eight zones were identified for seasonal sampling (monsoon, summer and winter) of plankton samples. Eight zones were selected for the study in the four sections based on the feeding and non- feeding habitat of the flamingos in the mudflat. The eight zones selected were RBF (Retibhandar feed), RBNF (Retibhandar non-feed), CF (Colgate feed), CNF (Colgate non-feed), MF (Mahul feed), MNF (Mahul non-feed), RDF (Rema Devi feed) and RDNF (Rema Devi non-feed). These eight zones were further divided into 5 stations each and sampling was done to get a better understanding on the distribution and abundance of biota as well as its relationship to the flamingo population.

The plankton samples were collected in shallow water not far from shore (such areas where flamingos normally feed). Samples were collected by wading out into the water, plunging a 3.5 l saucepan to mid-depth, pouring its contents through 55 µm-mesh plankton net, and samples were transferred into vials and taken to the laboratory for analyses (Hurlbert, 1986).

The biomass of plankton was determined based on the displacement method and then was made up to a known volume and expressed as ml/ m^3 (APHA, 1995). Suitable volume of samples were analyzed for phytoplankton and zooplankton and their numerical density was determined and expressed as no/m^3 (APHA, 1995; Davis, 1955; Ward and Whipple, 1959).

Benthic macro-invertebrates (Benthos)

Mud samples were collected from inter-tidal mudflats from flamingo feeding and non-feeding areas as explained for plankton. Samples were collected by pushing a 10.5 cm diameter PVC pipe into the substrate to a depth of 10 cm. The benthic samples were passed through a sieve of 500 micron and was analysed for different fauna and expressed as no/m^3 (Fauvel, 1953; Holme and Mc Intyre, 1971). The invertebrates thus collected were grouped into segmented worms (Polychaetes), aquatic worms, snails, bivalves and amphipods and analyzed in detail to get the composition, diversity and seasonal variation.

DATA ANALYSES

Species diversity, species richness(s), dominance index and evenness index were analyzed based on Magurran (1991).

<u>Shannon - Weaver diversity index (</u> H')

In the present study, the data were analysed for diversity index (H') of birds and plankton using the following Shannon - Weaver formula (1949):

$$H' = -\sum_{i=1}^{s} Pi \log 2\, Pi$$

where, H'= species diversity in bits of information per individual
ni = proportion of the samples belonging to the i^{th} species (number of individuals of the i^{th} species)
N = total number of individuals in the collection and
Σ = sum.

Simpson dominance index(Lambda) (D)

$$D = 1 - C$$

where, $C = \sum Pi^2$

$$Pi = \frac{ni}{N}$$

ni = number of individuals of i^{th} species and N= total number of individuals.

Margalef richness index (d)

$$d = (S-1) / \log N$$

Pielou's evenness index (j')

The equitability (J') was computed using the following formula of Pielou (1966):

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\ln S}$$

where, J' = evenness,

H' = species diversity and S = total number of species

The flamingo count for each station was taken for that particular season and it was correlated with the plankton abundance using Pearson correlation.

Other statistical tests such as ANOVA, Mann-Whitney, t-test were carried out to test the variation in different parameters or groups.

RESULTS & DISCUSSION

Abundance of Flamingos

Although we started the intensive studies in October 2006, the first record of flamingos for the season at Sewri was on 27th November 2006 which comprised eight individuals of the Lesser Flamingo. Comparatively fewer numbers of the Flamingo was observed till January 2007. However, during March 2007 their numbers increased rather abruptly from 1,430 individuals in the first week of March to 10,520 (± 3471) individuals by the end of the month. The first record of flamingos for the second season (2007-08) at Sewri was at the end of October 2007 which comprised fifty individuals. The population started increasing slowly and reached about 6000 in January 2008. However, during the end of February 2008 their numbers increased to about 9000 individuals (6900.8 ± 2115) (Table 2.1; Fig.2. 2) and in March 2008 to 12996 (± 227.85).

A comparison was made with the last year's data and it showed that the flamingos reached earlier in the second year and the number of flamingos was also more. In January 2007, there were only 169 flamingos recorded while in the second year in January (2008) it was about 6000 (Table 2.1; Fig. 2.3, 2.4). The population increased and reached the maximum of 14,047 birds by the end of March 2008. However, their number started diminishing from the first week of May and it reached 2284 birds by the end of May. During 2006-07 the flamingo's maximum number was observed in April and the population plummeted to 12 individuals during the second week of July but in 2007-08 the maximum was in April 2008 and started leaving the mudflats in early May. Similarly in Caribbean Flamingos (*Phoenicopterus ruber ruber*) the population at the non-breeding ground at Yucatan in Mexico increased from October onwards and reached the peak numbers in January (Espino-Barros and Baldassarre, 1989). In western Venzeula also erratic movements of Caribbean Flamingos were recorded (Pirela, 20000). Chilean Flamingos also showed a heterogeneous distribution pattern in Argentina, Bolivia, Chile and Peru (Caziani *et al.*, 2007). The abundance and distribution of Chilean (*P. chilensis*), Andean (*P. andinus*) and James' (*P. jamesi*) flamingos in Andes showed a strong seasonal variation with maximum number in summer and minimum in winter (Hurlbert, 1978, 1979,1981; Rocha, 1997 ; Valqui *et al.*, 2000), so also in Argentina (Caziani *et al.*, 2001). It was mainly attributed to the winter freezing of wetlands there (Rocha, 1997; Caziani and Derlindati, 2000; Caziani *et al.*, 2001, 2007).

Abundance of the Lesser and Greater Flamingos at Point Calimere in Tamil Nadu showed variation in their abundance within and between years and between the two species during a study from 1988 to 1991 (Manakadan, 1995; 1998). He found that the population of the Greater Flamingo fluctuated between less than 100 to above 4300 with a peak during November - December, whereas the Lesser Flamingo was in fewer numbers of a few to less than 1000 with the peak during April - May. The total number of individuals increased steadily in both the years in a similar pattern. Population of the Lesser Flamingos counted in the inland wetlands was only about 28000 sighted at 18 localities (Vijayan *et al.*, 2004). Islam and Rahmani (2004) had reported that the population of the flamingos increased since 1994 to 2003 when it was about 17000 including 15000 Lesser Flamingo in the study area. The decline in the population may be because of their shift in sites, erratic movements (Pirela, 2000) or even a result of the overall decline in the populations in Africa (Simmons, 2000).

A seasonal pattern is apparent, with flock size being the lowest in the dry, cool months of December- February and rainy months of June - July, and the highest in the humid, hot months of March, April and May. Favourable conditions with respect to water level and food supply partly determine the movements and abundance of flamingos (Tindle and Tindle, 1978). Flamingo's distribution and local movement in the Andean and the lowland wetlands were mainly determined by the pollution levels and the impact of tourism (Childress *et al.*, 2007; 2008). Most of these areas were mainly polluted by agriculture, mining, industrial projects, and unregulated tourism (www. Flamingo Research and Conservation in the Americas.com; www. Flamingo resources.org.uk). It is possible that the best conditions for flamingos at Sewri occur during April-May as shown by an average count of at least 10,000 birds in these two months as explained above (Fig. 2.4). Such seasonal variations are observed in many species of flamingos which are related to various environmental factors (Espino-Barros and Baldassarre, 1989; Pirela, 20000; Valqui *et al.*, 2000; Caziani *et al.*, 2007; Childress *et al.*, 2008).

Flock composition of the Lesser Flamingo

In the present study the flamingos were observed in the Sewri - Mahul mudflats and the flock composition of Lesser Flamingos were analyzed from the abundance data. The flamingo arrival in the study area was not in a uniform pattern with more juveniles at the beginning which changed to more adults later in February-March (Table 2.1). The relative number of adults and juveniles/sub-adults showed less variation during December 2006 – February 2007 (60.5- 64% and 36- 39.5% respectively). A surge in number of flamingos in March resulted in the changes in the composition with increase in the proportion of adults (84%) than juveniles (16%). Similarly in 2008, the adult flamingos were present in higher proportion (80.8 - 85.5%) than the juvenile / sub- adult birds (19.2 – 14.5%) during January-February, when flamingos increased in numbers (Fig.2.5). In 2007 more proportion of juveniles came early in December (36 %) than in the later flocks in March (Table 2.1; Fig 2.6). During the second season also more juvenile / sub-adult birds were sighted in the Mahul area during November and December 2007 (as reported by others). However, during January more adult birds arrived and the population increased with an increase in the proportion of adult birds similar to that in March 2007.

The trend was similar up to June when flamingos were abundant. This might be because of the usual phenomenon of non-breeding or unsuccessful adults remaining in the area for feeding while the family with chicks left for new feeding grounds as reported in Greater Flamingos (Johnson, 1997) and this might also explain the late and erratic arrival of flamingos at Sewri. Flamingos are opportunists and not true migrants and some birds are sedentary over long periods in the breeding ground itself, while others from the same colony undertake movements up to 3000 km. A similar phenomenon has been reported in many other migratory species with the early departure of the families with the young moving to the non-breeding and feeding areas (Rogers *et al.*, 2006). As more water was available at Rann of Kutch during the season, breeding was extended and more adults stayed back as reported by Parasharya (pers. Comm.). However, the origin of the flamingos coming to Mumbai is also not certain as reported by Ali and Ripley (1987), and Manakadan (1995) and Ali *et al.* (1998) for the Point Calimere sanctuary in Tamil Nadu. There are records of the Greater Flamingo moving to Iran and India from Russia while the Lesser Flamingo is believed mainly to be from Africa and partly from Kutchh (Manakadan, 1995). In the Sewri - Mahul region about 2000 Greater Flamingos were recorded earlier (Islam and Rahmani, 2004), but none during 2006-07. Similar fluctuation in different years in the population of the flamingos in different sites were recorded in the Southern Rift Valley of Kenya (Nasirwa, 2000; Owino *et al.*, 2002); here also the Lesser Flamingo was 92% of the total birds and the Greater only 2%.

Table 2.1. Comparative account of monthly average abundance and flock composition of Lesser Flamingos at Sewri - Mahul region during March -July 2007 and 2008.

Month/ year	Average abundance (with Std. deviations)	Flock composition (in %)	
		Adults	Immature / Subadults
December 2006	46.2 (SD ± 48.8)	60.5	39.5
January 2007	169.1 (SD ± 44.6)	63.3	36.3
January- 2008	5098.6(SD + 791.44)	85.49	14.5
February 2007	179.6 (SD ± 31.8)	64	36
February - 2008	6900.8 (SD + 2115.15)	80.83	19.16
March-2007	3808 (± 3471)	84	16
March-2008	11367.6(± 2548.12)	76.81	23.18
April -2007	10045 (± 339.4)	83.70	16.30
April -2008	12996 (± 227.85)	83.89	16.17
May-2007	10362.5 (±118.1)	83.10	17.10
May-2008	4528 (± 2057.14)	70.29	29.70
June -2007	2793 (±2469.2)	93.5	6.5
June - 2008	1276.67(± 889.57)	81.57	18.42
July-2007	7.5 (±11.9)	2	98
July -2008	13 (± 1.41)	0	100

As their numbers plummeted in July, the adult-juvenile proportion became skewed and juveniles were relatively abundant in small flocks; 98% immature birds and 2% adults (Table 2.1). In the second season during May the adult birds started leaving from the mudflats and the flock composition changed with more juvenile birds (100 %) during the second week of July and this trend was similar to that in July 2007 in the Sewri mudflats. However, in both the years (2007 and 2008) the adult and juvenile proportion was almost similar but the date of arrival differed. The adults might have left immediately after heavy rainfall for occupying better sites for nesting leaving more juveniles at the feeding grounds in the Sewri - Mahul region. Another major reason for this departure might be the decline in food abundance, mainly the preferred food as found here and in other studies (Tuite, 2000) In natural areas, breeding is dependent upon abundant rainfall prior to the onset of breeding (Johnson, 1997).

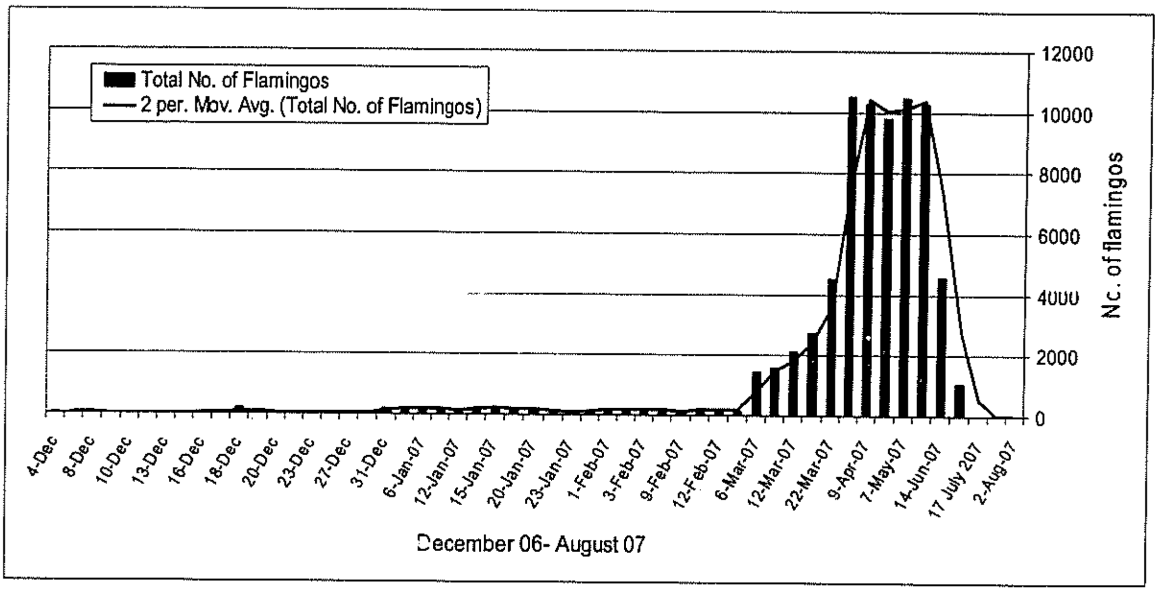


Figure 2.2. Overall frequency of sightings of the Lesser Flamingos at Sewri - Mahul region during 2006-2007.

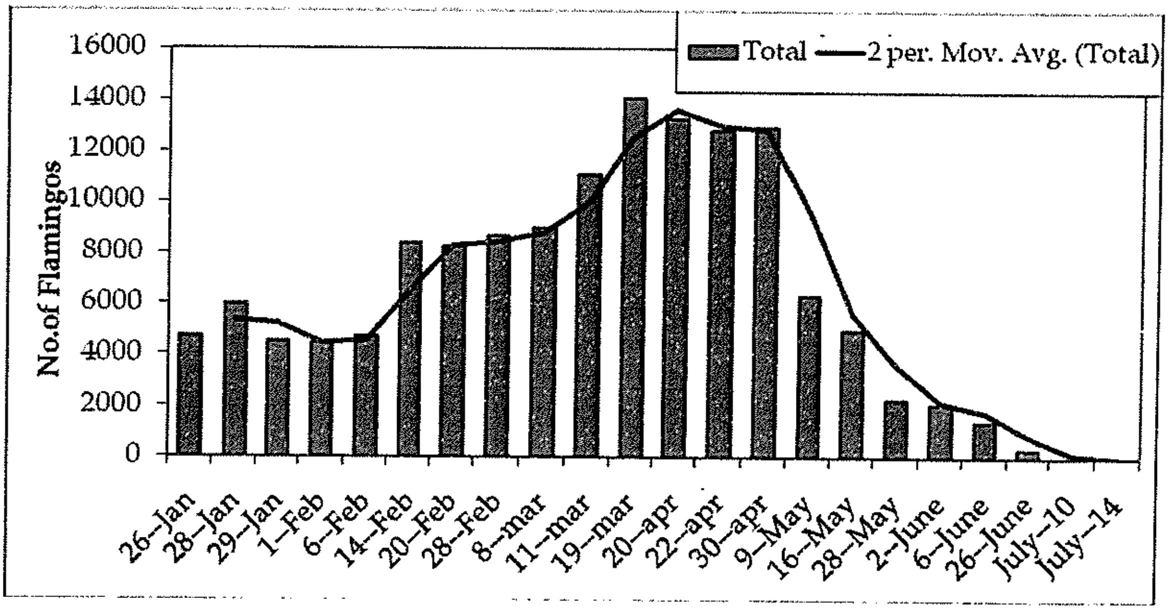


Figure 2.3. Overall frequency of sightings of the Lesser Flamingos at Sewri - Mahul region during 2008.

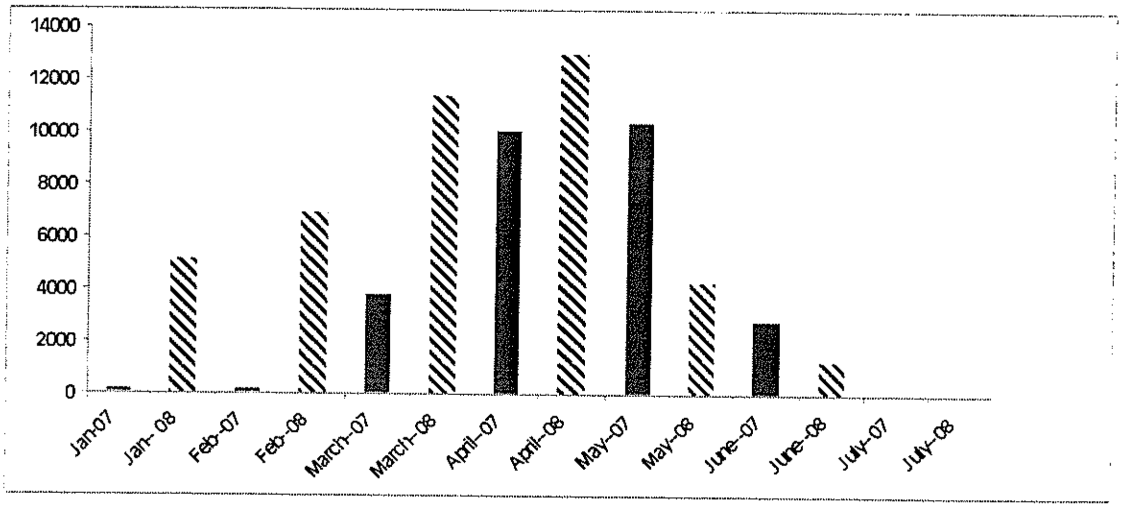


Figure 2. 4. Abundance of the Lesser Flamingo in the Sewri - Mahul region during January -July 2007 and 2008.

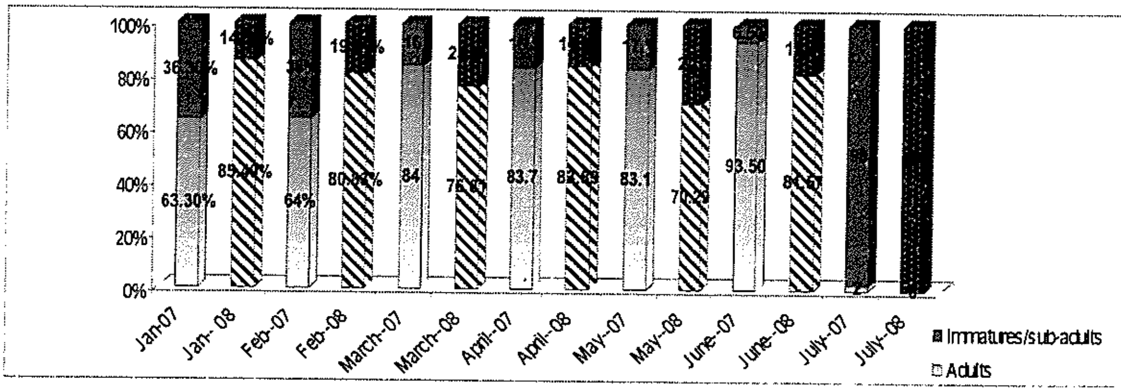


Figure 2.5. Flock composition of the Lesser Flamingos at Sewri-Mahul Creek during January -July 2007 and 2008.

Abundance and Flock composition of the Greater Flamingos

During the second season (2007-08) a few Greater Flamingos were sighted in the Sewri-Mahul region during October – November and their number increased unlike in the first year (2006-07) when only a few birds came in December 2006 and left and were not observed later in the season. During 2007-08, 324 Greater Flamingos were counted during January – February 2008 (Fig 2. 7) with slight fluctuations. The number of Greater Flamingos was almost constant up to the first week of March 2008 and then these birds started moving away from the mudflats. During March first week 235 Greater Flamingos were counted and the number constantly decreased and reached a single bird in the second week of May 2008 (Fig 2. 7). In many localities the same trend is observed as in Gujarat where a total count of the two species of flamingos in January 2003 showed a high population of about four lakhs of flamingos of which only 7% was of the Greater Flamingos and are reported to prefer saltpans (Jadhav and Parasharya, 2004) and in the Southern Rift Valley of Kenya, Lesser Flamingo was 92% of the total birds and the Greater only 2% (Nasirwa, 2000; Simmons, 2000; Owino *et al.*, 2002). The pattern was different in many other localities with higher abundance of the Greater Flamingos as at Point Calimere in Tamil Nadu during a study from 1988 to 1991 (Manakadan, 1995, 1998) with the population of the Greater Flamingo going up to above 4300 with a peak during November - December, whereas the Lesser Flamingo was less than 1000 with the peak during April - May as discussed earlier.

The adult and juvenile proportion was similar to that of the Lesser Flamingos having more adults, but percentage of juveniles was more (30-40%) in the Greater Flamingo (Fig. 2.8) while it was only about 15 -19% in the Lesser Flamingo. This change in the proportion of the juveniles in the Lesser Flamingo may be because of the aearly arrival of the larger flocks of more adults in January 2008 or less breeding success in the breeding season of 2007. Also, the greater proportion of juveniles in the Greater Flamingo may be because of the arrival of the families with chicks to this region and the larger flocks of adults to other areas in the country. It has been found that migration and dispersal are related to the body condition depending on the food availability at the breeding grounds and thus the weaker areas remain in the area or move to nearby areas (Green *et al.*, 1989; Nager *et al.*, 1996; Barbraud *et al.*, 2003). Almost all the juvenile birds left the area during April 2008 and a few adult birds left only during May and it was absent in the mudflats during June and July. The preferred habitat of the Greater Flamingos was salt pans and the juvenile birds need more nutrition for moult and this might lead the birds to move away from the mudflats (Manakadan, 1995; Tuite, 2000).

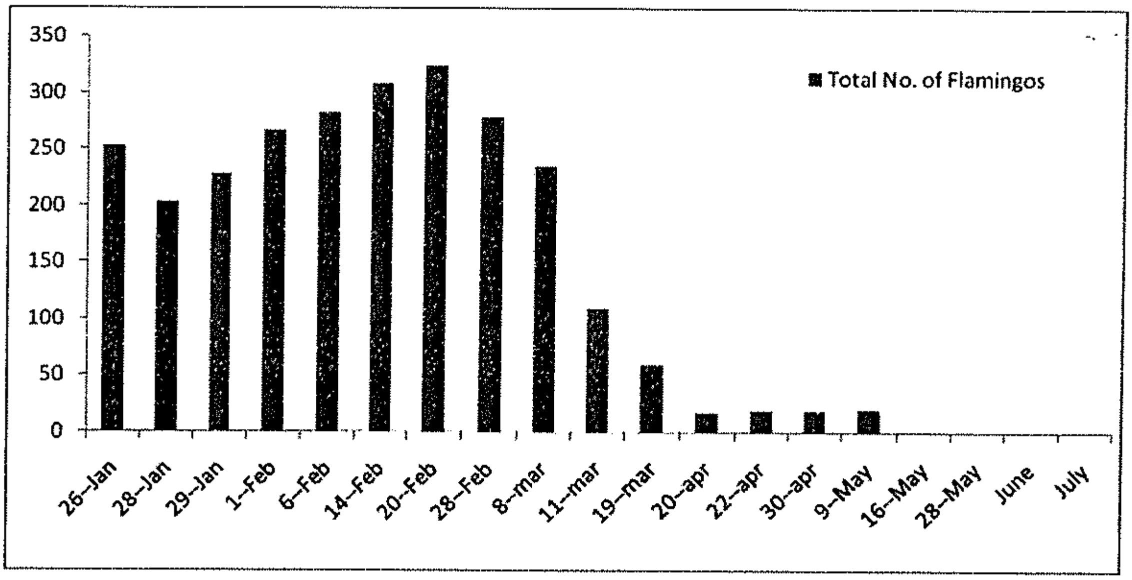


Figure 2. 7. Frequency of sightings of the Greater Flamingos in the Sewri-Mahul region during January - July 2008.

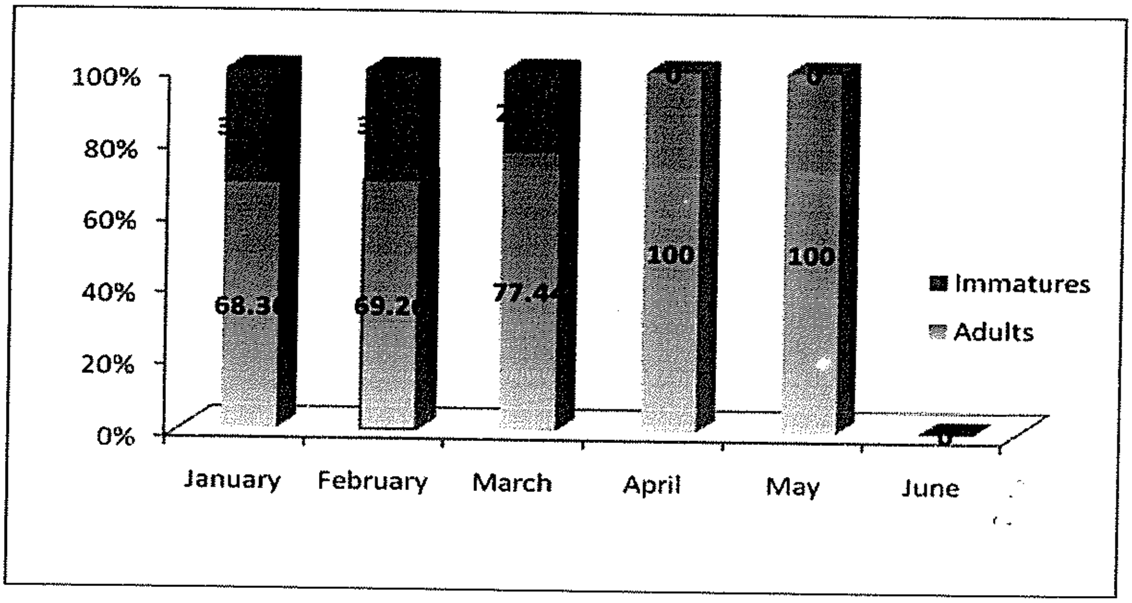


Figure 2. 8. Flock composition of the Greater Flamingos in the Sewri - Mahul region during January- June 2008.

Distribution pattern and movement of flamingos

Lesser Flamingo was distributed all along the mudflats in the Sewri-Mahul region from Retibhandar to Tata Power. Their distribution pattern during the study period was recorded at different times on a map as shown in Figures 2.9. Photographs of Lesser Flamingos feeding locations and other activities are provided in Figures 2.9- 2.15.

Distribution of flamingos varied in relation to the different regions of the Sewri mudflats. Movements and distribution of Lesser Flamingos were largely determined by the tidal water levels. Flamingos concentrated at the edge of the advancing/ receding water widely across the sites. At the time of the highest tides no flamingos remained at Sewri; instead all flew towards embankments close to Tata Power and alighted there on water close to walls and among sparse mangroves with embankment on the other side blocking high wave action and very little human disturbance. Immature birds were also observed roosting close to adult ones in the same location, but in separate flocks more towards the sparse mangroves. They have been observed in this location loafing on water in very high density flocks during the period of high tides (Fig.s 2.9-2.15). All shorebirds move according to the tide levels and prefer safe roosting and loafing sites ((Piersma *et al.*, 1993; Luı́s *et al.*, 2001; Rogers, 2003), preferring accessible sites where birds are safe and not thermally stressed. Accessibility is a function of the distance from the feeding grounds. Safety is a function of the risk of predator attack, perhaps in combination with human disturbance (Rosa *et al.*, 2006). Thermal stress, either because of wind and cold induced rises in maintenance costs (Wiersma and Piersma, 1994) or excessive heat load (Battley *et al.*, 2003), is a function of the geomorphological features of a place, and may also be influenced by human disturbance (Rogers *et al.*, 2006). During the second year they were disturbed for a short duration by the construction activities in between Tata Power and

Remadevi Island (Fig. 2.16), but they slowly returned back when the construction was over (Fig.2.17). Also they were disturbed by ship repairing activities at Sweri port (Fig. 2.18) and also by boats and tourists (Fig. 2.19), but tolerating to some distance. Flamingos moved away from the feeding locations occasionally when the crab-catchers chased them (Fig. 2.20), whereas many times they were not disturbed by these people (Fig. 2.21). Such disturbances to the flamingos in the Pampaa's wetlands in Argentina and their returning to the area in the absence of disturbance have been reported by Cardoni *et al.*, (2008). As water recedes they gradually approach Remadevi side in the north-eastern side of the Sewri Bay and get distributed along the mudflats from Mahul to Sewri and very rarely to Retibhandar. Greater Flamingos were mainly concentrating in the Mahul and Colgate regions and rarely in Retibhandar side (Fig. 2.23).

Flamingos as well as shorebirds preferred this area to embark upon since it is the first mudflat substratum that gets exposed as water level gradually reduces with receding high tide. As more mudflats get exposed in time, they fly from Remadevi section in successive flocks towards Mahul followed by Sewri and a few to Retibhandar. Immature birds' flock precedes the adult flocks. During December 2006 - February 2007, January 2008, July 2007 and June 2008, when they occurred in comparatively low numbers, no flamingos were seen foraging from Retibhandar/ Colgate section. A similar trend was observed in American flamingos in the Celestum estuary and the distribution was mainly correlated with the food abundance in the estuary (Arengo and Baldassarre, 1995). During April- June 2007 and March -June 2008 a fewer number of flamingos (10- 400 individuals) was seen foraging at Retibhandar section when compared to other sections, that too mainly of immature birds. This area has lower extent of mudflats than at Mahul. Although Sewri Fort and Port areas have more mudflats the flamingos were in low density flocks during the first season (2006-07) unlike in the last year, mainly because of the increased human activities of embarking and repairing boats (Fig. 1.12). Similar movement of boats disturbing the flamingos was reported by Galicia and Baldassarre (1997). In the second season (2007-08) the number of flamingos near Sewri Port was higher than in the previous year with less disturbance corresponding to the lower ship repair activities.

The prime habitat of the Lesser Flamingos were mainly costal mudflats and more than 75 % of them recorded in Gujarat was in the mudflats (Jadhav and Parasharya, 2004). Physiological adaptations and morphology of flamingos are important criteria for selecting feeding locations (Ramesh and Ramachandran, 2005). The activity and movement patterns of intertidal birds are controlled to a great extent by tidal cycles and feeding cycles, which may in turn be affected by seasonality and the location of the main feeding areas on the foreshore (Madsen *et al.*, 1992).

Evaluation of the habitat of the Flamingo

Flamingos are specialized filter-feeders (Zweers *et al.*, 1995) that use different feeding tactics to acquire food dispersed in different habitats. The Lesser

Flamingos usually fed from wet mudflats or shallow areas of up to about 30cm. They fed normally by treading the bottom and hence cannot feed like this when water depth exceeds 60cm (Allen, 1974). Other Flamingo *P. roseus* was also noted to forage in the shallow areas where the depth of water is around 15 cm to 30 cm (Jhonson, 1983). When there is heavy rain and tank is filled with fresh water, flamingos *(P. roseus)* leave to return after 15-21 days. They are reported to occur in a variety of habitats having different grades of salinity even high saline areas of salt works (Manakadan, 1995; Pirela, 2000). The shift in habitat use was also documented in the American Flamingo (Arengo and Baldassarre, 1995) and the flamingo numbers were not correlated with food abundance (Arengo and Baldassarre, 1998). Hence, the habitat quality was studied examining the physico-chemical properties of water and abundance of plankton and benthic macro-invertebrates in the feeding and non-feeding areas.

Water quality

Water quality parameters were studied after the flamingos arrived at the study area. Sampling was done twice a month both in feeding and non-feeding areas and at each site two water samples were collected and analyzed. Water quality measurements were done at the feeding and non-feeding sites of the Lesser Flamingo from March - July 2007 and January-June 2008 (Tables 2.2-2.4). Sampling could not be done in June 2007 because of heavy rain and gale.

The flamingos were found to use areas with less turbidity (Table 2.2); pH was almost neutral to slightly alkaline. Seasonal fluctuation in the turbidity, conductivity and salinity was very high, the former one higher during monsoon while salinity was lower because of the inflow of rain water through the inlets (Tables 2.3) However, Mann-Whitney test showed no significant difference between feeding and non-feeding areas in parameters such as turbidity, oxygen concentration, salinity, conductivity and p*H*. This might be because they use most of the areas for feeding depending on the water levels and selecting the non-feeding area by us was difficult.

The low p*H* at Sewri (i.e. within a range of 7.02-8.69) suggests that the conditions for profuse growth of *Spirulina*, which is the primary food source of Lesser Flamingos in East Africa, is below optimum here as it thrives well within a limited p*H* range of 10.3 - 10.5 (Tuite, 2000). Oxygen levels were low because of the polluted water. This indicates that Lesser Flamingos at Sewri mudflats are largely feeding on less productive secondary food source, ie. diatoms and probably on insect larvae and copepods as reported by Ali and Ripley (1987). In the breeding areas at Kutchh in India also they mainly fed on diatoms. Tuite (2000) also found a shift in diet of the Lesser Flamingo in East Africa according to the availability.

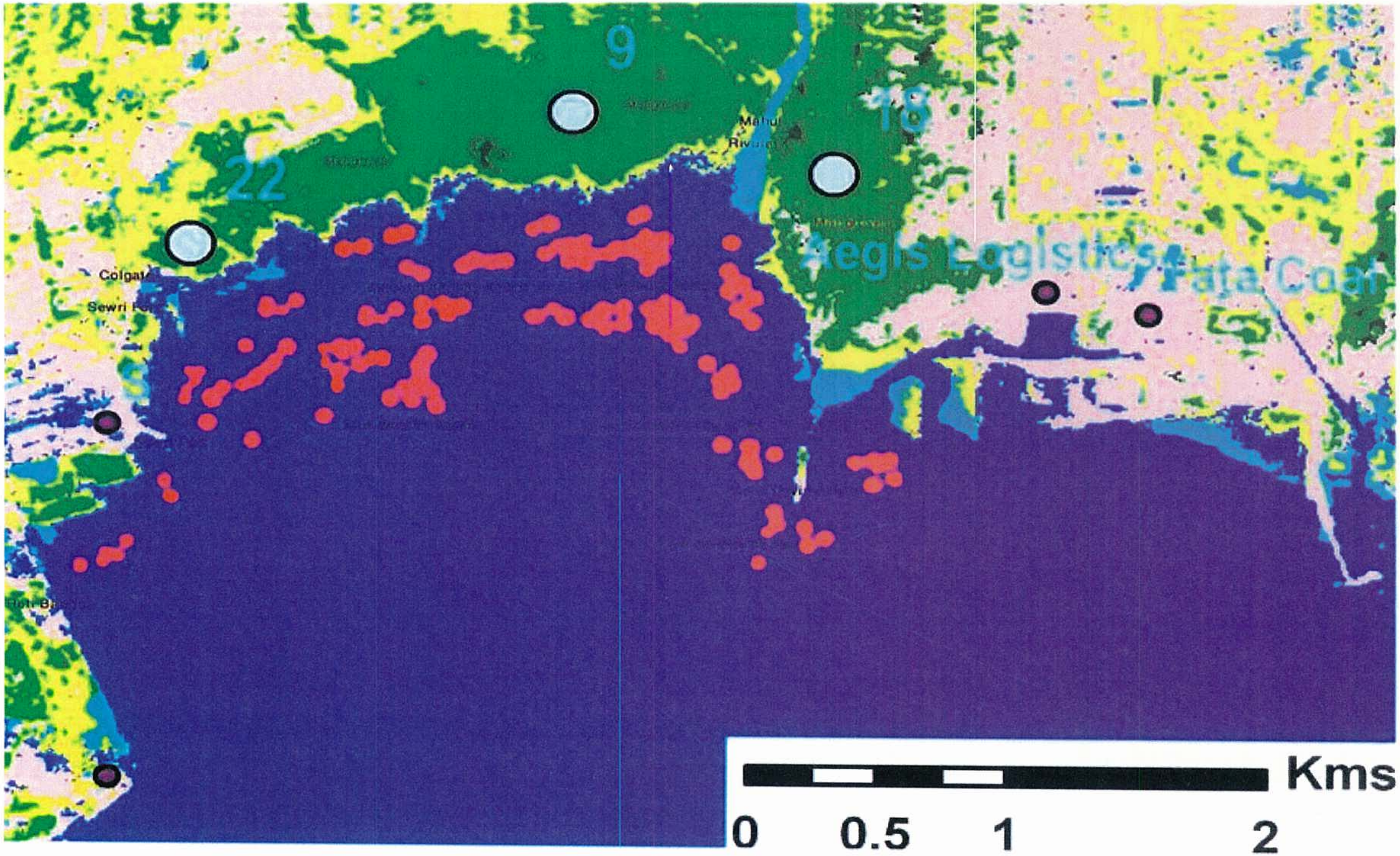


Figure 2.9. Distribution pattern of Flamingos during low tide in the Sewri-Mahul region during the study period.

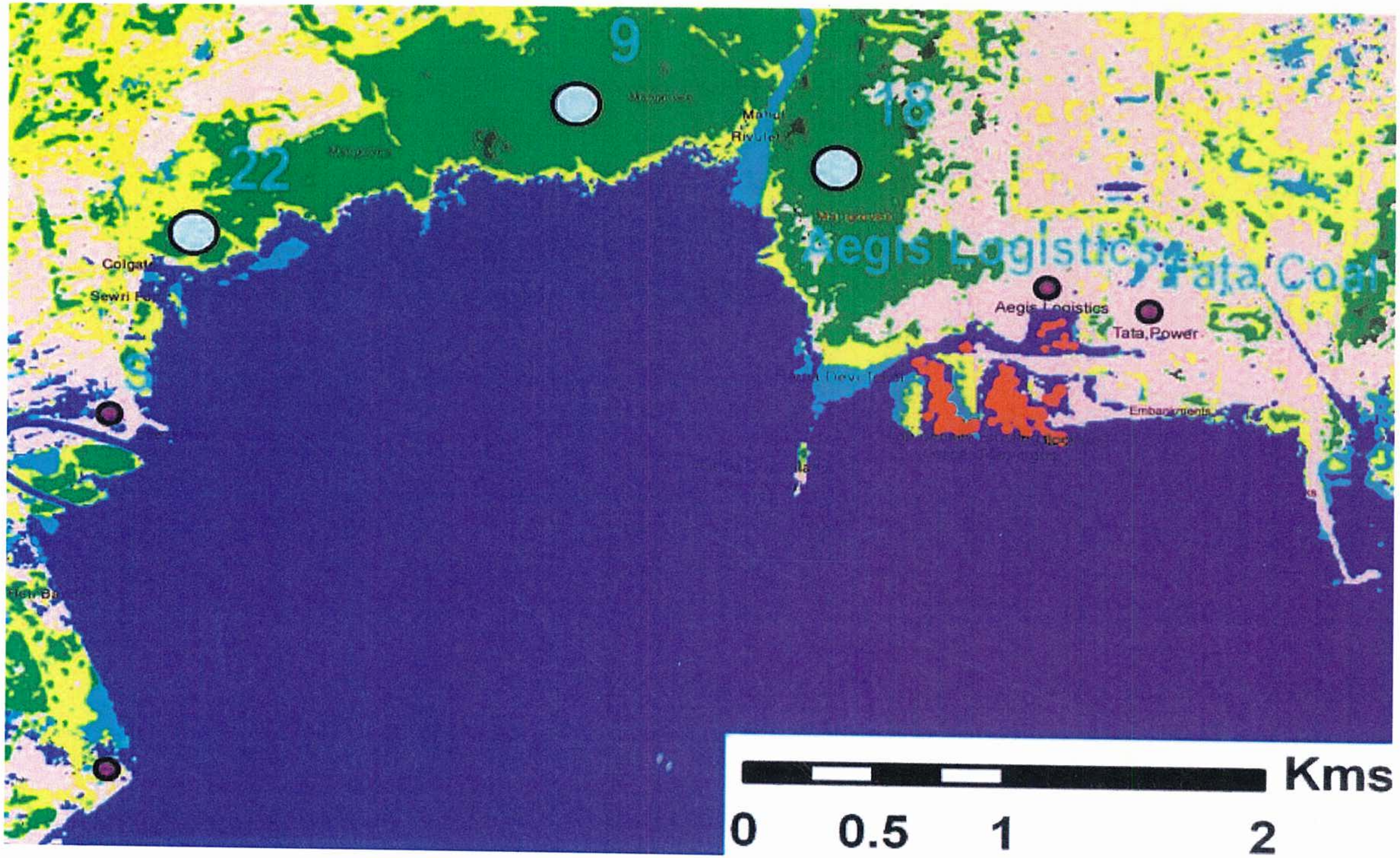


Figure 2.10 Roosting sites of Lesser Flamingos near embankments situated close to Tata Power during high tide.

Figure 2.11. Lesser Flamingos in the Sewri- Mahul region during March 2007 & 2008.

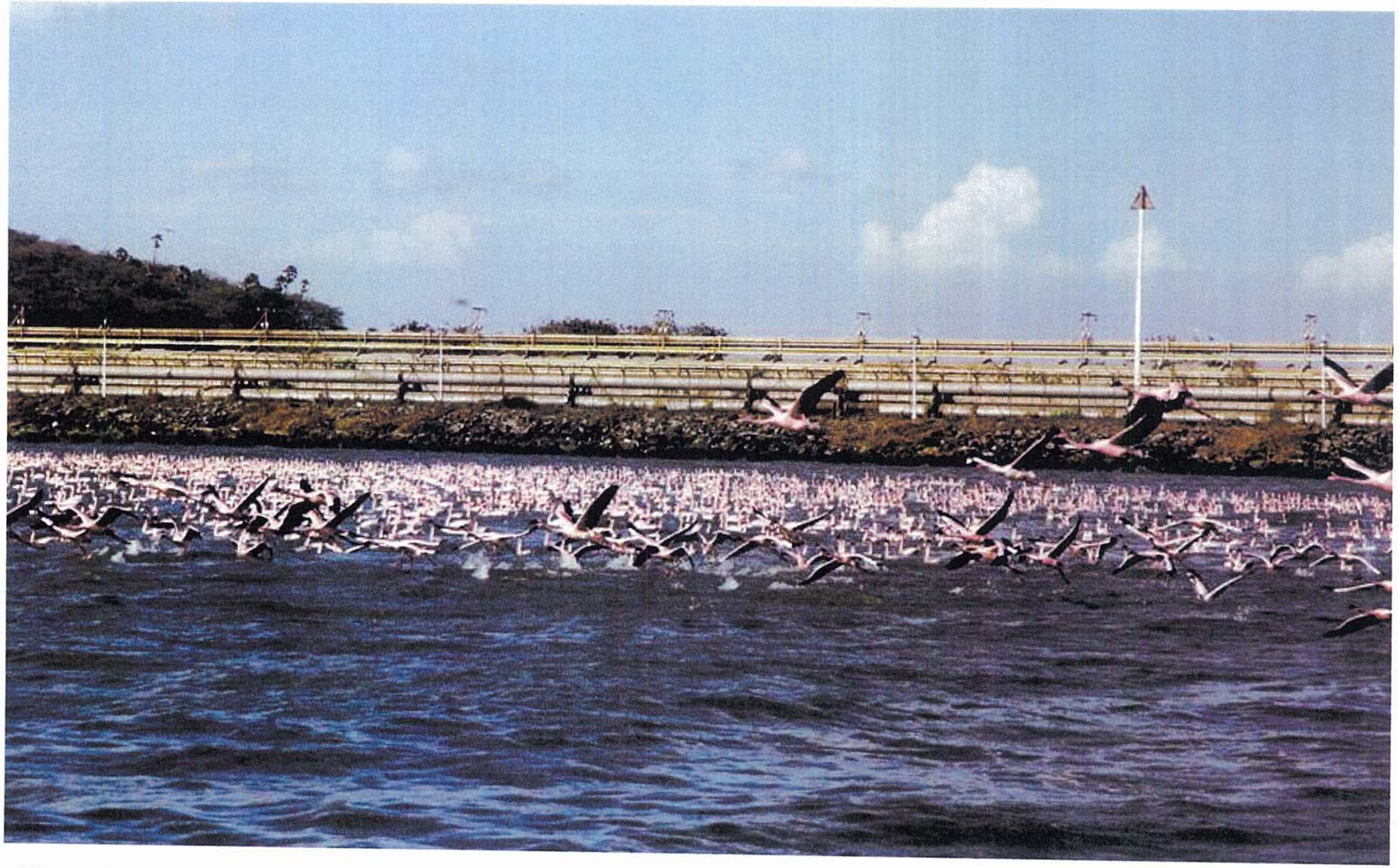


Figure 2.12. Lesser Flamingos roosting in high density flocks by floating on water near embankments near Tata Jetty.

Figure 2.13.Juvenile/ immature lature Lesser Flamingos roost in separate flock close to adult ones during high tides

Fig. 2. 14 Flamingos roosting near Tata Power

Fig. 2.15. Flamingos loafing during high tide near Tata Power.

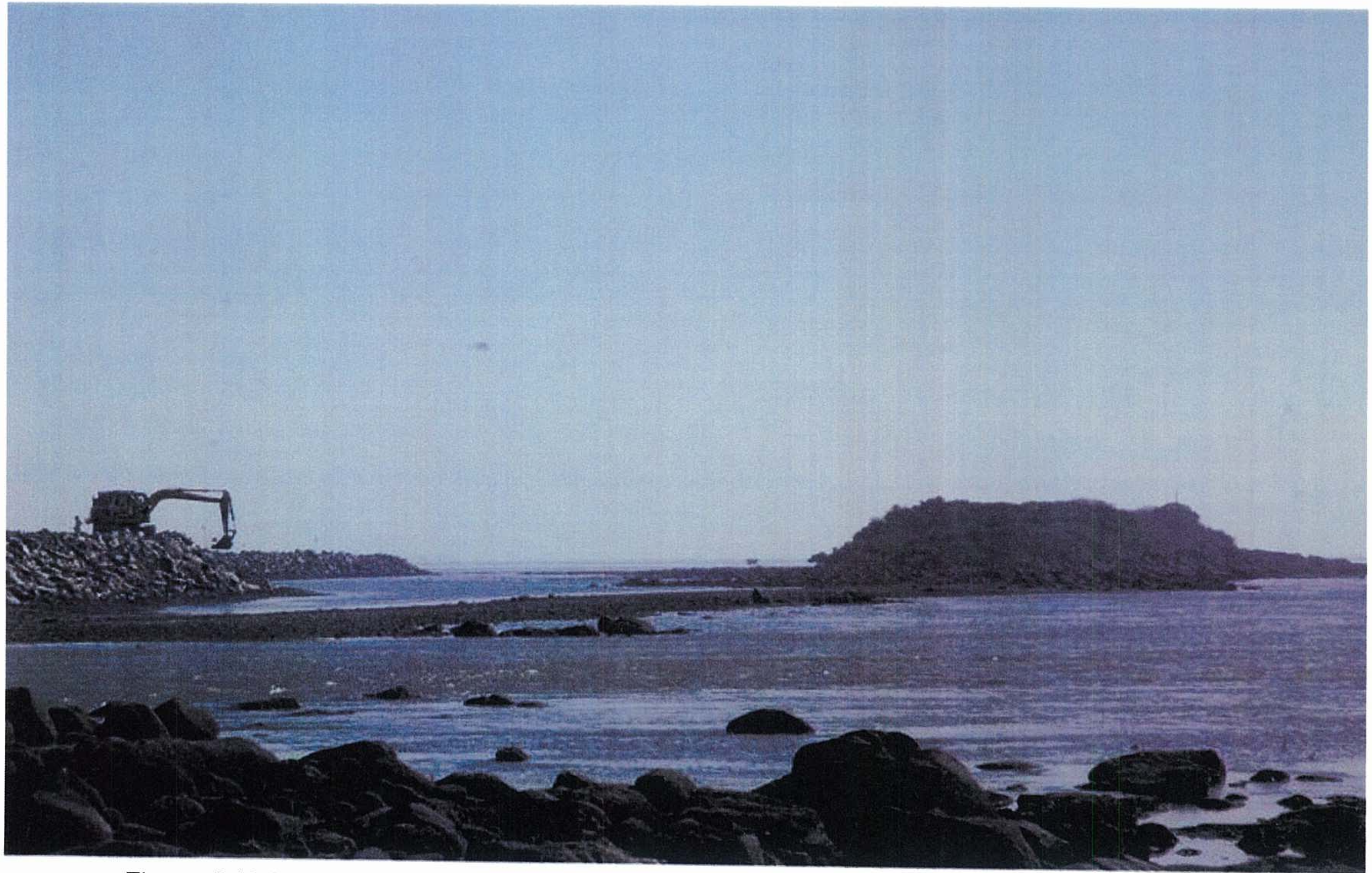


Figure 2.16.Construction work near tat Power causing disturbance to the flamingos at the roosting/ resting site during high tide

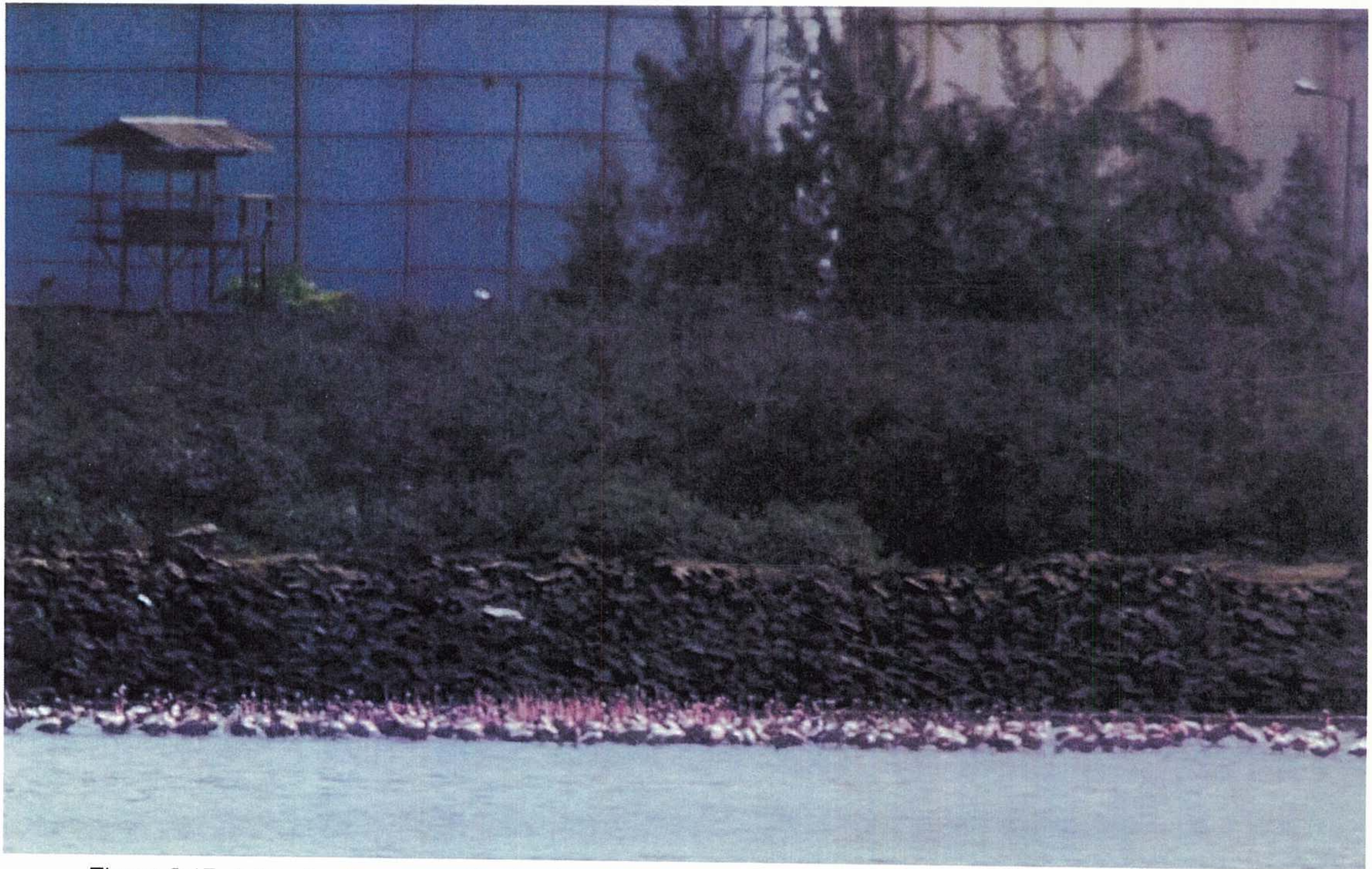


Figure 2.17. A few flamingos roosting/resting during high tide after the construction work rear Tata Power.

Figure 2.18. Disturbance at Sewri from ship repair and other activities.

Figure 2.19 Flamingos are at times disturbed by tourists moving closer to them

Figure 2.20. Flamingos are at times disturbed by crab-catchers chasing them.

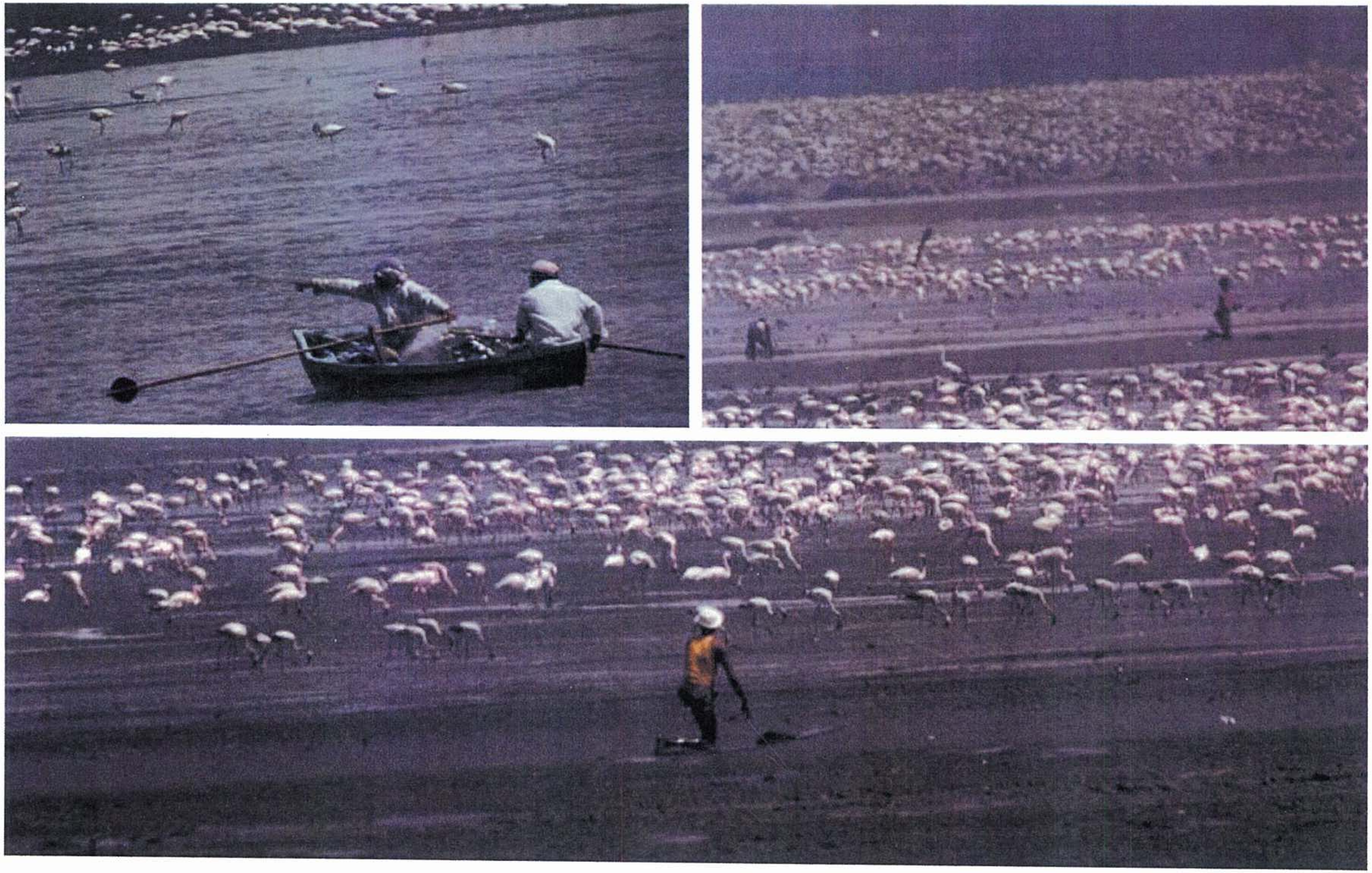


Figure 2.21. Fishermen moving very close to flamingos but not disturbed.

Figure 2.22. Courtship marches occurred among the flamingos at Sewri-Mahul region

Figure 2.23 Greater Flamingos in the Sewri-Mahul region

Comparison of the values among different sites, namely Retibhandar, Colgate, Mahul and Remadevi showed that turbidity was the highly varying parameter followed by salinity and conductivity, while *pH* varied the least across the sites. The maximum turbidity among the feeding locations was at Colgate (483 NTU) and minimum at Retibhandar (24 NTU). At the non-feeding sites turbidity was much higher being 930 NTU at Retibhandar and minimum at Mahul (33 NTU). The maximum oxygen concentration among the feeding sites was recorded from Colgate section (3.38 mg/l) and minimum from Remadevi (0.24 mg/l) (Table 2.4). At the non-feeding sites the maximum oxygen concentration was recorded from Retibhandar (3.42 mg/l) (Table 2.4). The maximum salinity among the feeding locations was at Mahul (47.7 SAL) and minimum at Retibhandar (4.10 SAL). At the non-feeding sites the maximum and minimum salinity was recorded from Retibhandar (48.05 and 3.40 SAL respectively). The maximum conductivity among the feeding locations was at Mahul (958.5 *mS*) and minimum at Retibhandar (8.48 *mS*) and at the non-feeding sites the maximum was noted from Colgate section (53.35 *mS*). The highest p*H* among the feeding, and non-feeding areas was measured from Colgate section (8.69 and 8.42 respectively) and the least from Mahul (7.08 and 7.02 respectively) where the domestic sewage and industrial effluents join. Low turbidity was observed during March and it might help in efficient feeding. Turbidity was higher during July mainly because of the heavy rain, run-off and wave action. Salinity, Conductivity and pH were less in July at all sites mainly because of the dilution factor because of the rain. The Lesser Flamingo is reported to be more restricted to the brackish lakes and tidal lagoons (Roberts, 1991; Ali and Ripley 1987), but not so in all cases (Manakadan, 1995a). Most of the species of flamingos fed from highly saline areas, even salt works (Arengo and Baldassare, 1998, 2000; Pirela, 2000).

Table 2.2. Average values for different water quality parameters from flamingo feeding and non-feeding sites at Sewri-Mahul region, March- July 2007 and January –June 2008.

Parameters	**Feeding areas**	**Non-feeding area**
	Mean (± SD)	**Mean (± SD)**
Turbidity	216.58 (± 75.44)	272.27(± 201.67)
Oxygen Conc.	1.23 (± 0.66)	1.36 (± 0.67)
Salinity	33.80 (± 15.62)	33.81 (± 14.44)
Conductivity	138.47 (± 257.26)	139.06 (±260.11)
p*H*	7.64 (± 0.48)	7.65 (± 0.48)

The abundance of plankton (phytoplankton and zooplankton) in water and benthic macro-invertebrates were studied in the four zones as done for the bird abundance and water quality. These zones were divided into eight locations including the feeding and non-feeding stations of the flamingos in different seasons as explained under methods. The total data showed a different pattern for the abundance of plankton and benthos in different seasons; the maximum abundance of plankton was in summer followed by winter and monsoon while for benthos it was in winter followed by summer and monsoon (Fig. 2.24)

Table 2.3. Water quality measurements from the feeding areas of the Lesser Flamingo during March-July 2007 and January-June 2008.

Seasons	Turbidity (NTU)	Oxygen (mg/l)	Salinity	Conductivity (mS)	pH
Summer 07	162.8	1.9	16.3	36.3	8.0
Monsoon 07	515.5	0.7	10.7	16.7	7.2
Winter 07-08	151.9	1.0	40.4	60.1	7.3
Summer 08	223.5	1.0	45.0	322.6	7.8
Monsoon 08	187.5	1.0	45.1	69.1	7.5

Table.2.4. Water quality measurements from the non-feeding areas of the Lesser Flamingo in different seasons during 2007 and 2008.

Seasons	Turbidity (NTU)	Oxygen (mg/l)	Salinity	Conductivity (mS)	pH
Summer 07	175.2	2.0	20.7	31.8	7.7
Monsoon 07	512.5	0.8	10.0	18.4	7.2
Winter 07-08	156.2	1.1	42.4	62.5	7.4
Summer 08	287.0	1.2	43.0	321.6	8.1
Monsoon 08	511.3	0.9	39.3	98.7	7.3

Abundance of invertebrates in water and sediment

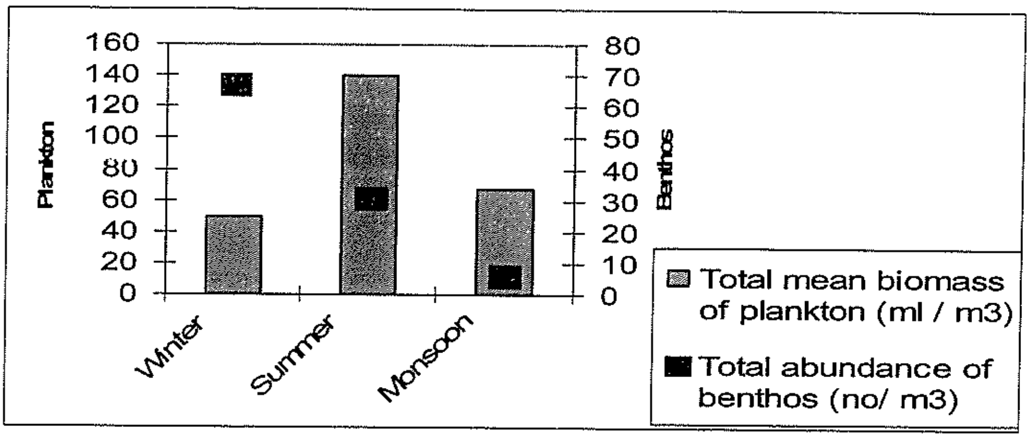


Figure 2.24. Mean abundance of plankton and benthos in different seasons in the Sewri-Mahul region

Composition, distribution and abundance of plankton

Biomass

The plankton biomass displayed wide variation between the different zones and seasons (Table.2.5). The presence of organic debris, feed of the birds, and other setting particles could have resulted in the higher plankton biomass in most of the study locations in the eight zones or sectors. The average biomass was highest during summer (139.8 ml/m3) followed by monsoon (67.9 ml/m3) and winter period (49.8 ml/m3). During the winter the maximum biomass was at Retibhandar followed by Colgate, during the summer it was at Mahul follwed by Colgate and during monsoon it was at Colgate followed by Retibhandar (Fig. 2.25). The pattern of abundance did not show significant difference between feeding and non-feeding areas in different zones as found in the case of the benthic macro-invertebrates, as it was difficult to differentiate feeding and non-feeding sites for sampling as the birds used the areas mainly depending on the water level and disturbances, besides abundance of food (Brown *et al.*, 1973).

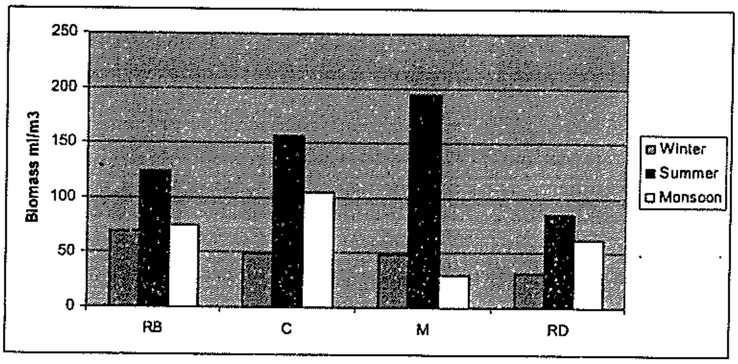


Figure 2.25. Mean abundance of plankton (ml/m3) in different seasons and zones (RB-Retibhandar, C-Colgate, M-Mahul, RD-Remadevi).

Table 2.5. Mean abundance of plankton (ml/m3) in different seasons and zones (feeding F and non-feeding NF).

Seasons/ Zones	RBF	RBNF	CF	CNF	MF	MNF	RDF	RDNF	Total
Winter	116	23	50	49	62	35	21	42	49.8
Summer	87	160	150	162	198	190	103	68	139.8
Monsoon	88	61	103	108	23	36	63	61	67.9

Phytoplankton

The occurrence, distribution and abundance of phytoplankton was highest during monsoon followed by summer. Chlorophyceae (green algae), Myxophyceae (blue green algae) and Bacillariophyceae (diatoms) formed the major groups of phytoplankton encountered during the study. The Myxophyceae followed by the Bacillariophyceae and Chlorophyceae showed the highest mean percentage abundance in the eight sectors in the three seasons. Season-wise analysis also showed a similar trend in the zones. During the summer and winter periods Myxophyceae was the dominant planktonic group followed by the Bacillariophyceae. The Myxophyceae was mainly contributed by the *Spirulina* spp which were the major food items of the flamingos (Jenkin 1957). He also found diatoms (Bacillariophyceae) as food of the Lesser Flamingo. In summer the variations between the Myxophyceae and Bacillariophyceae was only marginal whereas it showed wide difference with Chlorophyceae (Fig. 2.26). During the monsoon season, 22 species belonging to Myxophyceae, 68 species belonging to Bacillariophyceae and 19 species belonging to Chlorophyceae were recorded. Three species of *Spirulina* Viz. *S. major, S. subsalsa and S. subtilissima* represented the Myxophyceae during monsoon season. The summer had the highest species abundance of plankton, where 85% was contributed by Myxophyceae and the rest by the other two groups. The *Spirulina* spp. constituted the highest abundance during the summer. In the summer Myxophyceae displayed the highest percentage abundance in Colgate (56 %) and the Remadevi sections (46.26%), whereas during the monsoon, it was in Mahul (92%) and Remadevi (83%) (Table 2.6). The Bacillariophyceae showed its peak in Retibhandar (63%) and Remadevi (51%) in summer whereas it was in Mahul (18%) and Remadevi (17 %) stations during monsoon. Chlorophyceae had the lowest percentage abundance in all the seasons except in summer as compared to the other phytoplankton groups. In phytoplankton, variations among seasons and stations were significant at 1% level (ANOVA; F= 8.2&3.3 respectively), so also among groups during monsoon and summer, but not in winter and also not among sites in a zone within a season (ANOVA). The species diversity (Shannon) of phytoplankton also was highest during the summer (av. 1.386) followed by the monsoon (av.1.02) and the winter (av. 0.97). The richness and evenness indices also showed a similar trend as that of the Shannon-Weaver values (Table 2.7).

Table. 2.6. Season wise Phytoplankton abundance (numerical) in different sections in the study area.

Season	Phytoplankton	RB	C	M	RD
Monsoon	Myxophyceae	14175	8050	55475	30800
	Bacillariophyceae	1925	0	4725	5250
	Miscellanoeus	7175	7175	5075	5250
Winter	Myxophyceae	29839425	2767800	1795500	1724100
	Bacillariophyceae	1236025	735350	1236550	384300
	Miscellanoeus	1364300	366800	1960000	19950
Summer	Myxophyceae	6088250	11219250	12761000	6725250
	Bacillariophyceae	7155750	9807000	10125500	12066250
	Chlorophyceae	3965500	9394000	17589250	619500
	Miscellaneous	85750	54250	64750	82250

Table. 2.7. Mean diversity indices of phytoplankton during the three seasons.

Zones	No. of samples S	Abundance	d (species richness)	J' (species eveness)
Monsoon				
RBF	3	22750	0.20	0.87
RBNF	3	23800	0.20	0.69
CF	2	15750	0.10	0.96
CNF	2	14700	0.10	0.99
MF	3	80150	0.18	0.27
MNF	3	50400	0.18	0.68
RDF	3	66150	0.18	0.52
RDNF	3	16450	0.21	0.94
Summer				
RBF	4	13478500	0.18	0.67
RBNF	4	21112000	0.18	0.79
CF	4	20104000	0.18	0.64
CNF	4	40845000	0.17	0.78
MF	4	39588500	0.17	0.75
MNF	4	41492500	0.17	0.80
RDF	4	21609000	0.18	0.53
RDNF	4	17377500	0.18	0.59
Winter				
RBF	3	61365500	0.11	0.21
RBNF	3	3514000	0.13	0.86
CF	3	4418400	0.13	0.39
CNF	3	3321500	0.13	0.92
MF	3	8952300	0.12	0.95
MNF	3	1031800	0.14	0.57
RDF	3	1210300	0.14	0.63
RDNF	3	3046400	0.13	0.40

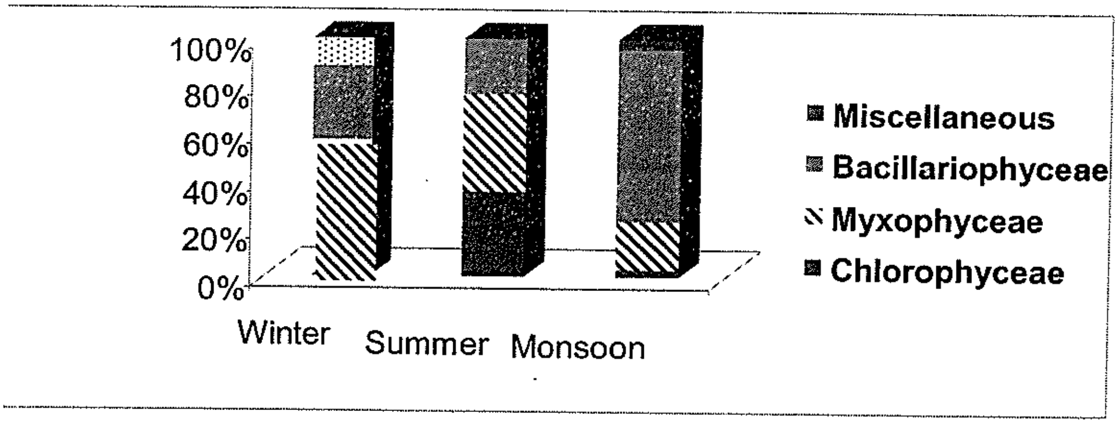


Figure 2.26. Composition of the phytoplankton groups in different seasons.

Zooplankton

The zooplankton population was represented by 11 groups in different zones of the study area. Copepods displayed the highest average percentage abundance (22%) in the 3 seasons followed by polychaete larvae (14%), crustacean larvae (16%), protozoans (9%) and cnidarians (8%). Season-wise analysis showed that the percentage abundance and diversity of plankton were higher in the summer followed by the monsoon and the winter (Table 2.8 & Fig. 2.27). The zooplankton population was composed of 9 species of copepods, 12 species of protozoans, 2 species of cnidarians, 2 species of nematods, 3 species of rotifers, 9 species of crustacean larvae, 2 species of echinoderms, 3 tunicates and also cladocerans and ostracods. The zooplankton abundance varied significantly among the seasons and groups (ANOVA; F= 42.3 and F= 6.2 respectively). Within season variation was significant among sites and groups in winter and summer, while only among groups in monsoon (ANOVA). The species composition and diversity was also highest in the summer as compared to the other seasons (Table 2.9).

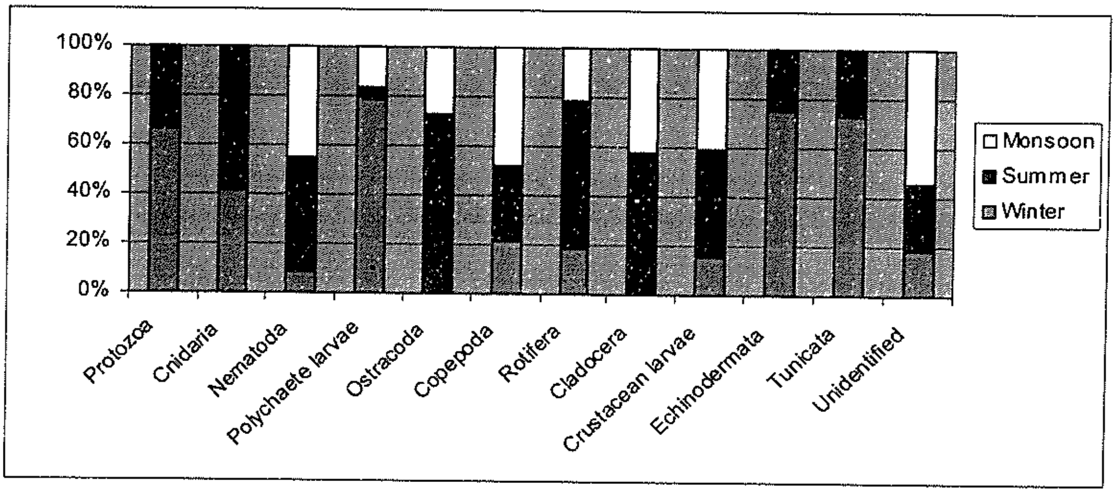


Figure 2.27. Composition of different groups of zooplankton in three seasons

The proportion of total (mean) abundance showed that crustacean larvae was the maximum (21.5%) followed by Copepoda (19.5%) and Cnidaria (13.4%) (Table 2.8). At Retibhandar Copepoda was the most dominant (21.5%) followed by Crustacean larvae (16.7%) and Cnidaria (15.8%); at Colgate it was Crustacean larvae (23.8%) followed by Copepoda (20.3%), at Mahul Cnidaria (19.6%)followed by polychaete larvae (17.3%) and at Ramadevi Crustacean larvae (28.8%) followed by Copepoda (24.9%). However there was no significant variation in abundance of the zooplankton between the feeding and non-feeding areas. This might be because of the problem we had separating between the feeding and non-feeding areas as the flamingos feeding areas changed mainily based on the water level as explanined under phytoplankton.

Table 2.8. Mean numerical abundance (no/m^3) of zooplankton in different zones in the Sewri-Mahul region

Zooplankton/Zones	Retibhandar	Colgate	Mahul	Remadevi	Mean
Protozoa	14.9	8.3	13.2	3.8	8.9
Cnidaria	15.8	7.7	19.6	13.1	13.4
Nematoda	0.7	8.6	5.7	4.2	5.0
Polychaete larvae	4.8	5.5	17.3	8.4	8.6
Ostracoda	0.0	0.3	1.3	0.0	0.3
Copepoda	21.5	20.3	6.4	24.9	19.5
Rotifera	1.3	5.0	3.2	1.1	2.6
Cladocera	1.5	4.8	3.6	0.8	2.5
Crustacean larvae	16.7	23.8	9.7	28.8	21.5
Echinodermata	0.0	1.0	0.3	2.2	1.1
Tunicata	3.8	3.5	2.6	3.6	3.4
Unidentified	19.0	11.3	17.1	9.2	13.1
Total	312200	444850	311383	575108	410885

Correlation between flamingo abundance and plankton

During arrival time (winter) of flamingos the plankton abundance was high and it was distributed equally in the study area. The plankton abundance started increasing during summer the plankton abundance was high and at the same time the maximum number of flamingos were also recorded. During monsoon the plankton abundance decreased because of the heavy rain and the flamingos number also diminished in the study area.

This shows that flamingo abundance in the study area mainly depended on the availability of the plankton. Departure of the flamingos was also a result of the seasonality, moving away for breeding. The abundance of the Lesser Flamingo in different zones and seasons was correlated with that of the phytoplankton (log transformed) and it showed a significant positive response (Fig. 2.28) and value ($r=0.78$, $p<0.05$) and in same way the zoo plankton abundance also correlated ($r=0.69$ 8, $p<0.05$).

Water temperatures influence food production. Invertebrate production in the water column may ultimately depend on water temperature and the ability of a wetland to produce algae (Nagarajan and Thiyagesan, 1996). Colwell and Taft (2000) have reported that the relation between wetlands and birds is shaped by many factors which include the availability, depth, and quality of water; availability of food and shelter; and the presence or absence of predators.

Table 2.9. Mean diversity indices of zooplankton in each of the three seasons.

Zones	No. of samples	Abundance N	d(species richness)	J'(species eveness)
Summer				
RDF	11	1524250	0.70	0.68
RDNF	9	934500	0.58	0.84
CF	9	626500	0.60	0.90
CNF	12	1634500	0.77	0.83
MF	9	675500	0.60	0.92
MNF	11	647500	0.75	0.85
RBF	6	658000	0.37	0.91
RBNF	9	675500	0.60	0.86
Monsoon				
RDF	4	39200	0.28	0.96
RDNF	3	16100	0.21	0.61
CF	5	38850	0.38	0.78
CNF	4	36750	0.29	0.86
MF	7	29400	0.58	0.85
MNF	5	17500	0.41	0.83
RBF	4	17850	0.31	0.71
RBNF	4	24150	0.30	0.76
Winter				
RDF	7	275800	0.48	0.82
RDNF	9	660800	0.60	0.90
CF	5	121100	0.34	0.80
CNF	7	211400	0.49	0.81
MF	6	356300	0.39	0.50
MNF	10	142100	0.76	0.82
RBF	8	322700	0.55	0.87
RBNF	4	175000	0.25	0.86

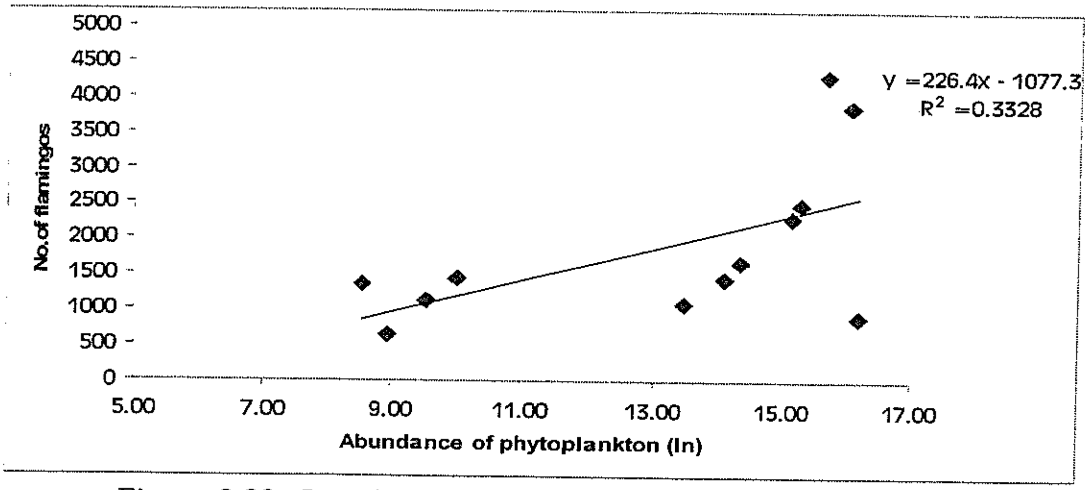


Figure 2.28. Correlation of abundance of the Lesser Flamingo with phytoplankton.

Mann-Whitney test found no significant difference in invertebrate abundance between feeding and non-feeding areas. Thus it was not possible to delineate any definite pattern in the selection of feeding sites. The criteria was probably the water level and the substratum ie. soft soil as mudflat as reported in many other studies on flamingos (Johnson, 1997; Arengo and Baldassare, 2000; Este and Casler, 2000). The major concentrations of the flamingos in the Sewri - Mahul region may be because of the nutrient flow from the rivulet joining at Mahul. In the Chilean Flamingo the nutrients supplied from the river plays an important role in the feeding and breeding in Argentina (Bucher *et al.*, 2000).

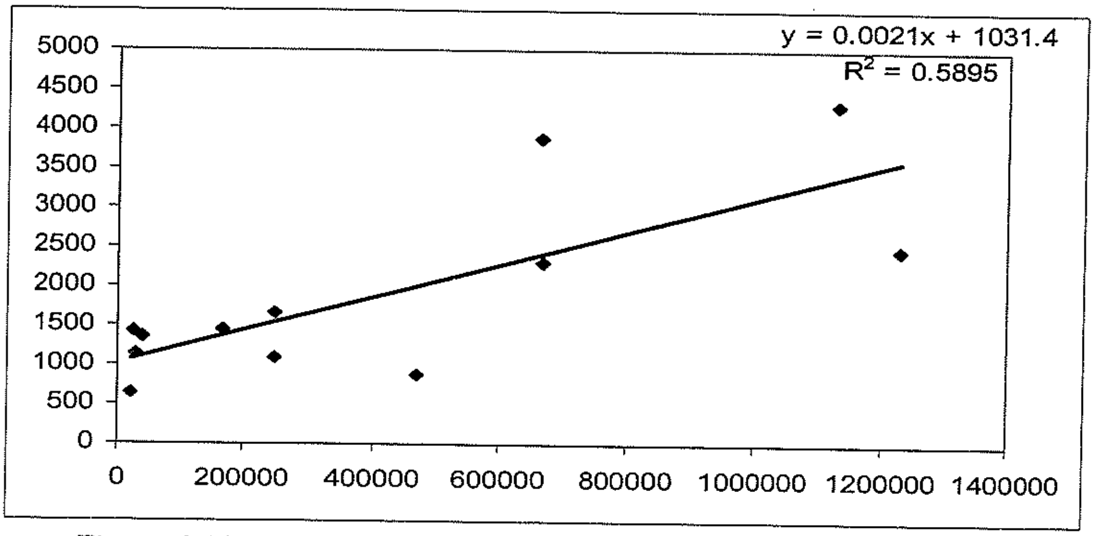


Figure 2.29. Correlation of abundance of the Lesser Flamingo with zooplankton.

American Flamingo studies (Arengo and Baldassarre, 1995) and some other studies have shown that flamingo numbers are not correlated with food abundance, but depend on the availability of a larger area of mudflats for shifting between the sites (Arengo and Baldassarre, 1999, 2000). The pronounced fluctuations in Lesser Flamingo numbers in Kenya were not correlated to algal densities presumed to be their main food item (Vareschi, 1978) and the distribution of Chilean Flamingos in Peru was also not related to food abundance but was negatively related to the densities of fish which compete with flamingos for food (Hurlbert *et al.*, 1986).

Abundance of Benthic macro-invertebrates (Benthos)

Many shorebird species prey mainly on crustaceans and polychaetes that live in sandy or muddy substrata (Davidson *et al.*, 1986). Bill length determines the depth to which birds can probe for prey and partly accounts for inter specific differences in prey size selection (Prater, 1981). The dynamics of the physical conditions of the sediment and the pattern of prey availability during a tidal cycle can have a direct effect on the feeding behavior and distribution of shorebirds in intertidal soft-sediment habitats (Grant, 1984). Receding tidal water has two important effects on feeding shorebirds. First, potential prey may follow the water table deeper into the substrate and become unavailable (Evans, 1979; Goss-Custard, 1984). Second, as the sediment dries it becomes more compact and foraging becomes energetically more demanding (Grant, 1984). Resistance to penetration varies widely among intertidal zone sediments. Soft sediments may also undergo substantial changes in resistance within each tidal cycle. Depth of interstitial water may affect prey availability and detectability during the tidal cycle over a given substratum (Grant, 1984; Zwarts and Esselink, 1989; Veldsquez and Navarro, 1993). Hence, it was necessary to examine the availability of macro-invertebrates in the surface soil of the mudflats.

Mud samples were collected from inter-tidal mudflats from flamingo feeding and non-feeding areas during March to July 2007 and January to June 2008, twice a month and analyzed for invertebrate abundance in the feeding and non-feeding areas as explained under methods. Total abundance of benthic macro-invertebrates showed maximum number in summer (629/m3) followed by winter (535/m3) while it was very low in monsoon (48/m3). Composition of the benthic macro invertebrates showed that polychaetes dominated during monsoon, aquatic worms in winter and gastropods (snails and bivalves) in summer (Fig. 2.30).

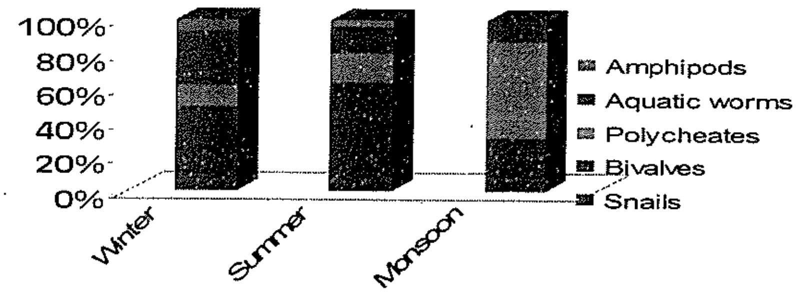


Figure 2.30. Composition of benthic macro - invertebrates in different seasons.

The number of macro-invertebrates considerably diminished during May-July in both feeding and non-feeding areas (Tables 2.10 & 2.11). This might be because of depletion after feeding by a large number of the flamingos. Such a phenomenon of decrease in benthic macro-invertebrates during rain has been reported in the habitats of the Caribbean Flamingo in Venezuela (Este and Casler, 2000). This may be one reason for spending more time for feeding by the flamingos in May and June. Also they needed more food as reserve for breeding later. Polychaetes and snails were the most abundant macro-invertebrates in both the areas. Maximum number of invertebrates among the feeding areas was recorded from Retibhandar and minimum from Colgate and Mahul sections. Among the non-feeding areas, the maximum number of macro-invertebrates was recorded from Colgate section and minimum from Remadevi.

Table 2.10. Mean macro- invertebrates collected from Lesser Flamingo feeding areas during the study period.

	Macro-invertebrates	Retibhandar	Colgate	Mahul	RamaDevi
Summer-07	Snail	19	10.33	3.33	13.33
	Bivalves	0.33	1.33	0.67	0.00
	Polychaets	20.00	11.67	16.00	15.00
	Aquatic worms	0.67	2.33	4.67	2.00
	Amphipods	0.33	0.33	0.67	0.00
Monsoon-07	Snails	0	1	1	2
	Bivalves	0	0	0	0
	Polychaets	5	1	4	1
	Aquatic worms	0	0	0	3
	Amphipods	0	0	0	0
Winter-08	Snails	19	5	22	38
	Bivalves	13	23	56	15
	Polycheates	15	8	6	7
	Aquatic worms	29	39	23	11
	Amphipods	1	12	5	4
Summer-08	Snails	29.33	2.00	1.33	5.67
	Bivalves ·	35.33	1.00	2.33	3.67
	Polycheates	6.67	1.67	4.67	4.67
	Aquatic worms	0.67	3.00	3.67	6.67
	Amphipods	0.00	0.67	1.67	2.00

Activity pattern of the Lesser Flamingo

Behavioral studies can play an important role in determining the extent to which environmental change will affect the population dynamics of wading birds (Goss-Custard *et al.*, 1990). Activity pattern of Lesser Flamingos were studied by scan sampling method (Altman 1974). Randomly selected ten individual's behaviour was observed as suggested by Schmitz and Baldassarre (1992). A total of 9195 individuals from 814 scan samples were used to study the activity budget of the flock during the study, of which 871 were juveniles / sub-adults.

Flamingos are filter-feeding wading birds, studies on the feeding biology of flamingos have included descriptions of the behavioral patterns used (Allen, 1956; Rooth, 1965; Ogilvie and Ogilvie, 1986; Ali and Ripley, 1987). Overall, the flamingos spent 65.4 % time for foraging followed by preening (9.53 %) and walking (8.16%) (Fig. 2.31). The overall activity pattern between the two seasons (2006-07 and 2007-08) did not show much significant difference (Fig. 2.32). The activity pattern was similar to that in the American Flamingos (Schmitz and Baldassarre, 1992). Arengo and Baldassare (1995) found 45-56% time for feeding while resting and preening were for 12 and 18% respectively.

This would indicate a less productivity or availability of food in the Sewri-Mahul region.

Table 2.11. Mean no. of benthic macro-invertebrates collected from Lesser Flamingo non-feeding areas during the study period.

Season	Macro invertebrates	Retibhandar	Colgate	Mahul	RamaDevi
Summer-07	Snail	27.67	43.33	8.33	19.33
	Bivalves	0.00	0.33	0.00	0.00
	Polychaets	5.50	1.50	1.50	4.00
	Aquatic worms	3.33	2.33	15.00	0.67
	Amphipods	1.00	1.33	16.00	2.00
Monsoon-07	Snails	0.00	9.00	1.00	1.00
	Bivalves	0.00	0.00	0.00	0.00
	Polychaets	7.00	5.00	3.00	1.00
	Aquatic worms	0.00	0.00	1.00	2.00
	Amphipods	0.00	0.00	0.00	0.00
Winter-08	Snails	17.00	3.00	8.00	8.00
	Bivalves	14.00	5.00	6.00	11.00
	Polycheates	2.00	13.00	5.00	10.00
	Aquatic worms	10.00	16.00	27.00	14.00
	Amphipods	2.00	4.00	5.00	4.00
Summer-08	Snails	9.33	10.67	1.33	2.67
	Bivalves	8.33	12.67	4.00	2.67
	Polycheates	0.50	2.00	4.50	2.00
	Aquatic worms	2.33	1.67	6.67	4.67
	Amphipods	0.67	2.67	0.33	0.00

In the present study the adult birds spent 77 % and 73 % for feeding with respect to the years2006-07 and 2007-08 (Fig. 2.33), whereas in juveniles / sub-adults it was only 53 % and 60 % (Fig. 2.34). Bildstein *et. al.* (1991) reported that juvenile flamingos do not forage as efficiently as adults and the rate at which food was being consumed by adult and juvenile flamingos was difficult to be observed and only the time spent for filter-feeding by members of the two age classes could be analyzed. The alert behaviour was also less in the juveniles compared to adults as reported in many other colonial birds in Bharathpur (Vijayan, 1991). The adult and juvenile activity pattern was almost similar. However the time spent for each activity had a little difference with no courtship behaviour in sub-adults during the study; a similar trend was reported in Caribbean Flamingos (Espino-Barros and Baldassarre, 1989).

Activity budget of adult and sub adult Lesser Flamingos in different seasons is depicted in Fig. 2.35-36. Feeding activity was the predominant one. Individuals in larger aggregations may allocate the minimal time necessary to monitor conspecifics and maximize feeding time because of the benefit of higher food density (Schmitz and Baldassarre, 1992). The minimum feeding was observed in the winter and feeding time gradually increased in the subsequent months to reach the maximum in monsoon. Once the birds reached the study area they spent more time on resting and preening activities compared to later months. The time spent for feeding increased from April to June; this behaviour is similar to that in many birds, especially migrants as food intake increased towards return migration for breeding. The incidence of rain in later months have reduced the food abundance at Sewri. Thus, the percent time spent feeding by flamingos increased which may also be inversely related to food abundance (Arengo and Baldassarre, 1995). Schmitz and Baldassarre (1992) found that flamingos fed 89% of the time, when food availability was thought to be lower.

Preening/comfort behavior was the next most frequent activity followed by walking and resting as found in other flamingos (Espino-Barros and Baldassarre, 1989; Arengo and Baldassarre, 1995). Preening was inversely proportional to feeding as it decreased with increase in feeding activity. Aggression among individuals happened only very occasionally; whenever it occurred it was largely between juveniles/sub-adults feeding in the flocks of adults. Flamingos were less disturbed by fishermen moving in canoes or crab-catchers who moved across the mudflats using wooden planks, but were disturbed by motor boats and boat repair activities at Sewri Port. Alert and disturbed flights among the flocks were rare. In other studies on flamingos, they found that motor boats could affect the non-breeding birds and such disturbances could reduce the feeding efficiency and increase the time spent for alertness (Galicia and Baldassarre, 1997).

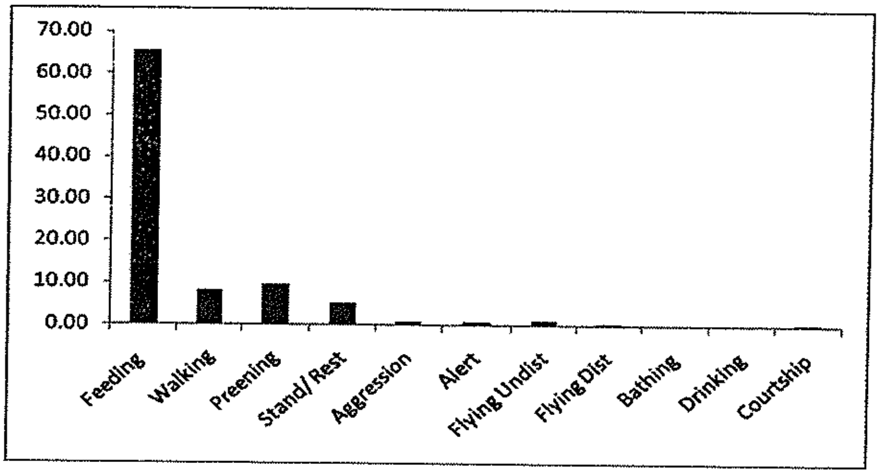


Figure 2.31. Overall Percent time spent in each activity by the Lesser Flamingo at Sewri-Mahul region during the study period.

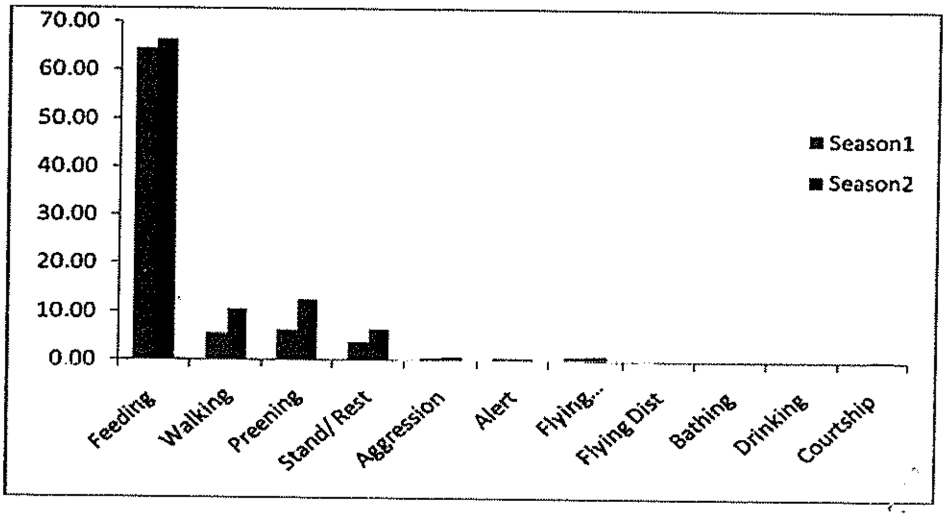


Figure 2.32. Percent time spent in each activity by the Lesser Flamingo at Sewri-Mahul region during season 1 and 2(2006-07 and 2007-08).

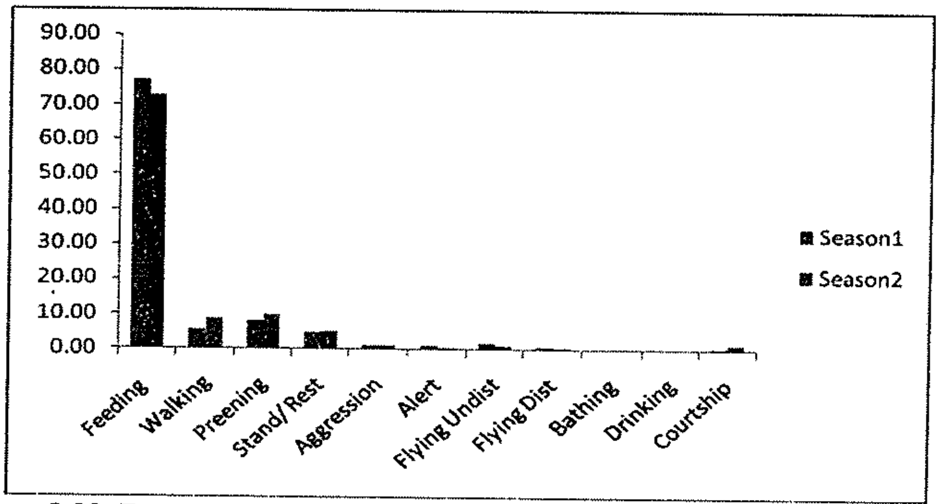


Figure 2.33. Percent time spent in each activity by adult Lesser Flamingo at Sewri- Mahul region during the study period.

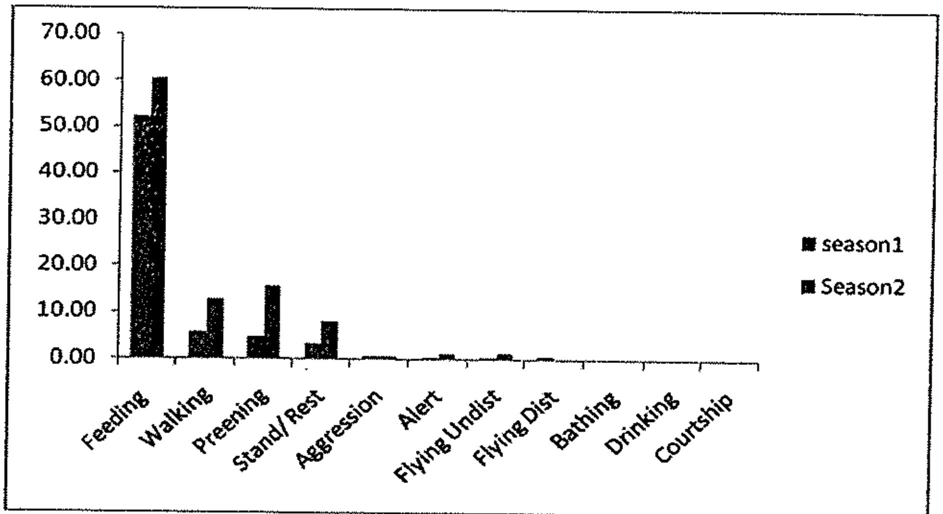
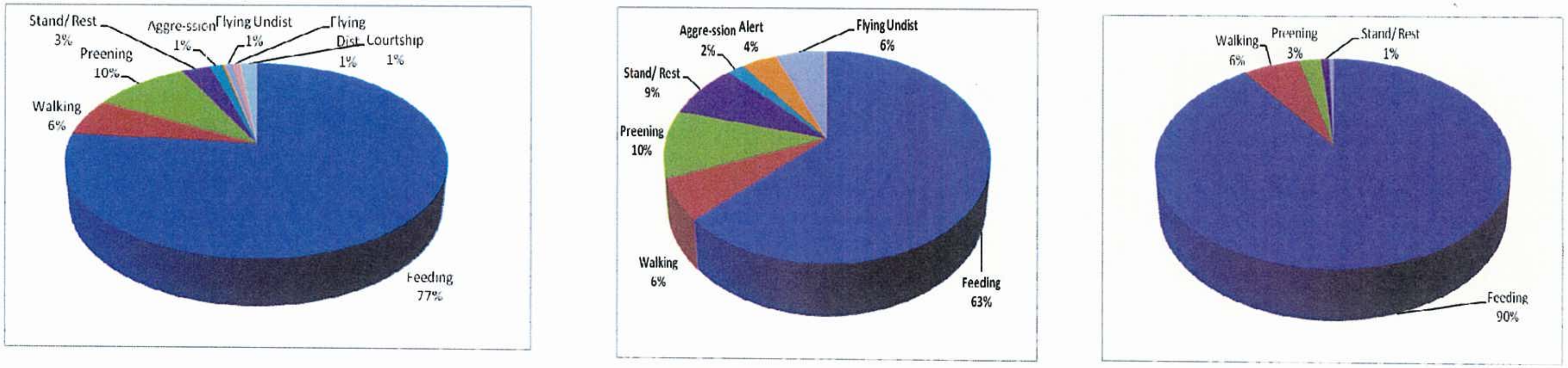


Figure 2.34. Percent time spent in each activity by Juvenile/sub-adult Lesser Flamingos in Sewri-Mahul region during the study period.

Largely flamingos were observed foraging in toe deep water at mud-water interface. The adults went slightly deeper up to about 30cm while feeding, whereas the immature birds kept to shallower areas towards the edge of water and wet mudflats. As the high tide approached, they even went inside the sparse mangroves on the border of the mudflats when the adults moved off to much safer place closer to Tata Power and the immature birds followed them. Roosting at high tide times near Tata Power was at deeper areas where they were loafing as explained under distribution.

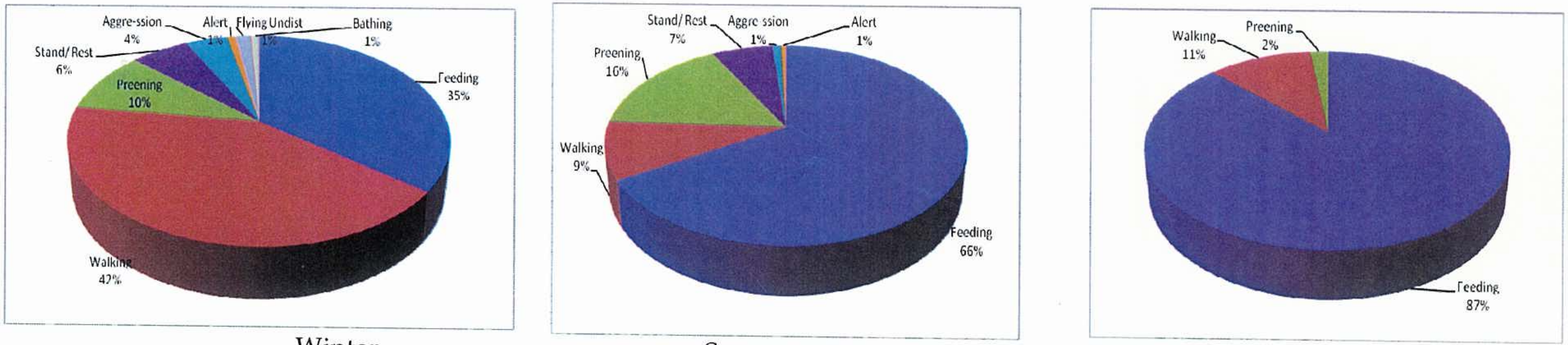
The activity budget of the adult and juvenile flamingos in different seasons was analyzed and compared within and between years. Feeding was the major activity in all the seasons for both the adults and juveniles but less in the latter (Fig.s 2.35 & 2.36) and increased from winter to summer and monsoon. Monsoon data was only for a month as the birds left in July during the heavy rains. The activity budget of the adult and juvenile flamingos showed significant difference among the seasons (ANOVA, F= 45, $p < 0.005$), whereas no significant difference was recorded within the season and between years. The juvenile spent more time for walking in winter as they arrived, but reduced walking and slowly increased feeding. Comparison of the activity budget in different seasons showed significant difference between winter and other seasons in both adults and juveniles (t-test) and the pattern was significantly different in all seasons between the adults and juveniles.

Juvenile birds spent more time walking between December and March, whereas from April to June the feeding time gradually increased from 50 % to 80 % in both the years with a little difference. This is the case with many species as the young become experienced in feeding and prepare for return migration which is a high energy demanding activity. Aggression was reported more only in February, probably because of the arrival of more birds and they were trying to settle down. Bathing and drinking were observed in January and March, but not regular as reported by Ali and Ripley (1987). Courtship activities are also observed in April and May much before they left; they form smaller flocks of a few individuals coming closer in a dancing posture with neck stretched upwards(Fig. 2.22) 'head- flag' and then 'wing-salute' giving a special type of call as explained by Johnson (1997) and Roberts (1991). Such behaviour is essential for the synchronization of breeding activities in these colonial nesters and started much before the nesting (Roberts, 1991). Such activities lasted for some time even for a few hours a few days before nesting as observed by Studer-Thiersch (2000) in his long-term study in Switzerland. Like adult birds the juveniles are also not much disturbed by the activities of the local people unless they go very close, but disturbed by motor boats and, boat repair activities at Sewri-port as explained earlier.



Winter Summer Monsoon

Figure 2.35. Activity budget of Adult Lesser Flamingo in different seasons during the study period



Winter Summer Monsoon

Figure 2.36. Activity budget of juvenile Lesser Flamingo during the study period in different seasons

General abundance of birds in the Sewri - Mahul region

General abundance of birds belonging to different species during different months in the Sewri-Mahul region was estimated. A total of 68 species of birds have been recorded during the study period at the study sites (Appendix 1). The total bird population in the Sewri-Mahul region ranged from 160 - 53,729 across the study period (Table 2.12 & Fig. 2.37, 2.38).The maximum number of species during 2006-07 was in December 2006 (47) while during 2007-08 it was in February 2008 (55) and minimum in June-July 2007 (9) and June 2008 (18). The maximum abundance was in January 2007 (53729) and March 2008 (51293). Bird abundance gradually increased and reached a peak in January-February with the influx of the migrants. The sharp decline in abundance by the end of May was due to departure of winter migrants from the area as observed in many studies on waterbirds (Vijayan, 1991). A similar trend was reported in Argentina and the movement was not affected by the abundance of invertebrates (Brayton and Schneider, 2000). An increased number of birds from Remadevi section were recorded as the result of high tide counts where huge flocks of waders congregate waiting for the water to recede and later dispersing to different parts of the study area; such a phenomenon was reported elsewhere in the world (del Hoyo *et al.*, 1992).

Between December and February the most abundant species were waders, namely Little Stint, Lesser Sandplover and Curlew Sandpiper followed by Brown- headed Gull. The former three were always found in mixed flocks and comprised 84.2 % of the entire bird population of the study area, whereas March onwards the Lesser Flamingo was invariably the most abundant species forming 59.9% of the entire bird population and Little Stint, Lesser Sandplover and Curlew Sandpiper found in mixed flocks formed 32.6 % of the entire bird population of the study area. The number presented here for small waders, especially of highly abundant mixed species flocks consisting of Lesser Sandplover, Little Stint and Curlew Sandpiper are rough estimates since they occurred in thousands and moved widely across the 4 km stretch mudflats. They were counted as a single group in 100s or 500s and subsequently samples were estimated for determining species composition in the flocks thus counted. They generally occurred in 2:5:2 ratios of the Lesser Sandplover: Little Stint: Curlew Sandpiper. After the migratory small waders such as the Little Stint, Lesser Sandplover and Curlew Sandpiper left the study area for their breeding grounds during late May, the egrets, especially the Cattle Egret was the dominant species. Two resident ducks, namely Lesser Whistling Duck *Dendrocygna javanica* and Comb Duck *Sarkidiornis melanotos* were sighted in the Mahul region in May 2007 and 2008. Passerines and raptors were comparatively fewer in numbers, the former group being largely associated with mangroves (Table 2.12).

Single Greater Spotted Eagle *Aquila clanga,* a globally threatened species, was seen on 14 February 2007 soaring over Sewri mudflats and it was observed in Uran in April 2008. The average number of Black-headed Ibis, a near threatened category species was found to be 18 and four juvenile birds were observed in Sewri during February 2008. Among resident bird species, egrets were the most abundant (Great Egrets and Median Egrets were difficult to be distinguished when they were foraging at far ends of the mudflats; in such cases their composition was calculated approximately). Seven species of birds of prey were sighted during the study period, of which three are migratory.

Retibhandar section, i.e. the region between Retibhandar and Sewri Port, had comparatively less area of mudflats exposed at low tide compared to other sections. Accordingly, the number of birds foraging in that area was also found to be less in comparison to other parts of the study area. This is more evident during days with minimal variation in tidal heights when water exposes only inland mudflat 'protrusion' at Colgate, and a few areas at Mahul side.

Shannon-Weaver Index was used to study the bird species diversity in the Sewri- Mahul region (Table 2.13) and it was maximum in February 2007(1.719) during 2006-07 and January 2008 (2.528) during 2007-08 because of the equal distribution of birds in a large number of species, whereas the minimum was in June in both the years (0.464 and 0.893 respectively).

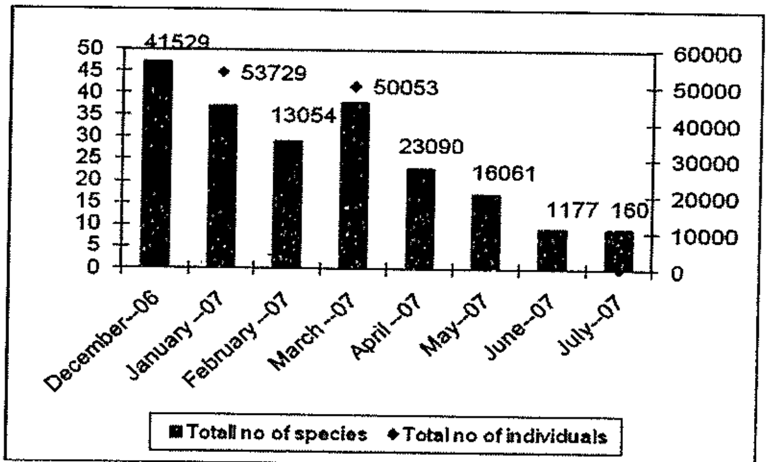


Figure 2.37. Average monthly fluctuations of bird abundance and number of species at Sewri- Mahul region during 2006-2007.

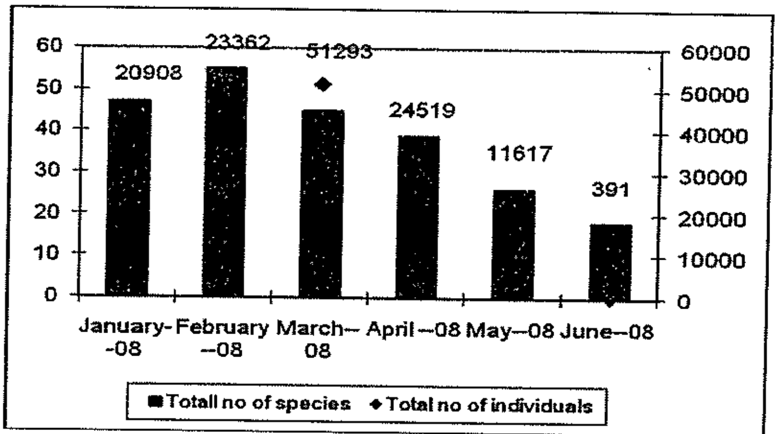


Figure 2.38. Average monthly fluctuations of bird abundance and number of species at Sewri- Mahul region during 2007-2008.

Table 2.12. No. of species and abundance of birds of different groups in the Sewri- Mahul region during the study period, 2006 to 2008 (No. of species & abundance in parenthesis).

Month	Ducks	Cormorants	Waders	Gulls & Turns	Raptors	Kingfishers & Pigeons	Passerines & others	Total
Dec-06	0	0	24(34208)	5(7187)	3(13)	3(9)	12(112)	47(41529)
Jan-07	0	0	20(51245)	6(2321)	3(21)	3(9)	5(133)	37(53729)
February	0	0	18(11653)	6 (2159)	1(2)	1(2)	3(153)	29(13054)
March	0	0	20 (47186)	6 (2613)	1(2)	3(6)	7(246)	38(50053)
April	0	0	18 (21109)	4 (1857)	2 (7)	1 (4)	8 (113)	23(23090)
May	1(46)	0	16 (15933)	3 (42)	1 (4)	1 (1)	5 (35)	17(16061)
June	0	0	6 (1154)	0	1 (1)	0	2 (22)	9(1177)
July	0	0	6 (136)	0	0	0	3 (24)	9(160)
Jan-08	0	0	24(18982)	6(1804)	3(17)	4(44)	11(61)	48(20908)
February	0	1(1)	27(20986)	6(2244)	2(16)	5(30)	14(75)	55(23352)
March	0	0	24(48192)	6 (2868)	3(9)	3(5)	9(219)	45(51293)
April	0	0	23(22682)	6(1627)	2(19)	1(1)	6(190)	38(24519)
May	1(320)	0	17(11151)	3(42)	1(9)	0	4(95)	26(11617)
June	0	0	8(388)	0	2(12)	1(1)	5(33)	18(391)

Table 2.13. Total No. of species and Shannon-Weaver diversity index values of birds in the Sewri - Mahul region during the study period.

Month	**No. of Species**	**Diversity Index**
December-06	47	1.541
January-07	37	1.404
February	29	1.719
March	38	1.648
April	23	1.451
May	17	1.009
June	9	0.464
July	9	1.438
January - 08	48	2.528
February	55	1.819
March	45	2.142
April	38	1.453
May	26	1.312
June	18	0.893

Abundance of birds at Nhava

General abundance of birds belonging to different species during the study period at Nhava, Shivaji Nagar mudflats was estimated. It showed a total of 38 bird species (Appendix 2). The Flamingos did not use Nhava during this study as reported. The abundance of shorebirds was fewer compared to the mudflats having similar surface area in the Sewri -Mahul region. At Nhava also the waders used mudflats, shallow water areas and the inland water bodies during high tides when no feeding sites were available at the coast including sparse mangrove areas. The only duck sighted was Spot-billed Duck in December 2006 which was not sighted in the Sewri - Mahul region. Little Cormorant was recorded in March 2008 and it was not recorded in the previous year (2006-07). The total bird population at Shivaji Nagar mudflats ranged from 24 - 2,121 across the study period in both the years (2006-07 & 2007-08). Bird abundance increased gradually to reach a peak in March and a sharp decline in abundance thereafter due to departure of winter migrants from the area as observed at the end of May in both the years (Table 2.14 & Fig. 2.39, 2.40). Warders formed the major group as in Sewri. The number of species and birds were much less in April as most of the migratory species had left the area for their breeding ground as explained for Sewri - Mahul region. Three species of birds of prey were reported during the study period of which two species were migratory. There was only two Black-headed Ibis, a near threatened category species recorded in January and May in the first year of study (2006-07), whereas in the second year it was observed throughout. Among resident bird species, egrets were the most abundant (composition of the Great Egrets and Median Egrets were approximately calculated as explained earlier for Sewri - Mahul region).

The bird species diversity (Shannon-Weaver Index) was calculated for different months of the study in Nhava, Shivaji Nagar mudflats area and it was maximum in December 2006 (2.182) during 2006-07 and in March 2008 (2.32) during 2007-08 while minimum was in July 2007 (1.294) and June 2008 (1.032) (Table 2.15).The species diversity values were higher compared to Sewri-Mahul region but the abundance and the number of species were less in Nhava which is mainly because of more equal distribution of species.

Table 2.14. No. of species and abundance of birds of different groups at Nhava mudflats (Shivaji Nagar) during 2006 – 07 and 2007-08 (No. of species abundance in parenthesis)

Month	**Ducks**	**Cormo-rant**	**Waders**	**Gulls & Turns**	**Rap-tors**	**King-fishers & Pigeons**	**Passer-ines & others**
December-06	1	0	12(257)	1(1)	0	2(2)	0
January-07	0	0	11(365)	3(3)	2(3)	1(1)	1(4)
February	0	0	10(105)	3(37)	0	0	1(4)
March	0	0	10(2026)	3(55)	0	0	3(40)
April	0	0	11(1273)	2(4)	0	0	1(15)
May	0	0	8(223)	1(2)	0	0	1(4)
June	0	0	4(12)	0	0	0	2(12)
July	0	0	4(13)	0	0	0	1(12)
January-08	0	0					
February	0	0					
March	0	1(5)	17(1981)	4(95)	2(6)	1(1)	2(22)
April	0	0	12(1975)	2(28)	1(2)	0	1(18)
May	0	0	10(152)	0	1(2)	0	2(11)
June	0	0	7(60)	0	1(3)	1(1)	2(15)

Table 2.15. Total No. of species and Shannon-Weaver diversity Index values of birds present in the Nhava mudflats (Shivaji Nagar) region during December 2006 - July 2007 and January 2008-June 2008.

Month	No. of Species	Diversity Index
December-06	16	2.182
January-07	18	2.010
February	14	2.048
March	16	1.551
April	14	1.535
May	10	1.542
June	2	1.593
July	2	1.294
January-08	15	1.817
February	26	1.714
March	27	2.320
April	16	1.412
May	13	1.214
June	11	1.032

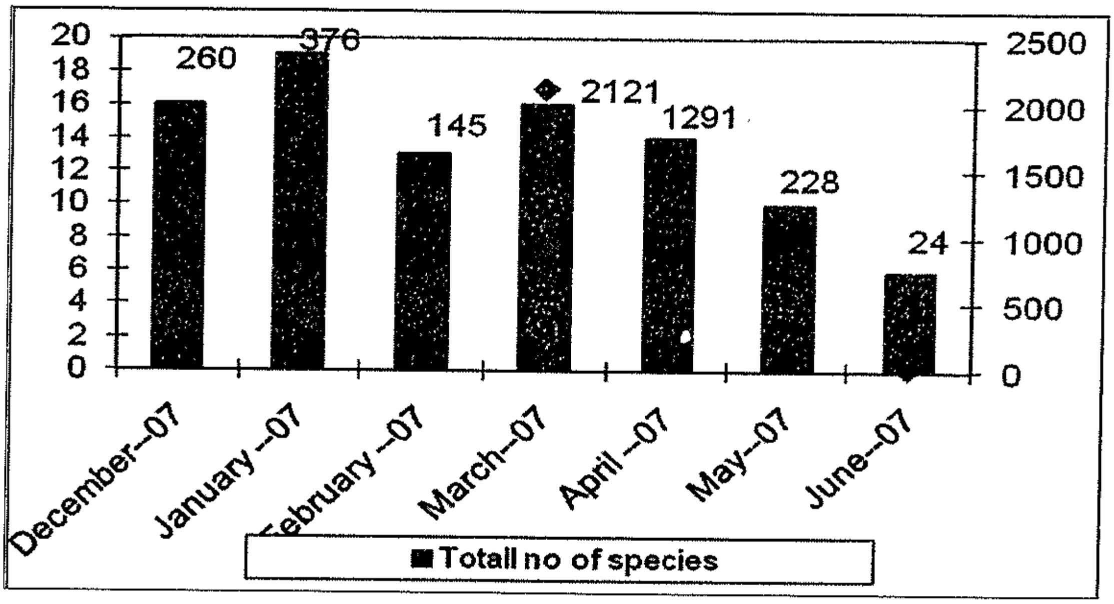


Figure 2.39. Average monthly fluctuations of bird abundance and total number of species at Nhava (Shivaji Nagar mudflats) region during December 2006 to July 2007.

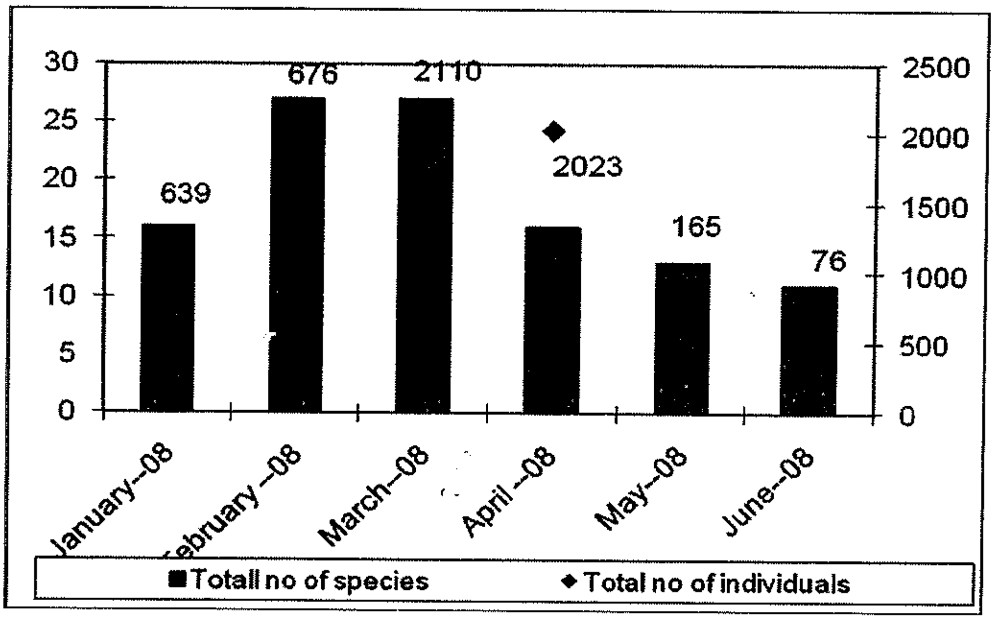


Figure 2.40. Average monthly fluctuations of bird abundance and total number of species at Nhava (Shivaji Nagar mudflats) region during the study period from January 2008 to June 2008.

Flamingos and other birds in other areas surveyed

Flamingo distribution in the east coast of the Thane creek on the mainland Navi Mumbai was surveyed during 2007-2008 to find the new sightings in the present season. The sites were selected based on enquiries with the local people and the bird-watchers. The surveys were carried out during January-February 2008. Totally five probable areas in Nhava region was surveyed, where the local people sighted flamingos and another probable area, Vashi was also surveyed. During the present survey only three sites had the Lesser Flamingo sightings, whereas the Greater Flamingo was not sighted. However, the local people had reported them. The surveyed places are Zasai village, Uran village, JNPT - salt pans 1 (near staff quarters), JNPT - salt pans 2 (near staff quarters), Nhava village side and Koliwada village. The Lesser Flamingos were recorded in Zasai village, JNPT - salt pans -2 and Vashi mudflats near bridge (Fig. 2.41). During the survey most of the salt pans were in dried condition and only a few waders were counted.

Zasai village

Nearer to Pune –Mumbai express highway there was a small wetland adjacent to the salt pans. The water spread area was about one hectare. Only a juvenile Lesser Flamingo was observed in the middle of the wetland. The other waders such as Little Stint, Lesser Sandplover and Common Redshank were recorded. In the adjacent small mangrove patch the Red-wattled Lapwing and White-throated Kingfisher were recorded. The local people reported that they often saw the Lesser Flamingos and some times they were available throughout the day. The number of individuals varied from 50 to 100 and most of them were juveniles.

Uran

The mudflats near Uran village were surveyed but there were no flamingos. However, a few were reported to have been seen here during the low tide. The number also varied in different times. The other waders such as Little Stint, Lesser Sandplover, Brown-headed Gull, Little Tern, Common Greenshank and, White-throated Kingfisher were recorded from here during the survey.

JNPT - salt pans 1 (near staff quarters)

The salt pans were almost in dried condition and there were no waders sighted. The Shikra was recorded. During November and December the flamingos and other waders were reported in the salt pans; around 300 Lesser Flamingos were sighted in the salt pans.

JNPT- salt pans 2 (near staff quarters)

In between the JNPT jetty and the JNPT staff quarters a four hectare marsh adjacent to the salt pans were surveyed. Water covered around three hectare and two sides were covered by salt pans and one side by road which leads to the JNPT and Uran and one side was train track and the mangroves. A total of 76 species of birds were recorded (Table 1.11) of which one was Globally threatened Greater Spotted Eagle and three were near threatened species, namely White Ibis, Painted Stork and the Lesser flamingo. In the present survey 20 to 100 Lesser Flamingos were recorded. Local people and the bird-watchers from the Uran area told that in the early December and January these salt pans had attracted more than 800 Lesser and 300 Greater Flamingos. During our survey there were no Greater Flamingos here.

Vashi

The mudflats near Vashi bridge had 20 to 325 Lesser Flamingos. During this season the juvenile and the sub-adult flamingos were observed feeding in the mudflats during April and May 2008. However, in this season also during the earlier months they were not observed. Probably when the population increased (more than 10,000) in the Sewri Mahul region the birds moved to adjacent suitable areas like Vashi mudflats.

Survey of Bhigwan

Bhigwan wetland (Co-ordinates – $18^{0}14'$ N, $74^{0}44'$ E) also known as Ujjani is a well-known wetland site and is situated 100 km from Pune on the Pune Solapur highway. The main shallow zone is near Bhigwan village on the bank of Bhima River where the backwaters of Ujjani dam form a shallow water body that attracts a variety of water birds. This is a large wetland with a total area of 300 ha. This wetland however is fairly heterogeneous, which is related to different water levels and peripheral land use (Fig. 2.42). This wetland, however, is fairly heterogeneous, which is related to different water levels and peripheral land use.

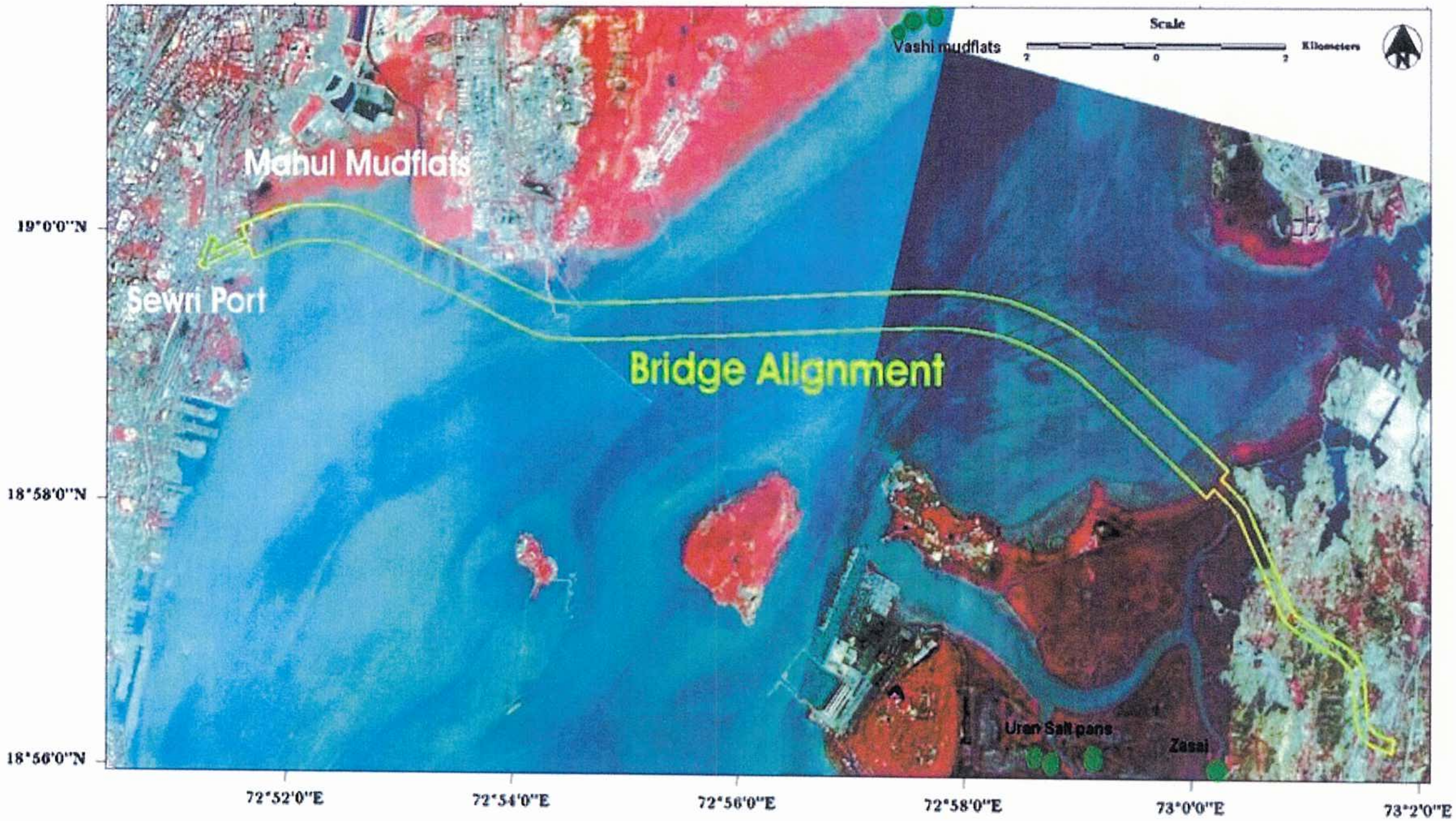


Figure 2.41. Distribution of the Lesser Flamingos in the new locations in the Thane creek during January - February 2008.

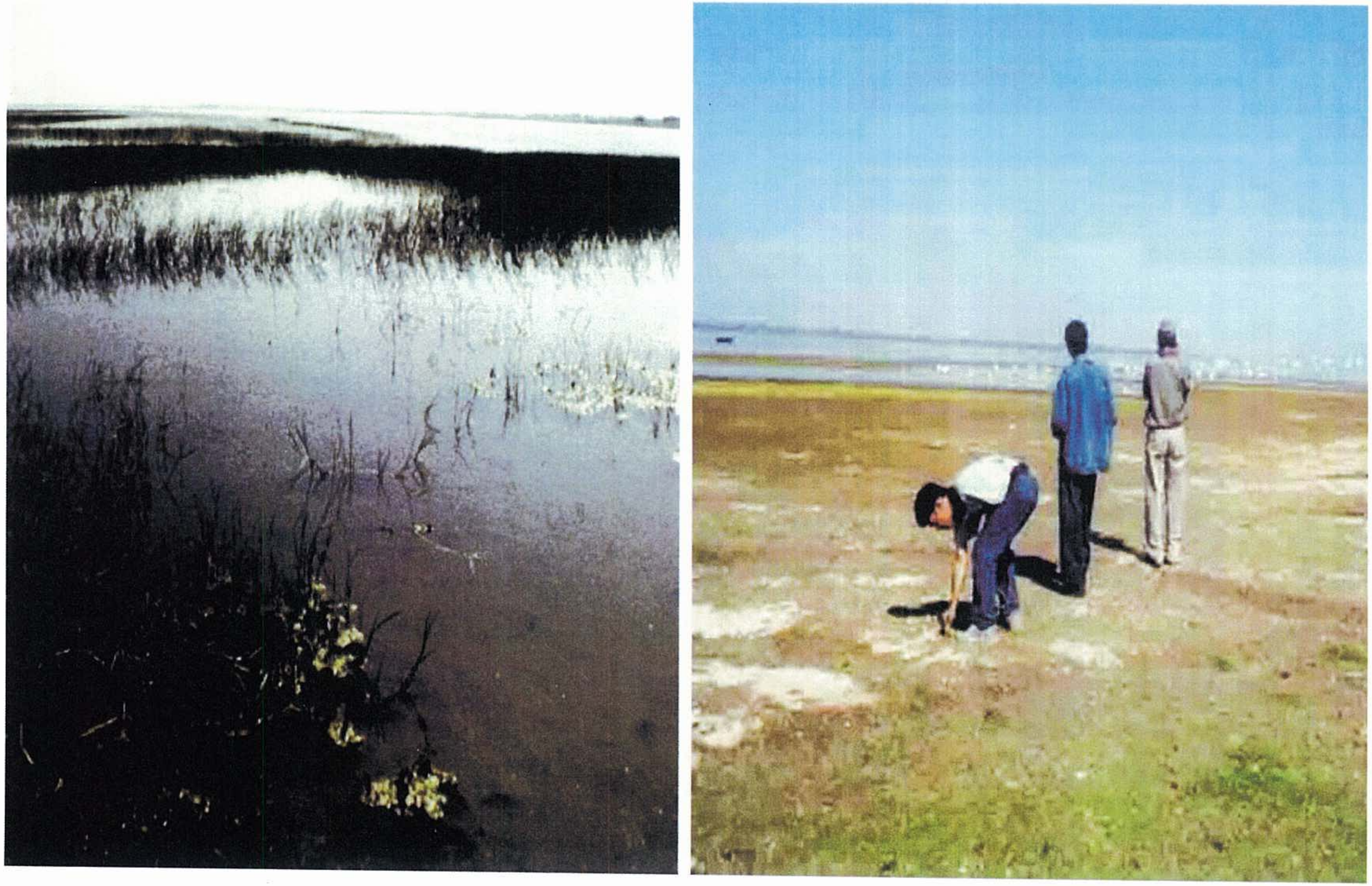


Figure 2.42. View of Bhigwan wetland (Source: BVIEER-Pune)

Most of the surrounding area of the water body (about 70%) is used as agricultural land. The major crops grown in the area are sugarcane, wheat, jowar, and vegetables. This water body has been used for grazing, fishing, irrigation, and social forestry operations, and drinking/ wallowing for cattle. The surrounding population is mostly dependent on agriculture and uses water for irrigation on the draw-down agriculture uses. There are 4 villages surrounding the wetland, having a population of approximately 40,000. Eight to ten thousand people are directly dependent on this part of the wetland.

The wetland of Bhigwan is under the Irrigation Department. The Forest Department has guards posted in some villages. As it is not a Protected Area, activities such as grazing cattle in the surroundings, fuel wood collection, harvesting aquatic weeds and other vegetation as fodder, washing cattle, clothes, utensils, vehicles etc. are carried out in the surrounding area of the wetland. Fishing is extensively carried out. However the area is rich in birds and other biodiversity.

We had several rounds of discussions with Dr. Erach Barucha, the Director of Bharathiya Vidyapeeth Institute of Environmental Education and Research, faculty members including Dr. Kranthi and other researchers. We visited the Bhigwan wetland in May and surveyed the area with special interest the flamingos. Many species of birds and large number of Openbill Storks (>800) were observed here. There were about 400 Greater Flamingos in the area, occupying the shallow edges of the wetland and mudflats. Since they were very far from the national highway and other roads they were not disturbed. It was understood that during the construction of the national highway also they were not disturbed as these birds are more than a kilometer away. The highway passes through one corner of the wetland.

Chapter-3

HABITAT MAPPING AND CLASSIFICATION

INTRODUCTION

A scientific management system for protection, conservation and restoration must be based on reliable information on bio-geophysical and geomorphologic processes, coastal erosion, sedimentation dynamics, mapping of vegetation, water quality, climatic change effects and, synergetic use of quasi-simultaneously acquired multi-sensor data may allow for a better approach of habitat evaluation (Zoran and Anderson, 2006). Remote sensing techniques have been primarily used to generate information on land cover/use changes and Geographical Information Systems (GIS) and remote sensing are used to provide a rapid or a large-scale understanding of the area and in developing management strategies (Prasad *et al.*, 2004; Vijayan *et al.*, 2004; Papastergiadou *et al.*, 2008). Assessment of coastal wetland resources using remote sensing data has been done in different regions in India (SAC, 1998; Jagtap *et al.*, 2001). High concentrations of suspended particulate matter in coastal waters directly affect or govern numerous water column and benthic processes which could be documented using remote sensing data (Miller and McKee, 2004; Miller *et al.*, 2005).

The present study has been commissioned by MSRDC to look at the population of birds with emphasis on the Flamingos, their behaviour and the quality of the habitat. The shorebirds use the mudflats according to the water level which changes with the tide levels (Weller, 1999). Wading birds such as flamingos, egrets, storks use shallow water areas while the smaller waders use these areas when water recedes and the mudflats are with still lower levels of water or partly exposed. Since the Sewri - Mahul region supports a large population of flamingos and other waders, it is important to understand their habitat, its extent and the distribution of these birds in the area and also in relation to the alignment of the proposed bridge using remote sensing and GIS techniques. The results of this study will help in taking necessary steps for the protection of the birds and the area.

As a part of this study we also tried to document the high tide and low tide levels and the sedimentation pattern (Miller *et al.*, 2005) in the Sewri- Mahul region of Thane Creek. Coastal land that lie between the highest spring tide (High tides that are higher than average) and the lowest neap tide (Low tides lower than average) is called the intertidal zone or the littoral zone. This complex marine ecosystem is found along coastlines worldwide. It is rich in nutrients and oxygen and is home to a variety of organisms. The plants and animals that are found in the tidal zone are adapted to being covered with water during high tides and exposed to air at low tides. Depending on the season and location, the climate can be cold or even freezing in winter and hot in summer. When submerged, however, the water mediates the extremes of temperature, since it is always either warmer than the land in winter or colder in summer. As the tide recedes, the tidal zone is exposed. Seabirds take the opportunity to feed on exposed organisms such as crabs and mussels and many species are adapted to utilize the mudflats according to the water levels and the morphology and behaviour of the species.

METHODS

The remote sensing technology has been advancing with data of different resolutions. The LISS-IV camera is a multi-spectral high resolution camera with a spatial resolution of 5.8m. This camera can be operated in two modes, (1) Mono and (2) Multi-spectral. In the Multi-spectral mode, data are collected in three spectral bands, whereas in Mono mode it is one band. It has a capacity of revisit of 5 days for any given ground area. Both LISS-III and LISS-IV multi-spectral sensors are quite useful for mapping different vegetation cover classes required for efficient land use, agriculture and forest resources assessment.

The required satellite data (IRS P6 LISS IV) were procured from NRSA Data Centre (NDC), National Remote Sensing Agency, Hyderabad. The respective LANDSAT Enhanced Thematic Mapper (ETM^+) datasets were downloaded from GLCF site. Two LISS IV scenes (dated 14 January 2005 & 12 November 2005) were procured for the study site (Table 3.1). The following flow chart (Fig. 3.1) shows the overall methodological approach towards the analysis of the remotely sensed data. The satellite datasets were registered with respective to LANDSAT images by giving common Ground Control Points (GCP) using ERDAS IMAGINE 8.7 software. Then, it was geometrically and radio metrically corrected using first order polynomial transformation model. Average root mean square error of less than a pixel was maintained while preparing transformation model.

Table 3.1. Details of remote sensing data used for the study area

Satellite-sensor	Path-row	Date of acquisition
Data used		
IRS-P6 LISS IV MX	103/25	14-Jan-2005
IRS-P6 LISS IV MX	204/03	12-Nov-2005
Reference data		
Landsat-TM	148/47	11-Sep-1992
Landsat-ETM+	148/47	25-Oct-2001

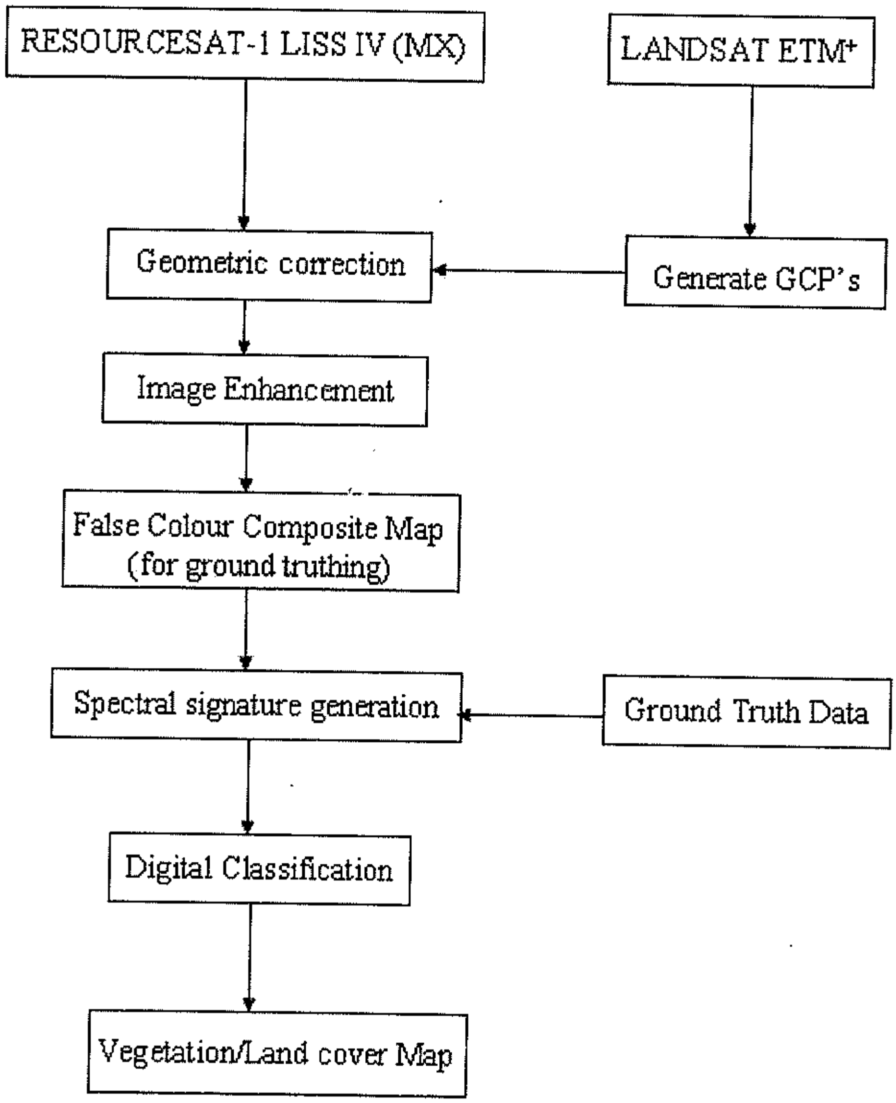


Figure 3.1. Methodological approach for analysis of remotely sensed data

Co-registration of spatial features on rectified image with that of LANDSAT image was verified using swipe procedure. All the datasets are in WGS 84 datum and UTM projection. The enhancement and contrast techniques are being extensively used in digital image processing as a first step after rectifying the scene. This is to improve the quality of an image for easy recognition of various earth features and understanding its relation in ground. Both the LISS IV scenes were mosaiced. Area of interest (AOI) for The Thane Creek, Mumbai coast along with its surrounding was separated out from the mosaiced scene. The False Color Composite (FCC) was generated from the image (Fig. 3.2).

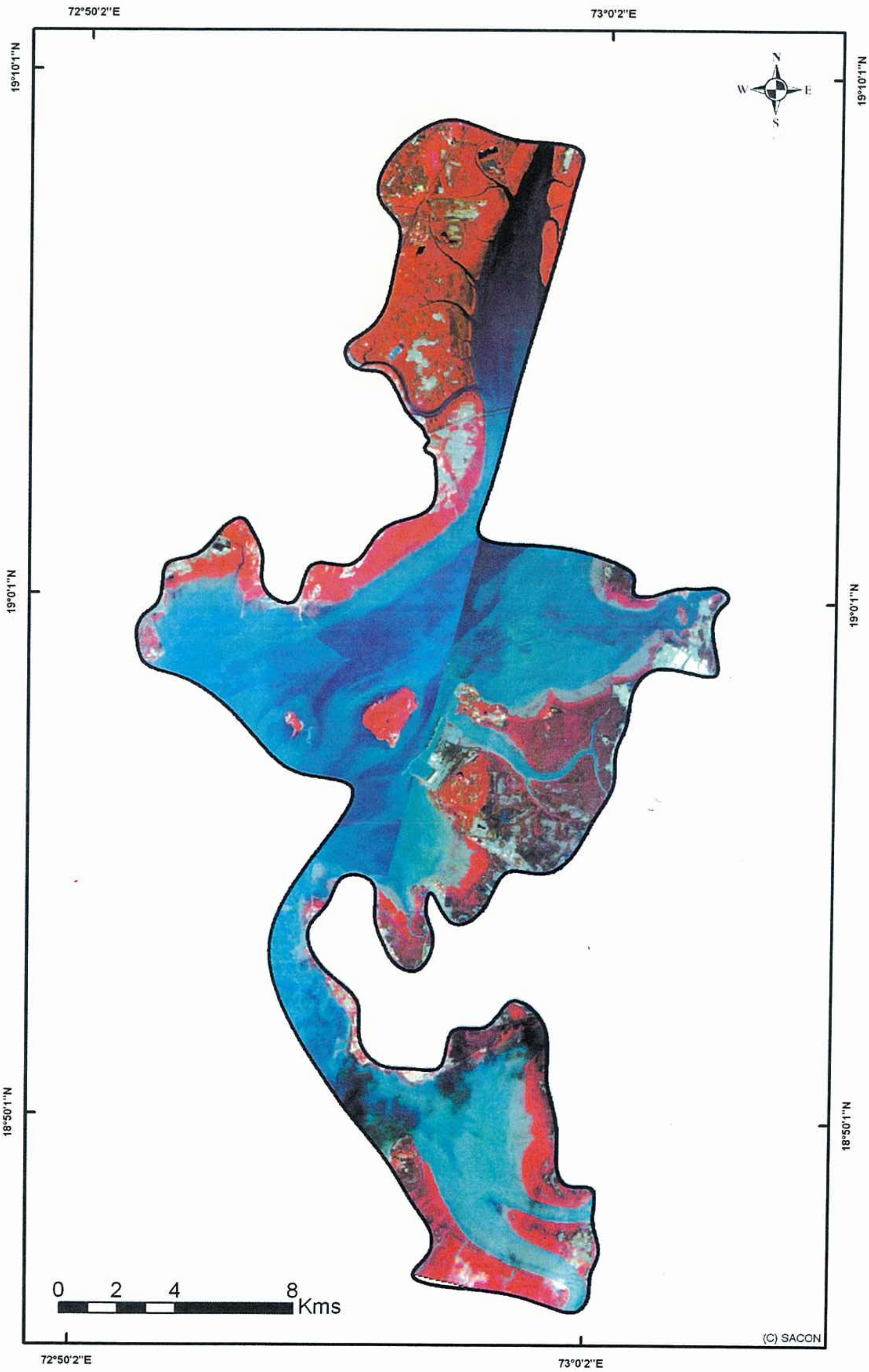


Figure 3.2. False Color Composite (FCC) of the study area.

Supervised Classification and GIS analysis

The supervised classification techniques based on known "training areas" about different surface features that are to be classified by the computer. The supervised classification technique uses the Maximum Likelihood Classifier (MLC) algorithm and MLC assumes Gaussian distribution of data. The classification process involves grouping the unclassified pixels in a satellite image into different specified classes basing on probability. Pixels are assigned to their most likely classes basing on highest probability values. Using feature signatures, each pixel with similar characteristic signatures is grouped and assigned to a respective class. All the thematic classes are extracted using above procedures. Finally, the classified land use and land cover map is generated. After, thorough ground truthing, all the required information was incorporated to get a good classified map of the area.

Co-ordinates for the alignment of the proposed bridge were obtained from MSRDC and these were overlaid on the classified imagery and vector map was generated. GPS locations of the flamingo distribution with approximate densities were overlaid on the classified imagery with the alignment of the bridge.

Study of inter-tidal sedimentation pattern

For this study, we used the best possible satellite data, viz. TERRA and AQUA MODIS. According to the Tide Chart received from the Mumbai Port, the high tide occurs during the afternoon of the day. The Indian satellites are passing at 10.30 am of the day. So it is very difficult to get the Indian satellite image during the high tide time. So using MODIS for evaluating the intertidal zone and sediment pattern was the best possible way to answer our queries. Out of 36 bands present in MODIS, we have used only three bands for our programme of work.

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (see MODIS Technical Specifications). These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

This study was carried out using 250 meter MODIS (TEERA and AQUA) Level 1B data set (Table 3.2). It contains calibrated and geo-located (UTM/WGS84) at-aperture radiances for 2 discrete bands (B1-0.620 - 0.670, B2- 0.841 -0.876) located in the 0.62 to 0.88 micron region of the electromagnetic spectrum. These data are generated from the MODIS Level

1A scans of raw radiance. GeoTiFF data downloaded from http://ladsweb.nascom.nasa.gov/data/search.html. To estimate littoral zone at Thane Creek, we considered two data sets corresponding to spring tide (22 Jan 2007; 14.06 PM; 4.05 meter) and neap tides (24 Feb 2007; 10.45 AM; 0.86 meter). With careful analysis based on the spring and neap tide times, we considered AQUA-MODIS data for 22 January 2007 and TERRA-MODIS data for 24 February 2007.

Delineation of sediment area

The following are the methodology used for delineation of sediment area using tide table data and remote sensing data.

1 MODIS level-1b 250m bands (B1 and B2) Geo-tiff files downloaded from data distribution server through ftp pull.

2 With two bands created FCC (R-1, G-2, B-2) image using ILWIS open source image processing software package.

3 We extracted the study area (Thane creek) of spring tide and neap tide times using Area of Interest (AOI).

4 Corresponding to Spring tide and Neap tide data sets digitized the tidal range (the water between the low-tide elevation and the high-tide elevation is known as the tidal range, or amplitude) using OpenJump Open source GIS package.

5 After comparing both tide maps the littoral zone area was extracted.

RESULTS AND DISCUSSION

Classification of the habitats in the area of interest

We have taken a boundary to mask out mangrove vegetation. The total study area of interest in the coast of Thane Creek selected covered 300.6 km^2. After digital classification of satellite image, we have identified eight land cover types as given below:

Table 3.2. Technical specifications of the MODIS satellite data

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular			
Scan Rate:	20.3 rpm, cross track			
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)			
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop			
Size:	1.0 x 1.6 x 1.0 m			
Weight:	228.7 kg			
Power:	162.5 W (single orbit average)			
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)			
Quantization:	12 bits			
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)			
Design Life:	6 years			
Primary Use	**Band**	**Bandwidth1**	**Spectral Radiance2**	**Required SNR3**
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 -1250	5.4	74

	6	1628 -1652	7.3	275
	7	2105 -2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric	17	890 - 920	10.0	167
Water Vapor	18	931 - 941	3.6	57
	19	915 - 965	15.0	250
Primary Use	**Band**	**Bandwidth1**	**Spectral Radiance2**	**Required NE[delta]T(K)4**
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07

Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.78-11.280	9.55(300K)	0.05
	32	11.77 -12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.15 -13.485	4.52(260K)	0.25
	34	13.485 -13.785	3.76(250K)	0.25
	35	13.785 -14.085	3.11(240K)	0.25
	36	14.085 -14.385	2.08(220K)	0.35

The study has resulted in the satellite-based map of Thane Creek in Mumbai coast with different land use land cover data at the scale of 1:12500 using digital interpretation techniques (Fig. 3.3). The area statistics of different classes is given in Table 3.3. A description of different land use and land cover classes is also given below.

(1) Dense Mangrove
(2) Open Mangrove
(3) Other Tree Cover
(4) Mudflat
(5) Open/Barren Land
(6) Sand
(7) Waterbody
(8) Built-up area

Dense Mangrove

These forests are typically a closed evergreen forest of moderate height composed of species specially adapted to survive on tidal mud, which is partially submerged with salt water or brackish water. This type of forest is characterized by mostly tree species with good canopy cover. Total area covered by these forests is about 21.5 km².

Table 3.3. Distribution of land use and land cover categories along the coast of Thane Creek, Mumbai.

Land use/ land cover classes	% area
Dense mangrove	7.2
Open Mangrove	9.3
Tree cover	3.5
Mudflat	12.6
Open land	6.9
Sand	3.7
Water body	54.2
Build-up area	2.7
Total area of interest (km2)	300.7

Open Mangrove

This type of forest is dominated by stunted tree species with less canopy cover. The tree species with shrubs are distributed randomly. It is of very low average height, often 3-5 m in height and represents the species of mangrove forest. These are not dense in structure and composition. We can find only scattered distribution with scrub vegetation. It covers 28 km² of the total study area.

Tree Cover Vegetation

This vegetation is found very close to mangrove vegetation and human settlements. These includes road side trees, plantation, trees found in parks and home gardens, some forest patches other than mangrove vegetation, etc. The vegetation is either planted or orchards in home gardens. It covers 10.5 km^2 of the study area.

Mudflat

Mudflat is a wetland, in which the salty water inundated the surface of the ground. The vegetation seen in this area is of herbaceous type and generally referred as mudflat (salt marshes) vegetation. Due to high moisture and salinity content, mostly halophytic species grow predominantly. It also includes some scrubby vegetation. Total area covered by 37.9 km^2 of the area.

Open/Barren Land

This class includes barren areas, abandoned saltpans, open space between construction, etc. It covers 20.7 km^2 of the total area.

Sand

Generally, it is considered as barren land. it found all along Mumbai coast. It covers 11 km^2 of the total area.

Waterbody

Maximum part of the study area is covered under water (Arabian Sea). It accounts for 162.8 km^2 of the total area.

Built-up Area

After classifying the vegetation, sand and water bodies, the rest of the area, which is left, considered as built-up area. Though our study area mainly focuses the mangrove vegetation of the area, we have taken only the mangrove vegetation portion for interpretation. Some built-up areas are found around the mangrove vegetation. It covers 8.2 km^2 of the total area.

Satellite remote sensing with substantial ground truth has enough potential to classify land use/cover. Mangrove mapping using remotely sensed data on a long-term basis would be desirable for understanding the pattern and dynamics of the vegetation. Digital image processing techniques enable speedy and accurate interpretation of the multispectral data received from remote sensing satellites. High-resolution datasets are also helpful in executing the classification in a better way than coarse resolution dataset. Introduction of the Recourses at satellite has offered an advantage of competitive spatial, spectral and temporal resolutions for vegetation studies. The study has emphasized the role of aerospace technology for vegetation monitoring, which can be further used in conjunction with extensive ground truth to provide quantitative habitat information.

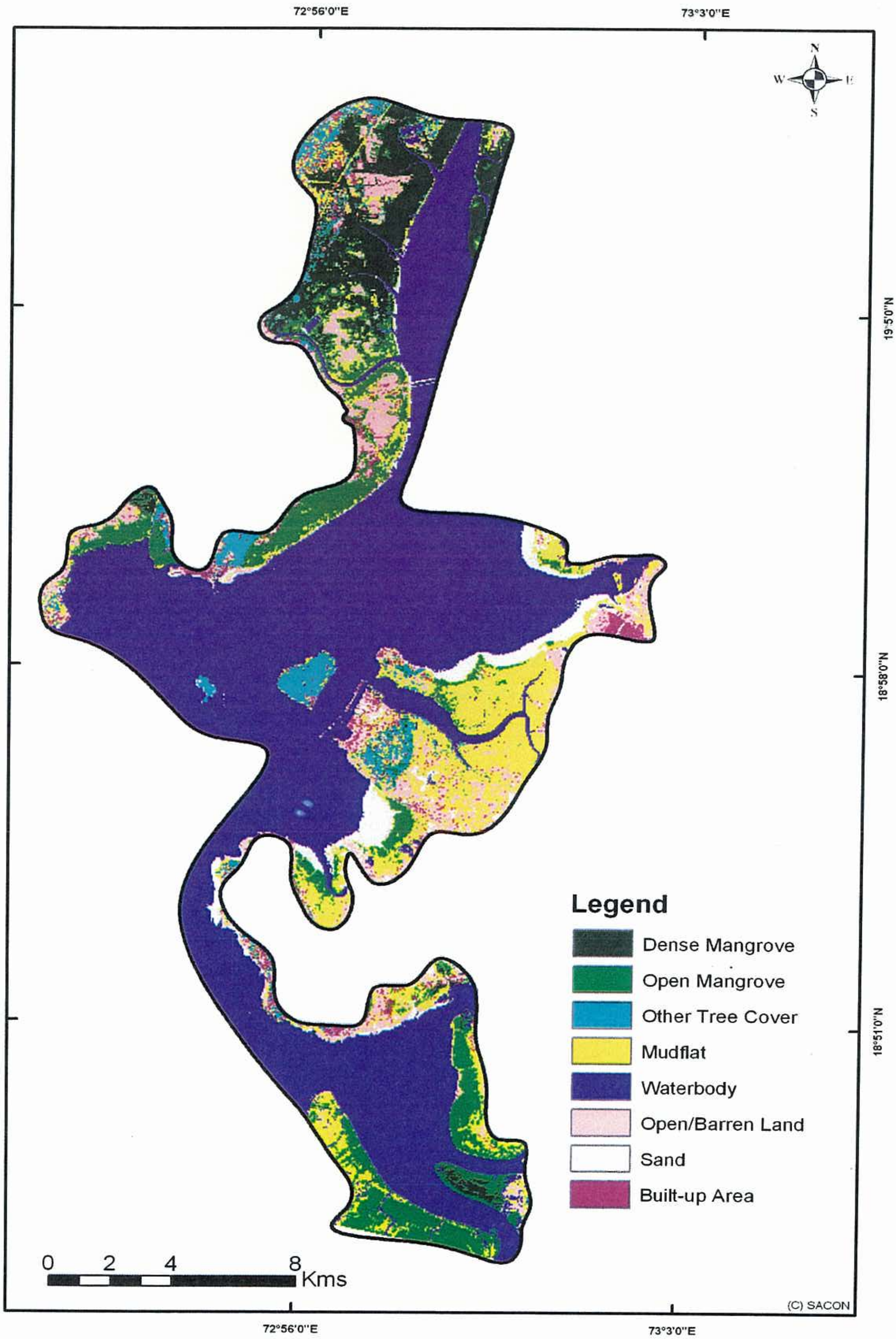


Figure 3.3. Land use and land cover map of the study area

Analyses of the flamingo habitats in relation to the proposed bridge

Further analyses were done with the location data generated on the distribution of flamingos feeding in the Sewri-Mahul region and also the mudflats where many waders, except the flamingos were sighted at Nhava, towards the other end of the proposed bridge (Fig.s 3.4 &3.5). Detailed analyses of the distribution of the flamingos in relation to the proposed alignment of the bridge showed that the portion of the bridge at the sewri end would pass through the mudflats used by the flamingos for feeding and up to the Tata Power Jetty where they roost during high tide (Fig.s 3.6 & 3.7).

Intertidal zone and sediment load in the Sewri-Mahul region

Based on the tide table of 22 January 2007 and MODIS data analyzed gave the satellite maps of high (spring tide Fig. 3.8) and of 24 February 2007 for low (neap tide Fig. 3.9). Using these data, we estimated the area of littoral zone as 5.3 sq km as shown in figure 3.10 A, B, C and D. This is the potential mudflat areas where always tides are flushing, leaving sediment particle. When high tide comes all the mudflats of Sewri and Mahul are inundated with water, whereas in low tide, water recedes leaving lot of sediment particles including food for birds. This sediment load is mainly responsible for the productivity and birds come here for feeding purpose so that they can gain energy reserve for return migration and breeding thereafter. The proposed bridge also goes across the potential mudflat zone. The sediment load (Fig. 3.11) and the density of the flamingo feeding flocks also corresponded showing the utility of this analysis for predicting the suitable areas for the flamingos and other waterbirds. In spite of pollution from industries and domestic waste flowing to the mudflat areas, still it is a good foraging ground for a large number of flamingos and other birds making the Sewri-Mahul mudflat an important bird area in India.

This makes it very essential to see that proper care is taken to avoid disturbance to the area during the peak period of the stay of the flamingos here and also during construction of the bridge.

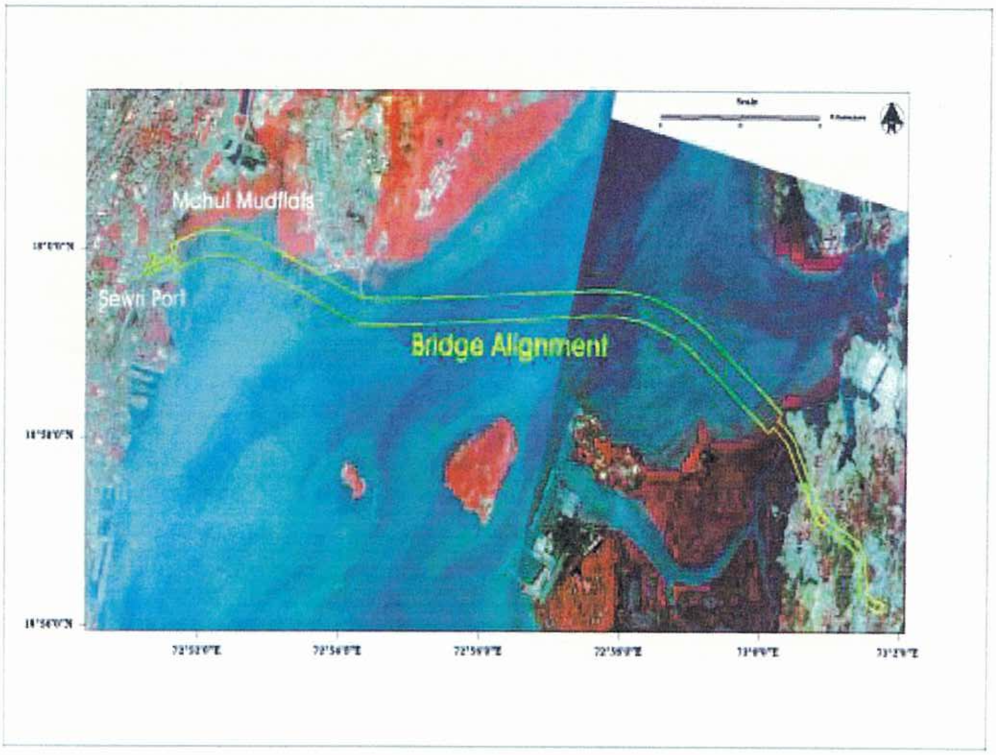


Figure 3.4. Alignment of the proposed bridge from Sewri to Nhava overlaid on the satellite imagery

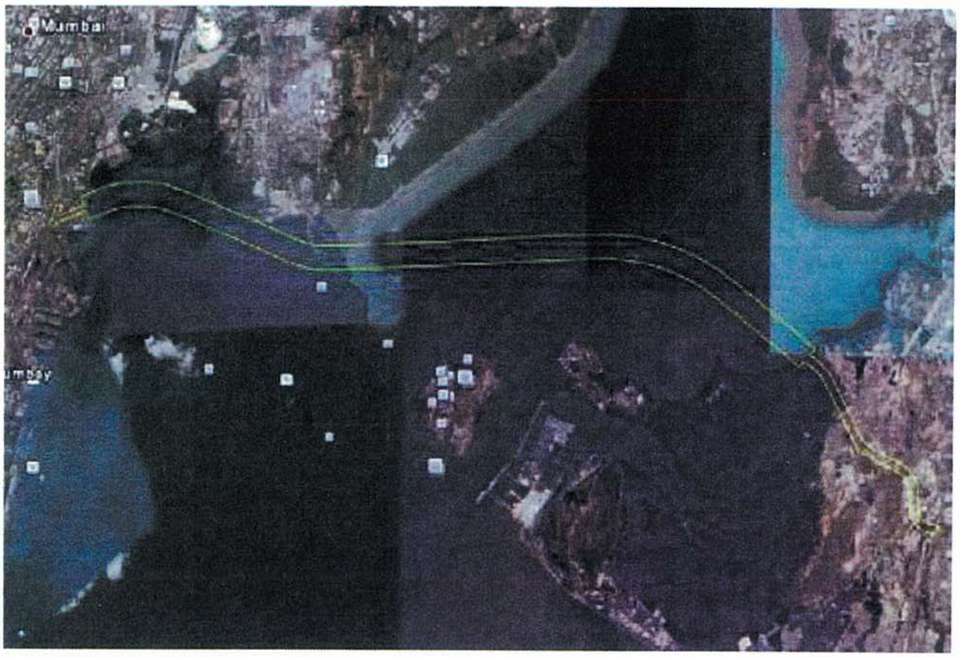


Figure 3.5. The proposed bridge shown on a high-resolution (0.6 m) data

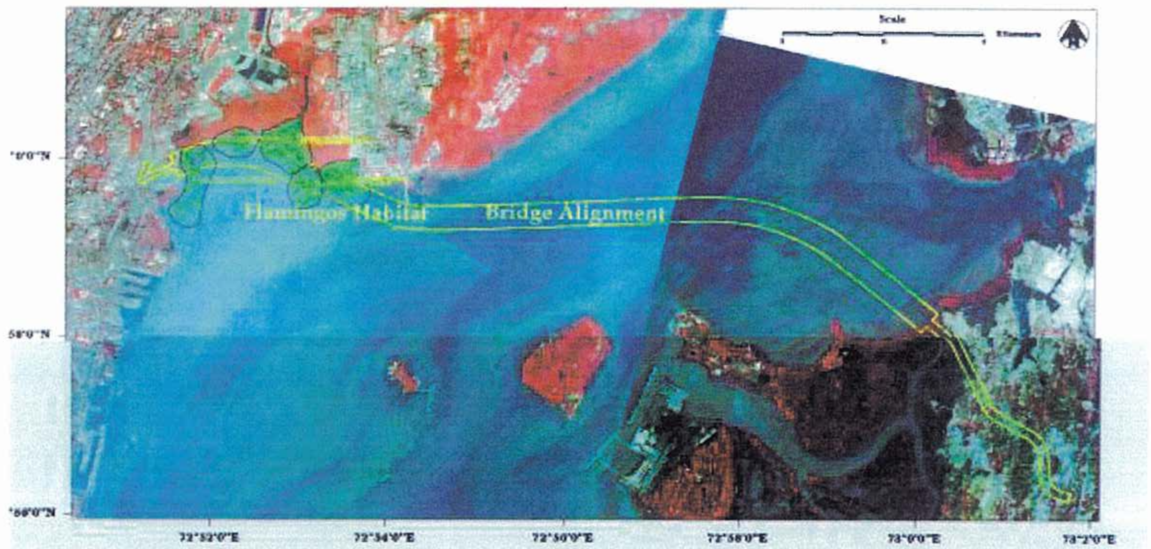


Figure 3.6 Details of the areas used by the Flamingos in the Sewri - Mahul region in relation to the proposed bridge

Figure 3.7 Details of the areas used by the Flamingos in the Sewri - Mahul region in relation to the proposed bridge

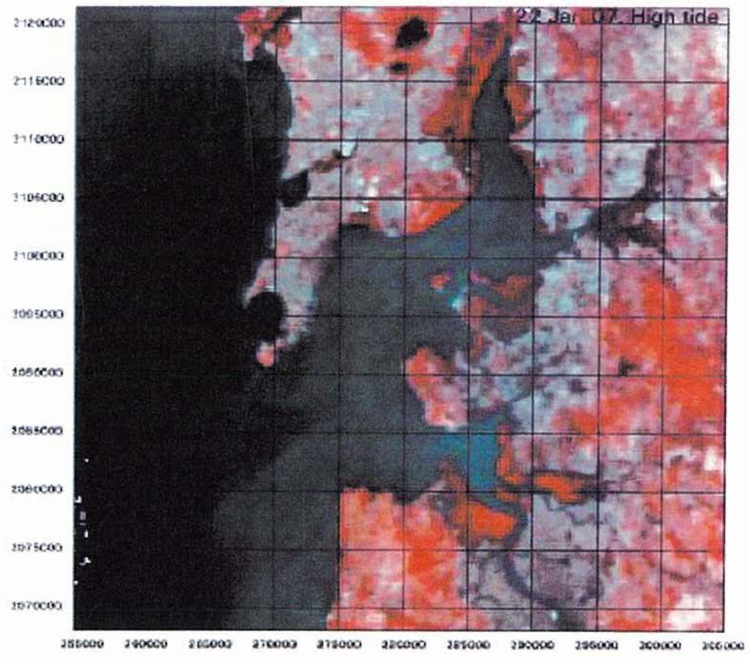


Figure 3.8 MODIS data showing high tide (22 January 2007)

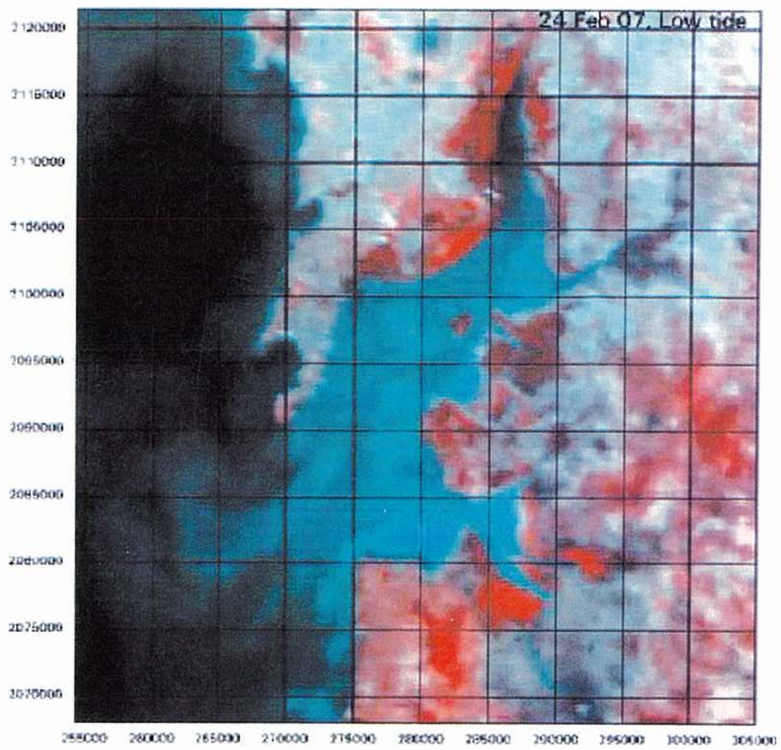


Figure 3.9 MODIS data showing low tide (24 February 2007)

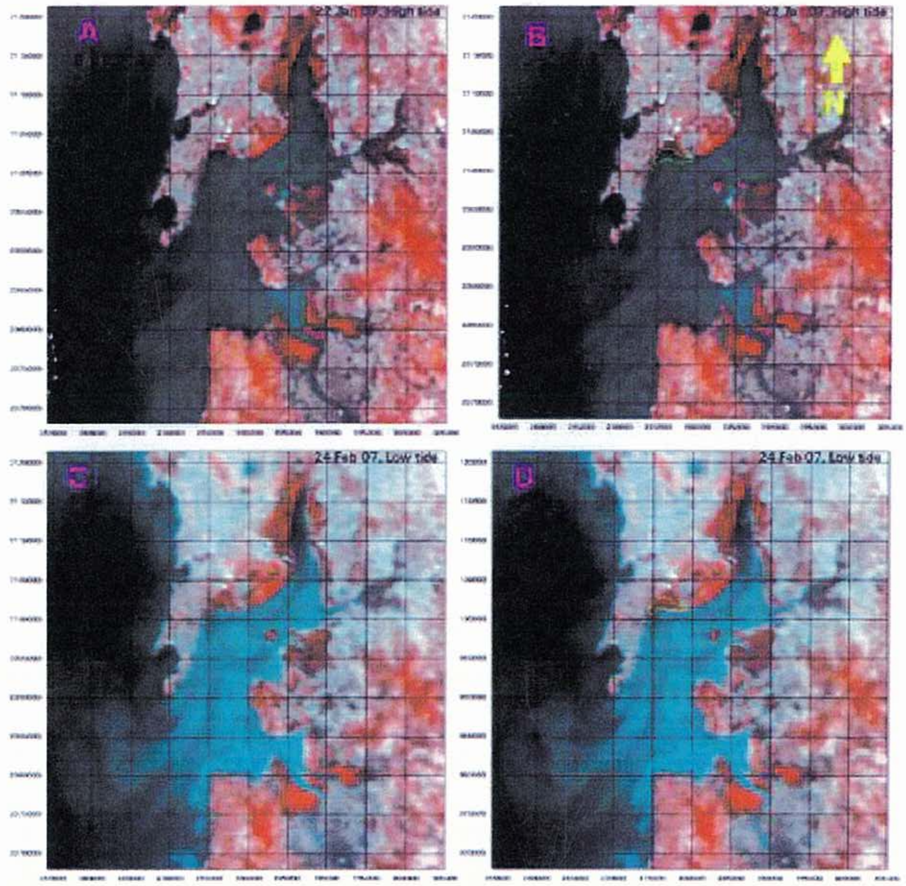


Figure 3.10 Littoral zone (sedimentation) in Thane creek using MODIS data

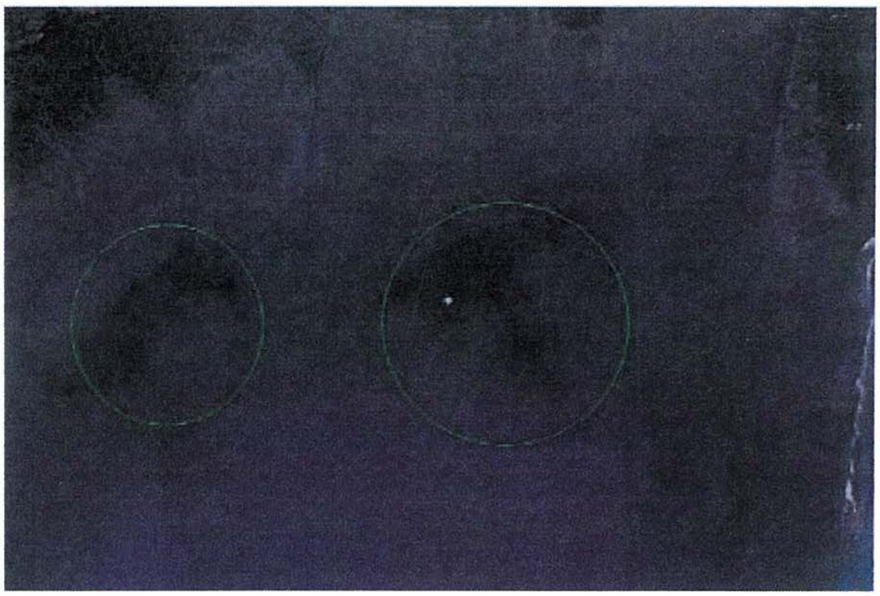


Figure 3.11 The greenish portion showing the sediment load in Sewri-Mahul mudfla

Chapter-4

ENVIRONMENTAL CONTAMINATION

INTRODUCTION

The rapid increase in human population, industrialization and urbanization have led to tremendous increase in waste loads which are discharged into rivers and seas with or without treatment. Only about 10% of the municipal sewage generated is reported to be treated by waste water treatment plants in India as well as in China. Major industries which contribute to contamination are fertilizer, paper, heavy chemicals, cement, Ferro-alloys etc. situated in the upstream. They drain their effluents into the riverine system and ultimately into the sea. Besides, these are number of ports wherein the ship and cargo handling activities contribute to marine pollution (Panigrahy *et.al.*, 1999).

Organochlorine pesticides (OCP), Polychlorinated Biphenyls (PCBs), Polycyclic Aromatic Hydrocarbon (PAHs), heavy metals, in marine environment are of great concern because of their residues in varying quantities in different compartments of the aquatic ecosystem. Moreover, they are ubiquitous anthropogenic pollutants that can be biologically amplified to high concentrations in food webs. Due to their lipophilicity, persistence and high toxicity, these residues are readily accumulated in the tissues of non-target living organisms where they may cause detrimental effects. Upon entering into the sea the compounds interact with various types of materials and undergo many transitions between different compartments such as water, sediments and organisms. Although the use of DDT and HCH has been officially banned, they are still detected in considerable levels in waters, sediments, soils and biological components.

Ship and cargo handling activities can contribute primarily to marine pollution. It also affects the pH, dissolved oxygen, biochemical oxygen demand and nutrients. Indian coast is continuously being threatened by effluent discharges from metropolis and industrial towns. This gives rise to immense environmental problems leading to deterioration of water quality. Mumbai is one the major cities in India, which has diversified industries. The coastal water of Mumbai receives industrial discharges up to 230 million liters per day (MLD) and domestic wastes of around 2200 MLD of which 1800 MLD are untreated (Zingde & Govindan 2000).

Distribution of various chlorinated contaminants in the marine environment depends up on the physico-chemical properties of the water as well as the partition coefficients of individual pollutants. Fish is on the top of food web in the aquatic ecosystem, they could be used as bio-indicators for contaminant levels in waters. The present study was carried out to determine the physico-chemical properties of water and persistent toxic organic and inorganic chemicals in water, sediment and fish samples collected from select locations along the harbour line, Mumbai.

MATERIALS AND METHODS

Table 4. 1. List of fish species collected along the harbour line, Mumbai during the study period

S. No.	Vernacular Name (Marati)	Scientific Name	Place of collection	N	Length (cm) Mean±SD	Weight (g) Mean±SD
1	Ravas	*Eleutheronema tetradactylum*	Sewri, Mahul	8	21.6 ± 8.02	138 ± 161
2	Mandeli	*Coilia dussumierie*	Sewri, Mahul, Nhava	77	15.4 ± 1.73	11.5 ± 3.22
3	Doma	*Otolithes rubber*	Sewri, Mahul, Nhava	22	17.9 ± 3.53	66.6 ± 37.5
4	Mathi	*Sardinella longiceps*	Sewri, Mahul	24	21.5 ± 1.00	102 ± 5.42
5	Singala	*Mystus singhalis*	Mahul, Nhava	11	17.3 ± 4.58	36.7 ± 61.4

Composite samples of 9 sediment and water samples (three from each location) were collected between September 2006 and August 2008 from Sewri, Mahul and Nhava. Sediment samples were collected using a pre cleaned PVC corer, immediately kept in polythene bags, and stored in ice. Commonly available fishes (Table 3.1; Appendix 3) were collected from each study location with the help of a local fisherman of the region. The morphometric measurements such as body weight and total length were recorded. All the samples were transported to the laboratory at SACON, Coimbatore, in ice box and stored in the deep freezer at -20°c until analysis. Samples are considered for four seasons namely season 1(September 2006), season 2(January 2007), season 3 (June 2007) and season 4(January 2008).

Processing and analysis of Samples

Physicochemical characters

Parameters such as pH, temperature, turbidity, COD and dissolved oxygen were recorded in the field using portable water analysis kit (LoviBond), while other parameters such as oil and grease, chloride, sulfate, phosphate, nitrate, alkalinity, total hardness, total organic carbon were analyzed using standard operating protocol.

Heavy metals

All the samples were analyzed in Atomic Absorption Spectrophotometer (AAS) for heavy metals.

Fish: About 1-1.5 g of tissue samples were digested using microwave digestion system (Milestone model 1200) using 10 ml of HNO_3 (69%) for 10 minutes, 1 ml of $HClO_4$ (70%) for 5 minutes and 5ml of H_2O_2 (30%) for 10 minutes at 250 W power settings. The digested solutions were made up to 25 ml and stored in well cleaned polythene vials in refrigerator till the time of analysis.

Water: Samples were acidified using nitric acid and pH was brought down to two and stored in the refrigerator till the time of processing. Samples were transferred in to beakers, cleaned well with high quality soap solution and later with double distilled and acidified distilled water and concentrated keeping on a hot plate in a fume hood adding 12-15 ml of analytical grade HNO3. The heating was continued till such time the sample became colourless and clean. However the samples were never allowed to dry completely. By and large, nitric acid alone was adequate for complete digestion of water samples. HClO4 (Perchloric acid) was added only to those samples which had high organic matter. Samples containing high organic matter were always treated in advance (pretreated) with HNO3 before adding HClO4. If necessary, more HNO3 was added and the volume was brought down to the lowest possible (10-25ml) before precipitation occurred. After completing the digestion, beakers were washed with double distilled water and the content transferred to 50ml volumetric flasks and made up to 50mL and stored in polyethylene bottles for analysis.

Sediment: Collected samples were transferred to polyethylene jars which were cleaned by high quality detergents and nitric acid. The samples were refrigerated until further analysis. The samples were taken out of freezer at the time of analysis and oven dried at 90°C, ground in a mortar with a pestle and a few grams were taken for analysis. Method suggested by Allen et.al., (1974) was followed to extract the metals from the sediment samples. Ammonium acetate at pH 7 was used as extract. About 200-300ml of distilled water was measured in a large beaker; 575ml of glacial acetic acid and 600mL of 0.88 ammonia solution were added in to the beaker and mixed thoroughly. Later the volume was made up to 10 liters and the pH maintained at 7 with drops of acetic acid or ammonia as necessary. About 10g of air dried and sieved sediment was taken in a conical flask and 250mL extract was added and stirred in a mechanical shaker for one hour. The contents were allowed to settle for some time and filtered through No 44 Whatman filter paper in to well clean polyethylene bottles and stored in refrigerator till analysis with AAS.

Pesticides, PCBs and PAH residues

Water: One litre of the water sample from each location in triplicate was extracted by liquid-liquid extraction in a separatory funnel using dichloromethane and then cleaned using silica gel column. The eluant was concentrated by rotary evaporator to 1 ml and one portion of eluant was re-dissolved with hexane for analysis of organochlorine pesticides and PCBs in GC-ECD. Another portion of eluant was re-dissolved with Acetonitrile and preserved for PAH analysis in HPLC.

Fish: About 10 g of the tissue was ground with anhydrous sodium sulphate (30 g) for 1 minute and the mixture was packed in a thimble (Whatman), which was desiccated overnight prior to extraction to remove moisture. The desiccated thimble was soxhlet extracted with 250 ml of hexane: dichloromethane (3:1) for 7 hours. Anhydrous sodium sulphate (30 g) was extracted in the same fashion as the sample and used as the blank. The extracted solvents were concentrated with a rotary evaporator to about 15 ml. This was transferred to concentrator tube and reduced with the help of nitrogen stream to 1 ml. This was transferred to 20 g silica gel packed glass column, followed by elution with 70 ml of hexane for PCB congeners fraction (F1). Then the column was eluted with 50 ml mixture containing 70% hexane and 30% dichloromethane for the pesticide fraction (F2). For PAH, samples were soxhlet extracted with Dichloromethane for 7hrs (Binelli & Provini 2004). About 100 ml DCM was used to elute PAHs from the column. The eluants were concentrated using rotary flask evaporation to a final volume of 1 ml in Acetonitrile and filtered using 0.45 µm syringe filter units. The eluant was blown using nitrogen, and re-dissolved in 2 ml ACN and transferred into HPLC auto sampler vials for PAH analysis.

Sediment: About 100 g of wet sediment was allowed to dry under room temperature and ground with pestle and mortar. About 10 g of dry sediment was weighted on to a piece of tarred aluminium foil. Latter sediment was mixed with sodium sulfate and then transferred into a 250 ml flask. All samples were kept at 30OC in ultrasonic bath and sonicated for 60 minutes. After sonication it was allowed to stand in 30OC water bath overnight (24 hrs.). The samples were again sonicated for 60 minutes at 30OC. The sample was filtered through glass wool placed on the pasteur pipette. The filtered samples were reduced in the flask to 15 ml using the rotary evaporator apparatus and further reduced to approximately 1 ml using the nitrogen evaporator apparatus. The samples were cleaned and eluted with the slurry of hexane in the 3 g deactivated silica gel. About 35 ml of hexane was used for first fraction to elute PCBs and 50 ml of dichloromethane in hexane (1:3) was used for second fraction to elute OCP residues. PAHs were extracted with the above method and the column was separated with 75 ml of DCM in silica gel column. The first and second fractions were reduced under nitrogen evaporator in water bath and transferred to sample vials, keeping volume of solvent to less than 1 ml.

Analysis of organic contaminants

Organochlorine pesticide and PCBs Analysis in GC-ECD

The fractions (F1 & F2) of the samples were analyzed for PCB congeners and organochlorine pesticides respectively, in Hewlett Packard 5890 series II gas chromatograph fitted with ECD. The operating conditions are given below. Column: DB-5; 30 m x 0.32 µm; (J & W Scientific, Folsom CA). Oven temperature 180oC/3 min- 4oC/min -260 oC/15 min. Injector and Detector temperature were 250 and 300oC respectively. Nitrogen was used as a carrier gas with the flow rate of 1 ml/min. Duplicate analyses and blanks were carried out. Residues are expressed in ppb wet weight basis.

Analysis of PAH in HPLC-FLD

Extracts were quantified using HPLC with programmable fluorescence detector at exited and emission wavelength of 270 nm and 360 nm respectively. About 10 µl of sample was injected through an auto sampler into a HPLC fitted with a C18 column (Zorbax 4.6 x 250 mm. 5 micro meter particle size) at 20°C. The mobile phase was water/Acetonitrile (CAN) with a flow rate of 1 ml/min. The initial content of ACN was 50 % and then increased into 60% (0-3 min) and 100 % (3-14 min).

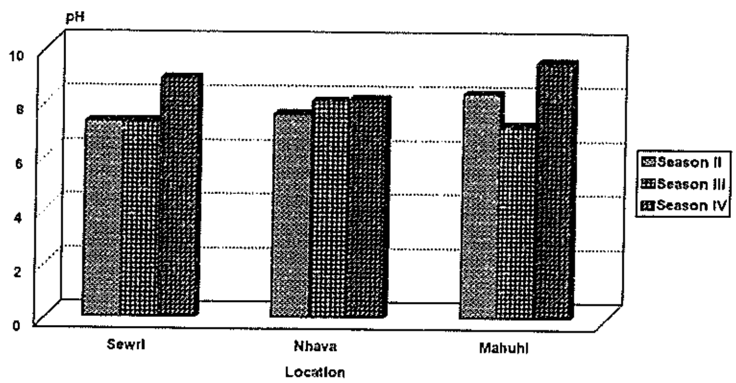
STATISTICAL ANALYSES

The distribution of the data for each parameter was viewed for normality using Kolmogrov Smirnov test. Although the data distribution was found to be normal, it failed to meet the Levene's test of Homogeneity of variances (P<0.05). Hence, non-parametric tests such as Kruskal Wallis test was performed to understand the variation. The significance was considered at P<0.05.

RESULTS AND DISCUSSION

Physicochmeical characters

Figure 4.1. Variation in pH among three locations

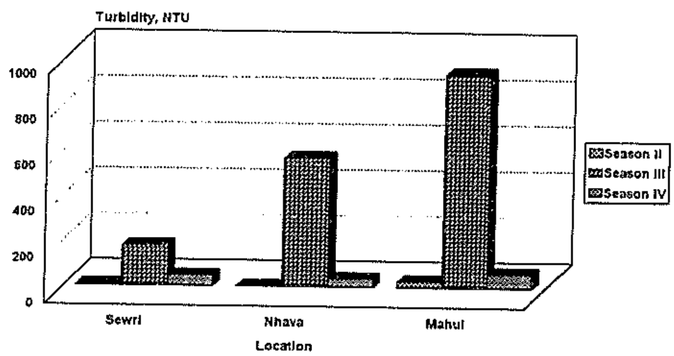


pH: The pH reported at Nhava and Sewri during the Season IV appears to be on a alkaline scale(Fig.4.1). Although Mahul had the highest alkaline pH during the Season IV it is understood that earlier seasons also showed its range to fall on a alkaline scale. No significant variation was observed in pH values of water samples collected during various seasons among the different locations ($\chi2$= 0.964; df=2;p=0.618). According to EPA (1986), this range is conducive for propagation of aquatic lives and also expected to help in minimizing corrosion and scaling in vessels. Desirable pH for aquatic organisms is 6.5 to 8.5. Deviation from this range may indicate the entry of acidic or basic effluent (Gawas *et.al.* 2006). The pH values were found to be generally lower in basin waters when compared to those in Bombay harbour waters (Swami *et.al.*, 2000). The pH in marine and brackish water system is always taken as the function of salinity (Nayak and Behera, 2004).

Temperature: On an average, during all seasons the temperature remained around 28°C in all the three sampling stations excluding specific dates. The annual average ambient temperature of Mumbai city is 82° F (i.e. 27.78° C). This indicates that the water temperature in all three locations will not be very high than the atmospheric temperature unless influenced by the industrial discharges. Temperature exceeding 45°C at the discharge points (industrial effluent/sewage) is reported to harm the receiving water body (Manivasakam, 1997). In the present situation, since an extensive area of the receiving water body had temperature around 50°C on a few occasions it is all the more serious than the harm that can emanate from the effluent which has a temperature of 50°C at the discharge point. Increase in temperature may alter the concentration of dissolved oxygen and other gases and may change the activities of microbial colonies (Kartikeyani *et. al.,* 2002) and also will lower the dissolved oxygen content. As water temperature increases, two factors, namely metabolic rate and availability of dissolved oxygen combine to make it more difficult for aquatic life to get sufficient oxygen to meet its needs. This causes an increase in the oxygen requirements of the organisms. No significant variation was observed in temperature of water samples during various seasons among the different locations ($\chi 2=1.727; df=2; p=0.422$). Discharges of cooling waters from power plants and municipal or industrial effluent are sources of thermal pollution in the coastal zone. The temperature observed in Bombay harbour water varied from 22.8° C in January to 32° C in the month of May (Swami *et.al.,*2000).

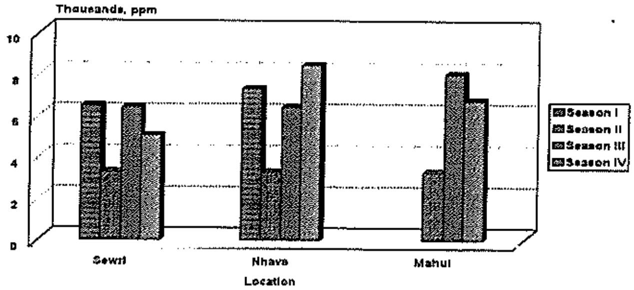
Turbidity: Irrespective of seasons, Mahul had the highest turbidity levels (Fig. 4.2) (340.43±148.30 NTU) followed by Nhava (199.62± 95.46 NTU) and Sewri (74.99±26.63 NTU). Turbidity in water mainly arises from colloidal matter, fine suspended particles and soil erosion. Generally greater the turbidity, stronger is the influx of sewage and industrial effluents which is considered as a measure of intensity of pollution. Degree of turbidity and changes in turbidity levels in the coastal and estuarine waters are an indicator for the state of environment. Algal blooms are often indicative of excessive loads and can be an important cause of turbidity in eutrophic systems. Increased turbidity will result in reduction of light available for photosynthesis (Duarte, 1995). Unnaturally high turbidity levels can lead to a reduction in the species diversity. It is easily perceivable that during season III the turbidity levels were comparatively very high. As the sampling was done during monsoon season, it is quiet obvious that such high levels are due to mixing of storm water with heavy suspended and dissolved materials. No significant variation in turbidity is observed among the locations ($\chi 2=2.075$; df=2; P=0.354).

Figure 4.2. Variation in turbidity among three locations



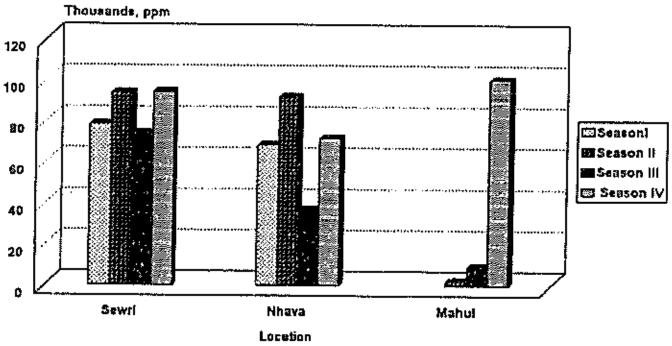
Alkalinity: Although no significant variation could be noticed among the locations ($\chi 2= 0.8081$;df=2; P=0.668). Nhava had the highest total alkalinity (6344.26±835.46 mg/ L) while Sewri the lowest (5300.24±829.68mg/L) (Fig.4.3). The total alkalinity represents the alkalinity due to CO_3^- and HCO_3^- together. Thus, the alkalinity in water is contributed by carbonate and bicarbonate ions which are characteristic of sea water. It is well understood that sea is the major sink for carbondioxide cycle and carbon is converted into carbonate or bicarbonate ions. Further, the sewage and industrial discharge do contribute substantially. Padma and Periakali (1999) conducted a study on physicochemical and geochemical studies on Pulicat Lake and reported that in the pre-monsoon period the alkalinity ranged from 65.9 to 100.0 mg/l and in the post-monsoon period it was from 229.4 to 275.5 mg/l. Three- time increase in alkalinity during the post-monsoon period is due to the input of fresh water and probable dissolution of $CaCO_3$ from the sediments which increases the carbonate and bicarbonate ion concentrations in the water column. This high alkaline water could produce deposition of scales on the shipping vessels and it might also corrode the pipelines.

Figure 4.3. Variation in alkalinity among three locations



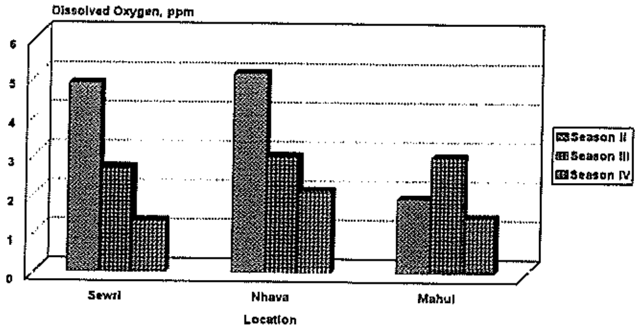
Chloride: It is a fact that the chloride values are usually high in coastal waters. On an average, irrespective of seasons, Sewri ranked first (84840.10±3614.93 ppm) followed by Nhava (66844.46±6125.27 ppm) and Mahul (43356.16±14263.07 ppm) (Fig 4.4). The chloride levels are influenced by the effluents discharged particularly by the paper and hardboard industries located in the surrounding. No significant variation was observed among the various locations during various periods ($\chi 2=5.043$;df=2;P=0.080).

Figure 4.4. Variation in chloride among three locations



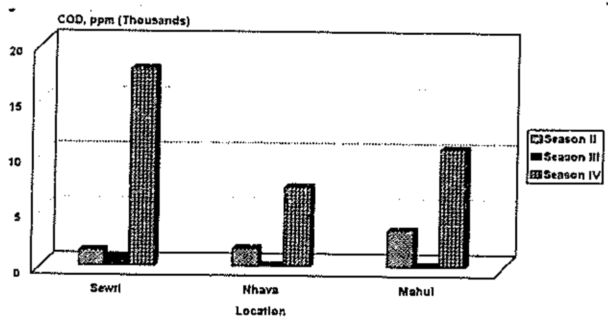
Dissolved Oxygen: Dissolved oxygen was estimated during all seasons except Season I due to certain technical constraints. Except Nhava (5.08 ±0.18 ppm) during season II the other locations had DO in the range of 2.5 ppm (Fig. 4.5). No significant variation could be observed among the locations ($\chi2=4.771$; df=2; P=0.092). Exposure to low oxygen concentrations can have an immune suppression effect on fish which can elevate their susceptibility to diseases for several years (Mellergaard and Nielson, 1987). In the present study, the dissolved oxygen levels are low and could be attributed to the above mentioned factors. However a good amount of water is readily and regularly removed from the basin by the vibrant water movements contributed towards the maintenance of normal DO despite heavy loading of organic matter. Further, quick dispersion and high terminal dilution of the same could be due to the bay water movement into the open sea (Swami *et.al.*, 2000).

Figure 4.5. Variation in dissolved oxygen among three locations



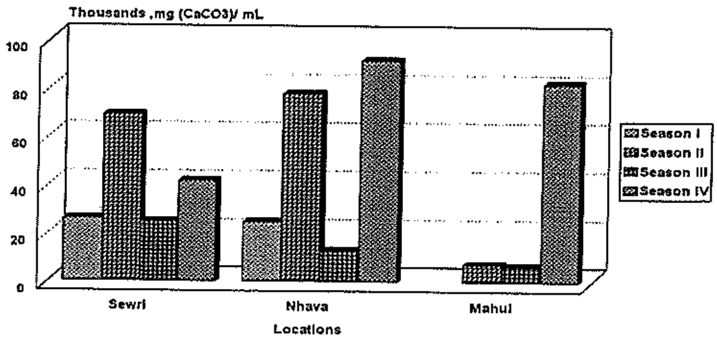
Chemical Oxygen Demand: On an average, Sewri had the highest COD levels (6666.44±2785.70 ppm) while Nhava the least (2961.33±1525.32 ppm)(Fig.4.6) with no significant variation among the locations ($\chi2=0.963$; df=2; P=0.618). During season IV, the COD levels were found to be very high at all locations. Higher the COD value, greater the pollution load. Hence the high concentration in Sewri indicates that it is highly contaminated when compared to other locations. If this load increase, it will lead to a severe deterioration of the plankton growth and totally impact the feeding areas of Flamingos and other waders.

Figure 4.6. Variation in chemical oxygen demand among three locations



Total Hardness: High amounts of hardness have been observed at all locations during all the seasons with no significant variation ($\chi2=3.509$; df=2;P=0.173). Between the locations, the hardness ranged between 5000 to 93000 mg $CaCO_3$/L. It is

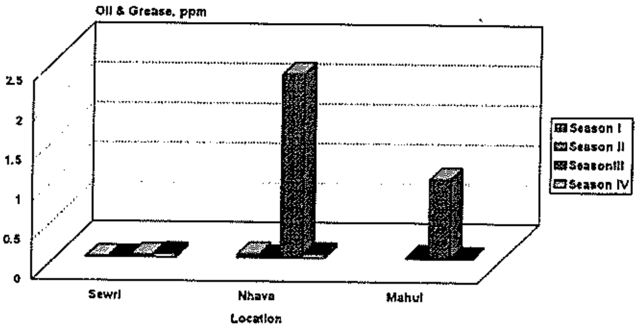
Figure 4.7. Variation in total hardness among three locations



well understood that the sea waters generally have high hardness contributed by varied sources including effluent discharges from domestic and industrial sectors.

Oil and Grease

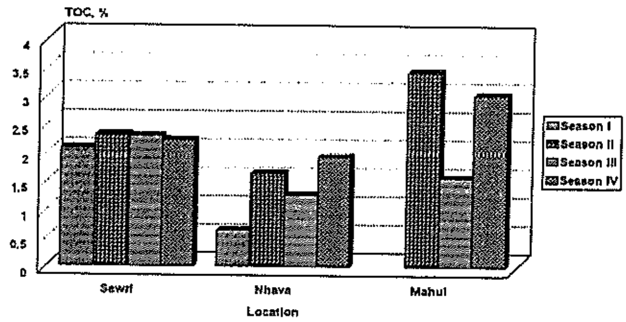
Figure 4.7. Variation in oil and grease among three locations



Nhava had the highest percent of oil and grease during season III (2.82±0.79 ppm) while Sewri had the lowest (Fig. 4.8) during season II (0.01±0.00 ppm) with significant variation among the locations ($\chi 2=7.477$; df=2; P=0.024). As the locations fall under ecologically sensitive zone, the oil and grease concentration should not exceed 0. 1mg/L as it may affect the fish eggs and larvae (EPA, 1986). All the three locations except Sewri exceeded the limit. High concentrations of oil and grease found in the coastal waters are anticipated to choke the marine life. When oil and grease are present in the surface layers, they prevent contact of atmospheric oxygen with water and also inhibit photosynthesis of plankton and aquatic plants (Sharma, 2005). Oil and its products endanger the aquatic life in the surface layers and also the coastal flora and fauna. One drop of petroleum could spread over a great area to isolate the water from contact with atmospheric oxygen, while continuous film inhibits photosynthesis and the formation of oxygen. Growth of plankton is also arrested. All aquatic animals depend, either directly or indirectly, on plankton, which is the basis of the trophic chain, but plankton can develop only in depths of water to which the solar radiation penetrates.

Total Organic Carbon

Figure 4.7. Variation in total organic carbon among three locations



The average TOC levels recorded at all locations was 2%. During Season IV, Mahul had the highest TOC (3%) while Nhava (0.63%) the least (Fig.4.9) during Season I with significant variation among the locations ($\chi 2=15.318$; df=2; P=0.00). When organic pollutants are high, organic carbon level often exceeds 5% (Alagarswamy, 1991). Since all the locations show organic carbon level within 5%, the load of organic pollutants could be called as low. Mixing of sewage is one of the principal sources of organic pollution in estuaries. In most unpolluted estuaries organic carbon content of the bottom sediment is < 5 % whereas in areas where organic pollutants are high, organic carbon level often exceeds 5 % (Alagarswamy, 1991). The low organic carbon content in the Nhava can be ascribed to the sandy nature of the substratum and the strong tidal currents, which continually drain out available suspended organic matter into the sea. AnilaKumary (2001) conducted a study on sediment characteristics of Poonthura estuary which faces enormous load of untreated domestic wastes emanating from the fastly growing Thiruvananthapuram city over the last few years. Organic carbon of the sediments in Poonthura estuary widely varied between 2.4 to 83.3 mg/g and showed enrichment always at the polluted zone. The upstream fresh water station is mainly characterized by weak tidal currents and high oxygen. These factors are detrimental to the supply and accumulation of organic carbon in sediments (Alagarswamy, 1991). The high values can be ascribed to the heavy sewage discharges and the absorption of organic matter by the increase in finer fractions of the sediment. High values of organic carbon may be attributed compaction, degradation, decomposition, loss of moisture and synthesis to other compounds during its diagenesis.

Macronutrients

Nitrate: In sediment the nitrate level ranged between below detection limit and 0.22± 0.01 ppm (Table 2). While the highest concentrations was recorded in Mahul, the variation among the locations was significant ($\chi2$= 9.506; df=2; P=0.009). Nitrate concentrations in water were found to be highest in Nhava during all seasons except season IV. (Table.4.2) with significant variation ($\chi2$=11.350; df=2; P=0.003). Gouda and Panigrahy, (1995) conducted a study, which dealt with the spatio - temporal distribution and behavior of NO_3^--N and PO_4^{3-}-P in the Rushikulya estuary in Orissa. They found spatio-temporal distribution in surface water concentrations of NO_3^- – N ranged from 0.37-18.48 µg-at. 1^{-1} in 1988 and 0.04-22.27 µg-at. 1^{-1} in 1989. Surface water PO_4^{3-} varied from 0.09-1.86 and 0.05-3.30 µg-at. 1^{-1} during 1988 and 1989 respectively. Bottom water concentrations of NO_3^- – N and PO_4^{3-} ranged from 0.05-13.14 and 0.08-2 µg-at. 1^{-1} in 1988 and from 0.28-10.44 and 0.09-2.14 µg-at. 1^{-1} in 1989 respectively. Between these two nutrients, the role of NO_3^- becomes more important with respect to phytoplankton production. Rapid increase of NO_3^- – N contents during the monsoon season suggests that freshwater discharge acts as the primary source of NO_3^- – N into the estuary. This also endorses the contention that the chief source of NO_3^- – N into the estuary is land runoff. The lower values of NO_3^- – N both during premonsoon (Feb-Jan) and postmonsoon seasons show that the input of NO_3^- – N from the sea is low. Nutrients entrapped in the bottom sediments might have also been released to water due to turbulence during the monsoon thereby enhancing nutrient content. Thus, when the data generated are viewed in comparison to the above mentioned study, it is very clear that spatio temporal distribution of nitrate is one of the important factors to be considered when nitrate levels in water and sediment are discussed. The concentration of NO_3-N in the water at Flic en Flac, Mauritius ranged from <0.1 to 0.2 mg/l. The nitrate values in Bombay harbour water varied from 0.43 to 50.66 µg-at.l^{-1} ,. Widely varying and high values noted in this study was attributed to the varying quantities of the wastes discharged into the basin waters (Swami *et.al,*2000). Nitrate contents in Chilika Lagoon ranged from 0.02 to 0.10 µg-at l^{-1}. Rapid replenishment of nitrate from surficial biogenic sediment by microbial activities favoured by increase in temperature and rapid mixing of surface subsurface water were the main reason for higher value was nitrate which was observed during premonsoon period (Nayak and Behera, 2004).

Phosphate: The sediment samples collected from Sewri had the highest concentrations of phosphate during all seasons except season 1. No significant variation was observed among the locations ($\chi2$=0.476; df=2; P=0.788). Alike the sediment samples, phosphate concentrations in water were found to be the highest in Sewri (6.2±0.68) (Table. 4. 2) with significant variation ($\chi2$= 18.437; df=2; P=0.000). Mahapatro and Padhy (2002) observed significant variations of nutrients among different seasons in Chilika Lake. Silicate and nitrate varied inversely with salinity in all the seasons whereas phosphate varied directly with salinity in premonsoon and monsoon and inversely with post monsoon. It has been reported that rainfall results in heavy river discharge leading to transportation of sediments and thus the increase in phosphate during monsoon. Low phosphate values are possibly due to dilution to some extent, of euxinic conditions (Setty and Rao, 1972). Inspite of the importance of phosphorous for phytoplankton growth, it is a potential pollutant if it is found at higher concentrations (Saad, 1973 a). The concentration of PO_4 in the water at Flic en Flac, Mauritius ranged from <0.01to0.06 mg/l. The higher level of phosphate may be attributed to the input of freshwater as evidenced by lower salinity and pH at the stations in that part of Lagoon (Chineah *et al.,* 2001). The phosphate values recorded in Bombay harbour and the basin varied from 0.27 µg-at.l^{-1} to 7.19 µg-at.l^{-1} and 1.56 to 9.79 µg-at.l^{-1} respectively. $PO4^{-P}$ was significantly in high concentration in the basin waters (Swami *et.al.,* 2000). Nayak and Behera (2004) reported 0.12- 0.4 ppm of phosphate in water at Chilika Lagoon and related the same to the inflow of drain rich with detergents.

Padma and Periakali (1999) conducted a study on physicochemical and geochemical studies on Pulicat Lake and reported that the nitrite (0.02ppm) and phosphate (0.58ppm) were comparatively low in the pre-monsoon. Meitei *et.al.* (2006) observed in purna river, the range of concentration of phosphate in river to be between 0.96 mg/L and 1.9 mg/L at upstream, 1.9 mg/L and 1.2 mg/L at midstream and 2 mg/L and 2.3 mg/L at downstream. Maximum concentration of phosphates was recorded in summer and minimum in winter. The levels of phosphate in an estuary can be taken as an index of potential fertility of the ecosystem as a whole (Redfield, 1934). As mentioned earlier the high levels reported in Mahul during monsoon could be due to heavy influx of sewage from the surrounding locality.

Sulphate: Among the various locations sediment samples collected from Mahul had highest levels during various seasons with no significant variation among the locations ($\chi2$=3.74; df=2; P=0.154). On an average the water samples collected from Nhava had the highest levels (0.004±0.00 ppm) No significant variation was observed among the different seasons. ($\chi2$=3.192; df=2; P=0.203)(Table. 4. 2). Sediment can be considered as heterogeneous mixture of dissimilar particles (detritus, organic and inorganic debris, plankton cells, etc.). Infact, sediment analysis can reflect the current quality of the system and the pollution history of a certain area (Samak and Aboul-Kassim, 1999). The direct discharge of raw sewage and industrial waste water causes high rate of pollution to the coastal waters. Satpathy (1996) reported the distribution, behaviour and seasonal variation of nutrients in coastal waters of Kalpakkam. High values (7-10 mg/l) of D.O were found during North East monsoon while the salinity was minimum. Nutrients (Nitrate, Phosphate, Nitrite and Silicate) showed high values during monsoon and low values during summer. The large scale discharge from land runoff during North-east monsoon might have contributed to the observed increase in nutrients during this period. Nutrients entrapped in the bottom sediments might have also been released to this water due to turbulence during the monsoon thereby enhancing nutrient content. The low nutrient levels observed in summer could probably be attributed to the utilization of nutrients by phytoplanktons as phytoplankton production reaches a maximum during summer as found at Kalpakkam (Sargunam, 1994). It is thus possible to infer that during monsoon season release of nutritents from bottom sediments and sewage influx should have elevated the levels at Mahul.

Heavy metals

Water: Cadmium and Chromium concentrations in water ranged between BDL and 0.06±0.01 ppm and BDL and 0.06±0.02 ppm respectively while Cd and Cr was found to be highest in Sewri waters. Cu level was the highest in both Nhava and Sewri (0.02±0.00 ppm). The nickel levels were the maximum in Mahul (0.09±0.04 ppm) which was twice and thrice higher than Nhava (0.05±0.03 ppm) and Sewri (0.003±0.00 ppm) respectively (Table 4. 3).

Iron levels were found to be more or less the same in Nhava (4.42±2.33 ppm) and Sewri (4.56±1.94 ppm). The levels reported appear to create toxicity to the aquatic organisms on a long term continuous and elevated exposure. High values of organic carbon should have enhanced the release of metals from bottom sediments to water. Further it is well understood that domestic sewage and industrial effluent discharge from the surrounding elevate the presence of metals in water.

Sediment: Among the three locations, the sediment collected from Mahul had the highest levels of Cd (0.42±0.14 ppm), Cr (3.44±1.39 ppm), Ni (16.72±6.83 ppm) while Cu (18.09±8.23 ppm) and Fe (835.30±271.44 ppm) were found to be the highest in Sewri (Table 4.3). The level of 0.3 and 50ppm of cadmium and chromium respectively, detected in the sediments are 10 times lower than the maximum limits considered safe for biota of aquatic systems (Elder and Mattraw, 1984). The detected concentrations fall within the range (BDL-3.270 ppm) reported by Balachandran *et al.,* (2005) in the Cochin estuary. Chromium concentrations were found maximum in Mahul (2.93 ± 0.37) and minimum in Nhava (1.96 ± 0.23). The detected concentrations of chromium were very less compared to the range (40-210 ppm) reported in sediments of Cochin estuary by Balachandran *et al,* (2005) and Kaviraj (1989). The metal levels reported in the present study appear to be comparably low with the levelsfor all metals except for Cu & Fe documented by Joseph *et.al* (2003) in the sediment of Cuddalore Coast. Concentration of trace metals in sediment south west monsoon include Cu (8.0 ppm), Cd (1.7 ppm), Ni(22.8 ppm), Zn (31.3 ppm) and Fe (11.6 ppm) whereas post monsoon concentration include Cu(3.4 ppm), Cd (1.2 ppm), Ni (33.7 ppm), Zn 919.3 ppm) and Fe 912.8 ppm) (Table 3). It is understood that industrial development along the coastline had shown some impact on the environment of the shelf region. Metal distribution in this shelf is controlled by the fine sediment dynamics which are mainly regulated by the low energy alongshore currents. As the shelf currents do not effectively disperse the anthropogenic discharges, the metal enrichment is restricted to the sediments of shallower regions only. The present study, in general, indicates that trace metals do not seem to constitute a potential threat to marine environment of this region and the release of metals into the coastal zone through anthropogenic activities are adequately dealt with by the dominant coastal processes of this region resulting in minimal biological impact. Taking the data presented here as baseline, it may be worthwhile to resurvey the area to understand the impact of the recent developmental activities and to what level the area has been polluted.

Fishes: Fishes collected from Nhava had the highest levels of copper (3.83±0.49 ppm) while fishes from Sewri had the highest values of Ni (3.42±0.74 ppm) and iron (16.36±3.41 ppm) (Table 4.3). Sewri (0.32±0.07) and Mahul (0.38±0.12 ppm) had near equal levels of chromium (Table 4.3). Concentrations of cadmium do not vary much among the locations and the average was (0.13±0.12 ppm). Except copper no other metal showed significant variation among the locations ($P>0.05$).

In a study conducted in Hoogly estuary, India during 1977-1981, 127.8 ppm of copper and 20 ppm of chromium were recorded in the various tissues of fishes. However, the levels reported in the present study are much lower. The metal concentrations was found to be high in fishes collected from Nhava and the levels appear comparable with the levels reported by Mathew (2004). The present levels are lower. However, species differences restrain us to comment on the impacts. The observed cadmium concentrations in the fishes collected from all the three locations fall within the range (0.16-2.53ppm) reported by Al-Mohanna (1994)and higher than the levels reported by Krishnamurti and Nair (1999) (0.03-0.4 ppm) in fishes from Thane and Bassein creeks of Bombay. Fish exposed to high concentration of trace metals in water may take up substantial quantities of these metals (Sultana and Rao, 1998). Effectiveness of metal uptake from the sources may differ in relation to ecological needs and metabolism of animals, species specific characteristics (Chen, 2002), feeding habits and also contamination gradients of water, food

Table 4.2. Phosphates, Nitrates and Sulfate in water and sediment collected from select locations along Harbour line, Mumbai

Parameter	Season I			Season II (june07)			Season III (January 08)			Season IV(may 08)		
	Mahul	Nhava	Sewri	Mahul	Nhava	Sewri	Mahul	Nhava	Sewri	Mahul	Nhava	Sewri
Water												
Phosphates (mg/L)	N/A	0.09±0.05	0.04±0.02	0.75±0.05	0.16±0.006	0.09±0.02	4.13±2.19	4.88±1.4	5.67±0.74	4.83±2.07	5.19±1.2	6.2±0.68
Nitrates (mg/L)	N/A	1.87±0.60	BDL	0.31±0.02	0.33±0.04	0.12±0.08	0.29±0.03	0.31±0.1	0.09±0.08	0.22±0.01	0.11±0.01	0.03±0.01
Sulphates (mg/L)	N/A	0.001±0.01	0.002±0.006	0.0005±0.0004	0.005±0.005	0.004±0.004	0.002±0.002	0.004±0.004	0.004±0.003	0.006±0.01	0.006±0.01	6.70±0.30
Sediment												
Phosphates (mg/L)	N/A	5.25±0.43	2.71±0.31	4.14±2.20	4.89±1.41	5.69±0.74	4.13±2.19	4.88±1.41	5.18±1.23	4.37±1.08	5.05±0.51	5.08±0.50
Nitrates (mg/L)	N/A	0.0031±0.001	0.0011±0.001	0.003±0.002	0.007±0.005	BDL	0.29±0.03	0.44±0.07	0.18±0.09	0.22±0.01	0.11±0.04	0.03±0.01
Sulphates (mg/L)	N/A	0.25±0.0	0.51±0.23	0.9±0.19	0.39±0.05	0.47±0.10	9.16±0.49	8.90±0.53	8.71±0.44	6.88±0.23	5.83±0.17	6.7±0.30

and sediments as well as other factors such as salinity, temperature and interacting agents (Heath, 1987; Langston, 1990; Roesijadii and Robinson, 1994; Barron, 1995 and Mason *et.al.*, 2000). The low temperature and high chloride levels could also influence the availability of the metals to fishes. Desirable pH for aquatic organisms is 6.5 to 8.5 and deviation from this range may indicate the entry of acidic or basic effluents (Gawas *et.al.*, 2006). Aquatic organisms are very sensitive to pH and they are severely stressed if pH drops below 5.5, and very few are able to survive when pH falls below 5.0. Moreover, as pH drops, certain toxic minerals such as aluminum, lead, and mercury, which are normally insoluble and relatively harmless, can turn lethal to fish and other organisms (Masters, 1991). However in the present context since the pH is alkaline such problems are not expected.

Table 4.3. Variation in heavy metal contamination (ppm) in water, sediment and fish samples collected from select locations along harbour line, Mumbai (Sep 2006- Jan 2008) (Mean±S.E)

Location	Component	Cd	Cr	Cu	Ni	Fe
Mahul	Water	0.01±0.00	0.05±0.02	0.04±0.02	0.09±0.04	6.87±2.4
	Sediment	0.42±0.14	3.44±1.39	9.44±3.23	16.72±6.8	488±156
	Fish	0.13±0.02	0.38±0.12	2.67±0.61	0.19±0.06	10.8±1.5
Nhava	Water	0.04±0.02	0.07±0.02	0.02±0.02	0.05±0.03	4.42±2.3
	Sediment	0.18±0.09	2.08±0.83	8.19±2.69	12.95±5.4	506±146
	Fish	0.13±0.01	0.22±0.08	3.83±0.49	0.25±0.07	13.3±2.1
Sewri	Water	0.06±0.01	0.06±0.02	0.02±0.01	0.003±0.00	4.56±1.94
	Sediment	0.25±0.08	1.62±0.56	18.09±8.2	12.51±4.1	835±271
	Fish	0.13±0.02	0.32±0.07	0.66±0.14	3.42±0.77	16.4±3.41

It is also important to note that nutrients such as nitrate, phosphate and sulphate do bear an important role in determining the metal concentrations. From the analysis it can be inferred that these levels tend to increase by the influx of the agricultural wash off, domestic and industrial discharges. Although the levels of these nutrients are not discussed here, it could be anticipated that the levels of metals such as iron could be due to the increased availability of these nutrients.

Further, ship wrecking activities in this area may also release substantial quantities of rusted iron in to the sea which in due course of time could settle in sediments and act as repository. In general, the levels reported in the fishes appear high with the values reported values and are anticipated to create an impact in the long run. It is very much anticipated that construction of bridge in the present situation may enhance the contamination levels. It might also have an impact on the biological system. On the other hand, this bridge may help to manage the traffic in Mumbai city.

Organic Contaminants

Organochlorine chemical residues in water: The distribution of data was not normal and therefore the values were log transformed to understand the variation among locations and season. There was no significant ($P>0.05$) variation observed for organochlorine pesticides among the sampling periods. However, significant variations in PCBs levels were observed among locations ($P<0.05$).

The concentration of total HCH ranged from BDL to 2.77 ppb among the study locations during various sampling period. Among various isomers of HCH, β-HCH appeared to be the highest due to its persistent nature. The concentration of total DDT varied between 0.01 and 3.19 ppb. Significantly higher load of total DDT (1.30 ppb) was recorded in waters of Mahul. *p,p'*-DDT contributes the major portion of total DDT. *p,p'*-DDT and its metabolites were not detected in water samples collected from Nhava during September 2006. The concentration of total endosulfan and dieldrin seen in water ranged from BDL to 4.46 ppb and BDL to 1.29 ppb respectively. The total PCB ranged between 0.01 and 39.9 ppb among the locations. Comparatively low levels of total heptachlor (0.02 to 0.05 ppb) were recorded among the study areas. On the whole, the organochlorine residue burden was high in Mahul water during January 2007.

The concentrations α, β, γ, δ HCH observed in this study in water are less than the levels reported in Chennai harbour and Cuddalore fishing harbour, where the levels were 5.44, 4.35, 10.1 and 2.41 ppb and 13.6, 4.88, 5.15 and 1.9 ppb respectively (Rajendran *et al.*, 2005). The dominant isomers α , and β HCH in all the three locations, indicate the recent and persistent nature of HCH in the harbour waters. The high concentration of DDT in comparisons to its metabolite (DDE) in the seawater samples could perhaps indicate the fresh input of DDT. The patern and levels of DDT and DDE in seawater recorded in the present study are similar to the findings of Pandit *et al.*, (2006) in Coastal marine environment of Mumbai. Muralidharan (2000) reported the total HCH in the wetland waters of Koeledeo National Park, Bharatpur to range between 0.004 and 0.58 ppb in 1989 and 0.05 and 3.43 ppb in 1990 and the concentration of total DDT from 0.01 to 0.5 ppb. The cyclodiene insecticide residues are almost equal to the concentration reported in surface water of Bay of Ohuira, Mexico. The residue burden of pesticides in seawater of the present study is similar to the levels reported in surface water from Bay of Ohuira, Mexico (Osuna - Flores and Riva 2002). Total PCBs in subsurface water from Daya Bay, China (Zhou *et al.*, 2001) varied from 91 to 1355 ppb. Rajendran *et al.*, (2005) reported 1.93 - 4.46 ppb in the Bay of Bengal water which was several fold higher than the concentration reported in the present study.

In India, while fair amount of information on the levels of persistent organic pollutants in fresh water ecosystem is available, similar information on marine ecosystem is inadequate. Moreover the available information are scattered. Although comparison with existing reports in India and abroad could be made, the implications are hard to predict. Nevertheless, if the levels continue to exist, in long run, due to bio concentrations and bio accumulation processes, ill effects could be recognized at higher levels in the food chain. The total PCB concentrations in water samples were higher than the prescribed ecotoxicological assessment criteria (EAC) level of 1-10 ppb (OSPAR commission, 2000).

Organochlorine chemical residues in Sediment: The levels of organochlorine contaminants in sediments from various regions along the harbour line, Mumbai are delineated in table 4.5. It has been observed that concentrations of various organochlorine pesticides are considerably high in sediment of Mahul samples than those in Sewri and Nhava. Of the various OCs tested γ-HCH, the lindane and total DDT showed significant variations ($p < 0.05$) among the locations. Sediment samples collected from Sewri had significantly ($p < 0.05$) higher load of OCPs and total PCBs.

The concentration of various pesticides in sediment of Sewri were in the range of total HCH, 0.51 - 153 ppb; total Heptachlor, 0.34 - 32.6 ppb; total DDT 5.40 - 480 ppb; total endosulfan 0.62 - 74.16 ppb; dieldrin, 0.52 - 8.14 ppb; total PCBs, 24.3 - 497 ppb. The same in Mahul were in range of 27.3 - 169; 0.89 - 37.4 ppb, 2.24 - 60.1 ppb; 4.83 - 41.6 ppb; 0.17 - 1.62 ppb; 40.7 - 316 ppb respectively (Table 4.5). The average concentration of total HCH, total DDT, total heptachlor, total endosulfan, dieldrin and total PCBs in Nhava samples were 117, 44.1, 18.3, 52.1, 11.1 and 221 ppb respectively (Fig. 3). Among the various isomers of HCHs, *a*-HCH appeared to be higher than the other isomers. *a*-HCH showed least contribution to the total HCH. Similarly the metabolites of *p,p'*-DDT, showed variation in its derivatives. The total *p,p'*-DDT, the parent compound showed major contribution to the total DDT followed by DDD and DDE.

The distribution of various organochlorine pesticides in sediment can be attributed to extensive use of pesticides for agricultural purpose along the west Coast of India. On an average 300MT of aldrin, 6000 MT of BHC, 10,000 MT of DDT are being used every year for agricultural and domestic purpose (Bami, 1992). The presence of HCH, DDT and cyclodiene pesticides has been well recorded in sediment of West Coast of India (Sarkar *et al.*, 1997).

The *p,p'*-DDT has higher mean concentration in comparison with metabolite *p,p'*-DDE and *p,p'*-DDT. The significant levels of *p,p'*-DDE, *p,p'*-DDD in sediment than the parent compound may be attributed to the presence of various kinds of marine benthic organisms, which accelerate the biodegradation process of DDT to its metabolites. The marine sediments were found to be alkaline with high salinity and organic matter (humaic substances). Organic matter is also likely to play an important role towards the degradation of DDT to DDE and DDD. The total DDT concentration recorded in Sewri, Mahul and Nhava are ten to forty orders higher than those reported in sediments from Coastal lagoons of Gulf of Mexico (Botello *et al.*, 1994).

The total DDT concentration obtained in this study is thirty times higher than the concentration reported by Rajendran *et al.*, (2005) in sediments (0.04 to 4.79 ppb) collected from the Bay of Bengal, India and fifteen times higher than the levels reported in sediment samples (5.68 ng/g) of Coastal marine environment of Mumbai (Pandit *et al.*, 2006). While decreasing trend on DDT in Coastal atmospheric air from East Coast of India has been reported by Rajendran *et al.*, (2005), no such information is available on aquatic environment. In contrast, the present study reported high concentration of DDT. The extent of contamination of coastal environment by various organochlorine pesticides can be understood from the fact that there are 232 industries situated along the West Coast of India. The most striking point of observation is that organochlorine pesticides and PCBs were detected in all the samples collected along the harbour line.

According to Strandberg *et al.* (2000), the ratio between *p,p'*-DDT and *p,p'*-DDE provides a useful index to know whether the DDT at a given site in fresh or aged. Further, a value <0.33 generally indicates an aged input. In the present study, the value greater than 0.33 was found in sediment (Table 4. 5) indicating fresh input of DDT to those locations. The presence of heptachlor, dieldrin, *p, p'*-DDT and endosulfan in the Coastal sediments indicates that the environmental conditions may originate their transformation and degradation. In some cases these secondary components are more toxic than their original component (Mc Ewen and Stephensen, 1979).

The reason for the higher concentration of PCBs, here is due to high degree of industrial operations. Similarly, Barakat *et al.*, (2002) reported the highest concentration of PCBs (1210 ppb) in sediments collected from inner harbour area of Alexandria harbour, Egypt. Hong *et al.*, (2003) reported higher load of PCBs is likely to be adsorbed to suspended particulate materials than low chlorinated chemicals. These materials probably settle onto the bottom sediment near the source. The earlier study also reported the presence of organochlorine residues in sediment from West Coast of India (Sarkar *et al.*, 1997; Pandit *et al.*, 2006), which was lower than the concentration recorded in the present study. This suggests that contamination in West Coast areas seems to be localized. Petrochemical and Industrial complexes are the potential sources. Organochlorine pesticides and PCBs concentration detected in the present study samples were compared with existing sediment quality criteria suggested by various statutory agencies. Among the three study sites, the total PCBs in sediment of Mahul and Sewri are higher than the sediment quality guidelines (total PCBs 277 ppb), above which adverse effect on aquatic biota are reported to occur frequently. These values are also equal to the levels recommended by National Academy of Science and National Academy of engineering (the protection value of aquatic biota are 500 - 1000 ppb) (NAS - NAE, 1972).

Organochlorine chemical residues in Fish: Varying concentrations of organochlorine residues were detected in the muscle tissue of 164 fishes comprising five species collected from Sewri, Mahul and Nhava (Table 4.6).

Among organochlorine pesticide residues analyzed, total HCH residues showed the highest concentration (Total HCH: 673 ppb in *Otolithes rubber)*. *Coilia dussumierie* had the maximum concentration of total DDT (61.7 ppb) followed by *Otolithes rubber* (38.3 ppb), and the minimum concentration was recorded in *Sardinella longiceps* (19.4 ppb). There is no significant variation in *p,p'*-derivatives of DDT. Among the cyclodiene pesticides, there was significant variation in total heptachlor. The highest concentration of total heptachlor was recorded in *Coilia dussumierie* (43.3 ppb). There was no significant variation observed among the species. The maximum concentration of total endosulfan and dieldrin was recorded in *Eleutheronema tetradactylum* (24 ppb) and *Coilia dussumierie* (1.57 ppb) respectively. Similarly the total PCBs was maximum in *Coilia dussumierie* (259ppb) followed by *Mystus singhalis* (238 ppb), while it was minimum in *Sardinella longiceps* (31 ppb).

Invariably, the concentration of total HCH in all the species studied shows several folds higher than the other organochlorine residues. Comparatively higher concentration *β*- HCH and *a*-HCH were also recorded in all the species. Of the all the isomers of HCHs, the predominant nature of *β*-HCH shows its most persistent nature. It is also concordant with the finding of Heeschen (1980) that *β*-HCH will accumulate ten to thirty times more in fatty tissues than lindane (γ-HCH). Presence of high concentration of *β*-HCH in various biological components were reported in many studies (Nayak *et al.*, 1995; Kumari *et al.*, 2001; Kole *et al.*, 2001). The HCH concentrations recorded in the present study species are fairly higher than values reported in eight species of fishes in Kaniyakumari, Tamil Nadu, India (Karunagaran *et al.*, 1994). The total HCH values are also higher than the levels detected in marine fishes available at Coimbatore which were received from Cochin and Rameshwaram (Jayanthi, 2004). The average concentration of total HCH in fish samples of the present study is two to three folds higher than the tolerance limit (200 ppb) prescribed for fish products (FDA, 1998; FAO/WHO, 1978). It is also several times higher than the values recorded in marine fishes of Mumbai coastal area (0.87 -33.73 ppb) (Pandit *et al.*, 2006) and in fishes (0.10 - 8.98 ppb) from various locations along Bay of Bengal (Rajendran *et al.*, 1992).

There was no significant variation ($P > 0.05$) in the average concentration of total DDT. Among the fish species studied, *Coilia dussumierie* showed the maximum average concentration of total DDT. The *p,p'*-DDE is very high, when compared with the concentration recorded (1 - 2 ppb) in the fishes of Ganga Estuary, Bangaladesh (Jabber *et al.*, 2001; Pandit *et al.*, 2006). Although DDT is banned for use in agriculture, it continues to be used for public health. Despite the ban in some places still is being used because of its low cost (Singh, 2001). However the concentration of DDT in all fish species are lower than the maximum permissible value of 1000 ng/g for DDT in fishery products set by China's National Environmental protection Agency (NEPA).

Levels are also well below the tolerance level prescribed for fish products in India (7µg/g) (Anonymous, 1995), FAO/WHO (2.5µg/g) and FDA (55µg/g).

Among the various cyclodiene insecticides, dieldrin showed the lowest concentrations in fishes and lower than the values (0.01 - 1.41 ppm) recorded in fishes available in and around Calcutta (Kole *et al.*, 2001). The endosulfan concentration in the present study are very much lower than the maximum residues limits (MRL) value (0.2 ppm) prescribed for meat (FAO/ WHO, 1978). Whereas the average concentration of dieldrin was more or less similar to the concentration (0.0006 - 0.006 ppm) recorded in fishes of Baltic Sea (Falondysz *et al.*, 2001).

The levels of PCBs recorded in the present study are higher than the levels reported by Kannan *et al.*, (1992) in fishes and prawns along the West and East Coast of India and lower than the values recorded (0.9 - 1.70 ppm) in fishes of Adriatic Sea (Stefanalli *et al.*, 2004). The Maximum residue level recently set by the European Union for PCBs in edible animals is 0.2 ppm; two of the present study species (*Coilia dussumierie, Mystus singhalis*) exceeded the limits. The consumption of contaminated fat food can be a potential risk for the consumer. The US EPA's human health screening values were 0.02

Table 4.4. Organochlorine chemical residues (ppb) in water collected from select locations along the harbour line, Mumbai (September 2006 – January 2008)

Area	S	α- HCH	β- HCH	γ - HCH	δ - HCH	Σ- HCH	Σ- HEP	p,p'- DDE	p,p' - DDD	p,p' - DDT	Σ DDT	Σ - Endo	Die	Σ - OCP	Σ- PCB
Sewri	I	BDL	BDL	0.14	BDL	0.14	BDL	BDL	0.01	BDL	0.01	BDL	0.01	0.16	.008
	II	0.42	2.12	0.01	0.20	2.76	0.05	BDL	0.57	0.67	1.24	3.51	0.79	9.00	39.9
	III	0.32	0.26	0.04	0.02	0.64	BDL	0.01	BDL	0.11	0.12	0.02	BDL	0.79	0.61
	IV	0.02	0.55	0.02	BDL	0.60	0.01	BDL	BDL	0.21	0.21	0.02	0.01	0.87	0.30
Mahul	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	II	0.15	0.06	1.81	0.74	2.77	0.05	0.01	1.38	1.80	3.19	4.46	1.29	12.21	26.9
	III	0.09	0.37	0.03	0.02	0.51	0.06	0.02	0.01	0.41	0.44	0.03	0.01	1.13	0.78
	IV	0.03	1.00	0.01	0.01	1.04	0.01	BDL	BDL	0.28	0.28	0.01	0.02	1.38	0.19
Nhava	I	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.02	0.03	0.01
	II	0.49	0.59	0.03	0.01	1.13	0.03	0.02	BDL	0.16	0.18	0.08	BDL	2.04	5.33
	III	1.16	0.24	0.09	0.06	1.54	0.11	0.15	0.04	BDL	0.19	0.05	0.04	2.05	2.48
	IV	0.03	0.53	0.04	BDL	0.61	0.01	BDL	BDL	0.13	0.13	0.01	0.01	0.80	0.31

S= Season, BDL= Below Detectable Limit, NA= Not Available, HEP= heptachlor, Endo= endosulfan, Die= dieldrin
I= September-2006, II= January-2007, III= June-2007, IV= January-2008

Table 4.5. Organochlorine chemical residues (ppb, DW) in sediments collected from select locations along the harbour line, Mumbai (September 2006 – January 2008)

Area	S	α- HCH	β- HCH	γ -HCH	δ -HCH	Σ- HCH	Σ- HEP	*p,p'*- DDE	*p,p'*- DDD	*p,p'*-DDT	Σ DDT	Σ -Endo	Die	Σ -OCP	Σ- PCB
Sewri	I	BDL	BDL	BDL	0.51	0.51	0.70	480	4.94	2.29	488	0.62	0.52	497	497
	II	85.9	0.40	61.2	5.54	153	32.6	0.61	81.81	4.96	87	74.16	8.14	364	364
	III	113	22.0	1.52	1.57	138	0.90	2.37	9.68	13.68	25.73	8.40	2.29	177	177
	IV	0.73	10.59	0.17	BDL	11.49	0.34	0.55	BDL	4.85	5.40	3.20	1.28	24.29	24.3
Mahul	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	II	92.4	8.32	51.0	17.7	169	37.4	1.80	52.67	5.63	60.10	41.64	0.17	316	316
	III	67.9	30.7	2.58	5.35	106	3.05	4.58	2.59	23.47	30.65	7.29	1.62	1569	156
	IV	5.23	20.5	0.79	0.77	27.31	0.89	0.14	BDL	2.11	2.25	4.83	0.34	40.71	40.7
Nhava	I	BDL	0.35	BDL	0.69	1.04	0.28	0.61	1.06	BDL	1.67	0.12	0.56	6.53	6.53
	II	63.7	3.12	102	32.37	201	59.7	0.13	48.31	53.39	101	200	41.88	627	622
	III	69.2	55.1	5.36	1.75	131	11.5	2.13	0.96	19.68	22.76	7.19	1.53	180	180
	IV	3.27	127	4.43	0.82	135	1.56	BDL	BDL	50.03	50.03	0.48	0.36	190	190

DW= dry weight, S= Season, BDL= Below Detectable Limit, NA= Not Available, HEP= heptachlor, Endo= endosulfan, Die= dieldrin
I= September-2006, II= January-2007, III= June-2007, IV= January-2008

Table 6. Organochlorine chemical residues (mean, ppb ± SE) among various species of fishes collected along harbour line, Mumbai (September 2006 – January 2008)

Name of Species	Σ-HCH	Σ-heptachlor	Σ-DDT	Σ-endosulfan	dieldrin	Σ PCBs
Otolithes rubber	673±196	9.46±3.26	38.2±12.3	19.39±10	0.76±0.27	112±56.1
Coilia dussumierie	605±150	43.3±23.8	61.7±24.0	18.62±6.37	1.57±0.27	259±92
Sardinella longiceps	477±157	5.80±1.47	19.4±4.37	13.5±5.77	0.22±0.08	69±23.4
Eleutheronema tetradactylum	343±260	12.4±4.23	22.5±4.56	24.0±9.03	1.38±0.69	31±11.3
Mystus singhalis	599±266	5.51±1.68	35.1±13.10	3.34±0.84	0.56±0.30	238±131

µg/g for carcinogenic effect and 0.08 µg/g for non carcinogenic effect. The above referred two species included in the present study exceeded the screening value. This indicated increased health risk to local fish consumers who routinely consume these fishes.

The higher load of HCH in sediment and fish samples of Nhava is probably attributed to intensive agricultural activity in the region compared to other two areas, whereas the higher load of DDT and PCB contamination in Sewri and Mahul can be due to intensive shipping and related activities.

PAHs

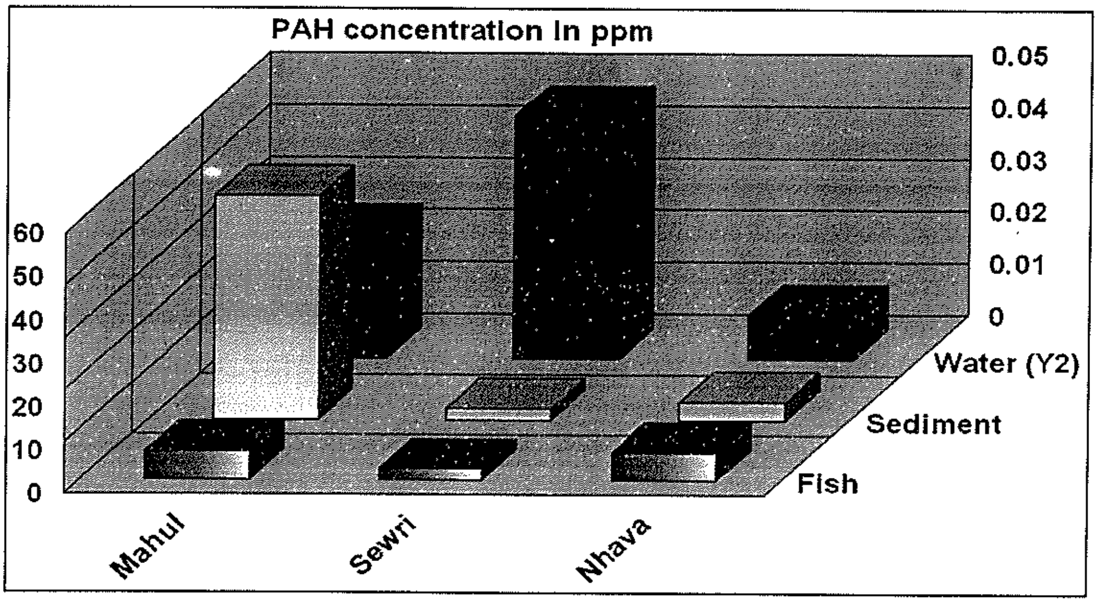


Figure 4.18. Residues of total Polycyclic Aromatic Hydrocarbons (PAHs) (mean, ppb) in water, sediments and fish of samples collected from select locations along the harbour line, Mumbai.

The level of total polycyclic aromatic hydrocarbons (PAHs) in sediment and fish samples collected from the three different locations (Sewri, Mahul and Nhava) were determined and presented in the Fig. 4.10. The mean and standard error of total PAHs in the sediment samples of Sewri, Mahul and Nhava were 2.60±1.75, 4.03±1.23 and 51.60± 30.03 ppm respectively. The total PAHs concentration reported in sediments collected from Mahul and Nhava exceeded the levels reported in a similar type of study conducted in coastal lagoons of Veracruz state, Gulf of Mexico (Botello *et al.*, 2001) and comparable with the concentration reported in sediment from Soda Lake, Casper, Wyoming (Ramirez ,1997)

The total PAHs concentrations in sediment samples collected in the present study are higher than the target values (0.02 - 0.05 ppm) set by Dutch Government for unpolluted soils (Ma and Chu, 2004). It is also reported that the total PAHs concentration above 1 ppm is regarded as heavy contamination (Maliszewska - Kordybach, 1996). The concentration of total

PAHs in sediments is notably elevated than the published ecotoxicological screening guidelines for sediment. The total PAHs concentration in sediment samples from all the study locations exceeded the maximum values of 4 and 2 ppm in sediment quality guidelines proposed by Ontario Ministry of the Environment (1993), Long *et al.*, (1995). Among the three study locations, Mahul sediments showed higher concentration of total PAHs ranging from 0.42 ppm to 104.44 ppm (Fig. 3). These levels are probably caused by the discharges of sewage, untreated industrial waste and other municipal waste in to the costal zone (Botello *et al.*, 2001).

Comparison of the levels recorded in the present study locations to those from other coastal and rivers studies reveled that all the study sites are with high PAHs levels. These high levels could be due to the pyrogenic and petrogenic origin of PAH, coming form the inflows of the rivers crossing industrial areas, oil and also through gasoline spills from boating operations. It is to be noted that higher concentrations of total PAHs found in sediment and fishes in the present study are demonstrated elsewhere to be carcinogenic and mutagenic for humans.

Organochlorine pesticides and PCBs detected in sediments in the present study were compared with the existing sediment quality criteria suggested by various statutory agencies. Among the study areas, PCBs concentration recorded in the sediment samples of Sewri was almost equal to the sediment quality guidelines (total PCB 277ppb) above which adverse effects on aquatic biota are expected to occur frequently. The total PCB concentration in water samples were below the water quality criteria (WQC) (Lee *et al.*, 2001) and equal to the prescribed Ecotoxicological Assessment Criteria 1.0- 10 ppb (OSPAR commission, 2000). Further the concentration of total PCBs was less than the levels recommended by the National Academy of Sciences and National Academy of Engineering for (the protection of aquatic biota (500-1000 ppb NAS-NAE 1972). The high concentration of PAH could be due to the pyrogenic and petrogenic origin, coming from the inflows of the rivers crossing industrial areas, oil and gasoline spills from boating operations. The PAHs concentration also exceeds the sediment guideline values suggested by various agencies. It is to be noted that higher concentrations of total PAHs found in sediment and fishes of present study are demonstrated to be carcinogenic and mutagenic. The overall concentration of organochlorine pesticides PCBs and PAH in Sewri samples were comparably higher and this may have some impact on resident organisms over a period of time.

REFERENCES

Akeley, G. E. 1912. Flamingoes of Lake Hannington, Africa. *American Museum Journal* 12:304-308.

Alagarsamy, R. 1991. Organic carbon in the sediments of Mandovi estuary, Goa, India. *Indian Journal of Marine Sciences* 20:221-222.

Alan, R., Johnson, Viallefont, A., Ruedi, G., Nager & Zilly, F. 1997. Local recruitment in the greater flamingo: a new approach using capture–mark–recapture data. *Ecology* 78 (5): 1431–1445.

Albanese, G., Baccetti ,N., Magnani, A., Serra, L. & Zenatello, M. 1997. Breeding of the greater flamingo, *Phoenicopterus ruber roseus*, in Apulia, southeastern Italy. *Alauda* 65(2):202-204.

Albro W.A., Corbett J.T. & Schroeder J. 1981. Quantitative characterization of polychlorinated biphenyl mixtures (Aroclor 1248, 1254 and 1260) by gas chromatography using capillary coloumns. *J Chromatog* 205: 103-111.

Alcocer, J. & Hammer, U. T. 1998. Saline lake ecosystems of Mexico. *Aquatic Ecosystem Health and Management* 1(3-4): 291-315.

Ali, S. & Ripley S.D. 1987. Handbook of the birds of India and Pakistan. Compact edition, Oxford University Press, Delhi.

Ali, S., Daniel, J.C. & Hussain, S.A. 1998. Studies on the movement and population structure of Indian avifauna 1980-1986. Final report. Bombay Natural History Society.

Allen S.E., Grimshaw N.M., Parkinson J.A. & Quarmby C. 1974. Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford.

Allen, R.P. 1956. The flamingos: their life history and survival. Research Report No. 5 of the National Audubon Society, New York.

Al-Mohanna M.M. 1994. Residues of some heavy metals in fishes collected from (Red sea coast) Jizan, Saudi Arabia. *J. Environ. Biol.* 15(2): 149-157.

Altmann, J. 1974. Observational study of behavior: sampling methods. *Behaviour* 48:227-265.

Amat, A.J., Hortas, F, Arroyo, M.G., Rendón, A.M., Ramírez, M.J.M. Rendón-Martos, A. Pérez-Hurtado & A. Garrido. 2007. Inter annual variations in feeding frequencies and food quality of greater flamingo chicks (Phoenicopterus roseus): Evidence from plasma chemistry and effects on body condition. Comparative Biochemistry and Physiology - Part A: *Molecular & Integrative Physiology* 147 (2):569-576.

Amat, J.A., Rendón, M.A. Rendón-Martos, M., Garrido, A. & J.M. Ramírez. 2005. Ranging behaviour of greater flamingos during the breeding and post-breeding periods: Linking connectivity to biological processes. *Biological Conservation* 125(2): 183-192.

AnilaKumary K.S. 2001. Sediment characteristics of Poonthura Estuary (Southwest coast of India) in relation to pollution. *Indian Journal of Marine Science* 30: 75-80.

Anonymous, Prevention of food adulteration rules 1995. (Government of India, New Delhi), 1990, 111.

APHA 1995, American Public Health Association *Standard Methods for the examination of analysis of water and waste-water* 19th edition.

Arengo, F. & Baldassarre, G.A. 1995. Effects of food density on the behavior and distribution of non-breeding American flamingos in Yucatan, mexico. The *Condor* 97: 325-334.

Arengo, F. & Baldassarre, G.A. 1998. Potential food availability and flamingo use of commercial salt impoundment in the Ria Lagortos Biosphere Reserve, Mexico. *Colonial Waterbirds* 21(2): 211-221.

Arengo, F. & Baldassarre, G.A. 1999. Resource variability and conservation of American Flamingos in coastal wetlands of Yucatan Mexico. *J.Wildlife, Management*. 63(4):1201-1212.

Arengo, F. & Baldassarre, G.A. 2000. A review of the ecology and conservation of Caribbean Flamingos in Yucatan, Mexico. *Waterbirds* 23 (suppl. 1): 70-79.

Arengo, F. & Baldassarre, A. 2002. Patch choice and foraging behavior of nonbreeding American Flamingos in Yucatan, Mexico. *Condor* 104: 452-457.

Arengo, F., & Baldassarre, A. 1998. Potential food availability and Flamingo Use of Commercial Salt Impoundments in the Lagartos Biosphere Reserve, Mexico. *Colonial Warterbirds* 21(2): 211-221.

Arengo, F., & Baldassarre, A.1999. Resource variability and Conservation of American Flamingos in coastal wetlands of Yucatan, Mexico. *Journal of wildlife management*, 63(4):1201-1212.

Balachandran, K.K., Raj, C.M.L., Nair, M., Joseph, T., Sheeba, P. & Venugopal, P. 2005. Heavy metal accumulation in a flow restricted, tropical estuary. *Estuarine, Coastal and Shelf Science*. 65: 361-370.

Baldassarre, G. A., Earengo, & K. L. Bildstein [EDS.]. 2000. Conservation biology of flamingos. *Waterbirds* 23 (Special Publication 1).

Bami, H.L. 1992. Pesticide's risk–an overview of Indian scene. Pesticides information, XVIII, No.3: 4-13.

Barakat, A.O, Kim, M., Qian, Y. & Wade, T.L. 2002. Organochlorine pesticides and PCB residues in sediments of Alexandria harbour, Egypt, *Mar. Pollut. Bull.* 44: 1421 - 34.

Barbraud, C., Johnson, R. & Bertault, G. 2003. Phenotypic correlates of post-fledging dispersal in a population of Greater Flamingos: the importance of body condition. *Journal of Animal Ecology* 72, 246-257.

Barron, M.G. 1995. *Bioaccumulation and concentration in aquatic organisms.* In: Hoffman D.J, Rattner B.A, Burton Jr. G.A and Cavins Jr. J (Eds). Handbook of Ecotoxicology, Lewis Publishers, Boca Raton, 652 - 666.

Barros R.E. & Baldassarre, G.A. 1989. Numbers, migration chronology, and activity patterns of non-breeding Caribbean flamingos in Yucatan, Mexico. *Condor* 91: 592-597.

Battley P.F., Rogers, D.I., Piersma, T.& Koolhaas, A., 2003.Behavioural evidence for heat-load problems in great knots in tropical Australia fuelling for long-distance flight. *Emu* 103, 97–104.

Bazigou, E., Apitz, H., Johansson, J., Lorén, E.C., Hirst, M.A., Chen, P., Ruth H., Palmer & Salecker, I. 2007. Anterograde Jelly belly and Alk Receptor Tyrosine Kinase Signaling Mediates Retinal Axon Targeting in Drosophila. *Cell* 128(5):961-975.

Beauchamp, G. & McNeil, R. 2003. Vigilance in Greater Flamingos Foraging at Night. *Ethology* 109, 511 – 520.

Berry, H. H. 1975. *South West Africa*. Pages 53-60 in J. Kear and N. Duplaix-Hall, editors. Flamingos. T. & A. D. Poyser, Berkhamsted, United Kingdom.

Bertault, G., Johnson, D.J.R. & Michel. 1999. Sex determination in greater Flamingo chicks through DNA Analysis. *Waterbirds* 22(2):282-284.

Bertelsen F., Klausen, J., Holm, E., Grøndahl, C. & Jorgensen, H. 2007. Serological response to vaccination against avian influenza in zoo-birds using an inactivated H5N9 vaccine. *Vaccine* 25(22): 4345-4349.

Bertram, B. C. R. 1978. Living in groups: predators and prey, In J. R. Krebs and H. B. Davies [EDS.], *Behavioural ecology*. Blackwell Scientific, Englewood Cliffs, NJ. p. 65-96.

Bharucha E.1988. Some aspects of Behaviour observed in the Greater Flamingo at Bhigwan. *J. Bombay Nat. Hist. Soc.* 84:677-678

Bibby. C., Burgess, N.D., & Hill, D.A., 1992. Bird Census techniques Academic Press, London, United Kingdom.

Bildstein *et al*,1993. Feeding Behavior, Aggression, and the Conservation Biology of Flamingos. *Amer. Zool.* 33: 117-125.

Bildstein, K.L., Frederick, P.C & Spaulding, M.G. 1991. Feeding patterns and aggressive behaviour in juvenile and adult American flamingos. *Condor* 93: 916-925.

Bird Life International. 2008. *Threatened birds of the World*. BirdLife International , UK

Botello, V.A, 2001. Diagnostico ambiental en la zona de influencia de la Central Termoelectrica Plutarco Elias Calles, Petacalco, Guerrero. Subproyecto monitoreo de la calidad del agua (zona costera y Bahia de Petacalco, Guerrero). Informe final, Control: PE-001-CFE/00. ICMYL, UNAM, p 531.

Botello, V.A., Diaz, G., Rueda, L., & Villanueva, S.F. 1994. Organochlorine compounds in Oysters and sediments from Coastal Lagoons of the Gulf of Mexico. *Bull. Environ. Contam. Toxicol.* 53: 238-245.

Boylan, T. 2000. Sonographic analysis of the vocalizations of Chilean and Caribbean flamingos. *Waterbirds* 23:179-184.

Brayton, A.F., & Schneider, D.C., 2000. Shorebird abundance and invertebrate density during the Boreal winter and spring at Peninsula Valdez, Argentina. *Waterbirds* 23, (2): 277-282.

Brito A.P.X., Veno V., Takahashi S., Tanabe S. 2002. Contamination by organochlorine compounds in Walleye Pollock (S) from the Berring Sea, Gulf of Alaska and the Japan Sea. *Marine Pollution Bulletin* 44: 167-177.

Brown, L. H. 1959. The mystery of the flamingos. Country Life Limited, London, United Kingdom.

Brown, L. H. 1975. East Africa. Pages 38-48 in J. Kear, & N. Duplaix-Hall, editors. Flamingos. T. & A. D. Poyser, Berkhamsted, United Kingdom.

Brown, M. J. & Pickering, S. P. C. 1993. The mortality of captive flamingos at Slimbridge 1975- 89. *Wildfowl* 43:185-193.

Brown, L.H, Powell-Cotton, D., Hopcraft, J.B.D. 1973. The breeding of the greater flamingo and great white pelican in East Africa. *Ibis* 115(3):352-374.

Bucher, E.H, Echevarria A.L, Juri M.D & Chani J.M. 2000. Long-term survey of Chilean Flamingo breeding colonies on Mar Chiquita Lake, Cordoba, Argentina.

Cardoni, D.A., Favero, M.& Isacch. J.P. 2008. Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: Implications for waterbird Conservation. *Biological Conservation* 141:797-806

Caziani, M, Olivo, O.R, Derlindati, J & Sosa H. 2007. Seasonal Distribution, Abundance, and Nesting of Puna, Adean and Chilean Flamingos. *Condor* 109: 276-287.

Caziani, S.M & Derlindati, E . 2000. Abundance and Habitat of High Andes Flamingos in Northwestern Argentina. Waterbirds: *The International Journal of Waterbird Biology*, Vol. 23: 121-133 (Special Publication 1)

Caziani, S.M, Derlindati E.J, Talamo, A, Sureda A.L, Trucco, C.E & Nicolossi, G. 2001. Waterbird richness in Altiplano wetlands of northwestern Argentina. *Waterbirds* 24: 103-117.

Ce´zilly, F., Viallefont, A., Boy, V. & Johnson, A. R. 1996. Annual variation in survival and breeding probability in the Greater Flamingo. *Ecology* 77:1143-1150.

Cezilly, F., Boy, V., Green, R. E. & Johnson. R. E. 1995. Interannual variation in Greater Flamingo breeding success in relation to water levels. *Ecology* 76:20-26.

Cezilly, F.1993. Nest desertion in the great flamingo, *Phoenicopterus ruber roseus*. *Animal Behaviour* 45(5):1038-1040.

Chen, K., & Jiao, J.J. 2007. Metal concentrations and mobility in marine sediment and ground water in coastal reclamation areas: A case study in Shenzhen, china, Environ. Pollut.doi:10.1016/j.envpol.2007.04.004.

Chen, M. 2002. Baseline metal concentrations in sediments and fish and the determination of bioindicators in the subtropical Chi-Ku lagoon, South West Taiwan. *Marine Pollution Bulletin*. 44, pp 697 – 714.

Cheung, K. C., Leung H.M, Kong K.Y, & Wong M.H 2007. Residual levels of DDTs and PAHs in freshwater and marine fish from HONG Kong and their health risk assessment. *Chemosphere*. 66: 460-468.

Childress, B., Nagy, S. & Hughes, B. (Compilers). 2007. *International Single Species Action Plan for the Conservation of the Lesser Flamingo (Phoenicopterus minor)*. AEWA Technical Series No. --. Bonn, Germany.

Childress, B., Arengo, F. & Bechet, A. (Eds.). 2008. *Flamingo, Bulletin of the IUCN-SSC/Wetlands International Flamingo Specialist Group*, No. 16. Wildfowl & Wetlands Trust Slimbridge, UK.

Chineah, V., Chooramun, V., Nallee, M., Rai, Y.B., Pillay, R.M. & Jyabalan, N., Terashima, H. & Terai, A. 2001. Status of the marine environment of the Flic en flac lagoon, Mauritius. Proceedings of the Annual meeting of Agricultural Scientists, Mauritius.

Colwell, M.A. & Taft, O.W. 2000. Water bird Communities in Managed Wetlands of varying water depth. *Waterbirds* 23(1):45-55.

Colwell, M.A. 1993. Shorebird Community Patterns in a Seasonally Dynamic Estuary. *Condor*, 95(1):104-114.

Cramps, S., & Simmons, K. E. L. 1977. The birds of the western Palearctic. Volume 1. Oxford University Press, Oxford, United Kingdom.

Cxzilly, F., Tourenq, C. & Johnson, A. 1994. Variation in parental care with offspring age in the greater flamingo. *Condor* 96: 809-812.

David, M., Mushigeri, S.B. & Philip, G.H. 2003. Alterations in the levels of ions in tissues of freshwater fish *Labeo rohita* exposed to fenvalerate. *Pollution Research* 22(3):359-363.

Davies, V. 1978. Cluster analysis applied to the classification of postures in the Chilean flamingo (*Phoenicopterus chilensis*). *Animal Behaviour* 26, Part 2: 381-388.

Davidson, N., Towinsiie C., D.J. & Pmokowske, R.S.1986.Why do Curlews Numenius have decurved bills? *Bird Study* 33:61-69.

Dickman, M.D. & Lengu, K.M.C. 1998. Mercury and organochlorine exposure from fish consumption in Kong Hong. *Chemosphere* 37: 991- 1015.

Duarte, C.M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia* 41:87-112.

ECO/OPS/OMS 1995. Alfa- y beta-hexaclorociclohexanos (Alfa- y beta- HCH's). Guia para la salud y la seguridad. No. 53. Mexico, p 34.
Eenie creek road Noosa environmental Project (http://www.ipwea.org.au/papers/download/Lee_John.pdf).

Elder, J.F. & Mattraw, H.C. Jr. 1984. Accumulation of Trace Elements, Pesticides, and Polychlorinated Biphenyls in Sediments and the Clam *Corbicula manilensis* of the Apalachicola River, *Arch. Environ. Contam. Toxicol* 13, 453-469.

Elder, J.F. 1988. Metal Biogeochemistry in surface water systems: A review of principles and concepts. U.S. Geological Survey Circular 1013.

Elder. J.F & Mattraw H.C., Jr. 1984. Accumulation of Trace Elements, Pesticides, and Polychlorinated Biphenyls in Sediments and the Clam Corbicula manilensis of the Apalachicola River. *Arch. Environ. Contam. Toxicol* 13, 453-469.

Envas, R. 1979. Adaptation shown by foraging shore birds to cyclical variation in the activity and availability of their intertidal invertebrate prey. Pp. 357-366 in 15. Naylos and R. G. Hartnoll, eds. Cyclic phenomena in marine plants and animals. Pergamon Press, Oxford, United Kingdom.

Environmental Protection Agencies (EPA) 1986. Http://www.cpcb.nic.in/standard64.htm.

Erwin, R. M. 1985. Foraging decisions, patch use, and seasonality in egrets (Aves: Ciconiiformes). *Ecology* 66:837-844.

Espino-Barros, R & Baldassarre, G.A. 1989. Activity and habitat-use patterns of breeding Caribbean Flamingos in Yucatan, Mexico. *Condor* 91: 585-591.

Este, E.E & Casler, C.L. 2000. Abundance of Benthic Macro invertebrates in Caribbean Flamingo Feeding Areas at Los Olivitos Wildlife Refuge, Western Venezuela. *Waterbirds* 23: 87-94

Falandysz, H., Wyrzykowska, B., Strandberg, L., Strandberg, B., Orlikowska, A., Puzyn, T., Bergqvist, P-A, & Rappe, C. 2003. Polychlorinated Biphenyls (PCBs) in Black Cormorants breeding at the coast of the gulf of Gdansk, Baltic Sea. *Fresenius Environmental Bulletin* 12:127-142.

Falandysz, J., Strandberg, L., Puzyn, T., & Gucia, M. 2001. Chlorinated Cyclodiene Pesticide residues in Blue Mussel, Crab, and Fish in the Gulf of Gdansk, Baltic Sea. *Environ. Sci. Technol* 35: 4163-4169.

FAO, 1983. *Compilation of legal limits for hazardous substances in fish and fishery products.* Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO/WHO, 1978. *Acceptable daily intake, residue limits and guide line levels proposals at joint committee meeting food and agriculture organization of the United Nations.* World Health Organization, p 23.

FDA (Food and Drug Administration). 1998. Action levels for poisonous or Deleterious substances in Human food and Animal Feed. *Food and Drug Administration* (21 CFR Parts 109 and 509). 1-18.

Fauvel P., 1953. *The Fauna of India including Pakistan, Ceylon, Burma and Malaya – Annelida Polychaeta,* The India Press Ltd.

Focardi, S., Gaggi, C., Chemello, G. & Bacci, E. 1991. Organochlorine residue in moss and lichen samples from two Antarctic areas. *Polar record* 27 (162) 241-244.

Frederick, P. C., Bildstein, K. L., Fleury, B. & Ogden J. 1996. Conservation of large, nomadic populations of White Ibises (*Eudocimus albus*) in the United States. *Conservation Biology* 10:203- 216.

Galicia, E & Baldassarre, G.A., 1997. Effects of motorized tour boats on the behavior of non-breeding American Flamingos (*Phoenicopterus ruber ruber*) in Yucatan, Mexico. *Conservation Biology* 11:1159- 1165.

Gawas, A.D., Lokhande, P. B. & Mujawar, H. A., 2006. Study of Physico-chemical parameters of surface waters in the Mahad industrial area. *Pollution Research* 25(1): 109-114.

Githaiga, J.M. 1995. The Lesser Flamingos of Lake Nakuru: past research and management implications. In E. N. Barua, editor. Use of research findings in the management and conservation of biodiversity. A case of Lake Nakuru National Park. Workshop pro- ceedings, Nakuru, Kenya 4-8 December 1994.

Gouda, R & Panigrahy, R.C. 1995. Seasonal distribution and behaviour of nitrate and phosphate in Rushikulya estuary, east coast of India. *Indian Journal of Marine Sciences*, Vol 24: 233-235.

Grant, P.R. 1984. Extended rainfall during the ElNiio event of 1982-83. *Noticias Gala-o a a os* 39:10-11.

Goss-Custard, J.D. 1984 Intake rates and food supply in migrating and wintering shorebirdsP. p. 233-270, in J. Burger and B. L. Olla, eds. Shorebirds migration and foraging behavior. Plenum Press, New York, New York.

Green, R.E., Hirons, G.J.M. & Johnson, A.R. 1989. The origin of long-term cohort differences in the distribution of Greater Flamingos Phoenicopterus ruber roseus in winter. *Journal of Animal Ecology* 58:543-555.

Greenwood, P.J. & Harvey, P.H. 1982. The natal and breeding dispersal of birds. *Annual Review of Ecology and Systematics*, 13, 1-21.

Grimmett, R, Inskipp, C, & Inskipp, T. 1998. *Birds of the Indian subcontinent*. Oxford University Press, Delhi.

Grootenhuis, J. G. 1995. An overview paper on wildlife disease in Lake Nakuru National Park. In E. N. Barua, editor. *Use of research findings in the management and conservation of biodiversity. A case of Lake Nakuru National Park.* Workshop proceedings. Nakuru, Kenya 4-8 December 1994.

Gunasekaran, S & Mutunayagam, S. 2003. Investigation of hydrocarbon pollutants resulting from oil spills using FTIR Finger printing Technique. *Pollution Research* 22(2): 169-177.

Guzman, H. M. 1986. Feeding areas and relative abundance of the American Flamingo along the coast of Venezuela. *Am. Birds* 40:535-541.

Hartmann, P.C., Quinn, J.G., Cairns, R.W., & King, J.W. 2004. Polychlorinated biphenyls in Narragansett bay surface sediments. *Chemosphere*. 57: 9-20.

Hazarika, R., 2003. A study of neurotoxicity of BHC in relation to residual accumulation on the brain tissue of Heteropneustes fossilis (Bloch). *J. Environ. Biol.* 24: 77-80.

Heath, A.G. 1987. *Water pollution and fish physiology*, CRC Press, Florida. 245.

Heechen, W. 1980. Toksikologische Bewertung von HCH-Ruckstanden. *Keil Milchwirtsch Forchungsber* 32: 151-155.

Hoffman, D.J., Melancon, M.J., Klein, P.N., Eisemann, J.D., & Spann, J.W. 1998. Comparative developmental toxicity of planar polychlorinated biphenyl congeners in chickens, American Kestrels and common terns. *Environmental Toxicology and Chemistry*. 17: 747 - 757.

Holland, P.T., Hickey, C.W., Roper, D.S., & Trower, T.M. 1993. Variability of organic contaminants in Inter - tidal sandflat sediments from Manukau harbour, New Zealand. *Arch. Environ. Contam. Toxicol.* 25: 456 - 463.

Holme N. A & Mc Intyre A. D. 1971. *Methods for study of Marine Benthos*, IBP Hand book No.6, Blackwell Scientific Publications.

Hong, S.H., YIm, U.H., Shim, W.J., Oh, J.R. & Lee, I.S. 2003. Horizontal and vertical distribution of PCBs and chlorinated pesticides in sediments from Masan Bay, Korea. *Mar. Pollut. Bull.* 46: 244 - 53.

Hoyo, D., Elliot, J.A. & Sargatal, J. 1992. Flamingos. Handbook of the birds of the world .Vol. 1. 508-526 .Lynx Edicions, Barcelona.

Hurlbert, H.S. 1979. Distribution and spatial patterning of flamingos in the Andean altiplano. *Auk* 96: 328-342.

Hurlbert, H.S. 1986. Fish-flamingo-plankton interactions in the Peruvian Andes. *Limnol. Oceanogr.*, 31(3):457-468.

Hurlbert, SH. 1978. Andean lakes and flamingo investigations. Technical Report 1, Department of Biology, San Diego state University, San Diego, CA.

Hurlbert, SH. 1981. Andean lakes and flamingo investigations. Technical Report 3, Department of Biology, San Diego state University, San Diego, CA.

International Wader Study Group (WSG) 2003. *Annual Conference Cadiz, Spain, 26-28 September 2003*. Ramsar Convention Bureau , Switzerland

Islam, M.Z. & Rahmani A.R. 2004. *Important Bird Areas in India: Priority sites for conservation*. Indian Bird Conservation Network, Bombay Natural History Societyand BirdLife International (UK).

Iwata, H., Tanabe, S., Sakai, N., Nishimura, A., & Tatsukawa, R. 1994. Geographical Distribution of Persistent Organochlorines in Air, Water and Sediments from Asia and Oceania and their Implications for Global Redistribution from Lower Latitudes. *Environ Poll* 85: 15–33

Jabber, S.M.A, Khan, Y.S.A, & Rahman, M.S. 2001. Organochlorine pesticide residues in the muscles of three fishes from the Ganges Estuary, Bangladesh. *Int. J Ecol Environ Sci.* 27: 111-116.

Jadhav, A & Parasharya, B.M. 2004. Counts of Flamingos at some sites in Gujarat State, India. *Waterbirds*. 27(2): 141-146.

Jagadeesan, P. 1986. Studies on the environmental inventory of the marine zone of coleroon estuary and inshore waters of Pazhayaru, Southeast coast of India, Ph.D thesis, Annamalai University, India.

Jagtap, T.G., Nayak, S. & Nagle, V.L. 2001. Assessment of coastal wetland resources of central west coast, India using Landsat data. *Journal of Indian Remote Sensing Society*, 29: 143-150.

Jayakumar, R. 2007. *Heavy metal contamination in fishes collected from Rameshwaran and Cochin*, Report submitted to CSIR, New Delhi.

Jayanthi, P. 2004. Persistent organochlorine pesticide residues in a few species of marine fishes sold in Coimbatore. Dissertation submitted to the Bharathiar University, Coimbatore.

Jenkin, P.M. 1957. The filter-feeding and food of flamingos (Phoenicopteri). Philosophical Transactions of the Royal Society of London Series B 240:401-493.

Jha, S.K., Krishnamoorthy, T.M. and Pandit, G.G. & Nambi, K.S. 1999. History of accumulation of mercury and nickel in Thane creek, using 210Pb dating technique. *Science of the Total Environment*, 236: 91-99.

Johnson, A.R. 1989. Movements of Greater Flamingos *Phoenicopterus ruber roseus* in the Western Palearctic. *La Terre etla* 44: 75-94.

Johnson, A.R. 1997. Long-term studies and conservation of Greater Flamingos in the Camargue and Mediterranean. *Colonial Waterbirds* 20 (2):306-315.

Johnson, J.M. 1983. Puddle-feeding of Flamingos *Phoenicopterus roseus* in inland tanks. *J. Bombay Nat. Hist. Soc.* 81:467-468.

Joseph, T., Balachandran, K.K., Nair, M., Das, V.K., Nair, K.K.C., & Paimpillii, J.S. 2003. *Trace metal levels in nearshore sediments close to industrial discharges off cuddalore (Bay of Bengal).* Contaminated sediments: characterization, evaluation, mitigation/ restoration and management strategy performance. ASTMSpec. Tech. Publ.1442.ASTM international. West Conshohocken, PA, USA.53-61.

Kahl, M. P. 1975. *Ritualized displays.* Pages 142-149 in J. Kear & N. Duplaix-Hall, editors. Flamingos. T. & A. D. Poyser, Berkhamsted, United Kingdom.

Kairu, J.K. 1996. Heavy metals residues in birds of Lake Nakuru, Kenya. *Afr. J. Ecol.*34, 397-400.

Kannan, K., Tanabe, S. & Tatsukawa, R. 1995. Geographical and accumulation features of organochlorine residues in fish from tropical Asia and Oceania. *Environ Sci Technol* 29:2673- 2683.

Kannan, K, Tanabe, S, Ramesh, A, Subramanian, A & Tatsukawa, R. 1992. Persistent organochlorine residues in foot stuffs from India and their implication on human dietary exposure. *J. Agric. Food. Chem.* 40: 518-524.

Karunagaran, U.M, Babu, S, Rajendiran, R.B & Subramanian, A.N. 1994. Organochlorine insecticides (HCH, and *p,p'*-DDE) residues in fishes from Kanniyakumari (80 04'N, 770 36'N). *Indian J. Mar. Sci.* 23:182-183.

Kathikeyani, T.P, Sashikumar, J.M & Ramesh, M. 2002. Physicochemical, Biological and Bacteriological study of Kadathur canal water of Amaravathi River, Tamil Nadu. *Pollution Research* 21(1): 21-23.

Kaviraj, A. 1989. Heavy metal concentration of fish and prawn collected from hoogly estuary. *Science and Culture*. 55: 257-260.

Kazmierczak, K. 2000. A Field Guide to the Birds of the Indian Subcontinent. Christopher Helm/A & C Black.

Kershaw, M & Cranswick , P.A. 2003. Numbers of wintering waterbirds in Great Britain, 1994/1995–1998/1999: I. Wildfowl and selected waterbirds. *Biological Conservation* 111: 91–104.

King, E. 2000. Captive flamingo populations and opportunities for research in zoos. *Waterbirds* 23:142-149.

Kirwan, G. 1991. Karapinar Ovasi, a little-known Turkish IBA. *Bulletin of the Ornithological Society of the Middle East* 27:24-27.

Kock, N.D., Kock, R.A., Wambua, J., Kamau, G.J. & Mohan, K. 1999. *Mycobacterium avium*-related epizootic in free-ranging Lesser Flamingos in Kenya. *J. Wildlife Dis.* 35,297-300.

Kole, RK, Banerjee, H & Bhattacharyya, A. 2001. Monitoring of Market Fish Samples for Endosulfan and HCH Residues in and around Calcutta. *Bull. Environ. Contam. Toxicol.* 67:554-559.

Kondratyev, K.Ya., Melentyev, V.V. & Pozdniakov, D.V. 1994. Application of remote sensing techniques to comprehensive monitoring of inland water ecosystems. Proceedings on Hydrological, Chemical and Biological Processes of Transport of Contaminants in Aquatic Environments, IAHS Publication, pp. 369-374.

Krebs, J. R. 1978. Optimal foraging: decision rules for predators,. In J. R. Krebs & H. B. Davies [EDS.], *Behavioural ecology*. Blackwell Scientific, Englewood Cliffs, NJ. p. 23-63.

Krienitz, L., A. Ballot, K. Kotut, C. Wiegand, S. Pütz, Metcalf, S.J, Codd, A.G. & S. Pflugmacher. 2003. Contribution of hot spring *cyanobacteria* to the mysterious deaths of Lesser Flamingos at Lake Bogoria, Kenya. FEMS *Microbiology Ecology* 43(2):141-148.

Krishnamurthi, A.J., & Nair, V.R. 1999. Concentration of metals in fishes from Thane and Bassein creeks of Bombay, India. *Indian Journal of Marine Sciences* 28: 39-44.

Kumari, A., Sinha, RK, Gopal, K & Prasad, K. 2001. Dietary intake of Persistent Organochlorine Residues through Gangetic Fishes in India. *International Journal of Ecology and Enviornmental Sciences* 27: 117-120.

Kumari, B., Singh, R., Madan, V.K., Kumar, R. & Kathpal, T.S. 1996. DDT and HCH compounds in soils, ponds and drinking water of Haryana, India. *Bull.Environ. Contam. Toxicolol.* 57: 787-793.

Kushlan, J.A. 1986. Responses of wading birds to seasonally fluctuating water levels: strategies and their limits. *Colonial Waterbirds* 9: 155-162.

Langston, W.J. 1990. Toxic effects of metals and the incidence of marine ecosystems In: Furness RW and PS Rainbow (Eds) Heavy metals in the marine environment, CRC Press, New York pp 256.

Lebreton, J.D., Burnham, K.P., Clobert, J. & Anderson, D.R. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological Monographs*, 61, 67-118.

Lee, K.T., Tanabe, S. & Koh, C.H. 2001. Concentration of Polychlorinated biphenyls (PCBs) in sediment from Kyeonggi Bay and nearby areas. *Korean Mar Pollute Bull* 42: 273- 279.

Lewis, A. & Pomeroy, D. 1989. A bird atlas of Kenya. A. A. Balkema, Rotterdam, The Netherlands.

Long, E.R, Macdonald, D.D, Smith, S.L, & Calder, F.D. 1995. Incidence of adverse biological effects within range of chemical concentrations in marine and estuarine sediments. *Environ manag* 19(1): 81-97.

Lugomela, H., Pratap, H.B & Yunus, D. 2006. *Mgaya Cyanobacteria* blooms:A possible cause of mass mortality of Lesser Flamingos in Lake Manyara and Lake Big Momela, Tanzania. *Harmful Algae* 5(5): 534-541.

Luı´s, A., Goss-Custard, J.D. & Moreira, M.H., 2001. A method for assessing the quality of roosts used by waders during high tide. *Wader Study Group Bulletin* 96, 71–74.

Luoma, S.N. 1983. Bioavailability of trace metals to aquatic organisms:A Review. *The Science of the total environment* 28, 1-22.

Madsen, C. S., de Kloet, D. H., Brooks, J. E., & de Kloet, S. R. 1992. Highly repeated DNA sequences in birds: The structure and evolution of an abundant, tandemly repeated 190-bp DNA fragment in parrots. *Genomics* 14(2): 462-469.

Magurran, A.E., 1991. *Ecological Diversity and its Measurement*. Chapman and Hall, London.

Mahapatro, T.R. & Padhy, S.N. 2002. Seasonal Variation of Micronutrients in Rushikulya Estuary (Bay of Bengal). *Pollution Reasearch* 21(1): 1-5.

Maliszewska-Kordybach, B. 1996. Polycyclic aromatic hydrocarbons in agricultural soils in Poland: preliminary proposals for criteria to evaluate the level of soil contamination. *Appli. Geochem*. 121-127.

Manakadan, R. 1995. Impact of salt works on the status and population of the Greater Flamingo Phoenicopterus ruber roseus and the Lesser Flamingo Phoeniconaias minor in the Great Vedaranyam Swamp. *J. Bombay Nat. Hist. Soc.* 92: 364- 371.

Manakadan, R. 1998. *Conservation of flamingos in the Great Vedaranyam Swamp.pp.48-49*. In: Vijayan, L. (ed.) (1995). Avian conservation in India. (Proc. of the Avian Conservation Workshop. Coimbatore, August 1993). SACON and BirdLife Asia Council.

Manirakiza, P., Covaci, A., Nizigimana, L., Ntakimazi, G., & Schepens, P. 2002. Persistent chlorinated pesticides and polychlorinated biphenyls in select fish species from Lake Tanganyika, Burundi, Africa. *Environmental pollution*. 117: 447-445.

Manivasakam, N. 1997. *Industrial Effluents Origin, Characteristics, Effects Analysis and Treatment*. Sakthi Publications, Coimbatore.

Maron, J.L. & Myers, J.P. 1985. Seasonal changes in feeding success, activity patterns, and weights of nonbreeding Sanderlings (Calidris alba). *Auk*. 102:580–586.

Martin, G.R., Jarrett, N., Tovey, P.& White. C.R. 2005. Visual fields in Flamingos: chick-feeding versus filter-feeding. *Naturw issenschaften* 92: 351–354.

Mascitti, V. & Castanera, M.B. 2006. Foraging Depth of Flamingos in Single – species and Mixed–species flocks at Laguna de Pozuelos, Argentina. *Water birds* 29(3): 328-334.

Mascitti, V. 1998. James Flamingo Foraging Behavior in Argentina. *Colonial Water birds* 21(2):277-280.

Mason, R.P, Laporte, J & Andres, S. 2000. Factors controlling the bioaccumulation of merry, methylmercury, arsenic, selenium and cadmium by freshwater invertebrates and fish. *Arch. Environ. Contam. Toxicol.* 38: 283–297.

Masters, M. 1991. Introduction to Environmental Engineering and Science. Prentice' Hall of India Private Limited. New Delhi.

Mathevon, N. 1997. Individuality of contact calls in the Greater Flamingo *Phoenicopterus ruber* and the problem of background noise in a colony. *Ibis* 139: 513- 517.

Mathew, S. 2004. Heavy metal contamination in select species of marine fishes sold in Coimbatore. Dissertation submitted to the Bharathiar University, Coimbatore.

Mc Even, F.L & Stephenson, G.R. 1979. The use and significance of pesticides in the environment. Wiley, New York.p. 538.

Meitei, N., Singh, S.P., Patil, P.M. & Bhosle, A.B. 2006. Studies on ammonia and phosphate content of Purna River, Maharashtra, India. *Pollution Research.* 25(2): 337-338.

Miller, R.L. & McKee, B.A. 2004. Using MODIS Terra 250 m imagery to map concentrations of total suspended matters in coastal waters. *Remote Sensing of Environment*, 93: 259-266.

Mishra, S.D., Panda, & Panigrahy R.C., 1993. Physico-chemical characteristics of the Bahuda estuary (Orissa), east coast of India. *Indian Journal of Marine Sciences* 22:75-77.

Morillo J., Usero J. & Gracia I. 2004. Heavy metal distribution in marine sediments from southwest coast of spain. *Chemosphere* 55, 431-442.

Muir D.C.G., Norstom R.J. & Simon M. 1990. Organochlorine in Arctic marine food chains: accumulation of specific polychlorinated biphenyl's and chlordane related compounds. *Environmental Science and Tecnology* 22:1071-1079.

Muralidharan S 1993. Aldrin poisoning of Sarus cranes (*Grus antigone*) and a few granivorous birds in Keoladeo National Park, Bharatpur, India. *Ecotoxicology* 2:196-202.

Muralidharan S 2000. Organochlorine residues in the waters of Keoladeo National Park, Bharatpur, Rajasthan. *Bull. Environ. Contam. Toxicol.* 65: 35 – 41.

Muralidharan S, Dhananjayan V & Jayanthi P 2008. Organochlorine pesticide residues in the commercial marine fishes of Coimbatore and their suitability for human consumption Environmental Research. doi:10.1016/j.envres.2008.08.006.

Nagarajan, R & Thiyagesan, K. 1996. Waterbirds population and substarte quality of Pichavaram wetlands, Southern India. *Ibis*138:710-721.

Nager, R.G., Johnson, A.R., Boy, V., Rendon-Martos, M., Calderon, J. & Czilly, F. 1996. Temporal and spatial variation in dispersal in the greater flamingo (Phoenicopterus ruber roseus). *Oecologia*, 107:204-211.

Nair A., Mandapati R., Dureja P., & Pillai M.K.K. 1996. DDT and HCH load in Mothers nd Their infants in Delhi, India. *Bull. Environ Contam. Toxicol.* 56: 58-64.

Nair M.N. & K.K. Ramachandran, 2002. Textural and trace elemental distribution in sediments of the Beypore esturary (South West coast of India) and adjoining inner shelf. *Indian Journal of Marine Science* 31(4): 295-304.

Nasirwa, O. 2000. Conservation status of flamingos in Kenya. *Waterbirds* 23:47-51.

Nasser, M.E., du Preez, J. & Herrmann, K.2003. Flight of the young flamingoes: alternative futures for young entrepreneurs in South Africa. *Futures* 35(4): 393-401.

National Academy of Science & National Academy of Engineering (NAS-NAE). 1972. Ecology Research Service Environmental, Washington, DC:1-62.

Nayak, S. 2002. Use of satellite data in coastal mapping. *Indian Cartographer*, 22: 147-156.

Nayak, S. & Bahuguna, A. 2001. Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian Journal of Marine Sciences*, 30: 195-213.

Nayak, A.,K., Raha, R, & Das A.K 1995. Organochorine pesticide residues in middle stream of Ganga river, India. *Bull. Environ. Contam. Toxicol.* 54: 68 – 75.

Nayak B., K., Acharya, B, C., Panda, U. C., Nayak B.B. & Acharya S.K. 2004. Variation of water quality in Chilka lake, Orissa. *Indian Journal of Marine Sciences*, 33 (2): 164-169.

Nelson, Y.M., Thampy, R.J., Motelin, G.K., Raini, J.A. DiSante, C.J. & Lion, L.W.1998. Model for trace metal exposure in filter-feeding flamingos at alkaline Rift Valley lakes, Kenya. *Environm. Toxicol. Chemist.* 17, 2302-2309.

Newton, I., 1998. Population limitation in birds. Academic Press, London.

Ockenden W.A., Corrigan B.P., Howsam M. & Jones K.C. 2001. Further developments in the use of semipermeable membrane devices as passive air samplers: Application to PCBs. *Environ Sci Technol* 35, 4536-4543.

Ontario Ministry of the Environment. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Water resources Branch.

OSPAR commission 2000. Quality status report. London: OSPAR Commission.

Osuna Flores & Riva M.C. 2002. Organochlorine pesticide residue concentrations in Shrimps, sediment and surface water from Bay of Ohuira, Topolobampo, Sinaloa, Mexico. *Bull. Envirn. Contam. Toxicol.* 68: 532 – 539.

Owino, A.O., Bennun L.A., Nasirwa, O. & Oyugi J,O. 2002. Trends in waterbird numbers in the Southern Rift Valley of Kenya, 1991-2000. *Waterbirds:* 25 (2): 191-201.

Padma, S. & Peiakali, P. 1999. Physico-chemical and geochemical studies in Pulicat lake, east coast of India. *Indian Journal of Marine Sciences*, 28:434-437.

Pandit, G.G., Sahu, S.K., Sharma, S. & Puranik, V.D. 2006. Distribution and fate of persistent organochlorine pesticides in coastal marine environment of Mumbai. *Environ. Int.* 32: 240-243.

Panigrahy, P.K., Das, J., Das, S. N. & Sahoo, R.K. 1999. Evaluation of the influence of various physico-chemical parameters on coastal water quality, around Orissa, by factor analysis. *Indian Journal of Marine Sciences*, 28: 360-364.

Papastergiadou, E.S., Retalis, A., Apostolakis, A. & Georgiadis, Th. 2008. Environmental monitoring of spatio-temporal changes using remote sensing and GIS in a Mediterranean wetland of Northern Greece. *Water Resources Management* 22: 579-594.

Parashya B.M. & Tere, A. 2006. Lesser Flamingos in India: a knowledge update. Anand Agriculture University, Anand, India. 23pp.

Pennycuick, C.J., & Bartholomew, G. A. 1973. Energy budget of the Lesser Flamingo (*Phoeniconaias minor*, Geoffroy). *East African Wildlife Journal* 11:199-207.

Perry, E., Swift, J. Gamboa, J., Reeve, A., Sanborn, R., Marin, L. & Villasuso, M. 1989. Geologic and environmental aspects of surface cementation, north coast, Yucatan, Mexico. *Geology* 17:818-821.

Picer M. & Picer N. 1991. Long term trends of DDTs and PCBs in sediment samples collected from the Eastern Adriatic Coastal waters. *Bull. Environ. Contam. Toxicolol.* 47:864 - 873.

Pickering, P.C. & Duverge, L. 1992. The influence of visual stimuli provided by mirrors on the marching displays of Lesser Flamingos *Phoeniconais minor. Animal Behaviour* 43(6): 1048-1050.

Piersma, T. & Poot, M. 1993. Where waders may parallel penguins: spontaneous increase in locomotor activity triggered by fat depletion in a voluntary fasting knot. *Ardea* 81: 1-8.

Pirela, D.E. 2000. Monitoring Caribbean Flamingos at Los Olivitos Wildlife Refuge, Western Venezuela. Waterbirds: The International Journal of Waterbird Biology:23:103-108. Special Publication 1:

Pocy, R. 1926. Biologie et migration du flamant rose, *Phoenicopterus ruber anticuorium. Bulletin de la Societe Zoologique de Gdneve* 3:5-433. (In French)

Poland A., & Knutson J.C. 1982. 2, 3, 7, 8- Tetrachlorodibennzo-para- dioxin and related halogenated aromatic-hydrocarbaons. Examination of the mechanism of toxicity. *Annu Rev pharmacology and toxicology* 22: 517-554.

Powell, G.V.N. 1987. Habitat use by wading birds in a subtropical estuary: implications of hudrography. *Auk* 104: 740-749.

Prasad, S.N., Tiwari, A.K., Kumar,A., Kaushik, P.,Vijayan,L., Muralidharan,S. & Vijayan, V.S. 2004. Inland wetlands of India-A conservation Atlas. SACON, Coimbatore.

Rajendran, R.B., Imaganwa, T., Tao H. & Ramesh, R. 2005. Distribution of PCBs, HCHs and DDTs, and their ecotoxicological implications in Bay of Bengal, India. *Environment International* 31(4) : 503-512

Rajendran, B.R., Karunagaran, V.M., Babu, S. & Subramanian, A.N. 1992. Levels of chlorinated insecticides in fishes from the Bay of Bengal. *Mar. Pollut. Bull.* 24: 567-569.

Rajendran, R.B, Imaganwa, T., Tao, H. & Ramesh, R. 2005. Distribution of PCBs, HCHs and DDTs, and their ecotoxicological implications in Bay of Bengal, India. *Environ. Int.* 31: 503-512.

Ramesh, D.A. & Ramachandran, S. 2005. Factors influencing flamingo (*Phoenicopterus roseuis*) distribution in the Pulicat Lagoon ecosystem, *Wetland ecology and management*. 13(1):69-72.

Ramirez, Jr P. 1997. *Environments in the Aquatic bird Food Chain of an Oil Refinery Wastewater Pond*. Contaminant Report Number: R6/ 712c/ 97, US Fish and Wildlife Service, Cheye.

Redfield, A.C. 1934. In: James Johnstone Memorial Volume, edited by R J Daniel (University Press, Liver Pool) p. 176.

Rehfisch, M.M., Austin, G.E., Armitage, M.J.S., Atkinson, P.W., Holloway, S.J., Musgrove, A.J. & Pollitt, M.S. 2003. Numbers of wintering waterbirds in Great Britain and the Isle of Man (1994/1995–1998/1999):II. Coastal waders (Charadrii). *Biological Conservation* 112; 329–341.

Rendon, M. M., & Johnson A. R. 1996. Management of nesting sites for Greater Flamingos. *Colonial Waterbirds* 19:167-183. (Special Publication 1)

Rendon, M.A., Garrido, A., Ramirez, J.M., Rendon-Martos, M. & Amat, J.A. 2001. Despotic establishment of breeding colonies of greater flamingos, Phoenicopterus ruber, in southern Spain. *Behavioral Ecology and Sociobiology*, 50: 55-60.

Rendon-Martos, M. 1996. La Laguna de Fuente de Pie- dra en la dinimica de la poblaci6n de flamencos (*Phoenicopterus ruber roseus*) del Mediterrineo Occi- dental. Dissertation, Universidad de Milaga, Mila- ga, Spain.

Rendon-Martos, M., J. M. Vargas, & J. M. Ramirez. 1991. Dinimica temporaly reproducci6n del fla- menco comfn (Phoenicopterus ruber roseus) en la Laguna de Fuente de Piedra (Sur de Espafia). Pages 135-153 in Agencia de Medio Ambiente, editor. Re- uni6n t6cnica sobre la situaci6n y problemitica del flamenco rosa (*Phoenicopterus ruber roseus*) en el Med- iterrineo Occidentaly Africa Noroccidental. Junta de Andalucia, Spain. (In Spanish with English summary).

Rendon-Martos, M., Vargas, J. M., Rend6n, M. A., Garrido A. & Ramirez, J. M. 2000. Nocturnal movements of breeding Greater Flamingos in southern Spain. *Waterbirds* 23:9-19. (Speical Publication 1)

Ridley, M.W. & Percy, R.C. 1953. Notes on the birds of Lake Elmenteita, Kenya Colony. Proceedings of the University of Durham Philosophical Society 12: 103-118.

Robertson, W.B. & Frederick, P.C. 1994. The faunal chapters: context, synthesis, and departures, In S. Davis and J. C. Ogden [EDS.], Everglades: the ecosystem and its restoration. St. Lucie Press, FL. p. 709-737.

Rocha O. 1997. Fluctuaciones poblocionales de tres especies de flamencos en Laguna de Mar Chiquita (Cordoba, Argentina): a little known, secularly fluctuating, saline lake. *International Journal of Salt Lake Research* 5: 187-219.

Roesijadi, G. & Robinson, W.E. 1994. Metal regulation in aquatic animals: Mechanism of uptake, accumulation and release In: Martins DC, Ostrander GK, editors, Aquatic Toxicology: Molecular, biochemical and cellular perspectives, Lewis Publishers, London, pp 539.

Rogers, D.I., 2003. High-tide roost choice by coastal waders. *Wader Study Group Bulletin* 100, 73–79.

Rogers, D.I., Piersma, T & Hassell, C.J. 2006. Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological conservation* 133:225 –235

Rooth, J. 1965. The flamingos on Bonaire (Netherlands Antilles): habitat, diet and reproduction of *Phoenicopterus ruber*. Uitgaven "Natuurwetensch. Stud. Suriname en de Ned. Ant.," No. 4 1. Utrecht, the Netherlands.

Rosa, S., Encarnacao, A.L., Granadeiro, J.P. & Palmeirim, J.M., 2006. High water roost selection by waders: maximising feeding opportunities or avoiding predation? *Ibis* 148: 88–97.

Rose, P., & D. Scott. 1997. Waterfowl population estimates. Second edition. Wetlands International, Wageningen, Netherlands.

Saad, M.A.H. 1973. Some limnological characteristics of the *Nozha hydrodrome*, Near Alexandria Egypt, *Hhydrobiologia*, 41(4): 477-499.

Safi-Harb, S & West, J. 2005. A Gemini observation of the anomalous X-ray pulsar 1RXS J170849-400910. *Advances in Space Research* 35(6):1172-1176.

Said, T.O. & Hamed, M.A. 2006. Mobility of Polycyclic Aromatic Hydrocarbons in Water of the Egyptian Red Sea Coasts. *Bull. Enviorn. Contam. Toxicol.*77: 126-136.

Sargunam, C.A. 1994. Studies on micro fouling in the coastal waters of Kalpakkam, east coast of India with reference to diatoms (*Bacillariophyceae*), Ph.D. thesis, Madras University, India.

Sarkar, A., & Sen Gupta, R. 1991. Pesticide residues in sediments from the west coast of India. *Mar Pollut Bull.* 22:42– 45.

Sarkar, A. & Gupta, S. 1989. Determination of Organochlorine pesticides in Indian coastal water using a Moored in- Situ Sampler. *Wat. Res.* 23(8): 975-978.

Sarkar, A., Nagarajan, A., Chaphadkar, S, Pal, S. & Singbal, S.Y.S. 1997. Contamination of Organochlorine pesticides in sediments from Arabian Sea along the west coast of India. *Wat Res* 31:195-200.

Sarker U.K., Basheer V.S., Singh A.K & Srivastava S. M., 2002. Organochlorine Pesticide Residues in Water and Fish Samples: First Report from Rivers and streams of Kumaon Himalayan Region, India. *Bull Environ Contam.Toxicol.*70: 485-493.

Sasamal, S.K., Rao, K.H. & Suryavansi, U.M. 2007. Sewage and industrial pollution in and around Thane creek, Mumbai using high resolution IRS data. *International Journal of Remote Sensing*, 28: 4391-4395.

Satpathy, K.K. 1996. Seasonal distribution of nutrients in the coastal waters of Kalpakkam, east coast of India. *Indian Journal of Marine Sciences*.25: 221-224.

Schmitz, R.A., Aguirre, A.A., Cook, R.S. & Baldassarre, G.A. 1990. Lead poisoning of Caribbean Flamingos in Yucatan, Mexico. *Wildlife Society Bulletin* 18:399-404.

Schmitz, R.A & Baldassarre, G.A. 1992a. Contest asymmetry and multiple bird conflicts during foraging among nonbreeding American Flamingos in Yucatan, Mexico. *Condor* 94: 254-259.

Schubel, J.R., & V.S. Kennedy. 1984. *The estuary as a filter*. Academic, orlando, FL, USA, pp.1-11.

Schulte E & Acker L 1974. Identifizierung und metaboliserbarkeit von polychlorierte biphenylen. *Naturw* 61: 79-81.

SenGupta, R., Fondekar, S.P., Kureishy, T.W., Singbal, S.Y.S. & S. Sanzgiri. 1980. *Pollution studies in the Arabian Sea*. Proc. Symp. On environmental Pollution and toxicology. Pp 67-82.

Sericano J.L., Wade T.L., Jackson T.J., Brooks J.M., Tripp B.W., Farrington H.W., Mee L.D., Readman J.W., Villeneuve H.P., Goldberg E.D. 1995. Trace organic contamination in the Americas: An overview of the US Ntional Status and Trends and the International 'Mussel Watch' Programme, *Mar Pollut Bull* 31: 214-225.

Setty, A.P & Rao, C.M. 1972. Phosphate, carbonate and organic matter distribution in sediment cores off Bombay- Saurashtra coast, India.

Shannon, P.W. 1987. Flamingo bibliography. AAZPA Library Special Interest Group.

Shannon, C.E. & Wiener, W. 1949. *The Mathematica Theory of Communication*, Univ. of Ilinois Press, Urbana.

Sharma, B.K. 2005. *Environmental Chemistry*. Goel Publishing House. Krishna Prakashan Media Private Limited. Meerut.

Simmons R.E. 2000. Declines and movements of lesser flamingos in Africa. *Waterbirds* 23:40-46.

Simmons, R.E. 1996. Population Declines, Viable breeding areas, and Management options for Flamingos in Sothern Africa. *Coservation Biology* 10(2): 504-514.

Sing, M.A., Mohan K.P., & Patel, D.K. 2004. Distribution Polycyclic Aromatic Hydrocarbons in Gomti river system, India. *Bull. Environ. Contam. Toxicol.* 72:1211-12

Singh, B. & Gupta, A. 2002. Monitoring of pesticide residues in different sources of drinking water of Jaipur, India. *Bull. Environ. Contam. Toxicolol.* 69: 49-53.

Singh, R.P. 2001. Comparison of organochlorine pesticide Levels in soil and ground water of Agra, India. *Bull. Environ. Contam. Toxicol.* 67: 126-132.

Singh, S. & Taneja, B. 2000. Prioritisation for biodiversity conservation values and criteria. - In: Singh, S., Sastry, A.R.K., Mehta, R., Uppal, V. (eds.) Setting biodiversity priorities for India, 1: 28-41. – World Wide Fund for Nature, India. New Delhi.

Singh *et al.* 2001. Setting Priorities for Biodiversity Conservation in India. World Wide Fund for Nature-India, New Delhi. II volumes.

Singh, S.K., Raha, P., & Banerjee, H. 2006. Banned organochlorine cyclodiene pesticide in ground water in Varanasi, India. *Bull. Environ. Contam. Toxicolol.* 76: 935 – 941.

Sprunt, A. 1975. *The Caribbean*. pp 65-74 in J. Kear & N. Duplaix-Hall, editors. Flamingos. T. & A. D. Poyser, Berkhamsted, United Kingdom.

Staine, K.J, & Burger J. 1994. Nocturnal foraging behavior of breeding piping plovers (*Charadrius melodus*) in New Jersey. *Auk*. 111:579–587.

Stevens, E.F., Beaumont, J.H., Cusson, E.W. & Fowler, J. 1992. Nesting behavior in a flock of Chilean Flamingos. *Zoo Biology* 11(3):209-214.

Stevens, E.F, & Pickett, C., 1994. Managing the social environments of flamingos for reproductive success. *Zoo Biology* 13(5):501-507

Stefanelli, P., Muccio, D.A., Ferrarra, F., Barbani, D.A., Generali, T., Pelosi, P., Amendola, G., Vanni, F., Muccio, D.S & Ausili, A. 2004. Estimation of intake of organochlorine pesticides and chlorobiphenyls through edible fishes from the Italian Adriatic Sea during 1997. *Food Control*. 15: 27-38.

Stern G.A., Halsall C.J., BarrieL.A., Muir D.C.G., Fellin P., Rosenberg B., Rovinski F.Y., Kononov E.Y., & Pastukhov B.V. 1997. PCBs in the arctic atmosphere I) Spatial and temporal trends: 1992–1994. *Environ Sci Technol* 31, 3619–3628.

Strandberg, B., Bandh C., Bavel, B., Bergqvist, P., Broman, D, Ishaq, R., Naf, C. & Rappe, C. 2000. Organochlorine compounds in the gulf of Bothnia: sediment and benthic species. *Chemosphere* 40: 1205 -1211.

Studer-Thiersch, A. 1974. Die Balz der Flamingogattung Phoenicopterus, unter besonderer Beriicksichtigung von *P.ruber roseus. Zeitschrift ffir Tierpsychologie* 36:212-266. (In German with English summary)

Studer-Thiersch, A. 2000. What 19 Years of Observation on Captive Greater Flamingos Suggests about Adaptations to Breeding under Irregular Conditions. *Waterbirds* 23:150-159. (Special Publication) 1

Studer-Thiersch. A. 2000. Behavioral demands on a new exhibit for greater flamingos at the Basle zoo, Switzerland. *Waterbirds* 23:185-192. (Special Publication 1)

Subba Rao, M.V., Rao, B.M.G., Rao, B.R. & Nanda. N.K. 1981. Hydrological studies of the brackish water Chilika lagoon, Orissa . *J. Environ Biol* 2, 59-62.

Sultana, R & Rao, D.P. 1998. Bioaccumulation Patterns of Zinc, Copper, Lead and Cadmium in Grey mullet, Mugil Cephalus from Harbour waters of Vishakapatnam, India. *Bull. Environ. Contam. Toxicol.* 60: 949-955.

Sumathi , T., Nagarajan, R. & Thiyagesan, K. 2007. Seasonal changes in the population of waterbirds with the special reference to filaminogs in Point Calimere Wildlife and Bird Sanctuary, Tamil Nadu, Southern India, *Mayur* 3: 1-11.

Sumathi, T., Nagarajan, R. & Thiyagesan, K. 2008. Effect of water depth and salinity on the population of Greater Flamingo (*Phoenicopterus ruber*) in Point Claimere , Wildlife and Bird Sanctuary, Tamil Nadu, Southern India. *Journal of scientific Transactions in Environment and Techno vision* 2(1): 9-17.

Swami, B.S., Suryawanshi, U.G. & Karande, A.A. 2000. Water quality status of Mumbai (Bombay) harbor – an update. *Indian Journal of Marine Sciences* 29: 111-115.

Tam, N.F.Y. & Wong Y.S. 2000. Spatial variation of metals in surface sediments of HongKong mangrove swamps. *Environmental pollution* 110, 195-205.

Tanabe, S. 1991. Fate of toxic chemicals in the tropics. *Mar Pollut Bull.* 22(6): 259– 260.

Tanabe, S., Iwate, H., Tatsukawa & Global. R.1994. Contamination by persistent organochlorines and their ecotoxicological impact on marine mammals. *Sci Total Environ.* 154:163– 77.

Tanabe, S., Prudente, M.S., Kan-arireklap, S. & Subramanian, A. 2000. Mussel watch; Marine pollution monitoring of butyltins and organochlorines in coastal waters of Tahailan, Philippines and India. *Ocean and Coastal Mangement* 43, 819-839.

Tindle, R.W & Tindle, L.E. 1978. Studies on the Greater flamingo. *Waterbirds* 23: 114-118.

Tourenq, C., Aulagnier, S., Durieux, L., Lek, S., Mesléard, F., Johnson, A. & Martin, J. 2001. Identifying rice fields at risk from damage by the greater flamingo. *Journal of Applied ecology* 38:170-179.

Tuite, C. H. 1979. Population size, distribution and biomass density of the Lesser Flamingo in the Eastern Rift Valley, 1974-1976. *Journal of Applied Ecology* 16:765-775.

Tuite, C. H. 2000. The distribution and density of Lesser Flamingos in East Africa in relation to food availability and productivity. *Waterbirds* 23:52-63. (Special Publication 1)

United National Environnemental Programme. 2002. Retrieved from the world Wide Web: http://www.unep.org.

USEPA, 2000. Guidance for assessing chemical contaminant, data for use in fish advisories, vol. 1: fish sampling and analysis, third ed. EPA 823-R-95-007. Office of Water, Washington, DC.

Valqui, M., Caziani, S.M., Rocha, O & Rodriguez, E. 2000. Abundance and distribution of the South American altiplano flamingos. *Waterbirds* 23: 110-113. (Special Publication 1)

Vareschi, E. 1978. The ecology of Lake Nakuru (Kenya). Abundance and feeding of the lesser flamingo. *Oecologia* 32:11-35.

Veldsquez, C.R. & Navarro, R.A. 1993. The influence of water depth and sediment type on the foraging behavior of whimbrels. *Journal of Field Ornithology* 64 (2):149-157.

Verhaar, M. A., Hijwegen, T. & Zadoks, J. C. 1996. Glasshouse Experiments on Biocontrol of Cucumber Powdery Mildew (Sphaerotheca fuliginea) by the MycoparasitesVerticillium lecaniiand Sporothrix rugulosa. *Biological Control* 6(3): 353-360.

Vijayan, V.S. 1991. Ecology of Keoladeo National Park, Bharatpur. Final Report. Bombay Natural History Society.

Vijayan, V.S., Prasad, S.N., Vijayan,L., & Muralidharan.L. 2004. *Inland Wetlands of India - Conservation priorities*. Salim Ali Centre for Ornithology and Natural History. Coimbatore. India.

Ward, H.B & Whipple, G.C, 1959. Freshwater Biology, Second *Edition*, John Wiley and sons, Inc. p.1248.

Ward, P., & Zahavi, A.1973. The importance of certain assemblages of birds as 'information-centers' for food finding. *Ibis* 115:517-534.

Weimerskirch, H., Martin, J., Clerquin, Y, Alexandre, P. & Jiraskova, S. 2001.Energy saving in flight formation. *Nature* 421: 697-698.

Weller, M.W.1999. Wetland birds: habitat resources and conservation implication. Cambridge University Press.

Wetzel, R. G. 1983. Limonology, lind. Edition. Ed: Welzel, .R.G., Michigan State.
Wiersma, P. & Piersma, T. 1994. Effects of microhabitat, flocking, climate and migratory goal on energy expenditure in the annual cycle of red knots. *Condor* 96, 257–279.
Woodworth, B.L., Farm, B.P., Mufungo, C., Borner, M & Kuwai, J.O. 1997. A photographic census of flamingos in the Rift Valley lakes of Tanzania. *Afr. J. Ecol.* 35: 326–334.
Yamaguchi N., Gazzard D., Scholey G., Macdonald D.W. 2003. Concentrations and hazard assessment of PCBs, organochlorine pesticides and mercury in fish species from the upper Thames: River pollution and its potential effects on top predators. *Chemosphere* 50: 265-273.
Yu, K.T., Lam, M.H.W., Yen, Y.F. & A.P.K. Laung 2000. Behaviour of trace metals in the sediment pore waters of intertidal mudflats of a tropical wetlands. *Environmental Toxicology and Chemistry* 19 (30), 535-542.
Zhou, H.Y. & Wong, M.H. 2000. Screening of organochlorine in freshwater fish collected from Pearl River Delta, People's Republic of China. *Arch. Environ. Con. Toxicol.* 46: 106-113.
Zhou, J.L., Maskaoui, K., Qui, Y.W, Hong, H.S & Wang, Z.D. 2001. Polychlorinated biphenyls congeners & organochlorinated insecticides in the waters and sediments of Daya Bay, China. *Environ. Pollut.* 113 - 37.
Zingde, M.D. & Govindan, K. 2000. Health status of costal waters of Mumbai and regions around.In environmental problems of coastal areas in India. Ed, Sharma V.K. Bookwell publ. New Delhi India. 119-132.
Zoran, M. & Anderson, E. 2006. The use of mutlitemporal and multispectral satellite data for change detection analysis of the Romanian Black Sea coastal zone. *Journal of Optoelectronics and Advanced Materials*, 8(1): 252-256.
Zwarts, L. & Esselink, P. 1989. Versatility of male curlews *Numenius arquata* preying upon *Nereis diversicolor*: deploying contrasting capture modes dependent on prey availability. *Marine ecology progress series* 56:255-269
Zweers, G., De Hong F., Berkhoudt H., & Berge, J.C.V. 1995. Filter feeding in Flamingos (*Phoenicopterus ruber*). *Condor* 97:297-323.

Appendix I. Checklist of birds recorded from Sewri-Mahul Creek and surrounding environs.

	Ducks
1	Comb Duck *Sarkidiornis melanotos*
2	Lesser Whistling Duck *Dendrocygna javanica*
	Egrets, Herons and Ibis
3	Great Egret *Casmerodius albus*
4	Intermediate Egret *Mesophoyx intermedia*
5	Little Egret *Egretta garzetta*
6	Western Reef Egret *Egretta sacra*
7	Grey Heron *Ardea cinerea*
8	Little Heron *Butorides striatus*
9	Indian Pond Heron *Ardeola grayii*
10	Black-headed Ibis *Threskiornis melanocephalus**
11	Painted Stork *Mycteria leucocephala**
	Bird of Prey
12	Greater Spotted Eagle *Aquila clanga***
13	Pariah (Black) Kite *Milvus migrans*
14	Brahminy Kite *Haliatur Indus*
15	Eurasian Marsh Harrier *Circus aeruginosus*
16	Osprey *Pandion haliaetus*
17	Shikra *Accipiter badius*
18	Barn Owl *Tyto alba* (?)
	Waders
19	Lesser Sand Plover *Charadrius mongolus*
20	Little Ringed Plover *Charadrius dubius*
21	Black-tailed Godwit *Limoas limosa*
22	Eurasian Curlew *Numenius arquata*
23	Whimbrel *Neumenius phaeopus*
24	Common Redshank *Tringa erythropus*
25	Common Greenshank *Tringa nebularia*
26	Grey Plover *Pluvialis squatarola*
27	Ruddy Turnstone *Arenaria interpres*

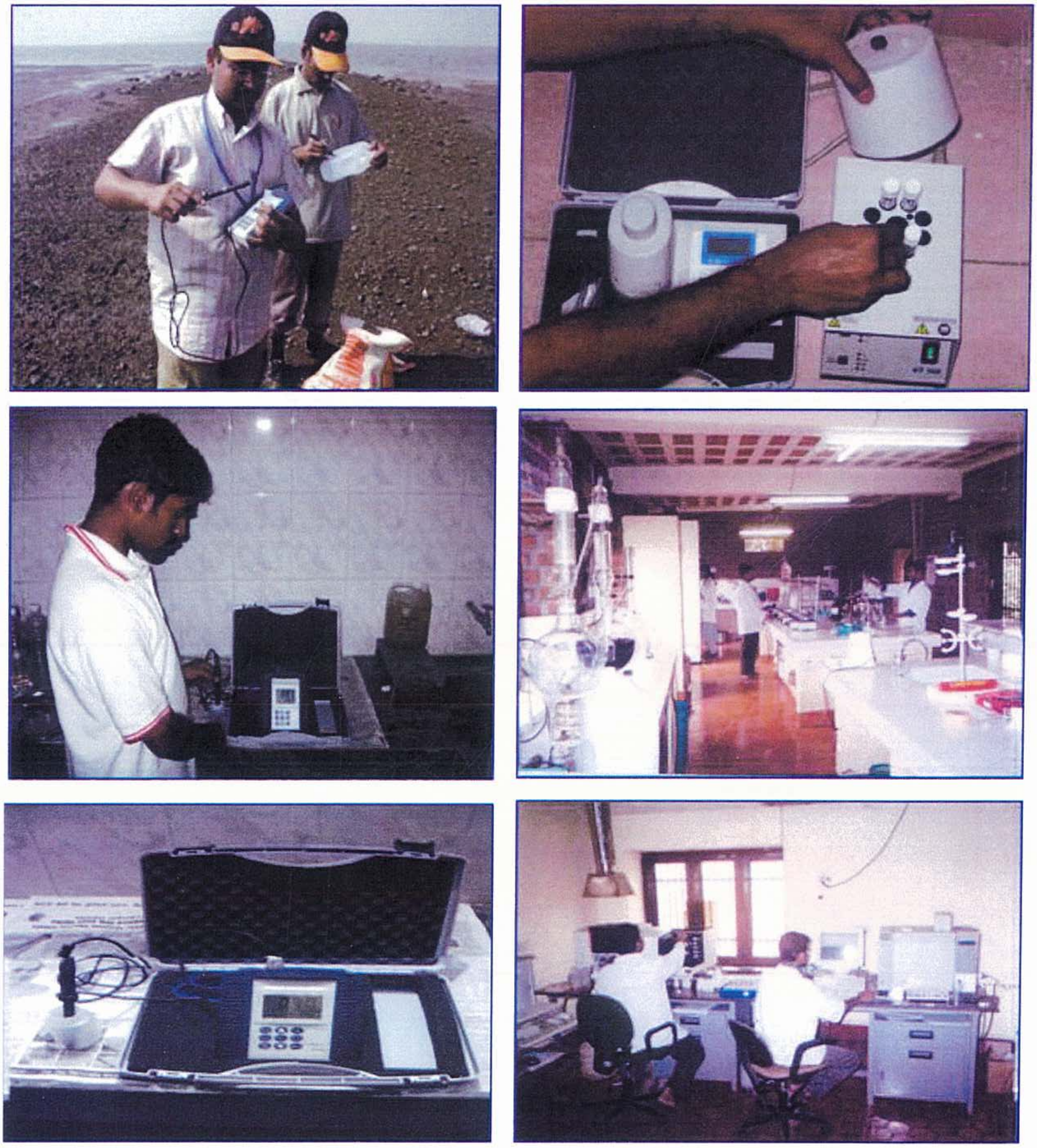
28	Common Sandpiper *Actitis hypoleucos*
29	Terek Sandpiper *Xenus cinereus*
30	Redwattled Lapwing *Vanellus indicus*
31	Curlew Sandpiper *Calidris ferruginea*
32	Little Stint *Calidris minuta*
33	Black-winged Stilt *Himantopus himantopus*
34	Dunlin *Calidris alpina*
35	Pied Avocet *Recurvirostra avosetta*
36	Temminck's Stint *Calidris temminckii*
37	Sandpiper *Tringa stagnatilis*
	Gulls and Terns
38	Brown-headed Gull *Larus brunnicephalus*
39	Black-headed Gull *Larus ridibundus*
40	Gull-billed Tern *Gelochelidon nilotica*
41	Caspian Tern *Sterna caspia*
42	Little Tern *Sterna albifrons*
43	Whiskered Tern *Chlidonias hybridus*
	Flamingos
44	Lesser Flamingo *Phoenicopterus minor**
45	Greater Flamingo *Phoenicopterus rubber*
	Pigeons, Parakeets and Coucal
46	Rock Pigeon *Columba livia*
47	Rose-ringed Parakeet *Psittacula krameri*
48	Greater Coucal *Centropus sinensis*
	Kingfishers
49	White-throated Kingfisher *Halcyon smyrnensis*
50	Common Kingfisher *Alcedo atthis*
51	Black-capped Kingfisher *Halcyon pileata*
	Passerines
52	Asian Pied Starling *Sturnus contra*
53	Asian Koel *Eudynamis scolopacia*
54	House Crow *Corvus splendens*

55	Large-billed (Jungle) Crow *Corvus macrorhynchos*
56	Golden Oriole *Oriolus oriolus*
57	White-throated Fantail *Rhipidura albicollis*
58	Barn swallow *Hirundo rustica*
59	Asian Palm Swift *Cypsiurus balasiensis*
60	Red-vented Bulbul *Pycnonotus cafer*
61	White-eared Bulbul *Pycnonotus leucotis*
62	Ashy Prinia *Prinia socialis*
63	Blyth's Reed Warbler *Acrocephalus dumetorum*
64	Common Tailor Bird *Orthotomus sutorius*
65	Oriental Magpie Robin *Copsychus saularis*
66	Purple-rumped Sunbird *Nectarinia zeylonica*
67	Citrine Wagtail *Motacilla citreola*
68	White Wagtail *Motacilla alba*
69	Yellow Wagtail *Motacilla flava*
70	House Sparrow *Passer domesticus*

Appendix II. Checklist of birds recorded from Shivaji Nagar mudflats(Nhava) and surrounding environs.

	Ducks
1	Spot-billed Duck *Anas poecilorhyncha*
	Egrets, Herons and Ibis
2	Great Egret *Casmerodius albus*
3	Intermediate Egret *Mesophoyx intermedia*
4	Little Egret *Egretta garzetta*
6	Western Reef Egret *Egretta sacra*
7	Little Heron *Butorides striatus*
8	Indian Pond Heron *Ardeola grayii*
9	Black-headed Ibis *Threskiornis melanocephalus**
	Bird of Prey
10	Osprey *Pandion haliaetus*
11	Brahminy Kite *Haliatur Indus*
12	Eurasian Marsh Harrier *Circus aeruginosus*
	Roller
13	Indian Roller *Coracias benghalensis*
	Waders
14	Lesser Sand Plover *Charadrius mongolus*
15	Eurasian Curlew *Numenius arquata*
16	Common Redshank *Tringa erythropus*
17	Common Greenshank *Tringa nebularia*
18	Grey Plover *Pluvialis squatarola*
19	Common Sandpiper *Actitis hypoleucos*
20	Little Stint *Calidris minuta*
	Gulls and Terns
21	Heuglin's Gull *Larus heuglini* (?)
22	Gull-billed Tern *Gelochelidon nilotica*
23	Caspian Tern *Sterna caspia*
	Kingfishers
24	White-throated Kingfisher *Halcyon smyrnensis*
25	Common Kingfisher *Alcedo atthis*
	Passerines
26	House Crow *Corvus splendens*
27	Large-billed (Jungle) Crow *Corvus macrorhynchos*
28	Barn Swallow *Hirundo rustica*
29	Spotted Dove *Streptopelia chinensis*
30	Small Green Bee-eater *Merops orientalis*
31	Rufous tailed Shrike *Lanius isabellinus*
32	White-eared Bulbul *Pycnonotus leucotis*
33	Indian Robin *Saxicoloides fulicata*
34	Clamorous Reed Warbler *Acrocephalus stentoreus*
35	House Sparrow *Passer domesticus*

** Threatened * Near Threatened.



Appendix 3. Collection of samples and analyses for Environmental quality