Introduction
1.1. Background of the work

1.1.1. Estuaries – a productive and precious ecosystem

Estuaries, which include mangroves, mudflats, and the lower reaches and mouths of rivers, have high aquatic biodiversity and play important roles as sheltering, feeding, nursery and spawning grounds of fishes and shellfishes. They are extremely important fishing grounds, with nearly 1000 fishes in South-East Asia as a whole.

Estuarine systems are among the most productive and valuable ecosystems on Earth (Costanza et al., 1997). Throughout the world, estuaries are among the most modified and threatened environments (Blaber et al., 2000). Scientific interest is increasingly focusing on the effects of major natural or human perturbations on estuarine ecosystems. Estuaries, in particular intertidal estuarine water, are generally considered as nursery areas because they provide food and refuge for juvenile marine fishes (Baker and Sheaves, 2005). Estuaries consist of a complex mixture of distinctive habitats and their importance, dynamics, functions and ecological connectivity are still poorly understood (Elliott and Hemingway, 2002). Estuarine fish assemblage changes significantly in relation to habitat characteristics, in particular to the degree of habitat complexity (Heck et al., 1989; Sogard and Able, 1991; Connolly, 1994; West and King, 1996; Jenkins and Wheatley, 1998; Paterson and Whitfield, 2000). Since the biological communities, being sensitive to changes in a wide array of environmental factors can reflect watershed conditions minutely, they have long been used in monitoring the health of estuarine ecosystems. Among them, fish has been used as bio-indicator of water quality by many researchers (Oguzie, 2003) for at least seven reasons (Plafkin et al., 1989): They (i) indicate the cumulative effects of multiple types of anthropogenic disturbances; (ii) integrate the effects of complex and varied stressors on their prey; (iii) provide a relatively long-term record of environmental stress; (iv) integrate broad-scale habitat conditions; (v) are relatively easy to identify to species; (vi) their identification offers considerable additional information about their environments and (vii) they are of great interest to persons.
concerned about losses in biological diversity (Moyle and Leidy, 1992). Therefore, the presence, absence and proportionate abundance of species within fish assemblages indicate the quality of the physical, chemical and biological conditions in which they live.

India has a coastline of over 8000 km long infringed with several rivers draining a total catchment of 3.02x10⁶ km² and their estuaries have a water-spread area of 2.7x10⁴ km². There are 14 major, 44 medium and 162 minor rivers which together discharge 1.56x10¹²m³ runoff every year greatly influencing ecology of their estuaries and coastal areas to which they drain. These estuaries with their wetlands, lagoons, mangroves and sea-grass beds are rich in natural resources including fisheries.

1.1.2. Mangrove ecosystem – a unique wetland

Mangroves are intertidal forested wetlands confined to the tropical and subtropical regions. The total global area of the mangroves is estimated at only 18.1 million ha (Spalding et al., 1997), against over 570 million ha of freshwater wetlands including peat lands globally (but excluding paddy fields; Spiers, 1999). Although mangroves have been exploited for many centuries, our scientific understanding of these wetland forests remained poor until the 1970s (Blasco, 1975; Chapman, 1976). During the past three decades or so, these wetland forests have received increasingly greater attention which is reflected in an exponential increase in the number of publications (Ellison, 2002). Many studies indicate that mangroves are among the most productive tropical habitats and play a vital role in sustaining commercial and artisanal fish stocks around the world (Robertson and Duke, 1990; Robertson and Blaber, 1992) much like their subtropical and temperate counterparts, salt marshes (Thomas and Connolly, 2001; Minello et al., 2003; Salgado et al., 2004). The use by fish of such fringing vegetated areas has been established even in cases of relatively short inundation times (Laffaille et al., 2001; Thomas and Connolly, 2001). Over the years
an increasing number of studies have been conducted on the composition and abundance of fish communities inhabiting mangroves and salt marshes around the world in tropical, sub-tropical and temperate environments (De Troch et al., 1996; Halliday and Young, 1996; Kimani et al., 1996).

More than 41% of the world’s mangroves occur in South and Southeast Asia of in Brazil, Australia and Nigeria (Spalding et al., 1997) (Figure 1.1). While practically all mangroves occur in small patches that develop in deltaic habitats, the mangroves in the Ganga-Brahmaputra-Meghna Delta, shared between India and Bangladesh, are the only contiguous and largest coastal wetland system in the world. Popularly known as Sundarbans, they currently cover about 1 million ha area, greater than the combined area of Wadden Sea wetlands that are shared between Denmark, Germany and the Netherlands.

The distribution of nekton is influenced by the arrangement of structurally complex microhabitats within larger landscapes. Fish and crustaceans are frequently associated with structurally complex habitats that provide a refuge from predators.
Submerged structure serves as a refuge from predators as it impairs predator movement (Bartholomew et al., 2000) and interrupts the predator's visual contact with prey items. Within the intertidal zone of salt marshes, the distribution of nekton has been linked to that of emergent vegetation.

1.1.2.1. Intertidal mudflats of mangrove estuaries

Intertidal areas in mangrove estuaries have a much higher productivity per unit area compared to subtidal areas. In order to exploit these resources, fish are committed to intertidal migrations at high tide. However, the patterns of food resource utilization within tidal flat fish assemblages have rarely been examined to date, although some information does exist. Intertidal mudflats are ecologically important but poorly studied coastal habitats. Mudflats are a dominant habitat in many estuaries, often covering a considerable part of the total estuarine area (Morrison et al., 2002). This particular type of habitat has been recognized to be of key importance for the estuarine food web due to its high productivity when compared to subtidal areas (Elliott and Dewailly, 1995). Mudflats are structurally less complex compared to mangroves, but they contain great abundance and diversity of invertebrates and are periodically immersed and emerged in each tidal cycle and are therefore only available to nekton during tidal inundation, which implies tidal migrations to use this habitat (Nagelkerken and van der Velde, 2002; Pihl and Wennhage, 2002; Weerts and Cyrus, 2002; Mumby et al., 2004; Kanou et al., 2005; Vinagre et al., 2006).

However, unlike estuarine salt marshes, which have long been considered highly productive habitats and thoroughly studied (Cattrijse et al., 1997; Halpin, 2000; Hampel et al., 2003), mudflats have only recently become an object of study (Melville and Connolly, 2005; Dolbeth et al., 2007; Nip and Wong, 2010). A review of fish habitats in European estuaries revealed that intertidal soft substratum accounted for almost 30% of the total surface of the estuarine systems in the Boreal/Atlantic region (Pihl et al., 2002). Intertidal areas are highly productive compartments in the estuarine environment. They contain a high density and large biomass of
macrobenthos, which provides abundant food for estuarine fish and macro-
crustaceans when the flats are covered by the tide (Lee, 2000). At low tide, they may
be important for waders and waterfowl (McLusky and Elliott, 2004). Intertidal
shallow waters may also act as nurseries for juvenile fishes: there where favourable
temperatures optimize growth and where they find a refuge against predators
(Gibson et al., 2002; Able et al., 2005). Therefore, tidal mudflats occupy a significant
component of the total estuarine habitat available to fishes and play important roles
as nursery and foraging grounds (Edgar and Shaw, 1995; Yamahira et al., 1996;
Horinouchi and Sano, 2000). Water depth, generally uneven over the surface of the
flooded intertidal zone, also shapes the distribution of nekton in a variety of habitats
(Blaber and Blaber, 1980). This effect is commonly exhibited in the intertidal zone as
a segregation of nekton by body size along the water depth gradient (Kneib, 1987;
Sogard et al., 1989), which may reduce predator-prey encounter rates (Gibson et al.,
1998; Linehan et al., 2001). Water depth has been identified by some as an important
determinant of the distribution of nekton within the mangrove intertidal zone
(Vance et al., 1996) while others have reported a lack of such an influence (Sheridan,
1992; Meager et al., 2003).

The flooded intertidal zone of coastal habitats is used extensively by nektonic
fauna (Thayer et al., 1987; Irlandi and Crawford, 1997; Layman, 2000; Clynick and
Chapman, 2002; Hindell and Jenkins, 2004). Although the drainage of the intertidal
zone can displace nektonic organisms by great distances into the subtidal zone
(Sweeney et al., 1998), they commonly return to the intertidal zone during
subsequent high tides (Gibson, 2003). Attempts to explain the association between
nekton and the intertidal zone include suggestions that intertidal areas contain
abundant resources and possess characteristics that could reduce threats from
predators (Sheridan and Hays, 2003). The intertidal distribution of nekton is seldom
spatially or temporally homogenous (Vance et al., 2002) suggesting that opportunities
for feeding and sheltering from predators are themselves unevenly distributed even within the intertidal zone (Brown and Quinn, 1988; Miltner et al., 1995).

1.1.2.2. Mangrove forest in India

India is fortunate to be gifted with a bounty of natural habitats; among them mangroves, being one of the most productive features of coastal ecosystems, are fertile enough for foraging, breeding, and sheltering of various kinds of animal such as fish, crustaceans, birds, reptiles, and mammals (Alongi, 2002). According to a status report of the Government of India publication, the total area of the mangroves in India was reckoned at about 6,740 km². This covered about 7% of the world mangroves (Krishnamurthy, 1987) and 8% of the Indian coastline (Untawale, 1987) (Figure 1.2). But a recent Indian remote sensing data (Nayak, 1993) showed that the total area of the mangroves decreased to 4,474 km² (Table 1.1). The values shown by satellite data shows a decrease in the mangrove area, which may be due to several reasons such as grazing by domestic cattle and exploitation of mangrove woods for fuel and timber the neo-tectonic movement of river courses abatement of upstream freshwater discharges due to construction of dams and reservoirs rapid trend of reclamation of mangrove forests for habitations pollutant discharges from cities and industries etc.
However, throughout the world, mangrove forests that once were abundant, particularly in tropical countries, are currently one of the world’s most threatened estuarine ecosystems (Barbier and Cox, 2002) due to drastic intrusion of human activities and global climatic changes, and mangrove in Sundarbans region is not an exception to that. However, no such extensive study has still been carried out to analyze the effect of environmental variation upon fish community structure in this region.

1.1.3. The Sundarbans

The Sundarbans (21°30' to 22°40' N, 88°05' to 89°55' E) comprises essentially of numerous islands formed by the sediments deposited by three major rivers, the Ganga, Brahmaputra and the Meghna, and a dense network of smaller rivers, channels and creeks. The maximum elevation within the Sundarbans is only 10 m above the mean sea level. The western and eastern limits of the Sundarbans are defined by the course of the river Hooghly (a distributary of river Ganga) and river

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Baleshwar respectively. The river Harinbhanga (known as Ichamati or Raimongal in Bangladesh) demarcates the border between India and Bangladesh. About 60% of the mangrove forests lie in the Khulna District of Bangladesh and the rest in the 24-parganas district of West Bengal (India). The estimates of the total area of Sundarbans in the two countries often differ considerably. According to recent estimates, the area of the Sundarbans in Bangladesh is 599,330 ha (1978 Landsat data; Rahman et al., 1979) and in India it is 426,300 ha (Sanyal, 1983).

Most rivers (distributaries) other than the Hooghly, that contributed to the formation of the Ganga delta (from west to east: Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Bidya), have lost their original connections with the Ganga because of siltation, and their estuarine character is now maintained by the monsoonal runoff alone (Cole and Vaidyaraman, 1966). Thus the delta-building process has nearly ceased in the west, but has accelerated in the eastern part. Species composition and community structure vary east to west, and along the hydrological and salinity gradients. Large areas of the Sundarbans mangroves have been converted into paddy fields over the past two centuries, and more recently into shrimp farms. The Sundarbans has been extensively exploited for timber, fish, prawns and fodder. The regulation of river flows by a series of dams, barrages and embankments for diverting water upstream for various human needs and for flood control has caused large reduction in freshwater inflow and

Figure 1.3: The Sundarban Biosphere Reserves.
seriously affected the biodiversity because of an increase in salinity and changes in sedimentation. During the past three decades, large parts of the remaining Sundarbans have been protected for wildlife, particularly tiger, through the creation of several sanctuaries and a biosphere reserve. Parts of the Sundarbans in both India and Bangladesh have been declared World Heritage Sites (Figure 1.3). However, its biodiversity continues to be threatened by a growing human population that not only places pressure on its biological resources, but also impacts on the freshwater inflows from upstream areas. Oil exploration in coastal areas is also emerging as a new threat. Further threats arise from global climate change, especially sea level rise. The future of the Sundarbans will depend upon the management of freshwater resources as much as on the conservation of its biological resources.

1.1.3.1. Intertidal mudflats of Sundarbans

The Sundarbans mudflats (Banerjee, 1998; Bose, 2004) are found at the estuary and on the deltaic islands where low velocity of river and tidal current occurs. The flats are exposed in low tides and submerged in high tides (Figure 1.4), thus being changed morphologically even in one tidal cycle. The interior parts of the mudflats are magnificent home of luxuriant mangroves. The morphology of the swamps is characterized by the occurrence of saltponds, ditches and banks with a thick mud substratum of decomposed organic matters (Naskar and Guha Bakshi, 1987). The Sundarbans mudflats control the food chain in the estuarine ecosystem. The estuarine system of Sundarbans – part of the world’s largest active delta have a network of tidal

![Figure 1.4: Schematic diagram of intertidal mudflats.](image-url)
rivers, channels, creeks, islands, mudflats, coastal dunes. But no systematic approach towards studying the ichthyofaunal diversities of different habitats of Indian Sundarbans for conservation purpose has been attempted so far (Alongi, 2002).

The dominance of a few species is a general feature in fish communities of salt marshes, mudflats and their creeks (Kneib, 1997; Jin et al., 2007). Fishes that occupy the intertidal and the upper subtidal zones of estuaries have proven to be difficult to classify in terms of their habitat use. Some species spend most of their life therein, others descend to deeper waters as they grow larger, and still others enter this zone only during high tide periods. Seasonal utilizations of these habitats by fishes are commonly observed patterns (Rountree and Able, 1992; Cattrijsse et al., 1994). Tidal shifts in fish assemblages have also been reported by several authors (Sogard et al., 1989; Rountree and Able, 1993; Gray et al., 1998; Griffiths, 2001; Methven et al., 2001).

1.1.4. Fish assemblages

Besides the differences in fish assemblages associated with the various habitat types, ichthyofaunal compositions and structure can also undergo consistent cyclical and temporal changes within habitats. Seasonal shifts in fish communities are common, as a result of sequential immigration and emigration of certain fish species. Several environmental factors, in addition to habitat availability may contribute to fish assemblage structure in different spatial and temporal scales.

1.1.4.1. Tidal migration of fishes

Many fish species undertake short movements synchronously with the tide to take advantage of the intertidal zone. These tidally-synchronised migrations have been attributed to increased feeding potential (Wirjoatmodjo and Pitcher, 1984) and predator avoidance (Ellis and Bell, 2004; Franco et al., 2006). Predation pressure and feeding may be spatially and temporally unevenly distributed in the intertidal zone. This translates in both seasonal and depth-related differences in the distribution of
fishes in the intertidal zone (Hernández et al., 2002; Griffiths, 2003). Where the primary function of upshore movements is feeding, zonation has been linked to the behaviour of both predator and prey, the avoidance of competition and a heterogeneous distribution of prey species. Furthermore, physical factors like temperature often vary with water depth and may influence fish's intertidal distribution as growth which is mainly regulated by ambient temperature.

1.1.4.2. Factors affecting fish assemblages

The impact of seasonal and temporal variation on the movements, abundance, size composition, diversity and structuring the fish community has been well studied. Riverine fish communities show seasonal changes in the composition and relative abundance of species, which may be influenced by constant fluctuations in environmental factors.

Tropical coastal ecosystems differ in several respects from those of higher latitudes; in particular they have been noted for minor seasonal changes or seasonality and more uniform temperatures (McClanahan, 1988). This is particularly true for many mangroves which are influenced by the annual rainy seasons causing fluctuations in salinity as river discharge reaches the coast. This may have an effect on the composition of juvenile fish found in the estuarine mangroves. Another factor potentially affecting fish assemblages is the history of disturbance of the studied habitats.

1.1.5. Feeding ecology of fish - resource partitioning and feeding guilds

Food is one of the most important factors to determine habitat quality and as such has an effect on fish recruitment and survival. The diet of most species largely reflects the seasonal composition of the prey community in the brackish part of the estuary. Competition for food may be an important factor in structuring fish communities and is usually demonstrated by measuring the dietary overlap within and between species (Elliott et al., 2002; Vinagre et al., 2005). Studies of resource requirements by various
species have been used in attempts to understand factors controlling the distribution and abundance of organisms. In addition, studies on food habits of organisms utilizing each habitat help to illustrate the role of the latter in the ecology of several organisms. Many studies on feeding ecology having been conducted for different fish communities (Pausey et al., 1995; Piet et al., 1999; Garrison and Link, 2000), although most have been made in temperate regions (Horinouchi et al., 1996). Food habits and feeding ecology research are a fundamental tool to understand fish roles within their ecosystems since they indicate relationships based on feeding resources and indirectly indicate community energy flux (Hajisamaea et al., 2003), which allows inferring competition and predation effects on community structure. The term generalist, specialist and opportunist are used to describe food habits. Generalists eat a broad spectrum of foods in terms of prey species or microhabitats in which the prey live. Specialist implies a diet restricted to a relatively small number of species. Specialists are more clearly delineated when the food base is abundant, and generalists when food is scarce. One fish species may switch from specialist to generalist during a period when food abundance declines abruptly. More recently, studies have concentrated on a functional analysis of community structure in which the species present are assigned to groupings or guilds, each of which denotes certain attributes. Root (1967) defined a guild as a group of species that exploit the same class of environmental resources in a similar way. Ross (1986) identified that in aquatic environments food is the main factor and that its partition defines functional groups within the community, which get together in guilds according to trophic similarity. These trophic guilds seem to be a consequence of such resource partitioning, which could explain how several species can coexist in the same space by differing in use of several resource dimensions.

1.1.6. Digestive adaptability of fishes

Most vertebrates, including fishes, possess digestive enzymes that allow them to digest the food that they consume, but variation exists among species in the activity
of individual enzymes (Chakraborty et al., 1995; Kuźmina, 1996; Alarcón et al., 1998). Documented information on the digestive enzymes of fishes with different feeding habits is relatively rare although several workers have reviewed the physiology of digestion of fishes (Barrington, 1957). By understanding the digestion and assimilation of specific dietary components, the type of prey that the animals prefer and those that they are best equipped to digest could be identified (Hobson and Chess, 1986; Laprise and Blaber, 1992; Sackley and Kaufman, 1996; Silvano, 2001).

Although the array of digestive enzymes in bony fishes is the same as that in other vertebrates (Stevens and Hume, 1995; Hidalgo et al., 1999), fish digestive enzymes are less well-studied. The prevailing paradigm is that digestive enzyme activities in fishes are indicative of feeding ecology, correlating well with diet (Fernández et al., 2001). Animals are thought to be plastic in their digestive enzyme production in response to diet, because the metabolic expense of producing large amounts of digestive enzymes would be wasted by animals ingesting low levels of the substrates for those enzymes (Caviedes-Vidal et al., 2000). Digestive enzyme activities in fishes, however, vary among species and can be influenced by age as well as by the quantity and composition of diet (Péres et al., 1998).

The influence of age and diet on digestive enzyme activities can best be compared in species that undergo ontogenetic shifts in diet, thus eliminating interspecific differences in digestive enzyme activities as a confounding variable. The question remains, however, whether fishes are genetically programmed to undergo ontogenetic shifts in digestive enzyme activities, or whether these activities are modulated in response to ingested items. Would the enzyme activities change if a fish were raised on a diet different from that consumed in nature? Previous investigators of digestive enzyme activities in cultured fishes grown on a formulated diet did not compare the data from these fishes with those from members of the same species on their natural diet (Kawai and Ikeda, 1972; Reimer, 1982; Lindner et al., 1995; García-Carreño et al., 2002). Also lacking are comparative studies that analyze digestive
enzyme activities of more than two related fish species in a phylogenetic context.

The biodiversity associated with a diverse and dynamic environment makes the study of fish assemblages and feeding habits of fishes from the mudflats of Sundarbans unique, since the environmental changes require continuous adjustments at all levels of the biological organization (Val and Almeida-Val, 1995; López-Vásquez et al., 2009). These adjustments undoubtedly affect how fishes acquire their food as well as how they metabolize them. Conservation of different guilds and conservation of meta-ecosystem is important leading to stabilization and subsequent conservation of the whole community.
1.2. Review of Literature

The fish communities inhabiting estuaries have been studied worldwide and many studies have recently described and interpreted the community structure and function of fishes inhabiting those estuaries and other transitional waters. Fish assemblages have been recognized as reliable indicators in reflecting aquatic ecosystem health (Ibarra et al., 2003; Rashleigh, 2004).

Therefore, the literatures have been surveyed in this section emphasizing the following points: (1) fish assemblages, (2) Factors affecting fish assemblage pattern, (3) fish assemblages in mangrove and salt marshes, (4) fish assemblages in intertidal mudflats, (5) fish assemblages in Sundarbans, intertidal and diel movement of estuarine fishes, (6) feeding ecology of fish, (7) trophic niche, niche breadth and niche overlap, (8) trophic guilds in fish communities, (9) digestive enzymes of fish, (10) proteolytic enzyme activity in fish and (11) carbohydrases activity in fish.

1.2.1 Fish assemblages

Fish assemblages are recognized as sensitive indicators of habitat degradation, environmental contamination, and overall ecosystem productivity. Sale (1980) worked on whether the assemblages of fish on patch reefs were predictable or not. Grossman (1982) studied the dynamics and organization of a rocky intertidal fish assemblage and observed the persistence and resilience of taxocene structure. The seasonal occurrence and food resource use of an assemblage of near shore fish species in the Bothnian Sea, Sweden were observed by Thorman and Wiederholm (1983). The species composition and dietary relationships in a brackish shallow water fish assemblage were also studied by them (Thorman and Wiederholm, 1984). Young et al. (1986) studied the seasonal and spatial distribution of fish larvae in waters over the northwest continental shelf of Western Australia. Claridge et al. (1986) reported the seasonal changes in movements, abundance, size composition and diversity of the fish fauna of the Severn estuary. Seasonal occurrence of larval fishes was also studied by
Walker et al. (1987) in the nearshore southern California. Drake and Arias (1991) investigated dial and tidal variations in fish fauna in a shallow coastal inlet in southwest Spain and studied the factors contributing to colonization and retention. The structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River in Taiwan were studied by Tzeng and Wang (1992). Doyle et al. (1993) compared the larval fish assemblages in the temperate zone of the northeast Pacific and northwest Atlantic Oceans. Moser and Smith (1993) studied the larval fish assemblages and oceanic boundaries. They also worked (1993) on the hydrography and distribution dynamics of larval and juvenile fishes in the coastal waters of the Tanshui River estuary, Taiwan, with reference to estuarine larval transport. Elliott and Dewailly (1995) studied the structure and components of European estuarine fish assemblages. Utilization of the intertidal zone by epibenthic fishes during high tide has been found in a wide variety of littoral habitats, including sandy beaches and salt marshes, and is usually related to feeding on intertidal organism available at high tide (Gibson et al., 1996; Kneib, 1997). Jenkins et al. (1997) evaluated the fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Philip Bay and Corner Inlet, Victoria, Australia. The seasonal, annual and regional variations in ichthyofaunal composition in the inner Severn Estuary and inner Bristol Channel were studied by Potter et al. (1997). Whitfield (1999) observed the ichthyofaunal assemblages in estuaries of South Africa. The seasonal and diel changes in a subtropical mangrove fish assemblage were studied by Lin and Shao (1999). Mathieson et al. (2000) observed the fish assemblages of European tidal marshes and performed a comparison based on species, families and functional guilds. Kneib (2000) noticed the salt marsh ecoscapes and production transfers by estuarine nekton in the southeastern United States. The distribution and abundance patterns of flatfishes in the Sado estuary were reported by Cabral (2000). Costa et al. (2002) carried out a comparative analysis of a temperate (Mira estuary, Portugal) and tropical seagrass bed (Mussulo lagoon Angola) fish assemblages in two estuarine systems. The spatial and temporal variations of the estuarine larval fish
community on the west coast of Taiwan were also studied by Tzeng et al. (2002). Pombo and Rebelo (2002) worked on the spatial and temporal organization of a coastal lagoon fish community of Ria de Aveiro, Portugal. Seasonal patterns in fish and epibenthic crustaceans community of an intertidal zone with particular reference to the population dynamics of plaice and brown shrimp was studied by Amara and Paul (2003). Lobry et al. (2003) had compared the structure of the Gironde estuarine fish assemblages with the European estuaries. The composition and community structure of the ichthyofauna of the upper Scheldt estuary were studied by Maes et al. (2005). Miller and Skilleter (2006) observed the temporal variation in habitat use by nekton in a subtropical estuarine system. The fish assemblage of the Mondego estuary and reported the composition, structure and trends over the past two decades were studied by Leitão et al. (2007). Martinho et al. (2007) stated the use of nursery areas by juvenile fish in a temperate estuary, Portugal. The structure, diversity and somatic production of the fish community in the same estuarine coastal lagoon were performed by Pombo et al. (2007). Selleslagh et al. (2009) observed the fish composition and assemblage structure in three Eastern English channel macrotidal estuaries and compared it with other French estuaries. The nursery use patterns of commercially important marine fish species in estuarine systems along the Portuguese coast were reported by Vasconcelos et al. (2010). Hsieh et al. (2011) studied the monsoon driven succession of larval fish assemblage in the East China Sea shelf waters off northern Taiwan. Similar work was also performed by Lo et al. (2010). Distribution patterns of larval fish assemblages in the Taiwan Strait between the Northeasterly and Southwesterly Monsoons was compared by Hung-Yen et al. (2011). Cardoso et al. (2011) worked on a functional approach of fish assemblages of small estuaries of the Portuguese coast.

1.2.1.1. Factors affecting fish assemblage pattern

It has been found that the structure of fish assemblages depends on many abiotic factors (Barbour and Brown, 1974; Amarasinghe and Welcomme, 2002; Zhao et al.,
Introduction

2006), physico-chemical parameters (Petry et al., 2003; Mello et al., 2009), and biotic factors (Crowder and Cooper, 1982; Savino and Stein, 1982). Loneragan and Potter (1990) analysed the factors influencing community structure and distribution of different life-cycle categories of fishes in shallow waters of a large Australian estuary. The environmental factors as forces structuring the fish community were stated by Thiel et al. (1995). Bell et al. (1997) worked on the characterization of physical environmental factors on an intertidal sandflat of Manukau Harbour, New Zealand. The fish assemblage structure of a hydrologically altered coastal lagoon of Portugal was studied by Gordo and Cabral (2001). Cabral et al. (2001) also investigated whether the Tagus estuary fish community reflected environmental changes or not. The factors influencing fish and macrocrustacean communities in the surf zone of sandy beaches in Belgium were analyzed by Beyst et al. (2001). Maes et al. (2004) constructed a statistical modeling of seasonal and environmental influences on the population dynamics of an estuarine fish community. The spatial and temporal distribution patterns of fish assemblage in relation to environmental variation of Koycegiz Lagoon-estuary in Turkey were observed by Akin et al. (2005). Harrison and Whitfield (2006) worked on the estuarine typology and the structuring of fish communities in South Africa. The environmental factors structuring fish composition and assemblages in a small macrotidal estuary of eastern English Channel were reported by Selleslagh and Amara (2008). Hsieh et al. (2010) observed the influence of hydrographic features on larval fish distribution during the south-westerly monsoon in the waters of Taiwan, western North Pacific Ocean.

1.2.1.2. Fish assemblages in intertidal mangroves and salt marshes

Over the years an increasing number of studies have been conducted on the composition and abundance of fish communities inhabiting mangroves and salt marshes around the world in tropical, sub-tropical and temperate environments. Weinstein and Heck (1979) described the composition, structure and community ecology of ichthyofauna of seagrass meadows along the Caribbean coast of Panama.
and in the Gulf of Mexico. Comparative ecology of nekton residing in a tidal creek and adjacent seagrass meadow along with the community composition and structure was described by Weinstein and Brooks (1983). The spatial and temporal patterns in densities, biomass and community structure of mangrove fish-communities was performed by Robertson and Duke (1990) in tropical Queensland, Australia. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods was performed by Sogard and Able (1991). Sheridan (1992) studied the habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, Florida. The consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay was observed by McNeill et al. (1992).

The nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence was reported by Rozas and Reed (1993). Kneib and Wagner (1994) studied the nekton use of vegetated marsh habitats at different stages of tidal inundation. The fish assemblages from seagrass and unvegetated areas of a southern Australian estuary were compared by Connolly (1994). Costa et al. (1994) investigated if the eel grass beds and salt marsh borders act as preferential nurseries and spawning grounds for fish or not. Laegdsgaard and Johnson (1995) stated the mangrove habitats as nurseries and described the unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. The patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary were explained by Szedlmayer and Able (1996). Gray et al. (1996) monitored the intra and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. The diel changes in assemblages of fishes associated with shallow seagrass and bare sand was also observed by Gray et al. (1998). Jenkins and Wheatley (1998) worked on the influence of habitat structure on nearshore fish assemblages in a southern Australian embayment and made a comparison of shallow seagrass, reef-algal and unvegetated sand habitats. Nekton use of salt marsh, seagrass, and non-vegetated habitats in a south Texas (USA) estuary was observed by Rozas and Minello (1998). Few studies have looked at the juvenile stages and, due to
logistical difficulties associated with sampling among dense root structures; even fewer have tried to quantify juvenile densities inside intertidal mangrove microhabitats (Rönnbäck et al., 1999). Rönnbäck et al. (1999) found that structural complexity within the mangrove intertidal zone influenced the distribution of shrimp and fish. Others have not found this relationship in mangroves (Sheridan, 1992; Mullin, 1995; Meager et al., 2003) despite evidence that mangrove structures offer increased survivorship in the presence of predators (Acosta and Butler, 1997; Primavera, 1997). Nagelkerken et al. (2000) stated the importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes with the patterns in biotope association, community structure and spatial distribution. The habitat use by an intertidal salt-marsh fish and trade-offs between predation and growth was studied by Halpin (2000). Paterson and Whitfield (2000) investigated that whether the shallow-water habitats function as refugia for juvenile fishes or not. The nursery function of the intertidal areas in the western Wadden Sea for 0-group sole Solea solea (L.) was studied by van der Veer et al. (2001). Fish use of subtropical salt marshes in Queensland, Australia and its relationships with vegetation, water depth and distance onto the marsh was explained by Thomas and Connolly (2001). Jackson et al. (2001) stated the importance of seagrass beds as habitat for fishery species. The habitat use by fishes in estuaries and other brackish areas was observed by Pihl et al. (2002). Lazzari et al. (2003) reported the nursery use of shallow habitats by epibenthic fishes in Maine nearshore waters. The salt marshes as nurseries for nekton with the testing hypotheses on density, growth and survival through meta-analysis were stated by Minello et al. (2003). Nagelkerken and van der Velde (2004) compared the fish communities of subtidal seagrass beds and sandy seabeds in 13 marine embayments of a Caribbean island, based on species, families, size distribution and functional groups. The comparison the fish assemblages in tidal salt marsh creeks and in adjoining mudflat areas in the Tejo estuary (Portugal) was performed by Salgado et al. (2004). Bloomfield and Gillanders (2005) observed the fish and invertebrate assemblages in seagrass, mangrove, salt marsh and non-vegetated habitats. The
community structure of Corals and reef fishes at multiple scales was studied by Connolly et al. (2005). Polte and Asmus (2005) observed the influence of seagrass beds (Zostera noltii) on the species composition of juvenile fishes temporarily visiting the intertidal zone of the Wadden Sea. The structure and temporal variations of fish assemblages of the Castro Marim salt marsh, southern Portugal was observed by Veiga et al. (2006). Connolly and Hindell (2006) reviewed the nekton patterns and ecological processes in seagrass landscapes. The habitat specific fish assemblages in estuaries along the Portuguese coast were assessed by França et al. (2009).

1.2.1.3. Fish assemblages in intertidal mudflats

Unvegetated tidal flats in temperate estuaries and inlets support large numbers of fishes and provide nurseries for a number of species (van der Veer, 1986). Clayton (1986) reviewed and identified a number of intertidal macrofaunal communities and their zonation patterns based on non-quantitative sampling. Although seasonal and spatial changes in fish fauna on tidal mudflats have been reported by many authors and numerous studies have been devoted to the ecology (Tytler and Vaughan, 1983; Collins et al., 1984; Clayton, 1986; Snowden and Clayton, 1995; Kanou et al., 2000), population biology (Clayton and Vaughan, 1988; Snowden et al., 1991), and systematic (Jones and Clayton, 1983; Al-Khayat and Jones, 1996) of macrofauna on intertidal mudflats of Sulaibikhat Bay, there have been only a few studies that have investigated the abundance and sizes of fishes moving onto intertidal mudflats with rising tide (Morrison et al., 2002). Kanou et al. (2000) studied the diversity of the ichthyofauna of tidelands in the inner Tokyo Bay. Morrison et al. (2002) noticed the diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. De Boer and Prins (2002) studied the community structure of a tropical intertidal mudflat under human exploitation. Kanou et al. (2005) also worked on the occurrence of larval and juvenile fishes with flood tide on an intertidal mudflat in Tama river estuary of central Japan.
1.2.1.4. Fish assemblages in Sundarbans estuary

Sundarbans – part of the world’s largest active delta have a network of tidal rivers, channels, creeks, islands, mudflats, coastal dunes. The Sundarbans mangrove ecosystem supports a large group of fish, shrimps (Basu and Pakrasi, 1979), and crabs. Sunderbans mudflats control the food chain in the estuarine ecosystem. Mahmood (1995) studied the significance of the mangroves on fishery. Rainboth (1990) worked on the fish communities and fisheries of the Sundarbans, with a framework for future studies. Chantarasri (1994) studied the integrated resource development and fisheries resources management of Sundarbans. Hoq and Islam (2007) observed the composition and seasonal dynamics of post larval and juvenile fishes in the Sundarbans Mangrove waters, Bangladesh.

1.2.1.5. Intertidal and diel movement of estuarine fishes

In addition to supporting their own resident fish community, estuaries are nursery grounds, migration routes and refuge areas for a variety of fish species (Whitfield, 1990, 1998; Potter and Hyndes, 1999; McLusky and Elliott, 2004). Movements, foraging groups, and diurnal migrations of the striped parrotfish *Scarus croisensis* Bloch (Scaridae) was studied by Ogden and Buckman (1973). Seasonal shifts in fish communities are common, as a result of sequential immigration and emigration of certain fish species (Hyndes *et al.*, 1999). Gibson (1973) studied the intertidal movements and distribution of young fish on a sandy beach with special reference to the plaice (*Pleuronectes platessa* L.). Wolff *et al.* (1981) stated this tidal migration of plaice and flounders as a feeding strategy. Quinn and Kojis (1981) revealed the lack of changes in nocturnal estuarine fish assemblages between new and full moon phases in Serpentine Creek, Queensland. Tidal shifts in fish assemblages have also been reported by several authors. Raffaelli *et al.* (1990) studied the tidal migrations in the flounder (*Platichthys flesus*). Rooker and Dennis (1991) observed the diel, lunar and seasonal changes in a mangrove fish assemblage off southwestern Puerto Rico. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats was
reported by Rountree and Able (1997). The movement and homing of juvenile plaice \textit{(Pleuronectes platessa)} in relation to predators, competitors, food availability and abiotic factors was studied by Gibson \textit{et al.} (1998) on a microtidal nursery ground. He also worked (Gibson, 1999) on the movement and homing in intertidal fishes and on the tidal migration in marine animals. The majority of the studies on mangrove fishes have sampled and described habitat preferences of adult or sub-adult life stages of estuarine fish while some have focused on migratory patterns between reefs and adjacent seagrass beds and mangroves, primarily through visual census techniques (Cocheret de La Morinie’re \textit{et al.}, 2002; Nagelkerken and van der Velde, 2002). Hampel \textit{et al.} (2003) observed the tidal, diel and semi-lunar changes in the faunal assemblage of an intertidal salt marsh creek. Tidal and diel changes in the structure of a nekton assemblage in small intertidal mangrove creeks in Northern Brazil were stated by Krumme \textit{et al.} (2004). Hindell and Jenkins (2004) studied the spatial and temporal variability in the assemblage structure of fishes associated with mangroves \textit{(Avicennia marina)} and intertidal mudflats in temperate Australian embayment.

1.2.2. Feeding ecology of fish

Patterns of resource utilization are a fundamental property of ecological systems (Winemiller and Pianka, 1990), aiming to assess the role of interspecific competition on the coexistence of a great number of species (Schoener, 1974). Mitchell (1953) analyzed the stomach contents of California tide pool fishes. Optimal foraging and prey selection by the bluegill sunfish \textit{(Lepomis macrochirus)} was studied by Werner and Hall (1974). Apparent size determinacy of prey selection by bluegill sunfish was studied by O’Brien \textit{et al.} (1976). Chesson (1978) proposed the theory of measuring preference in selective predation. Horn \textit{et al.} (1982) observed the dietary selectivity in the field and food preferences in the laboratory for two herbivorous fishes \textit{(Cebidichthys violaceus} and \textit{Xiphister mucosus)} in a temperate intertidal zone. Schmitt and Coyer (1982) worked on the foraging ecology of sympatric marine fish in the genus \textit{Embiotoca} (Embiotocidae) and illustrated the importance of foraging

1.2.2.1. Trophic niche, niche breadth and niche overlap

Mechanisms of species coexistence and interactions remain a main topic in assemblage ecology, and niche differences among species have been evoked as fundamental for the maintenance of biodiversity in different scales (Leibold and McPeek, 2006). Several studies carried out in aquatic systems have demonstrated that the same food resource can be shared by several species, and that each species might explore many different resources. The niche exploitation pattern of the blue-gray gnatcatcher was observed by Root (1967). Colwell and Futuyma (1971) worked on the measurement of niche breadth and overlap. Niche breadth as a function of social dominance was reported by Morse (1974). Keast (1977) explained the mechanisms expanding niche width and minimizing intraspecific competition in two centrarchid
fishes. The estimation and analysis of preference and its relationship to foraging models was depicted by Chesson (1983). Horn et al. (1982) studied the dietary selectivity in the field and food preferences in the laboratory for two herbivorous fishes (Cebidichthys violaceus and Xiphister mucosus) from a temperate intertidal zone. The intertidal vertical distribution and diets of five species of central California stichaeoid fishes were monitored by Barton (1982). Gladfelter and Johnson (1983) observed feeding niche separation in a guild of tropical reef fish. The constancy of niche width of a species with length and size of food during growth and development, for maximizing energy intake was suggested by Pearre (1986). Thorman and Wiederholm (1986) studied the food, habitat and time niches in a coastal fish species assemblage in a brackish water bay in the Bothnian Sea, Sweden. The optimal foraging and habitat shift in perch (Perca fluviatilis) in a resource gradient was estimated by Persson and Greenberg (1990). Cardona (1991) measured trophic niche breadth using occurrence frequencies. Trophic polymorphism and plasticity in vertebrates was studied by Wimberger (1994). The feeding ecology of freshwater fishes in two rivers of the Australian wet tropics was elucidated by Pausey et al. (1995). Edgar and Shaw (1995) worked on the production and trophic ecology and shallow-water fish assemblages in southern Australia. The use of shallow water habitats by fish assemblages in a Mediterranean coastal lagoon was stated by Franco et al. (2006). The distribution and feeding patterns of the mudflat nekton assemblages in the Tagus estuary (Portugal) were observed by França et al. (2008).

Food and space has been recognized as the major resource axes for niche partitioning in vertebrates (Schoener, 1974), and in aquatic systems food is recognized as the main axis (Ross, 1986). Kohn (1959) and Pianka (1973) had pointed out that coexistence among closely related or ecologically similar species is permitted by niche separation or the partitioning of resource along one or more axes. Predatory behaviour of some shore fishes was studied by Hobson (1965). More recently MacArthur (1972) and Roughgarden (1974) had tried to place such evidence of niche

1.2.2.2. Trophic guilds in fish communities

The concept of guilds was first developed for fishes inhabiting estuaries in the early classical works by McHugh (1967), Wallace and Vander Elst (1975) and Haedrich
(1983), which separated the components of the estuarine nekton into ecological groupings. The guild concept could also be used to identify species that are likely to be involved in competitive interactions. Sale (1975) studied the patterns of use of space in a guild of territorial reef fishes. Simberloff and Dayan (1991) also worked on the guild concept and the structure of communities. A number of more recent studies have focused on dietary guild structure of fishes in coastal waters (Muñoz and Ojeda, 1997). Ontogenic niche shifts have been shown to be important for the guild structure in coastal fish assemblages (Muñoz and Ojeda, 1998). The demography of the fish population is also important, since there are numerous reports of shifts in the diet with ontogeny (Platell and Potter, 1999). Garrison and Link (2000) highlighted the dietary guild structure of the fish community in the Northeast United States continental shelf ecosystem. Study of fish assemblages of European tidal marshes and a comparison based on species, families and functional guilds had been performed by Mathieson et al. (2000). Nagelkerken et al. (2001) worked on the feeding guild of fishes along a gradient of bay biotopes and coral reef depth. The composition, temporal changes and ecological guild classification of the ichthyofauna of large European estuaries such as the Tagus (Portugal) and the Elbe (Germany) were studied by Thiel et al. (2003). Young (2004) worked on the asymmetric competition, habitat selection, and niche overlap in juvenile salmonids. Elliott et al. (2007) had done a global review on the guild approach to categorizing estuarine fish assemblages.

1.2.3. Digestive enzymes of fish

The prevailing paradigm is that digestive enzyme activities in fishes are indicative of feeding ecology, correlating well with diet. The study of digestive enzymes in fish has a wide range of potential interest and is used as an effective tool for identifying particular components of an animal's diet. Kawai and Ikeda (1972) observed the effect of dietary change on the activities of digestive enzymes in carp intestine. Hsu and Wu (1979) established the relationship between feeding habits and digestive proteases of some freshwater fishes. Reimer (1982) studied the influence of diet on
digestive enzymes of Amazon fish Matrincha. Lee et al. (1984) analyzed the digestive proteases of *Penaeus vannamei* Boone and established the relationship between enzyme activity, size, and diet. Uys and Hecht (1987) also observed the change in digestive enzyme activities of *Clarias gariepinus* after feeding. Utilization of dietary protein by the eel and trout were studied by De la Higuera et al. (1989) and García-Gallego et al. (1995) respectively. Brèthes et al. (1994) reported that enzymatic activity as an index of trophic resource utilization by the snow crab *Chionoecetes opilio*. Zhu and Zhang (1993) worked on feeding habits and histological structure of digestive tract of the mudskipper, *Boleophthalmus pectinirostris*, in intertidal zone of Jiulong River Estuary. Chakraborty et al. (1995) studied the digestive enzymes in 11 teleost fish species in relation to food habit and niche segregation. Kuźmina (1996) ascertained digestive enzymes as an indicator of feeding ecology of wild fish. Moyano et al. (1996) characterized the digestive enzyme activity during larval development of gilthead seabream (*Sparus aurata*). Johnston and Yellowlees (1998) established the relationship between dietary preferences and digestive enzyme complement of the slipper lobster *Thenus orientalis*. Feng et al. (1999) studied the digestive enzymes in alimentary tract of southern sheatfish larvae. Hidalgo et al. (1999) compared the digestive enzymes in fish with different nutritional habits. Comparison of the Proteolytic and amylase activities in fish with different nutritional habits was also performed by Hidalgo et al. (1999). Cara et al. (2003) assessed the digestive enzyme activities during larval development of white bream. Drewe et al. (2004) observed the ontogenic changes in gut morphology and digestive enzyme activity in characid fish *Brycon guatemalensis* from Costa Rican rain forest streams. Comparisons of digestive enzyme activities in carnivores and herbivores from a California rocky intertidal habitat were performed by Chan et al. (2004).

Many studies have been conducted to assess the development of the important digestive enzymes in different species of fishes. The concentration of proteases, amylase and lipase in certain marine fishes were estimated by Chesley (1934). Ishida
(1936) studied the distribution of the digestive enzymes in the digestive system of stomachless fishes. The comparative activity of some digestive enzymes in the alimentary canal of tilapia and perch were studied by Fish (1960). Amylase, lipase and proteolytic enzyme activities were studied by Stroganov and Buzinova (1969) in grass carp. Cockson and Bourne (1972) worked on the enzymes in the digestive tract of two species of euryhaline fish. The digestive enzymes of the stomachless bonefish *Carassius auratus gibelio* and three tropical catfish were studied by Jany (1976) and Olatunde and Ogunbiyi (1977) respectively. Kuzmina (1978) worked on the adaptations of digestive system to the diet of fish from the various ecological groups. Differences in digestive enzymes between cyprinid and noncyprinid fish were also determined by Hofer et al. (1982a). Bitterlich (1985) also studied the digestive enzyme pattern of two other stomachless filter feeders, silver carp, *Hypophthalmichthys molitrix* and bighead carp, *Aristichthys nobilis*. The assays on the digestive enzymes of sharptooth catfish, *Clarias gariepinus* was carried out by Uys and Hecht (1987). Das and Tripathi (1991) studied the digestive enzymes of grass carp. Some digestive tract enzymes in the sterlet, *Ascipenser ruthenus* were characterised by Kuzmina and Kuzmina (1991). Kohla et al. (1992) studied the growth, digestion enzyme activities and hepatic glycogen levels in juvenile *Colossoma macropomum* from South America during feeding, starvation and refeeding. A quantitative study of some digestive enzymes in the rabbit fish, *Siganus canaliculatus*, and the sea bass, *Lates calcarifer* were performed by Sabapathy and Teo (1993). Divakaran et al. (1999) studied the digestive enzymes present in Pacific threadfin *Polydactylus sexfilis* and bluefin trevally *Caranx melampygus*. The digestive enzyme activities in the alimentary tract of redclaw crayfish, *Cherax quadricarinatus* was estimated by Figueiredo et al. (2001). The development of the important digestive enzymes in different species were assessed by many workers, such as European sea bass (*Dicentrarchus labrax*), Japanese eel (*Anguilla japonica*), Senegalese sole (*Solea senegalensis*), California halibut (*Paralichthys californicus*), Atlantic cod (*Gadu morhua*), and red porgy (*Pagru pagrus*) (Gawlicka et al., 2000;
Zambonino-Infante and Cahu, 2001; Pedersen et al., 2003; Alvarez-González et al., 2006; Kvále et al., 2007; Suzer et al., 2007). Digestive enzyme activities in mudskipper Boleophthalmus pectinirostris and Chinese black sleeper Bostrichthys sinensis was studied by Renxie et al. (2010).

1.2.3.1. Proxelytic enzyme activity in fish

In fishes, protein is digested initially in the stomach by pepsin and acid, and then further degraded into smaller peptides and free amino acids in the intestine by the combined actions of various alkaline proteases (Hirji and Courtney, 1982). Trofimova (1973) worked on the dynamics of total proteolytic activity along the digestive tract in carp in relation to incubation temperature. Preliminary investigations on the proteolytic digestive enzymes in carp fry was carried out by Ragyanszky (1980). Hofer and Schiemer (1981) worked on the proteolytic activity in the digestive tract of several species of fish with different feeding habits. Proteolytic digestive enzymes of carnivorous, herbivorous, and omnivorous fishes were studied by Jónás et al. (1983). The level of total proteolytic activity in some species of fish from the Volga basin was assayed by Kuźmina and Kuźmina (1991). García-Carreño (1992) elaborated the protease inhibition in theory and practice. The influence of diet on pepsin and some pancreatic enzymes in sea bass (Dicentrarchus labrax) larvae were observed by Zambonino-Infante and Cahu (1994). Einarsson et al. (1997) observed the seasonal variation in trypsin activity in juvenile Atlantic salmon upper and lower modal groups. The exogenous protease derived from zooplankton in the intestine of the Japanese sardine (Sardinops melanoticus) larvae was quantified by Kurokawa et al. (1998). The functional properties of digestive proteases in two sparids; gilthead seabream (Sparus aurata) and common dentex (Dentex dentex) were characterized and studied by Alarcón et al. (1998). Similar work was performed in developing discus Symphysodon aequifasciatus larva by Chong et al. (2002). Rathore et al. (2005) worked on the digestive enzyme profile and evaluation of protease classes in Catla catla and Cyprinus carpio during ontogenic development. The digestive enzyme

### 1.2.3.2. Carbohydrases activity in fish

Fish in general utilize dietary carbohydrate poorly. Dietary fiber generally refers to all indigestible plant matter, mainly cellulose and other complex polysaccharides, abundant in many freshwater environments and cellulose, being the main structural material of plants, is the most abundant carbohydrate in nature. Crosby and Reid (1971) found out the relationship between foods, phylogeny and cellulase digestion in the bivalves. Wojtowicz and Brockerhoff (1972) worked on isolation and some properties of the digestive amylase of the American lobster (*Homarus americanus*). Stickney and Shumway (1974) established the occurrence of cellulase activity in the stomachs of fishes. Stickney (1975) also quantified cellulase activity in the stomachs of freshwater fishes from Texas. Niche separation by cellulase activity in freshwater gastropods was studied by Calow and Calow (1975). Relationships between food and cellulase activity in freshwater fish was also been studied by Prejs and Blaszczyk (1977). Denison and Koehn (1977) studied the cellulase activity of *Poronia oedipus.* Hofer (1979) depicted the adaptation of amylase to temperature and season in roach, *Rutilus rutilus* and rudd *Scardinius erythrophthalmus.* Lindsay and Harris (1980) studied carboxymethyl-cellulase activity in the digestive tracts of fish. Kesler (1983) observed that cellulase activity varies among *Physa heterostropha* and other species of gastropods. Cellulase activity in natural and temperature acclimated populations of *Fundulus heteroclitus* was demonstrated by Moerland (1985). Lesel *et al.* (1986)
1.3. Gaps to be satisfied

The description and classification of biological communities usually uses one or more of three sets of attributes: first, and most commonly, are taxonomic-based entities, as summarized by traditional species/site/abundance matrices; secondly, on the size and biomass spectra of the individuals present and thirdly, on the functional attributes of the recorded organisms (Nagelkerken and van der Velde, 2004; Akin et al., 2005). When used in combination, these attributes give a large amount of information about the structure and functioning of communities. More recently, studies have concentrated on a functional analysis of community structure in which the species present are assigned to groupings or guilds, each of which denotes certain attributes.

The maintenance of mudflats is important in preventing coastal erosion. However, mudflats worldwide are under threat from predicted sea level rises, land claims for development, dredging due to shipping purposes, and chemical pollution. These give rise to unresolved gap areas such as: no systematic approach towards studying the ichthyofaunal diversities of different habitats of Indian Sundarbans for conservation purpose has been attempted so far. The study of feeding habits of fishes from the mudflats of Sundarbans is unique, since the environmental changes require continuous adjustments at all levels of the biological organization (Val and Almeida-Val, 1995; López-Vásquez et al., 2009). Although, no studies on the feeding habits of fishes within such assemblages in Sundarbans mudflats have been conducted, few have been made in temperate regions only (Edgar and Shaw, 1995; Horinouchi and Sano, 2000). Digestive enzymes however, may be a complementary tool useful for determining which dietary components are most effectively metabolized (Bréthes et al., 1994). Documented information on the digestive enzymes of fishes with different feeding habits is relatively rare although several workers have reviewed the physiology of digestion of fishes (Barrington, 1957; Kuźmina and Kuźmina, 1991).

This type of information on estuarine fish community structure and functioning is important for an understanding of the biological features of estuaries,
but it is becoming increasingly important to classify and categorize those estuarine faunae as an aid to the understanding and management of the effects of human activities in estuaries (Whitfield and Elliott, 2002; McLusky and Elliott, 2004).

1.4. Objectives of the study

In attempting to partially fulfill the above void areas we need to examine the organism and its environment as well as their physiological adaptations in more detail, and to place these in the context of modern evolutionary theory.

Therefore, this study aims to -

1. Characterize the nekton assemblage of a mudflat area of the Indian Sundarbans and to assess its structure and seasonal distribution patterns in its high tidal and low tidal conditions in terms of taxonomic composition, species richness, fish diversity, fish density and standing stock. This will enable to understand habitat quality and its effect on fish recruitment and survival.

2. Determine dietary preferences for each of the fish species so as to understand the survival strategies of fish with regard to resource partitioning and nutritional profiling correlated with availability of food in unique mudflat habitat in estuarine system.

3. Quantify the activities of a range of digestive enzymes in each fish species to determine the utilization of various food sources available to the fishes. This study will determine the degree of dietary overlap among species and composition of dietary guild based on niche differentiation between different fishes.
1.5. Work plan

**Objective 1**

Landscape attributes

**Mudflat habitats of Indian Sunderbans**

- Hydrology
- Edaphic
- Diversity & assemblage pattern
- Species richness

**Objective 2**

Resource partitioning of mudflat fishes

Stomach content

Feeding guild

- Stochastic (random, no explanation)
- Deterministic

Feeding

Breeding (not considered in present study)

- Density & standing stock
- Ecological guild
- Niche breadth
- Niche overlap
- Prey selectivity

Digestibility of available food

?-?

Phylogeny (OR) Adaptability

**Objective 3**

Digestive enzyme analysis

- Alpha amylase
- Invertase
- Cellulase
- Pepsin
- Alkaline protease