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1. ESTUARINE ECOSYSTEM: HABITAT STRUCTURE AND FUNCTION

1.1 Estuarine Habitat Characteristics

Estuaries are the intermittent ecosystems between riverine and marine systems. The most widely accepted definition of an estuary which was given by Pritchards (1967) states that "*estuaries are a semi-enclosed coastal body of water, which has a free connection with the open sea, and within which sea water is measurably diluted with freshwater derived from land drainage*." Wolanski (2007) coined a more thorough definition of estuary relevant to its processes and hydrolology stating estuaries as "*a semi-enclosed body of water connected to the sea as far as the tidal limit or the salt intrusion limit and receiving freshwater runoff; however the freshwater inflow may not be perennial, the connection to the sea may be closed for part of the year and tidal influence may be negligible."* Estuaries form a transition zone between river and ocean environments and are subject to both marine influences, such as wave action, tidal and current movements and the influx of saline water; and riverine influences, such as flows of fresh water and sediments (Figure 1). The hydrodynamics of an estuary, manipulated by freshwater inflows and tidal variations, design the geomorphology of the coast. Thus, hydrodynamics play pivotal role in determining the complexity of the system and the sediment characteristics. These are probable causes of broad scale community pattern variation spatially and temporally. The sediment deposition, grain composition and variations on a diurnal, seasonal and annual basis define the micro habitat conditions (Johannesson et al. 2000).

1.2 Estuarine Hydrodynamics

Estuaries have different habitat types: (1) soft bottom substratum containing mud or fine to relatively coarse-grained hard-packed sand, (2) sand flats described as "fine sand" containing some silts and clays and harbour rich communities of both deposit and suspension feeding invertebrates and (3) mudflats. Fine-grained sediments (i.e., clay) and organic detritus accumulate on mudflats. Despite the many different habitat types, relatively large and unpredictable variations in salinity (physiological stress) and water movement or turbidity (physical stress) tend to limit the number of animal and plant species capable of adapting to these rigorous conditions (Day et al., 1989). As a result, an estuary generally harbours less species than either the freshwater river above the tidal limit or the truly marine habitat outside the estuary. Although, estuaries generally contain relatively few species; the abundance and biomass of organisms is usually very high (Miere et al., 2005). The type of estuarine ecosystem in a specific area is primarily controlled by the physical environment; i.e., geomorphology, climate, salinity, and the availability of fresh water. The absolute values of the abiotic factors are not as important as the degree of fluctuation of factors such as the microclimate, water movement, chemical cycling, and physical structure (Day et al. 1989). In addition, the residence time of water in an estuary can influence overall water column pollutant concentrations.

The abiotic features thought to be important in determining the specific nature of estuaries as proposed by Day et al. (1989) are:

- The degree of protection and buffering from direct oceanic forces;
- The quantity of freshwater input and associated dissolved and suspended materials;
- The water circulation patterns that are determined by riverine and tidal currents, geomorphology and wind. Tides play a critical role in influencing circulation, and biochemical and biological processes.
- Depth—stronger interactions between the water column and the bottom occur in shallow estuaries, thereby expediting the release of sediment nutrients for use by the phytoplankton;
- Variability of salinity and the sharpness and pattern of the salinity gradient from the mouth to the headwaters. Water circulation influences the salinity gradient and the distribution of biological assemblages;
- The rate of geomorphological change generated by various physical forces that control sediment transport.

Habitat Types

Use of a single habitat to characterize biological assemblage condition would minimize the requirements for expenditure of time and resources but estuaries and coastal marine waters are inherently heterogeneous systems. This may be due to the unpredictable nature with which the brackish water zone varies along the length of the estuary; driven by the strength and intervals of freshwater inflow. In addition to a salinity gradient, estuarine habitats vary in bottom substrates, and in the predominance of erosional versus depositional environments. The variations in these characteristics will lead to differences in the way pollutants and other stressors will affect the biota. Habitats in estuaries and coastal marine waters can be classified into nine major categories.

(1) Open water (2) Soft bottom substrate (3) Hard bottom substrate
(4) Aquatic macrophytes (5) Beaches (6) Sandflats (7) Mudflats
(8) Emergent marshes and (9) Mangroves.

1.3 Salinity Gradient

Different definitions of estuaries have emphasized that estuarine systems contain ‘‘sea water measurably diluted by freshwater derived from land drainage’’. Estuarine system can be classified geographically with two types: (1) classical northern hemisphere macrotidal estuary (Figure 2a), (2) south-western Australian estuaries, which typically comprise a short and narrow entrance channel, wide central basin and the lower reaches of their tributary river (Figure 2b and 2c). Estuarine system also classified according to direction of salinity gradient by two types: (1) The salinity gradient is unidirectional and represents a gradual progression from freshwater to seawater (Figure 2a, 2b), e. g. most Indian Estuaries, (2) The waters in estuaries that become hypersaline change from being fresh to hypersaline and then to full-strength natural seawater (Figure 2c). The connectivity between the catchment and the sea via a river provides estuaries with one of their most important and unique characteristics. The presence of a river is essential for providing a route through which catadromous fish species, such as certain salmonids and lampreys, can migrate from their main feeding areas in the sea to their spawning areas in freshwater in the rivers and by which catadromous species, such as certain anguilids, can migrate from their feeding areas in rivers to their spawning grounds in oceanic waters (Elliott et al., 2007).

2. Gulf of Khambhat

India owes three gulfs on its coastal line viz. Gulf of Kachchh, Gulf of Khambhat and Gulf of Mannar; in which Gulf of Kutch and Khambhat are on the western end of the country and Gulf of Mannar on the southern end of the country. Amongst these, Gulf of Khambhat owes its own peculiarity in terms of its geomorphology and hydrodynamics. Gulf, being funnel shaped with wide mouth and narrow head (width 200 km at mouth of Gulf terminating to 6 km at the extreme end of Gulf i.e. mouth of Mahi estuary, (Figure 4) provides geo assistance to tidal amplitude and turbulence. The Tapi, Narmada, Mahi, Sabarmati, Shetrunji and several other rivers have deposited large volumes of alluvium which together with the marine recession have resulted in Saurashtra being joined to the mainland of Gujarat. Large quantities of silt are still being deposited and there are extensive areas of intertidal mud and sand flats, coastal salt marshes and degraded mangroves especially in the deltas of the Mahi and Sabarmati (Scott, 1989). A general tidal actions prevailing according to the moon days can be summarized in Figure 3 wherein highest high water occurs at Full moon day and No moon day respectively. Since the lowest low tide is seen during no moon day these are the best days for intertidal study and were preferred in the present study also. The Gulf receives the full force of monsoon waves so that there is little shelter for marine life, unlike the Gulf of Kutch. Its shape and orientation in relation to the southwest monsoon winds account for its high tidal range (40 feet = 12 m) and the high velocity of the entering tides. Thus Gulf of Khambhat shows high tidal amplitude, extreme water current and churning of bed material.

Moreover, sediment input and drainage from major rivers like Narmada, Tapi and Mahi contribute to high turbidity. Owning to these peculiarities, the geomorphology and hydrodynamic of the Gulf of Khambhat makes the estuary very specific in terms of sedimentology as well as water quality. These features of gulf amplify the harshness of the estuary and challenge the life of the benthic animals within.

3. BENTHIC FAUNA

Benthic fauna are those organisms that live on or inside the deposit at the bottom of a water body (Barnes and Hughes, 1988; Idowu and Ugwumba, 2005). In the brackish water ecosystem, they include several species of organisms, which come across different phyla including annelids, coelenterates, molluscs, arthropods and chordates. The benthic fauna have been categorized based on the habitat utilization, their size, and feeding specifications as follows:

- Habitat wise classification: Epibenthic, semi-infauna, infauna, interstitial.
- Size wise classification: Macro benthos, meiobenthos, micro benthos.
- Feeding wise classification: Suspension feeders (active and/or passive), Deposit feeder, Herbivorous, Micro-algal grazers, Carnivores, Scavengers.

Benthic organisms play a vital role in the circulation and recirculation of nutrients in aquatic ecosystems. They constitute the link between the unavailable nutrients in detritus and useful protein materials in fish and shellfish. Most benthic organisms feed on debris that settle on the bottom of the water and in turn serve as food for a wide range of fishes (Adebisi, 1989; Ajao and Fagade 1990; Idowu and Ugwumba, 2005). They also accelerate the breakdown of decaying organic matter into simpler inorganic forms such as phosphates and nitrates (Gallep et al., 1978). All forms of aquatic plants, which are the first link of several food chains existing in aquatic environment, can utilize as a nutrients by benthic organisms. Benthic organisms therefore form a major link in the food chain as most estuarine and marine fishes, birds and mammals depend directly or indirectly on the benthos for their food supply (Barnes and Hughes, 1988).

3.1 Population Ecology, Microhabitat variation and Community Interaction Patterns

The geometry and the resultant hydrodynamics of the gulf cause high churningof water during the tidal cycles and resultant upwelling of loose bed material. Also the deposition of fluvial and marine sediments, especially at the estuarine mouth, forms variable habitat depending on the hydrodynamic forces. These mosaics ofhabitat with different sedimentology thus are ideal habitat for varied benthic animalsand each supports its unique diversity. The Mahi River channel is filled with depositsranging from non marine (fluvial), through estuarine (tidal) to open marine makingthe sediment composition quite complex. Moreover, there is an established correlationbetween physical property of habitat and macro benthos distribution (Bolam, 2003). Small-scale textural properties of the sediment grain may affect stabilityof sediment patches and hence the spatial patchiness of the benthos (Peter et al., 2001). Hydrodynamic regime and physico–chemical factors play pivotal role in determining the complexity and dynamics of the system, and in determining the sediment characteristics. These cause gradients on one hand andpatchy structure on the other (Attrill and Rundle, 2002) and can be considered as theultimate cause of broad scale community pattern spatially and temporally. Benthicforms depend on the sediments and use them as a tool in various ways to over comethe ecological stress. Sediment type and strata formation are some of the importantfeatures of habitat selection by different animals (Snelgrove and Butman, 1994). Studies suggest habitat specific distribution/occupancy by different crab species along theintertidal area (Chakrabarti et al., 2006, Vachhrajaniand Pandya, 2011).

Zonation patterns in intertidal habitats are imposed by physicaland/or biological factors. The upper limit is mainly defined by factors such as salinity, temperature, oxygen availability and humidity which cause dissecation or respiration problems (Newell 1979, Halperin et al., 2000) which define the upper limit of species distributions (Newell 1979, Bertness and Leonard, 1997). The lower distribution limits, instead, are most likely established by biological factors like food abundance, prey avoidance or competition (Bertness and Leonard, 1999).Thesefactors control distribution limits at species levels, especially with sessileorganisms. Mobile species, instead, can deal with these physical or biological forces leading in some species to spatial segregation by sex and size in different zones (Giménez 2004, Casariego et al., 2011). Ontogenetic changes in osmorregulatory ability (Charmantier et al., 2002), air exposure resistance, diet choices, predator avoidance (Hunt &Scheibling 1997) and reproductive behaviour (Carr et al., 2004) may cause variations in habitat use during life cycle of organisms (Lipcius et al., 2005). In addition, structured habitats may affect these habitat choices influencing possible interactions with other species or ages (Hines et al., 1987).

Among crabs, ontogenetic shifts in habitat use are often the result of changes in predator–prey interactions. Typically, as they become larger, vulnerability to predators decreases (Hunt and Scheibling 1997), so emigration from safer places during juvenile stages became a strategy to mitigate crowding effects and reduce density-dependent negative processes (Almeida et al., 2008). A common process in crabs is intraspecific aggression and cannibalism (Moksnes, 2004). Cannibalism occurs mainly between cohorts rather than crabs of similar size (Moksnes 2004) leading to spatial (Pardo et al., 2007) or temporal (Almeida et al., 2008) segregation among adults and juveniles.

3.2 Animal – Sediment Relationship and Burrowing activity

Animal-sediment relationship is the study of interaction between the organisms and sediments, where the organisms alter the particular sediment in which they live to fulfil their essential requirements of their life, like respiration, feeding, reproduction and protection (Bromley 1996). These sediment-processing activities of animals in turn form bioturbation structures (tracks, trails, burrows and borings), in which animals may spend the entire or partof their life. These structures have wide ecological implications in their micro habitat that helpin understanding the behavioural and ecological pattern of endemic animals. Benthic animals select specific substrata for their settlement thus establishing a strong correlationship between sediment type and distributionof animals (Bolam, 2005). Benthic animals are, therefore, directly associated with the substratum and hence, animal–sediment relationship has become an inevitable aspect in the benthic faunal studies.For example, in marine and intertidal systems, meiofaunal organisms secrete mucus while feeding (Klause, 1986), and other organisms produce organic coating in the walls of burrows which enhance sediment cohesion (Watling, 1991). These biostabilization processes largely influence intertidal sediment strength by increasing cohesion mainly through secretion of polymers (Paterson, 1997). However, destabilization of cohesive sediments may be promoted by Macrofaunal bioturbation, which directly affects sediment porosity and permeability (Widdows et al., 1998). In addition, invertebrates may consume microphytobenthic organisms thus indirectly promoting sediment destabilization (Daborn et al., 1993). Thus, different biological activities can stabilize or destabilize intertidal sediments significantly affecting sediment transport (Wood and Widdows, 2002) and geomorphology (Murray et al., 2002).

Within biological processes, burrowing activity can affect sediment erosion, transport, and sedimentation patterns (e.g., Cadee, 2001). A burrow can be a temporary excavation made by an organism while it slides through sediment or while it settling from the water column (e.g., Jones and Jago, 1993). Active burrowing species can increase the rates of erosion and the mobility of the sediment, particularly when occurring at high densities (Talley et al., 2001; Perillo et al., 2005). While constructing burrows, these organisms bring sediments to the surface where it will be available for transport by currents (Murray et al., 2002) and waves. However, intertidal decapods often construct open burrows with funnel-shaped entrances that facilitate trapping of organic matter and sediment (Botto et al., 2006). Ocypodid crabs inhabit sandy or muddy estuaries and dig burrows in tidal flats, to hide from predators and as a refuge at high tide. The burrows are also used as breeding sites, for underground mating, and for incubation (Murai et al. 1987).

3.3 Behaviour

3.3.1 Waving Display

The waving display is a characteristic behaviour of ocypodid crabs in which the body moves rhythmically while the chelipeds are raised and lowered. The claw-waving display occurs in the majority of the 97 *Uca*species around the world (Rosenberg 2001).The function of this display has been suggested from observation of its behavioral context. Waving of male fiddler crabs (genus *Uca*) is known to increase either females approach (Asprey 1971, Backwell et al. 1998, Reading and Backwell, 2007) or when other larger male approach (Salmon 1987, Jaroensutasinee and Tantichodok 2002) or for both (How et al. 2007Milner et al. 2010). In other ocypodid species *Ilyoplax pusilla* (Wada 1981), *Macrophthalmus japonicus* (Wada 1984), *M. setosus* (Zucker 1988) and tropical *Ilyoplax* species (Kosuge et al. 1994), Male wave when female approach, while in *Scopimera inflata* (Fielder 1970) and *I. pusilla* (Wada 1993), Male also wave to repel other crabs.

3.3.2 Burrow defence

The burrows are indispensable for their life, and struggles for the burrows are frequently observed. Burrow defense and fighting behavior have been studied in several ocypodid species such as *Uca pugilator*, *U. pugnax* (Hyatt and Salmon 1978),*U.annulipes*(Jennions and Backwell 1996, Yamaguchi and Tabata, 2004), *U. paradussmieri* (Koga et al. 1999), *Ilyoplax pusilla* (Okuda 1992), *Ocypode ceratophthalmus* (Brooke 1981), and *Scopimera globosa* (Wada 1981). In these ocypodid species, it has been found that the outcome of struggles for the burrows is influenced by residency in *U. pugilator*, *U. pugnax*, and *U.dussmieri*, residency and body size in *U. annulipes* and distance from a burrow In *I. pusilla*.

3.3.3 Mating behaviour

Mating behaviour of the family Ocypodidae has been studied mainly in the fiddler crabs (genus *Uca*) e.g., *Uca pugilator* (Christy, 1987; Christy and Salmon, 1984), *Uca mjoebergi* (Reading and Backwell, 2007; Reany and Backwell, 2007), *Uca crenulata* (deRivera 2005), *Uca annulipes* (Backwell and Passmore 1996). Fiddler crabs (genus *Uca*) are a classic example of a group in which males compete for access to mates and females are often highly selective in their choice of males (Backwelland Passmore 1996; Backwell et al. 1998; Backwell and Jennions 2004; deRivera 2005).In most American species with broad fronts (i.e., with wide spaces between their eyestalks), males court wandering females from their burrows, using complex visual and acoustic signals. Receptive females select a mate by entering his burrow and permitting a copulation, which occurs underground. Complex courtship display and female choice based on resource (burrow) characterize mating system of American species (Christy and Salmon, 1984). On the other hand, in Indo-Pacific species with narrow fronts (i.e., with narrow spaces between their eyestalks), e.g., *Uca arcuata* (Murai, 1992), males encounter females by wandering. They approach and capture resident females and copulation occurs on the surface near female burrows and Males have a relatively simple waving display which may not be used in courtship. In these species, females do not choose a mate based on resource and the mating system involves somewhat forceful components.

Some fiddler crabs adopt both mating tactics (surface and underground copulations), e.g., *U. vocans* (Nakasone et al., 1983), *U. beebei* (Christy, 1987), and *U. lactea* (Murai et al., 1987). Goshima and Murai (1988) described the mating behavior of *U. lactea* as follows. In surface copulations, resident males court nearby resident females and copulate beside burrows of females for several minutes. About 30% of these females spawn in their own burrows, but the remainder continues surface activities (Murai et al., 1987). In underground copulations, resident males attract wandering females into their burrows by lateral claw waving. Courting males enter their burrows first and females may or may not follow. If they follow, males plug their burrows from within. Pairs stay together for a few days, during which time they may copulate and spawning occurs. Males then abandon their burrows, while females close the burrows and remain in them until hatching. Resident males use both mating tactics, but about 75% of copulations occur on the surface (Murai et al., 1987).

3.3.4 Chimney Building Activity

Many species of ocypodid crabs build mud structures at their burrow entrances. These structures include hoods (Zucker, 1981; Clayton, 1988), shelters (Yamaguchi, 1971; Zucker, 1974), pillars (Christy, 1988a, b), pyramids, and mounds (Wada et al., 1994).There have been two explanations offered for the construction of these structures. In some cases, the structures appear to function to reduce aggression between neighbouring males (Zucker, 1974, 1981) and to assist in the maintenance of territories (Wada et al., 1994). In other cases, the structures may be sexual signals that function to attract females to a male's burrow (Christy, 1988b). Crane (1975) described another doughnut shaped mud structure, termed a chimney that some fiddler crabs (genus *Uca*) build around their burrow openings. Chimney is different from other structures in that the wall completely surrounds the mouth of the burrow.

Chimneys are circular walls of mud that surround the entrance to a crab's burrow (Crane 1975; Thurman 1984). At least 11 fiddler crab species build chimneys but the proposed functions vary greatly among species (Wada and Murata 2000; Shih et al. 2005). In *Uca arcuata*, juveniles and adults of both sexes build chimneys (Wada and Murata 2000). In other fiddler crabspecies, chimneys tend to be built by a specific size class or sex. In *Uca formosensis*, chimneys are built only by males that have recently attracted a female into their burrow to mate. They are assumed to hide the malefrom rivals while he expands his burrow for the female (Shih et al. 2005). By contrast, only large reproductive females build chimneys in *Uca thayeri*, *Uca urvillei*, *Uca coarctate* and *Uca forcipata* (Crane 1975; Salmon 1987). The adaptive value of chimneys is unknown for all butone species: in *U. arcuata* and *U. capricornis* the chimney decreases the likelihood of burrow intrusion by wandering crabs (Wada & Murata 2000; Slatyer et al. 2014).

3.3.5 Behavioral Responses to Lunar Tide Cycle

Tidal variations influence the life cycle of animals inhabiting the coastal zones, acting directly on the general pattern of activities. The tides are significant abiotic factors determining the pattern of distribution of benthic organisms in estuarine areas. They act on animals' behaviour and also provide decisive roles in fishing strategies adopted by the dependent human populations (Cordell, 1978). All estuarine and coastal zones are influenced by the tide cycles. The tides are part of the existence of people who live close to the sea, emphasizing that human populations use their practical wisdom for predicting events related to fishing and navigation. Some fishermen, as pointed out by Ruddle (1994), produce calendars and mental maps that enable them to localize fishes according to the phases of the moon. The lunar cycle provides a strong and predictable set ofenvironmental cues for marine species. Environmental cycles liketidal water movement affect endogenous reproductive cycles, synchronizing gameterelease within a population and ensuring that movement, feeding and reproduction occur under favorableconditions (Taylor 1984, Omori 1995).Reef fishes often gather on a specificlunar and seasonal cycle for spawning aggregations (Robertson et al. 1990). Lunar cycles have also beendetected in spawning and settlement of intertidal and pelagic-spawning fish and invertebrates(Taylor 1984, Crabtree 1995, Robertson et al. 1999).Lunarcycles in fish behaviour have long been recognized and exploited by artisanal and commercial fisheries (Parrish 1999).

Perkins (1974) and Thurman (1997) state that when the sun, the moon, and the earth are aligned (conjunction oropposition), the gravitational attraction forces are magnified, a situation is called springtide, during which the highest amplitudes between highand low tides occur. For an approximate period of sevendays the sun and the moon pull at right angles to theearth, causing a situation that is called neap tide, During neap tides, thesmallest difference between high and low tides occursbecause the gravitational pull is slight. For a few days nearthe neap tide, a minimum variation occurs between highand low tides, a situation called 'dead tide'; and at the end, when themoon starts changing to another phase called 'head of dead water'. Knowledge of phases of the moon and their influences on the movement and concentration of marine organisms is crucial to successful coastal fisheries (Cordell, 1978). Nishida et al (2006) pointed out those gatherers of the land crab*Ucidescordatus* in Paraiba associate thephases of the moon and the tide variations affects the distinctphases of the life cycle of that crustacean, includingecdysis, mating, and spawning. Gatherers of Paraiba associate tidal variations to life cycle ofdifferent crustaceans and molluscs they exploit, e.g. theyare able to recognize the influence of tides on femalecrabs' and molluscs' reproductive period, distribution of those animal species in mangrovehabitats and estuaries is directly related to variation of tides hence Gatherers' knowledge can provide a useful basisfor understanding local crab and mollusc stocks and theirpopulation dynamics (Nishida et al, 2006).

Many marine animals show reproductive rhythms following the semilunar or lunar tidal cycle (Morgan and Christy 1994, 1995; Mizushima et al. 2000). Some fiddler crabs in the genus *Uca* are known to have synchronous reproductive cycles (Christy 1978, 1986; Morgan and Christy 1994, 1995). Reproductive synchrony in fiddler crabs describe by male courtship activity (Zucker 1978; Salmon 1987), or the synchronous release of larvae from the female which follows the semilunar tidal rhythm (Christy 1978; Morgan and Christy 1994, 1995; Kellmeyer and Salmon 2001).With the tidal cycle is assumed to be an adaptation that increases larval survival (Christy 1978, Morgan and Christy 1994, 1995; Kellmeyer and Salmon 2001).*Uca lactea* has a particularly strong semilunar rhythm of activity (Yamaguchi 1971; Crane 1975). Study suggested that the mating behavior of *U. lactea* is synchronous and peaks near to spring tide, a pattern which is consistent with other species of the genus. (Murai et al., 1987; Yamaguchi, 2001a, 2001b, 2001c).

3 ECOTOXICOLOGY

Ecotoxicology is a specialized area within environmental toxicology that focuses more specifically on the impact of toxic substances on population at the community and/or ecosystem level. Ecotoxicology is the integration of toxicology and ecology. Main aim of ecotoxicology is to quantify the effects of stressors upon natural populations, communities or ecosystems.

The marine pollution is mainly contributed by industrial, domestic and agricultural wastes. Effluents, particularly from the industries containing hazardous heavy metals and organic toxicants have posed threat to the marine life. The term 'heavy metal' is used synonymously with 'trace metal' and includes both essential and non-essential trace metals (Rainbow, 1995). All of these have the potential to be toxic to living organisms if present at an availability above a threshold which varies between taxa, probably even at the specific level. It is employed here to denote a species which accumulates heavy metals in its tissues, and may therefore be analyzed as a measure of the bioavailability of the metals in the ambient habitat. Three measures of levels of heavy metals in marine habitats are usually available, namely concentrations in waters, sediments and biota. Dissolved concentrations, moreover, vary greatly over time, for example with tidal cycle, freshwater run-off. Measurements of dissolved heavy metal concentrations provide an assessment of total metal present, not of that portion which is bioavailable that is available for uptake and accumulation by marine organisms. It is the bioavailable fraction only that is potentially toxic and of Ecotoxicological relevance.

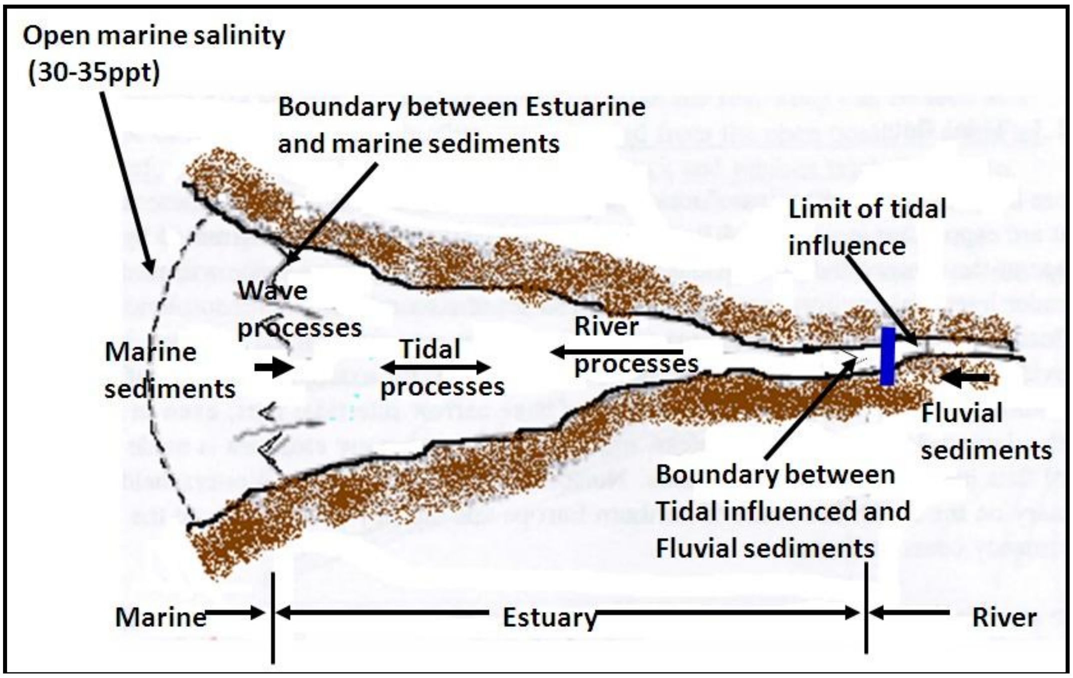
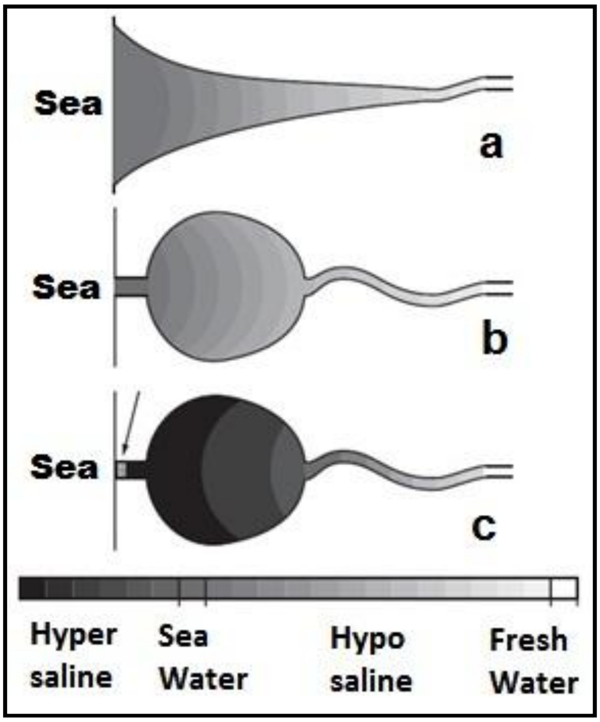


Figure 1: Shows generalized physical processes at the estuarine scale with marine and riverine influences.



(Modified after Potter *et al.* (2010)

Figure 2: Stylised examples of (a) a classical macrotidal estuary with a longitudinal salinity gradient and (b, c) estuaries which typically comprise a short and narrow entrance channel, wide central basin and the lower reaches of their tributary river(s). Arrow indicates sand bar.

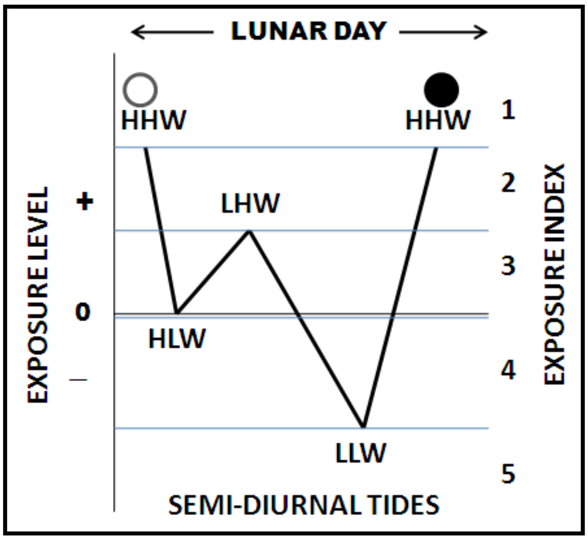
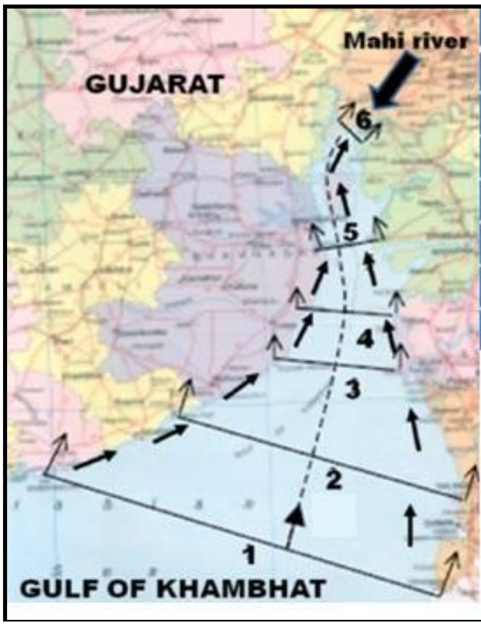


Figure 3: Represents tidal actions on different moon days



Cross Section		X- Co-ordinate	Width
No.	Location	(km)	(km)
1	Diu-Umargam	0	200
2	Pipavav-Valsad	45	150
3	Methla-Hazira	90	66
4	Alang-Mor	120	50
5	Ghogha-Dahej	1150	27
6	Mouth of Mahi River	210	06

(Cited from Vachhrajani and Pandya, 2011)

Fig. 4: Geometry of Gulf of Khambhat with broad mouth and narrow Inner end with the sharpdecline in the width. The numbers correspond to the cross section locations; distance from mouth to inner end is thus 210 km between sections 1 and 6.

Figure 4: Geometry of Gulf of Khambhat