SECTION GENERAL DISCUSSION

The benthic communities living in changeable estuarine ecosystems exhibit low diversity and high resistance to their highly variable environment (Dauvin, 2007). Patterns of species distribution are strongly and directly coupled to physico-chemical processes, with salinity levels explaining much of the observed variations. The pollution problem in estuaries is characterized by interconnected, complicated interactions, often making the interpretation of the disturbance effects in such ecosystems complex and confusing. In addition, these dynamic physical, chemical and geologic conditions can hinder efforts to assess the impact of anthropogenic activity on estuarine biotic integrity. The geomorphology of gulf of Khambhat is very specific; steep narrowing of gulf from ~ 200 km at gulf mouth to ~6 km at tail i.e. mouth of Mahi estuary. As a rule, a large volume of tidal water enters gulf from mouth which narrows down exponentially causing high tidal amplitude and churning of water current. The churning of the ingressed water and thereby the upwelling of the bottom sediments eventually results in the suspended sediment load at the downstream which decreases gradually moving towards upstream. High level of total hardness at downstream showed the marine salts. The sedimentation pattern and the substratum composition are one of the important factors governing the animal distribution. The estuarine salinity is mainly governed by freshwater discharge which decides the salinity levels. In most of the cases in estuaries like Mahi, marine tidal flow dominates the riverine inflow exceptionally during the monsoon season in which the high inflow of freshwater pushes the saline boundary more downstream towards the marine side.

The basic interest of the study was to access the general habitat condition of the downstream estuary and assessment of benthic fauna of estuary with their habitat interactions. Habitat assessment has been an

integral part of any study as it governs animal distribution and abiotic status to certain extent. In an estuarine ecosystem, the geomorphic alteration and thereby the resultant hydrodynamics roots a variety of habitat at different estuarine zones or even at point level. A mosaic of patches with different environmental characteristics, at different states of recovery, can contribute to the spatial heterogeneity within ecosystems (Pandya, 2011). The lower estuarine mudflats and intertidal flats show a characteristic deposition of sediments creating a mosaic of sediment zones at different levels from high tide line to low tide line which is best seen at Kamboi. Sediment deposition and sorting at macro and micro level is an important phenomenon creating a diverse macro and microhabitats. Looking at this point, a gradient of sediment sorting is clearly seen at the Kamboi with a distinct zonation from high tide line to the low tide line on estuarine intertidal area. The muddy sediments (silt/clay) towards the upper intertidal zones represent the sediments deposited on the bank side and are mostly the fluvial sediments mixed with marine inputs. The fine sandy sediment composition dominating the lower intertidal zones (Zone 5) represents the marine sand mixed with settling silt. A study of Tasmanian estuaries indicated that silt loading had a widespread and detrimental effect on estuarine communities (Edgar and Barrett, 2000). Sediment type and strata formation are some of the important features of habitat selection by different animals (Snelgrove and Butman, 1994; Pandya, 2011). Studies suggest habitat specific distribution/occupancy by different crab species along the intertidal area (Chakrabarti et al., 2006). This phenomenon was clearly observed in the present study. The morphology of dominant species is usually specialised and adapted to some aspect of the substrate of the habitat in which they are found (Abele, 1974).

Fiddler crabs are surface deposit feeders, and therefore the sediment type can be expected to be an important factor governing their abundance and distribution. In deposit-feeding crabs the mouthparts sort out food particles from the sediment for ingestion. The mouthparts of *Uca pugilator*, *U. minax* and *U. pugnax* are closely-linked to the habitats in which these crabs occur in abundance in the wild (Miller, 1961). Crane (1975) concluded that the normal

habitat of a given species, whether sandier or muddier, can be surmised by examining the setae on the endites of the second maxilliped: the more spoon-tips, the more nearly sandy the environment. Quantitative comparisons of the second maxillipeds *U. annulipes* with other *Uca* species, there were significantly more spoon-tipped setae in *U. annulipes* and hence preferred loamy composition (Lim, 2004). Besides substrate composition, other factors such as interspecific competition and burrowing activity can also determine the distribution of *Uca* species (Aspey, 1971). *Dotilla spp* was only found in sediments with water content of 15 % or higher (Allen, 2010). One of the distinguishing features of *Dotilla* crabs is the presence of a band of setae on the fourth abdominal segment which function in water uptake. The abdomen can be lowered, pressing the setae into the sand allowing the uptake of interstitial water (Hartnoll, 1973). The presence of such an adaptation indicates the evolutionary importance of water to *Dotilla*. Hence, upper limit of *Dotilla sp.* was limited by present of water. The lower boundary of the Dotilla zone was governed by the tide. The activities that *Dotilla sp.* can perform are limited by the time between each successive immersion by the tide. Particle size determines the distribution of *Ilyoplax* crabs by influencing the organic matter content of the substrate, as the fine grained sediments generally have high organic matter content (Saher and Qureshi, 2010). Fine sands with admixture of clay are more suitable to *I. sayajiraoi*. The study also suggests that abiotic factors regulate the distribution pattern of brachyuran fauna however; also the biotic factor like recruitment pressure further control the distribution pattern and temporary alter the existing distribution pattern.

Fiddler crabs of the genus *Uca* are model organisms for testing theories of sexual selection; they provide one of the most extreme examples of sexual dimorphism in the animal kingdom and their mating system involves both competition among males and female choice. Whereas female crabs have two small claws used for feeding, males have one small feeding claw and one greatly enlarged major claw that can comprise nearly half the total body mass in some species (Crane 1975). Males use the major claw as a weapon in

agonistic contests with other males for control of breeding burrows in preferred locations and wave it in species-specific displays to attract receptive females for mating (Crane 1975; Christy 1982, 1983; Pope 2000). Fitness benefits accruing to large males with relatively large claws are well documented; such males win more contests, display with greater vigour and are attractive to females (Hyatt and Salmon 1978; Christy 1983; Jennions and Backwell 1998). Previous studies have demonstrated that waving and fighting associated with courtship by fiddler crabs is physiologically demanding (Matsumasa and Murai 2005), and that reproductive activity of several species can be limited by food availability (Jennions and Backwell 1998; Kim and Choe 2003). Our work provides an explanation for these observations and shows that cheliped waving frequency of *U. annulipes* decreased during limited food duration of neap tide. Mass movement of soldier crab is always takes place from burrowing area to water-logged area. Earlier study described that soldier crab move from upper intertidal area to lower intertidal area where water-logged bodies present (Wada, 1981; Koga, 1995) whereas, in present study reverse pattern observed. Chimney building activity and 'Drove' formation observed during peak juvenile recruitment when density was highest and linked with competition of food and space.

Circatidal rhythmicity in the locomotor activity of the Brachyuran crab has been studied since long past (Naylor, 1958; Crothers 1968). A large proportion of this type of research has been directed towards elucidating the nature of the endogenous clock or clocks involved in regulating locomotor activity (Reid and Naylor, 1989; 1993). Sediment water content was higher in the lower intertidal zone compared to higher intertidal zone. During progression tidal cycle sediment water content changes, it is high during spring tide and low tide during neap tide. In present study recorded that brachyuran crab distribute at higher intertidal zone showing different activity pattern with tidal cycle whereas, activity pattern of brachyuran crab distributed at lower intertidal zone did not affected much with tidal cycle progress. Seasonal changes in density, distribution and activity pattern had been recorded predominantly.

The Effluent Channel receives a complex mixture of wastes from a large number of different sources on the Nandesari industrial estate discharged wastewater to the Mahi River estuary on the Gulf of Khambhat via the opens at downstream site Sarod. As Sarod received heavy load of pollution, Sarod as well as its upstream and downstream site showing degrading water quality as well as soil quality. Bioaccumulation of certain heavy metal also recorded from crab and vegetation tissue collected from Sarod. Gohil and Mankodi (2013) surveyed downstream of Mahi estuary for fish fauna and stated that the large scale industrialization and the consequent effluent discharge are going to make the river almost lifeless or dead resulting massive destruction of this riverine fauna and flora. Low density of brachyuran crab at Sarod can be linked with heavy metals present in the water and sediment and bioaccumulation in the tissue of animal and vegetation. Evidence of population effects can be decisive in attributing changes in marine ecosystems to pollutants. The evidence that chlorinated hydrocarbons (DDT and other pesticides) were contributing to the near extinction of species of piscivorous marine birds contributed to the ban on that class of pollutants in the 1970's. In the late 1980's, a similar sequential series of discoveries conclusively linked organotins (TBT) to decimation of mollusc populations. Exposures were linked to widespread effects on development and reproduction of several species (snails such the predator *Nucella*, the clam *Scrobicularia plana* and oysters, *Crossostrea gigas*) (Bryan and Langston, 1992). Despite its significance, population biology is insufficiently exploited in ecotoxicologic studies, possibly because population responses to stresses are complex and the causes of population change can be difficult to differentiate. Lower order adverse effects on survival, growth or reproduction not only have direct consequences for populations but the costs of surviving pollutant exposure via physiological compensation may also translate into impairment of processes important to populations (e.g. reduced growth rate or reductions in fecundity) (Sibly and Calow, 1989). Indirect effects on changes in food availability or quality are another source of population disturbance. The population failed, but only after several generations of reduced recruitment. Similar results were observed in a separate study with *Ampeliscu ubditu*.

Signs of stress included suppressed birth rates, reduced growth rates and delayed time to first reproduction (Scott and Redmond, 1989). Population models showed that the population would disappear due to reduced recruitment. Habitat, food availability, natural disturbances and pollutants can all affect population dynamics. As a result, many populations are characterized by periodic large natural fluctuations and natural differences in abundance at different locations. In estuaries, populations of opportunistic species can exploit natural disturbances and persist through fluctuations in recruitment and episodes of mortality (Luoma, 1989). For example, complex age structures allowed polychaetes populations to persist despite episodic recruitment failures and age-specific mortality caused by dredging (Zajac and Whitlach, 1989). In present study, Presence of comparatively dence population of *Dotilla sp.* during recruitment period (From March to June) and further decline in density provide clue of episodic recruitment failure of the species at particular location. Specific tolerance to pollutants (via physiological adaptation or selection for tolerant genomes) (Luoma, 1977) can allow populations of adult fish (Klerks and Weis, 1987), oligochaetes (Klerks and Levinton, 1989), polychaetes (Bryan and Hummerstone, 1973) or clams (Luoma et al., 1983) to persist in highly contaminated estuarine habitats. Survival of *U. annulipes* and *I. sayajiraoi* at Sarod can correlate with physiological adaptation to the pollution load.

Thus, it is critical that sediment contamination in estuaries, and its biological and ecological significance, be properly and fully assessed. Evidence of the effects of pollution at the level of the cell and the individual has been confirmed in several estuaries, including the Seine estuary (Kennish, 2002). However, the effects of pollution on populations and communities, and their responses to this pollution (Kennish, 2002), have proved more difficult to identify in estuaries, probably due to the limited numbers of species and communities present in such variable environments. These observations lead to a serious question: Do contaminated environments influence the diversity and structure of the benthic communities in such estuaries? The estuarine biological characteristics (low diversity and low numbers of species) as

compared to those in fresh or marine waters have rendered studies of the effect of contaminants on the fauna particularly difficult. It is known that salinity can affect the bioavailability of contaminants in estuarine sediments (McLusky et al., 1986). Rygg (1985) has studied the relationship between species diversity in benthic fauna communities and concentrations of heavy metals (Cu, Pb and Zn) and organic matter in the sediments at 71 sites in the Norwegian fjords. He found a strong negative correlation between diversity and copper concentration, a moderate negative correlation was found for lead, and only a weak negative correlation for zinc.

In present studies, it was possible to describe the benthic faunal diversity, distribution of brachyuran crabs, habitat (sediment) association of benthic fauna and their interactions. I also attempted to assess the pollution load of various components of the ecosystem and find out whether that influenced the diversity, distribution and interactions of benthic fauna.