SUMMARY

An ecosystem is a complex matrix in which biotic and abiotic components interact and influence each other directly or indirectly. Estuaries are amongst the critical zones that form an ecotone which serve as buffer; linking land, freshwater habitat and the marine habitat. Estuaries have been studied with reference to hydrodynamics, oceanographic influences, migratory bird supporting wetlands and biotic diversity by researchers of different disciplines. During last couple of decades the anthropogenic activities have induced changes in varied aspects of estuarine ecosystem. Several reports demonstrated dependence of estuarine faunal diversity and distribution of physical and physico-chemical features. The hydrodynamic fluctuations result in surge in temperature, salinity, hardness and water column and some other parameters thus restricting the animal diversity in the harsh environment. The complexity of estuarine ecosystem thus creates dynamic critical mosaics which are challenges to understanding

Estuaries are important natural places. Since histories, estuaries have been of importance to humans and civilizations. Mankind has preferred to be settled on the river banks or near estuaries. An estuary provides settlements, food and transport to humans. Thus they have always been esthetically important. They provide goods and services that are economically and ecologically indispensable.

Estuaries harbor unique faunal and floral biota due to the constant water flux in terms of salinity and other water quality parameters. They are often called nurseries of the sea where they provide breeding, feeding and nesting ground for many of the faunal groups. Estuaries produce very high amount of organic matter as well as provide variety of habitats and microhabitats which is the cause of attraction for many of the marine animals. Many of the organisms make estuaries their permanent home while some of them pass only a part of their lifecycle in estuaries. Benthic fauna are the vital component of the estuarine food chain. Most of the benthos feed on either

detritus or the organic matter thus controlling the ecological functioning. In estuary, these organisms work as a super creatures adapting to the harshness of the environment. On the estuarine intertidal mudflats, they are acted upon by variety of environmental factors like desiccation stress, temperature, predation and change in salinity etc. Moreover, the daily tidal fluctuations imply flux in water quality and sediment depositions.

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, hydrodynamics and high tidal amplitude. 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,

Mahi River (583 km long and 34,842 km in drainage surface) is one of the major rivers of Gujarat. It originates from the Mahi Kanta hills in the Vindhyachal ranges of Madhya Pradesh. The Mahi River basin spreads over Rajasthan, Madhya Pradesh and Gujarat states. The estuarine stretch of Mahi river extends up to 50 km upstream (Vasad - 22° 26 'N and 73° 04 'E) and opens into Gulf of Khambhat at Kamboi (22° 12 N and 72° 36 °E).

For convenience of the study, the entire estuary was divided into 3 zones; Upstream, Midstream and Downstream based on salinity, total dissolved solids as well as area division. In general, the study area comprises of various geomorphic features, such as total freshwater region, freshwater and marine mixing zone, lagoon, small uplands, sand flats/dunes, tidal mudflats, ridge and runnel systems and fine sandy low intertidal areas. A total of 14 sites were considered for present studies of which 10 sites were located on the south bank and 4 sites were located on the north bank of Mahi estuary. The section wise distribution was; 4 sites in upstream, 5 sites in midstream and 5 sites in downstream. Since all the sites were not approachable throughout the year, particularly during monsoon, Fajalpur from upstream, Dabka from midstream and Sarod and Kamboi from downstream were considered as representative sites and visited frequently for studies.

Comparatively very sparse published data exists on the benthic diversity from estuaries of Gujarat. The Indian literature is very sparse on benthic fauna and their habitat association studies.

Fig. 1: The study area.

In order to apply overall justification to the study and for correlation, abiotic, biotic sampling was done with water and sediment assessment as part of abiotic study while benthic faunal study from various aspects as part of the biotic curriculum. The aim of the study was to integrate classical study in form of taxonomy, basic abiotic status and distribution with recent approaches like behaviour, animal-sediment relationship etc using newer methods like resin casting, Pipe core and X-ray study, Computer tomography (CT scan study). More or less the study rolled in following phases:

Understanding the study area (Habitat assessment – geomorphology)

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Baseline survey of abiotic condition (water and sediment study)

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Benthic faunal diversity assessment and proper identification

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Animal distribution and density (along the estuary and the intertidal area)

↓

Animal-sediment relationship

↓

Probable correlations

The preliminary survey and the prevalent hydrodynamics classify the Mahi estuary as a partially mixed kind wherein the marine influx mostly dominates the riverine output. The midstream and downstream shows high amount of churning of bed material during tides. Moreover, the estuary shows prominent meandering at several points which has caused prominent erosional and depositional sites. The generalized overview to the sedimentological features states that upstream site is dominated by sandy bed material and bank depositions. Interestingly, the lower estuarine part prominently shows a mudflat zone on the intertidal side adjoining the younger terrace. These mudflats, distinctively seen at Kamboi and adjoining lower estuarine sites are one of the vital parts of the Mahi estuary serving as an important habitat for benthic fauna. Furthermore, as an anthropogenic addition, the common industrial effluent channel running 55km from the industrial belt of Vadodara opens into the downstream site of Mahi estuary (Sarod) and releases treated effluent at an average rate of 145 million liters per day into the Mahi estuary. A beach slope was seen from upper intertidal zone to lower intertidal area at Kamboi. Overall, an elevation difference of 8 m was found over the study area, from the upper surf zone to the lower intertidal mark. Based on sediment analysis, five distinct zones were identified from upper to lower intertidal line respectively. Each zone represented a specific nature in terms of sedimentology or topographic features. Zone 3 and 4 dominated with silt and clay making them a muddy habitat. The lowermost intertidal area Zone-5, was mostly dominated by fine sand.

Various water quality parameters like pH, total alkalinity, acidity, phosphate, salinity, total hardness and total and dissolved solids (TS and TDS) were analyzed individually for upstream, midstream and downstream as well as compared. One way ANOVA was used to compare the parameters at three estuarine grades (upstream, midstream and downstream). Salinity, total hardness, TS and TDS were the governing factors which defined the estuarine gradient and their peak values were observed towards downstream while opposite was the case with upstream.

Data were analyzed and represented at 3 levels in following fashion;

— At estuarine gradient (upstream, midstream, downstream)

— Comparison among different zones at Kamboi

— Depth wise comparison for selected zones in Kamboi.

Sediment composition, organic matter, bulk density and water holding capacity were the main aspects wherein upstream had sandy composition, midstream and downstream had silty-clayey composition. Pertaining to varied sedimentological aspect, variation was seen in total carbon and sediment organic matter among different zones at Kamboi. Zone-3 appeared as an organic matter rich zone (SOM 3.26 ± 0.86) followed by Zone-4 (1.38 ± 1.14), Zone-5 (1.0 ± 0.83) and Zone-2 (0.84 ± 0.66). High amount of organic matter in Zone 3 and 4 can be one of the strong reasons of high density of crabs in respective zones. Overall, a very small variation was seen between upstream and downstream values, while midstream showed lower values.

Animal Collection and Preservation: Benthic animals were collected on field and carried to the laboratory for further preservation. The macrofauna like crabs, mollusks, polychetes were collected, narcotized with either menthol crystals or adding freshwater in case of crabs to avoid shrinking of appendages.

Foraminiferan sampling: During the course of study sediment samples for foraminiferan analysis were collected to in different ways depending on the site of collection. A core of nearly 1.5m was taken from downstream Kamboi mudflat for depthwise analysis. Regular cores of 36cm were also used for the purpose. In midstream site where coring was not possible, a vertical trench was made on the exposed bank by removing superficial eroded sediment. In case of upstream, in order to obtain a marine clay traces (having foraminifera), a trench was dug which showed different layers of sediments which were collected for analysis.

Quantitative Faunal Studies (Transects, Quadrates and Biomass): In order to reveal the brachyuran crab distribution on the estuarine intertidal area, transect sampling method was employed. A total 16 line transects, extending up to 175 m perpendicular to the shore line (surf zone to lower intertidal area) and covering all specified regions, were laid, spreading nearly 5 km of the length of the estuary. A burrow count technique involving counting of open burrows falling on transects line was employed to analyse the density and distribution pattern, keeping in mind both efficiency and reliability of the method. Quadrate sampling (0.25 X 0.25 m) was done for each zone randomly and amplified to density per sq. m. Multiple quadrates were taken from each zone to study the distribution pattern, as well as to minimize the error and support the transect data. Biomass samples were taken by digging 25 cubic cm of the sediments. The sediments were sieved and after their separation the wet weight was recorded.

Burrow Casting: Species specific burrow architecture pattern exists in different macrofaunal groups. Burrows of crabs and mudskippers were casted in present study. Initially, paraffin wax (congealing point 58-60°C) was used. A clear cast epoxy resin was used and poured in burrows. Resin was allowed to stand and harden and was dug out finely to get a burrow model (Plate 4a). After reaching laboratory, the casts of different species were subjected to morphometric studies like burrow cast length, diameter at different levels (opening, trunk diameter, neck diameter, resting chamber diameter etc.), number of bending points, number of resting chambers etc. in order to get the detailed subsurface structure of the burrow.

Radiological Studies: In instances to check the subsurface biogenic structures, radiological tools were used. Pipe cores after sealing at the ends were carefully taken to the radiological laboratory. Digital X-ray of pipe cores were taken to see the inner burrow structure other fine structures. In case of finer biogenic structures produced by smaller benthos like amphipods, isopods and few polychetes, resin or wax casting was not possible and moreover, X-ray did not give substantial results. In such cases, sediments blocks were directly taken to the radiological laboratory and were studied using Computed Tomography Scan (CT Scan). The result generates a 3D view and was even able to slice the sediment block at required levels to see the complex burrow structure virtually.

Behavioural Studies: Cryptic activities of benthos on exposed intertidal area can be well studied by their behavioral displays. The track and trail marks, burrowing patterns, feeding and burrowing expels by crabs and other benthic forms are some of the indirect evidence which mark the presence of the species in the ecosystem and provides clues to habitat interactions. Track and trail marks of different species were visually and photographically documented and standardized. The burrowing pattern of different crabs, mudskipper and few arthropods were documented with their marking specificity and dimensions. The feeding range and pattern of crab species was studied by taking a scaled photograph and measuring the area covered by crab using Bersoft Image measure software.

In present studies, of the total 292 benthic faunal **species** obtained, 241 species were identified while 51 were unidentified while of these species were identified to family or genus level. The details of the obtained species is as under:

Category	Sub category		No. identified species	No. of unidentified species	Total no. of species
Benthic microfauna	Foraminiferans		22	09	31
	Ostracods		-	05	05
	Mollusca		-	05	05
	Total		22	25	41
Benthic macrofauna	Nemaotda		-	02	02
	Mollusca		24	-	24
	Sipuncula		-	01	01
	Annelida		-	03	03
	Arthropoda	Spider	-	01	01
		Crab	11	03	13
		Amphipod	01	00	01
		Isopod	-	01	01
		Barnacle	-	01	01
		Insect larvae	01	01	02
		Ant	01	-	01
	Chordata: Mudskipper		01	-	01
	Total		38	14	51
Associated fauna	Planktonic		60	15	65
	Avifauna		118	-	118
	Fishes		15	-	15
	Reptiles		01	-	01
	Mammals (Dolphin)		01	-	01
	Total		185	15	200
Grand Total			238	54	292

DISTRIBUTION PROFILE OF BENTHIC FAUNA

The distribution of obtained benthic faunal species followed an estuarine gradient as per their individual tolerance level and habitat/microhabitat availability. Traces of foraminiferans were found from slight upstream sediments which showed past marine evidences or rather occasional marine intrusion. Though the detailed qunatitative survey of foraminiferans was not possible during the study phase, the priliminary observations and sample analysis strongly suggests that the diversity and density of foraminiferans increased gradually as moving towards downstream. Mollusca remained predominantly distributed from upstream to downstream no matter the density varied from sparse to abundant. Rich molluscan assemblage was seen in upstream sites.

Crabs and mudskippers showed their presence staring from midstream sites to downstream, though on less occasions at midstream. Larval stages of crabs were mostly seen seetling at the midstream site instead of adult ones with exeptional case of few larger species like *scylla serrata* which intruded midstream and upstream occassionally along with high tides. *Neries sp.* showed occassional sightings between midstream and downstream which increased ultimately towards downstream. In case of arthropods, most of them viz. amphipods, isopods, spider, insect larva, ant sp. were reported only from the downstream sites. Distribution of Sipuncula sp. was restricted to downstream especially in the calcritized hard sediments of Kamboi.

Distribution of brachyuran crabs at Kamboi: Brachyuran crabs showed a heterogeneous distribution pattern on the estuarine intertidal area of Kamboi. Different crab species showed a zonal distribution starting from zone 2 to zone 5 respectively depending on the general beach profiling and sedimentological features. In case of brachyuran crab community, an increase in diversity of brachyuran species was noted as going from Zone 2 to Zone 5. Though, many of the species remained restricted to specific zone, few of the species even shared a common habitat/microhabitat and exhibited community overlapping. Zone 3 and 4 were the most comfort zone harbouring many common species like *Uca lactea*, *Cardisoma carnifex* and *Macrophthalmus depressus*.

Zone wise distribution/ habitat/ microhabitat preference: Zone 2 was predominantly covered by coastal grass and silty in composition. The area was only preferred by *Uca lactea annulipes*. Moreover, few arthropods like ants, beetles also inhabited the area as the area remained dry most of the time. Zone 3 with more silt and clay was the best preferred zone in terms of density of crabs. Even, zone 4 showed two distinct microhabitats; a gentle beach slope and a runnel system with pools and patches of hard substratum. In case of *mudskipper sp.* they mostly preferred a more watery condition within the zone and hence forth use to create depression in surrounding of their burrow to facilitate water logging. Moreover, the shallow water pools were occupied by mudskipper young ones and at some instances nemertine worm. A higher affinity to watery (loose) substratum was seen by polychete, *Neries sp.* which also inhibited sandy substratum at zone 5 in higher density, though the encounter rate of their juvenile form was more frequent. In many cases, in the exposed ends a fine layering of sediment was seen indicative of regular tidal deposition. *D.clepsydrodactyla* mostly preferred a gentle slope within Zone 4 mosaic with fine sandy plaster mixed with silt. In Zone 5, the hydrodynamics and the bed structures formed various types of rippels ranging from large to very small ones which provided a distinct microhabitat to animals. The same species distinctly used two different microhabitats and made a niche selection.

Burrowing pattern: *Uca lactea* was one of the prominent burrower found at Kamboi mudflat. The species showed no external sculpture in terms of dome or a chimney over the burrow opening. The expelled burrowing sediments were usually dumped on one side which later on formed a small bulge. The burrowing pellets were usually oblong in case of females and large balls in case of males with well developed chela. The species usually prepared two types of burrows viz. 'S' and 'J' shaped. The burrows were simple, with single entrance and unbranched with distinct features like burrow opening, burrow neck, main shaft and different chambers. As a peculiar character of fiddler crab, *U. lactea* showed a waving display using larger chela.

M.depressus was the dominant species at downstream mudflat. After a specific interval of low tide, the species actively starts burrowing. The second phase follows is a feeding phase, wherein the species starts actively feeing on the adjacent area surrounding the burrow. Further, the species was one of the most sensitive species which swiftly entered the nearest burrow even at very slight disturbance/movement at few meters. After entering the burrow, the species passed sometime in the burrow allowing the predatory risk to pass on.

D. crepsyrodactyla was one of the dominant crab on the lower intertidal mudflats of Kamboi. Even in terms of density the species showed its higher abundance. The species was distributed mostly from Zone 4 and 5 preferring fine sandy substratum. The species used to build a chimney over the burrow opening. This type of sculpture was seen mostly in Zone 5. The chimneys were made up of small mudballs excavated from the burrow. The species arranged excavated/burrowing pellets on the edge of the burrow entrance subsequently by carrying them between their legs. The pellets were piled up on each other to giving a structure of chimney.

Bioturbation: It is a process of upwelling of the aquatic sediments aided by the benthic animals. It is one of the vital processes taking place at any aquatic/marine ecosystem. During the present study, the bioturbatory potential of few of the macorfaunal species was studied to understand their contribution to the prevailing habitat/environment. Burrowing was the most common and cost efficient activity reported by many of the crab species which was followed by feeding. The burrow excavation done by different species was the main assessment tool to calculate their bioturbatory potential. Three brachyuran species mainly taken in account were *Uca lactea, M.depressus* and *D. crepsydrodactyla*. Bioturbation done by single species annually and by community per sq.m was calculated derived from their density (Table 4.6). Individually, *Uca lactea* was showed highest turnover with a rate of 11.43kg/crab/year followed by *D. crepsydrodactyla* 7.2kg and *M.depressus* 3.9kg per year (Fig. 4.9). A different picture emerged on calculating the data with their population (density) as bioturbation per square meter by members of same species. As a whole, *D. crespydrodactyla* contributed with highest level of bioturbation of 1526 kg/sq.m/year followed by *M.depressus* (329kg) and *U. lactea* (327 kg) (Fig. 4.10). Additionally an impressive figure of surface processing was seen by *Dotilla crepsydrodactyla* through feeding area exploration. A single species explored an average of 124 sq.cm of area during a single tide giving 248sq.cm per two low tides a day, yielding 90520sq.cm i.e. 0.9 sq.km annually.

Interestingly, during the course of study one of the hypotheses was to check whether selected benthic species follow any specific rule of distribution. A species specific habitat preference was seen. Sediment type and strata formation are some of the important features of habitat selection by different animals. Studies suggest habitat specific distribution/occupancy by different crab species along the intertidal area. The extent and type of burrowing by crabs reflects their adaptation to the habitat and prevailing habitat conditions. The extent of habitat exploration by crabs is influenced by ecological factors, salinity being one of the major controlling factors. The distribution and abundance of crabs depend on their ability to make and maintain their burrows in a given habitat. Other important physical factors are tidal variations, slope, sorting, composition, and compactness of the sediments and the ease of excavation. At present, no information is available for mahi estuary on the larval recruitment, preferences of juveniles or adults, predation pressure, or factors determining community composition and, therefore, it is difficult to interpret the heterogeneity of the distribution of *M. depressus.* During the present investigation, only a single species *Dotilla crepsydrodactyla* was seen forming a chimney over the burrow. Based on the field observations and data available few of the possible hypothesis can be proposed and discussed regarding chimney formation by *Dotilla crepsydrodactyla* as i) The sexual attraction hypothesis, ii) Protection from abiotic factors, iii) Hypotheses of Ventilation and aeration, iv) Hypotheses of territoriality.

Mudskipper sp. tends to be one of the important macrofauna on Kamboi mudflat and one of the foremost bioturbator and forager. Few of the species confined to the hard substratum like amphipod, isopod, Sipuncula etc. showed a very restricted distribution and remained confined to their niche.

These animals highly perforated the sediment block which were soft and organic matter rich. The CT scan study has revealed that these animals preferred boring the sediment with less density and avoided an intermediate places in the block where there was a compaction and calcrete formation.

Overall it can be said that most of the benthic forms tend to overcome the harsh environment and roll on their bodily processes. The Uca species by forming the simple burrow instead of branched one tends to minimize the energy needs. Similar case is seen in isopods and amphipods also wherein by sharing a common microhabitat and selecting a soft part of the sediment the species tries to overcome and save the energy inputs.

CREDENTIALS DURING Ph. D. PROGRAMME

Academic Achievements:

Medals

. Prof.Vimal Sharma **Young Scientist award** and **Gold medal** from **Society of Science and Environment** for best paper presentation, National Conference on Environmental Sciences: Current Status and Emerging Challenges, Udaipur, December 2007.

As Resource person:

- **Resource Person** for *Brachyuran taxonomy* at **National Workshop on Invertebrate Taxonomy**, Department of Zoology, M. S. University of Baroda, Vadodara. 18th – 19th Nov. 2009.

Research Publications:

1. **2009 Pandya P. J.** and Padate G. S. 2009: Urbanization influence on the status of wetland and avifauna: A short term preliminary study. *Electronic Journal of Environmental Sciences Vol. 2, 5-11.*
2. 2009 **Pandya P. J.** and Vachhrajani K. D. Preying activity and habitat utilization by *Matuta planipes* (Fabricius, 1798). *Pan American Journal of aquatic Sciences.* 4(2). (***Scientific*** note with Photograph)
3. 2010 **Pandya P. J.** and VACHHRAJANI K. D. Birds of Mahi River estuary and its ambience, Gujarat, India. **J Threatened Taxa** 2: 994-1000 (ISSN 0974-7907).
4. 2010 **Pandya P. J.** and VACHHRAJANI K. D. Spatial distribution and substratum preference of brachyuran crab Macrophthalmus depressus (Decapoda: Ocypodidae) along the lower estuarine mudflats of Mahi River, Gujarat, India. **Crustaceana** 83: 1055-1067. **(Brill Publications, The Neatherland)**

Abstracts/Conference Presentations/ Attended:

International: **02 (Presented)**

National: **17 (14 Presented + 03 attended)**

(04 selected as best Presentations)

1) 2007 **Pandya P. J***, Effect of Urbanization on quality of Wetland with reference to Avifauna. National Conference on Environmental Pollution and Toxicology, Thakur College, Mumbai, December.

2) 2007 **Pandya PJ***, Vachhrajani KD and Mankodi PC: Substratum characteristics: Importance in benthic fauna studies. Natl Conf Varied Perspectives of Biodiversity, NCLES MJ College, Navi Mumbai, Feb.

3) 2007 Parikh Ankita*, Shinde Komal, **Pandya PJ**, Vachhrajani KD and Mankodi PC: Ecological status of Mahi River estuary, Gujarat. Natl Conf Varied Perspectives of Biodiversity, NCLES MJ College, Navi Mumbai, Feb.

4) 2007 Patel Bhairavi*, **Pandya PJ**, Vachhrajani KD and Mankodi PC: Molluscan Fauna of Mahi River, Gujarat: A preliminary report. Natl Conf Varied Perspectives of Biodiversity, NCLES MJ College, Navi Mumbai, Feb.

5) 2007 Shinde Komal*, Parikh Ankita, Nanda Aditi, **Pandya PJ**, Vachhrajani KD and Mankodi PC: Zooplankton diversity of Mahi river estuary, Gujarat. Natl Conf Varied Perspectives of Biodiversity, NCLES MJ College, Navi Mumbai, Feb.

6) 2007 Shewale Vaishali*, Bhattji Nayruti, **Pandya PJ**, Vachhrajani KD and Mankodi PC: Distribution, diversity and sediment relationship of crabs at Kamboi, Mahi River estuary, Gujarat. Natl Conf Varied Perspectives of Biodiversity, ICLES MJ College, Navi Mumbai

7) 2007 Bhattji Nayruti*, Shewale Vaishali, **Pandya PJ**, VACHHRAJANI KD and Mankodi PC: Study of various biogenic structures of benthos at Kamboi, Mahi estuary, Gujarat. Gujarat Science Congress, Patan

8) 2007 **Pandya PJ***, VACHHRAJANI KD and Mankodi PC: Role of hydrodynamics and habitat characteristics in the distribution pattern of benthos at Kamboi, Mahi estuary, Gujarat. Gujarat Science Congress, Patan.

9) 2007 **Pandya PJ***, VACHHRAJANI KD, and Mankodi PC: Habitat characteristics and benthic faunal diversity of Mahi river estuary, Gujarat. National Conference on Environmental Sciences: Current Status and Emerging Challenges, Udaipur. **PJP: Awarded Prof. Vimal Sharma Gold Medal for Best Paper Presentation.**

10) 2008 Ranpara Darshita*, **Pandya PJ**, Mankodi PC and VACHHRAJANI KD: Distribution and biogenic structures of brachyuran crab (Macrophthalmus depressus) at Kamboi, Mahi estuary. XXII Gujarat Science Congress, Bhavnagar. RD: Awarded 2nd Best Poster Prize.

11) 2008 Gadhvi Mayurdan*, **P. J. Pandya**, P. C. Mankodi and K. D. Vachhrajani: Foraminifera of Kamboi estuarine sediments. XXII Gujarat Science Congress, Bhavnagar. GM: Awarded 3rd Best Poster Prize.

12) 2008 Kotadia Bhoomika*, **P. J. Pandya,** P. C. Mankodi and K. D. Vachhrajani: Tidal cycle influence on water quality of Mahi river. XXII Gujarat Science Congress, Bhavnagar

13) UGC Sponsored National Conference on Taxonomy Teaching and Research: The Relevance in the National Context, Petlad. (Attended)

14) Seminar on Current Trends In Environmental Sciences, Vallabh Vidyanagar. (Attended)

15) 2009 **P. J. Pandya**: Predicting vulnerability of estuarine brachyuran taxa using animal-sediment relationship as an effective tool. Student Conference on Conservation Science, University of Cambridge, Cambridge, UK.

16) 2009 State level conference on Modern Trends in Taxonomy teaching. Held at M.G. Science College, Gujarat University, Ahmedabad. 14th July. (Attended)

17) 2009. **Pranav Pandya** and K.D. Vachhrajani. Habitat preference and sediment relationship of brachyuran crabs of Mahi river estuary, Gujarat. International conference on Environmental Biotechnology, Kalyan , Mumbai.

18) 2010. National Semianr on Air Pollution management in changing global environmental scenario. Department of Botany, M. S. University of Baroda, Vadodara, 7th February 2010 (Attended).

19) 2010 **Pandya PJ** and VACHHRAJANI KD: Microhabitat preference and sediment relationship of estuarine brachyuran crab *Dotilla clepsydrodactyla* Alcock, 1900. National Conference on Interdisciplinary Approaches in Environmental Sciences, The M. S. University of Baroda, Vadodara. **Awarded Second Best Oral Paper Presentation Prize.**

Training and Workshops

- National training on "Genotoxicity Biomarkers in Fishes" at National Bureau of Fish Genetic Resources (NBFGR), Lucknow, February, 2007.
- Workshop on "Taxonomy of Molluscs" held by Bombay Natural History Society (BNHS) Dept. of Zoology, M. S. University of Baroda, 2008.
- Workshop on "Dynamic Trends of Coastal and marine environment of Gujarat and Developmental pressure" organized by Gujarat Ecological Society, Vadodara, Feb.2008.

SPATIAL DISTRIBUTION AND SUBSTRATUM PREFERENCE OF THE BRACHYURAN CRAB, *MACROPHTHALMUS DEPRESSUS* (DECAPODA, OCYPODIDAE) ALONG THE LOWER ESTUARINE MUDFLAT OF MAHI RIVER, GUJARAT, INDIA

BY

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ABSTRACT

The distribution of the ocypodid crab, *Macrophthalmus depressus* Rüppell, 1830, was studied on the lower intertidal mudflats of the Mahi River estuary of the Gulf of Khambhat, Gujarat, India. Zoning of the study area was done based on coastal morphology and sediment composition. Distribution pattern and density were studied using transect and quadrate sampling methods. Five zones with variable sand, silt, and clay composition could be distinguished perpendicular to the shore line. Zones 1 and 2 represented the upper inter tidal area (⩾60% sand), Zones 3 and 4 the mid-inter tidal area (70-80% silt + clay) and Zone 5 the lower inter tidal area (⩾50% sand). Quadrant analysis showed the density of *M. depressus* burrows as follows: Zone 1, no animals present (hence not further included in the study); Zone 2, 28.66 ± 9.86; Zone 3, 83.20 ± 33.87; Zone 4, 62.00 ± 9.16; and Zone 5, 52.50 ± 24.74 individuals per m^2. The mean density of the crab varied from 0 to 83 individuals per linear metre along the transect all over the above mentioned zones. The densier distribution in, and thus presumed preference for, Zones 3 and 4 can be attributed to the sediment composition as well as to the slope, which together make the substrate firm and suitable for easy burrow construction. The study revealed a significant correlation between the distribution of *Macrophthalmus depressus* and these habitat characteristics, thus describing the microhabitat preferences of the species.

RÉSUMÉ

La distribution du crabe ocypodidé *Macrophthalmus depressus* Rüppell, 1830, a été étudiée dans les zones intertidales de l'estuaire de la rivière Mahi dans le golfe de Khambhat, Gujarat, Inde. La zonation de l'aire étudiée a été faite sur la base de la morphologie de la côte et de la composition du Sédiment. La distribution et la densité ont été étudiées en utilisant des transects et des quadrats pour l'échantillonnage. Cinq zones avec une composition variable en sable, vase et argile ont pu être distinguées perpendiculairement à la côte. Les Zones 1 et 2 représentent l'aire haute intertidale (70-80% vase + argile), Zones 3 et 4 l'aire moyenne intertidale (⩾60% sable), et la Zone 5 l'aire basse

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Also available online: www.brill.nl/cr
Crustaceana 83 (9): 1055-1067
DOI:10.1163/001121610X521235

intertidale (⩾50% sable). Les analyses des quadrats montrent la densité de terriers de *M. depressus* comme : Zone 1, pas d'animal présent (donc plus inclus dans cette étude) ; Zone 2, 28.66 ± 9.86 ; Zone 3, 83.20 ± 33.87 ; Zone 4, 62.00 ± 9.16 ; et Zone 5, 52.50 ± 24.74 individus par m^2. La densité moyenne des crabes varie de 0 à 83 individus par mètre linéaire le long du transect dans toutes les zones mentionnées. La plus dense distribution et donc la préférence pour les Zones 3 et 4 peut être attribuée à la composition du sédiment, ainsi qu'à la pente qui, ensembles, font un substrat ferme et stable propice à une construction facile des terriers. L'étude révèle une corrélation significative entre la distribution de *Macrophthalmus depressus* et ces habitats caractéristiques, permettant ainsi de décrire la préférence de l'espèce en micro-habitats.

INTRODUCTION

Among the estuarine fauna, brachyuran crabs are noteworthy for their abundance and species richness (Virnstein, 1987; Sheridan, 1992; Flores et al., 2005). Some species have been recognized as regulators of the estuarine community structure (Dittel et al., 1995). The genus *Macrophthalmus* has an Indo-Pacific distribution, occurring from South Africa (Barnard, 1950, 1955) to the Tuamotu Archipelago (Nobili, 1906), and from Japan (Sakai, 1965) to Australia (Ortmann, 1897). Hydrodynamic conditions, the resultant beach profile, sediment sorting, and variation in sediment characteristics cause environmental gradients on the one hand, and a patchy habitat structure, on the other (Attrill & Rundle, 2002), and may be considered the ultimate cause of broad scale community patterns, both spatially and temporally. The Mahi River channel is filled with deposits ranging from nonmarine (fluvial), through estuarine (tidal), to open marine, making the sediment composition quite complex. Sediment zoning within the beach forms a typical niche for many elements of the macrofauna, like crabs. Studies have suggested that macrobenthic communities could be distinguished on the basis of sediment composition (Sanders, 1958; Glémarec, 1973; Buchanan et al., 1978). There is an established correlation between physical properties of habitat and macrobenthos distribution (Flint, 1981; Bolam, 2003). Small-scale textural properties of the local grain population may affect the stability of sediment patches and hence the spatial patchiness of the benthos (Snelgrove & Butman, 1994; Peter et al., 2001). The activities of burrowing crustaceans like crabs strongly influence sediment properties on estuarine mudflats (Botto et al., 2000). Population densities of the soft-sediment infuana are difficult to estimate, due to the cryptic burrowing of the inhabitants and the nature of the sediments (Morrisey et al., 1998). Several studies have used the number of burrow openings (hole count) to estimate macrofaunal density. It has been successfully used to estimate densities of the estuarine crab, *Heloecius cordiformis* H. Milne Edwards, 1837 (cf. Warren, 1990) and the ghost crab, *Ocypode cordimanus* Latreille, 1818 (cf. Borros, 2001). Bias was minimized by assuring that most of the ocypodid crab burrows have a single entrance and are occupied by a single crab (Warren, 1990).

In India, the estuaries of the western region have been rather ignored in regard of benthic community surveys. Studies scattered over more than a hundred years in the Gulf of Kachchh have recorded few species of Decapoda only (Southwell, 1909; Ramanandan, 1966; Chhapgar & Mundkur, 1995; Chhapgar et al., 2004). Most of the species recorded so far in India have been described from southern and eastern regions (Chhapgar, 1957; Sethuramalingam & Khan, 1991; Khan et al., 2005). Other studies have analysed only the physico-chemical parameters of the estuary, hence are of lesser significance for comparison with reference to faunal distribution and diversity (Zingde et al., 1985; Ansari & Paruleker, 1993). So far, a comprehensive study has not been carried out in any estuary of a western Indian region. Thus, an attempt has been made to study the distribution pattern of *Macrophthalmus depressus* Rüppell, 1830 and its substrate preference, with as a hypothesis that its density and distribution are controlled by sediment composition and overall habitat characteristics.

METHODOLOGY

The study area was visited during various seasons in 2007 and 2008. Crabs obtained were identified using standard identification keys (Sethuramalingam & Khan, 1991; National Institute of Oceanography database).

Study area. — Mahi River is one of the major rivers of Gujarat. The estuarine stretch extends up to 50 km, from Kamboi at the coast (22°12′52.38″N 72°37′17.89″E) to Fajalpur (22°26′08.95″N 73°04′26.98″E) upstream. The geomorphology and hydrodynamics of the Gulf of Khambhat make the estuary very specific in terms of sedimentology as well as water quality. The study site Kamboi is situated at the mouth of the Mahi estuary (fig. 1) and is under high tidal/marine influence, as the main freshwater channel of the Mahi River is narrow and about 0.5 km away from the study site. The area also experiences a heavy sedimentation load, which is one of the key components of the Gulf of Khambhat. The area as a whole may be recognized as an estuarine mudflat with a silt-clay composition.

Zonation of study site. — The slope profile was delineated using available satellite data, while taking into account the mean sea level. Horizontal zoning (perpendicular to the shore line) of the study area from the surf zone to the lower intertidal area was based on the beach profile and the substratum characteristics. Keeping in view the ongoing succession processes in the ecosystem, minor variations of one metre in zoning were ignored. The uppermost region was not included in the crab distribution study, as it was the surf zone beyond high tide line, which mostly remained dry, with no benthic assemblage present.

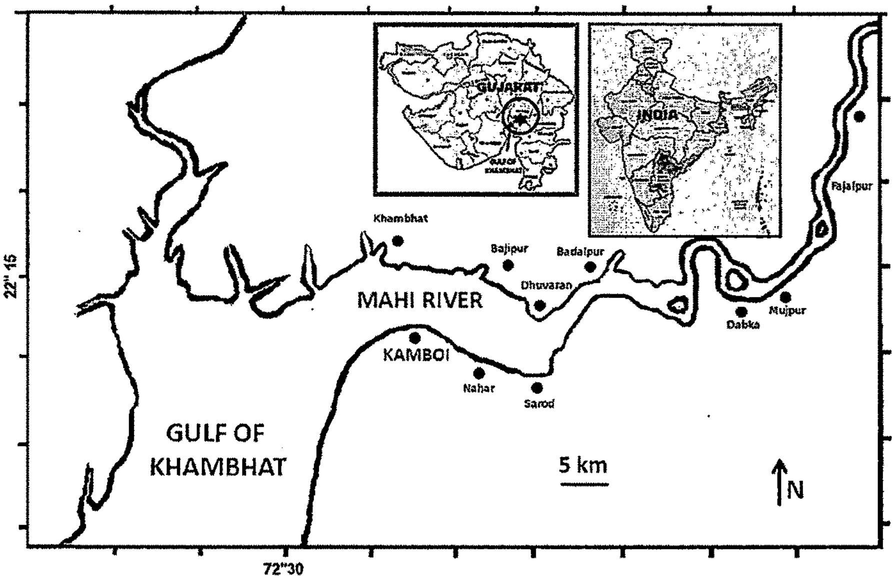

Fig. 1. The study area: Mahi River estuary, Gujarat, Western India.

Sedimentology. — Cores up to 38 cm depth were taken using a 75 mm diameter PVC pipe, from different regions randomly and brought to the laboratory for grain size analysis. The sediments were analysed at two depths, i.e., 0-12.5 cm and 12.5-25 cm, using the mechanical dry sieving method (Folk, 1957). Sediments were distinguished into standard grain size classes.

Faunal sampling. — The initial surveys showed that *Macrophthalmus depressus* was the dominant crab species at Kamboi, and was variably distributed throughout the study area. Its burrow pattern and other characteristic features were studied for unambiguous identification of *M. depressus* burrows. During the study period, a total of 16 line transects, extending up to 175 m perpendicular to the shore line and covering all specified regions, were laid, spreading nearly 5 km of the length of the estuary. A burrow count technique involving counting of open burrows falling on the transect lines was employed to analyse the density and distribution pattern, keeping in mind both efficiency and reliability as discussed by Butler & Bird (2007). All crab burrow openings falling on the transect line and within 5 cm in its vicinity on both the sides were counted. Characteristics of the crab burrow openings, trail marks, as well as specific sediment pellets expelled by the crabs, had earlier been studied and were keenly observed while sampling, so as to minimize any miscount. The transect line was divided into 35 units, in which each unit represented 5 m length of transect and the burrow counts for every 5 m (= 1 Unit) were considered to easily demarcate the different zones and correlate burrow counts with linear distance and estuarine zoning. Quadrate sampling (0.25 × 0.25 m) was done for each zone randomly. The total numbers of burrow openings per quadrate were counted and calculated as density per m^2. Multiple quadrates were taken from each zone to study the distribution pattern zone-wise, as well as to minimize the error.

Statistical analysis. — The data were subjected to Pearson's correlation, One Way ANOVA, and Principal Component Analysis. The distribution found is represented by a Kite Diagram.

RESULTS AND DISCUSSION

The elevation difference from Zone 1 towards Zone 3 was marginal only and a prominent slope was seen from the mid region of Zone 3 up to Zone 5. Overall, an elevation difference of 8 m (fig. 2) was found over the study area, from the upper surf zone (Zone 1) to the lower intertidal mark (Zone 5). This considerable variation in slope plays an important role in sediment stability as well as in relative macrofaunal distribution, since the beach profile reflects the local hydrodynamics and thus the degree of sediment sorting. Based on sediment analysis, five distinct zones were identified: Zone 1, sandy-silty; Zone 2, silty-sandy; Zone 3, silty-clayey; Zone 4, clayey-silty; and Zone 5, silty-sandy. Zones 1 and 2 had a high sand content (⩾60%), Zones 3 and 4 had 65-79% silt and clay, and Zone 5 had 55-94% sand composition (fig. 3).

The distribution of *Macrophthalmus depressus* showed a specific pattern and thus a microhabitat preference. Zones 3 and 4 (units 13 to 24, linear length 65-120 m, profile elevation deceasing from 7.3 m to 4.6 m) had the highest crab density. Quadrate analysis showed that the density of *M. depressus* burrows was: Zone 2, 28.66 ± 9.86; Zone 3, 83.20 ± 33.87; Zone 4, 62.00 ± 9.16; and Zone 5, 52.50 ± 24.74 per m^2, respectively. The mean density of the crab varied from 0

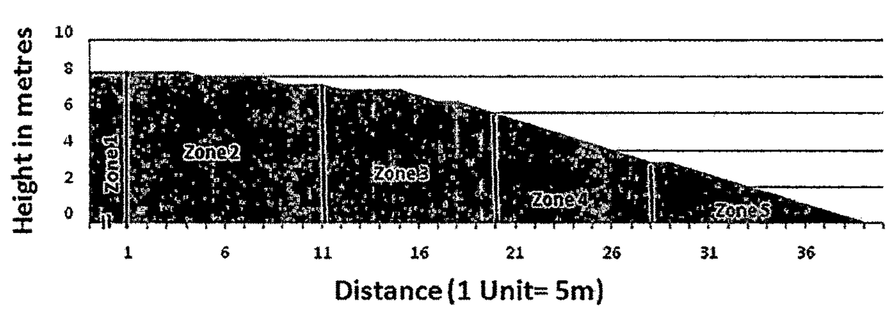

Fig. 2. Beach profile and slope (cross sectional view) from the upper surf zone (Zone 2) to the lower intertidal mark (Zone 5) up to 200 m, at the study site.

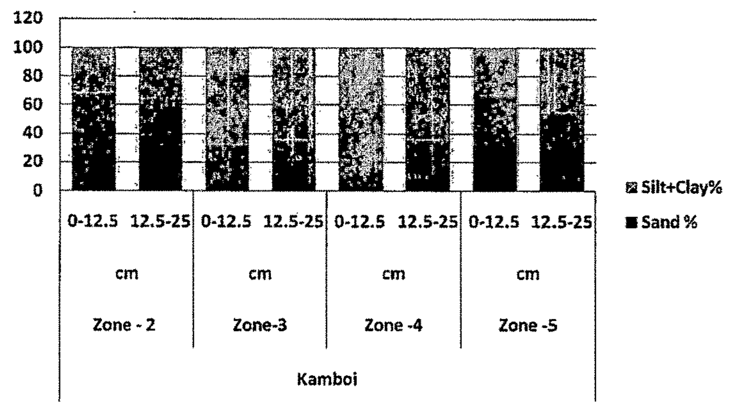

Fig. 3. Graphic representation of the sedimentology of the study area in the Mahi River estuary.

to 83 individuals per linear meter along the transect all over the above described zones. The scatter analysis showed wide variations in distribution of *M. depressus* along the estuary. The total burrow count by transect and by zones is presented in table I. The averages of burrow openings of all transects for respective zones was counted in order to see the distribution pattern in each zone (table II). The Kite

TABLE I

Open burrow count for *Macrophthalmus depressus* Rüppell in the Mahi River estuary by zone, falling on individual transects lines (Transect 1 to 16)

Transects	Zone 2		Zone 3		Zone 4		Zone 5	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
T 1	1.6	3.0	8.6	6.1	5.6	4.1	1.2	1.2
T 2	1.1	2.6	13.2	5.9	5.0	5.0	22.5	9.6
T 3	0.1	0.3	2.4	1.2	5.0	2.7	0.1	0.3
T 4	0.3	0.6	49.7	24.2	29.7	22.3	7.1	3.1
T 5	0.9	2.1	18.6	8.0	8.7	3.7	1.4	1.6
T 6	2.0	4.1	18.4	8.4	56.8	19.4	22.7	22.5
T 7	2.9	4.4	36.3	35.0	15.1	6.3	9.1	12.3
T 8	1.9	2.3	5.2	3.6	12.8	10.2	4.5	6.8
T 9	0.0	0.0	6.8	4.8	10.5	4.4	1.0	1.4
T 10	0.1	3.0	8.8	7.9	7.1	7.4	1.4	2.1
T 11	2.9	5.2	37.2	20.6	10.2	6.4	0.0	0.0
T 12	1.4	2.6	2.4	3.2	0.0	0.0	0.0	0.0
T 13	3.2	4.4	10.7	6.2	2.0	1.7	0.0	0.3
T 14	1.7	3.0	8.5	5.8	5.6	4.1	1.2	1.2
T 15	2.6	3.3	1.2	1.7	0.0	0.0	0.0	0.0
T 16	1.0	1.6	6.7	6.1	4.2	2.5	5.2	2.8

p value 0.003, i.e., significant (ANOVA, P (0.003) $<$ 0.005, F $=$ 4.96, R^2 $=$ 0.19, df $=$ 3, confidence level.

TABLE II

Mean burrow count for *Macrophthalmus depressus* Rüppell in the Mahi River estuary, distributed zone-wise

Zones	Distance in metres	Mean burrow count	SD
Zone 2	5	0.13	0.34
	10	0.00	0.00
	15	0.44	1.50
	20	0.13	0.34
	25	0.19	0.40
	30	0.00	0.00
	35	0.63	1.26
	40	1.13	1.67
	45	3.06	3.26
	50	4.94	5.20
	55	5.13	3.72
Zone 3	60	7.13	7.84
	65	10.69	12.45
	70	15.94	18.09
	75	15.38	14.30
	80	18.19	19.37
	85	18.50	27.46
	90	17.69	21.85
	95	15.56	22.00
	100	13.44	17.45
	105	12.44	16.63
	110	13.94	18.37
Zone 4	115	12.13	14.16
	120	8.81	9.50
	125	11.00	13.38
	130	12.06	16.95
	135	8.81	15.52
	140	10.19	23.13
	145	6.13	14.68
	150	7.50	14.25
	155	5.75	9.33
Zone 5	160	5.63	8.40
	165	5.06	9.58
	170	4.06	9.84
	175	2.25	5.84

diagram drawn from the mean values of all the transects describes the density per zone exhibited by the species (fig. 4). Overall, a higher burrow count was obtained in Zones 3 and 4, with totals of 160 and 127 burrow openings, followed by Zones 5 and 2 with 71 and 15 burrows, respectively, with a less significant linear regression ($R^2 = 0.007$) (fig. 5). The Pearson correlation was calculated between the open burrow count on each transect and the distance (m) on the transect line to check

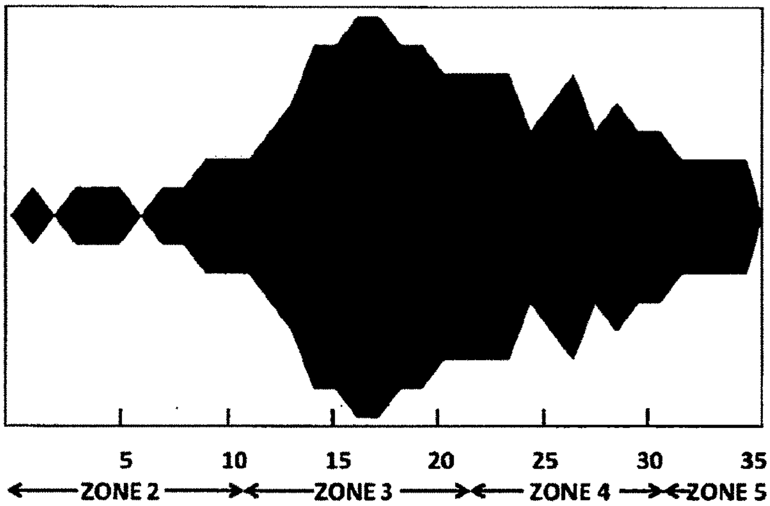

Fig. 4. Average distribution pattern of *Macrophthalmus depressus* Rüppell, 1830, drawn from transect 1 to 16 (distance: 1 Unit = 5 meter), using a Kite diagram.

distribution pattern (table III). Out of 16 transects, 12 transects showed positive correlation (max. 60% and min. 6%) suggesting a random distribution pattern. The Principal Component Analysis suggested a correlation among the distribution profile of the crabs, the slope, and the distance (fig. 6).

Ocypodid crabs exhibited distinct distribution patterns along the intertidal area. *M. depressus* was the dominant macrofaunal species and showed significant spatial heterogeneity. Through different zones, the number of crabs varied from 22 to

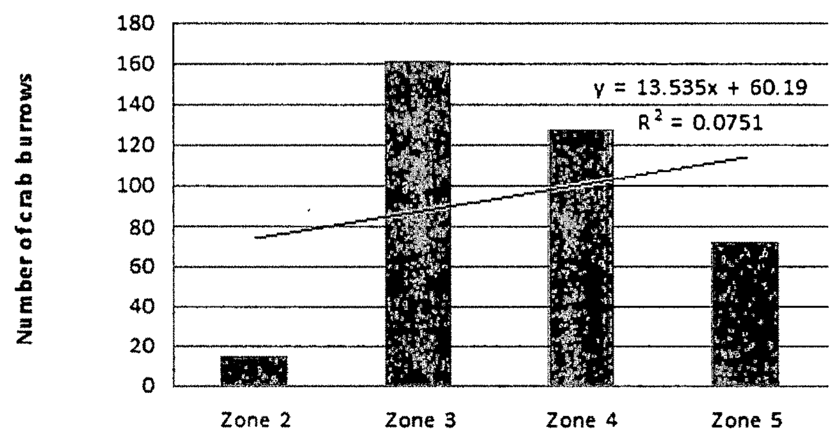

Fig. 5. Sum of total burrow openings per zone of *Macrophthalmus depressus* Rüppell, 1830, falling on each transect line.

TABLE III

Pearson's correlation between transects in Mahi River estuary, to determine the distribution of *Macrophthalmus depressus* Rüppell burrows

Transects	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12	T 13	T 14	T 15	T 16
T 1	0.08	0.36	0.5	0.63	0.17	0.5	0.3	0.5	0.47	0.42	0.35	0.64	1	−0.14	0.23
T 2	...	−0.18	0.08	0.14	0.13	0.23	−0.03	−0.09	−0.1	0.07	−0.02	0.12	0.08	−0.23	0.43
T 3	...	...	0.5	0.45	0.5	0.34	0.38	0.76	0.46	0.28	0	0.16	0.36	−0.27	0.26
T 4	...	...	...	0.87	0.21	0.63	0.07	0.79	0.86	0.59	−0.06	0.4	0.5	−0.26	0.36
T 5	...	...	...	...	0.13	0.61	0.03	0.69	0.63	0.7	0.14	0.63	0.63	−0.15	0.41
T 6	...	...	...	...	...	0.02	0.65	0.48	0.21	0	−0.23	−0.18	0.18	−0.38	0.06
T 7	...	...	...	...	...	...	−0.02	0.44	0.53	0.27	0.01	0.4	0.49	−0.23	0.12
T 8	...	...	...	...	...	...	...	0.25	0.12	−0.05	−0.07	0.02	0.31	−0.18	0.03
T 9	...	...	...	...	...	...	...	...	0.76	0.26	−0.18	0.15	0.5	−0.3	0.21
T 10	...	...	...	...	...	...	...	...	...	0.36	−0.17	0.13	0.47	−0.3	0.06
T 11	...	...	...	...	...	...	...	...	...	...	0.46	0.67	0.43	−0.02	0.51
T 12	...	...	...	...	...	...	...	...	...	...	...	0.73	0.35	0.12	0.26
T 13	...	...	...	...	...	...	...	...	...	...	...	...	0.65	0.08	0.54
T 14	...	...	...	...	...	...	...	...	...	...	...	...	...	−0.13	0.24
T 15	...	...	...	...	...	...	...	...	...	...	...	...	...	...	−0.07

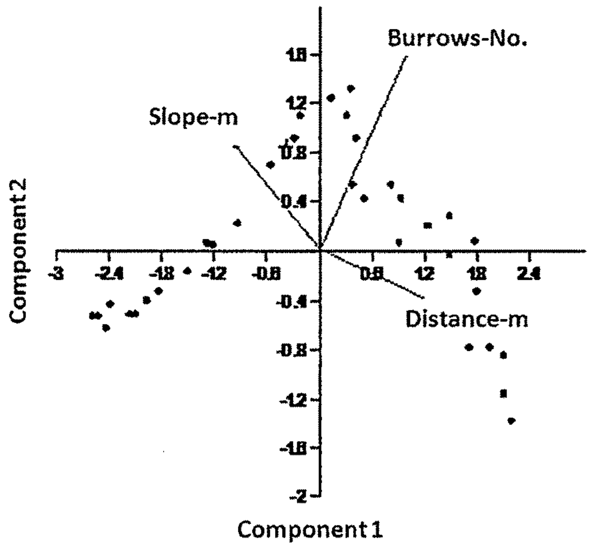

Fig. 6. PCA showing the distribution of *Macrophthalmus depressus* Rüppell, 1830 burrows, along with other related geomorphological components.

120 individuals/m^2. Each zone defined a specific sedimentological feature as well as a slope. The highest congregation of crabs in the Zones 3 and 4 suggested substratum preference of the species. A substrate-based microhabitat selection has been reported for *Uca uruguayensis* Nobili, 1906 (cf. Ribeiro et al., 2005). Thus, the density of and preference for Zones 3 and 4 can be attributed to the sediment characteristics as well as to the slope, which together make the ground firm and suitable for easy burrow construction. At Zone 5, the alluvial substratum is exposed and devoid of sufficient silt/clay covering, which makes it unfavourable for the animals to make deep burrows, and thus is less occupied. Since Zone 2 is well hydrated only during spring tides, the distribution of *M. depressus* is sparse. No significant relationship was observed between the distribution pattern on different transect lines, probably because 5 km distance along the estuary may not contribute to major physio-chemical gradation; however, variation in the horizontal zonal distribution was observed. The probable reason behind the selection of silty/clayey sediments can be the facilitation of burrow formation, which is otherwise difficult in the fine sandy substratum of Zone 5.

Brachyuran crabs use their habitat variably for burrowing to overcome harsh estuarine conditions, for protection from predation, and for feeding, moulting, mating, etc. (Leme, 2002). The extent of habitat exploration by crabs is influenced by ecological factors, salinity being one of the major controlling factors (Frusher et al., 1994). The distribution and abundance of crabs depend on their ability to make and maintain their burrows in a given habitat. The important physical factors are tidal variations, slope, sorting, composition, and compactness of the sediments and the ease of excavation (Bertness & Miller, 1984; Weissburg, 1992). The availability of nutrients, larval recruitment, community composition, and interactions are other such influencing factors (Travis, 1996; Bradshaw & Scoffin, 1999). At present, no information is available on the larval recruitment, preferences of juveniles or adults, predation pressure, or factors determining community composition and, therefore, it is difficult to interpret the heterogeneity of the distribution of *M. depressus*.

Previously, Chappgar et al. (2004) have reported seven species of crabs form the Mandvi coast, Gulf of Kachchh, Gujarat, where an analysis of distribution pattern and habitat morphology were not included. No other study has been carried out in Gujarat describing the distribution or diversity of crabs. The present study reveals an important correlation between the crabs and the characteristics of their habitat: specifically the beach morphology and the types of substratum. Hence, it may be concluded that sediment composition is a determining factor for the distribution of the *Macrophthalmus depressus*, at least in the area studied.

ACKNOWLEDGEMENTS

The authors are thankful to Department of Science and Technology, New Delhi, India, for financial support under the special scheme "Science of Shallow Subsurface", (DST Sanction No: SR/S4/ES-21/Baroda Window/P5). PJP is thankful to DST for the award of a research fellowship under the scheme. The authors also thank Prof. L. S. Chamyal, coordinator of Gujarat Corridor, Department of Geology, The Maharaja Sayajirao University of Baroda, Vadodara, for encouragement and guidance.

REFERENCES

ANSARI, Z. A. & A. H. PARULEKAR, 1993. Distribution, abundance and ecology of meiofauna in the tropical estuary along west coast of India. Hydrobiol., **262**: 115-126.

ATTRILL, M. J. & S. D. RUNDLE, 2002. Ecotone or ecocline: ecological boundaries in estuaries. Estuar. coast. Shelf Sci., **55**: 929-936.

BARNARD, K. H., 1950. Descriptive catalogue of South African decapod Crustacea. Ann. South African Mus., **38**: 1-864.

— —, 1955. Additions to the fauna list of South African Crustacea and Pycnogonida. Ann. South African Mus., **43**: 1-107.

BERTNESS, M. D. & T. MILLER, 1984. The distribution and dynamics of *Uca pugnax* (Smith) burrows in New England salt marsh. Journ. exp. mar. Biol. Ecol., **83**: 211-237.

BOLAM, S. G., 2003. Spatial patterns of estuarine macrobenthic assemblages: relationship with hydrodynamic regime: 1-27. (Estuarine Process Research Project, CEFAS, March 2003 Report).

BORROS, F., 2001. Ghost crab as a tool for rapid assessment of human impacts on exposed sandy beaches. Biol. Conserv., **97**: 399-404.

BOTTO F., G. PALOMO, O. IRIBARNE & M. MARTINEZ, 2000. The effect of southwestern Atlantic burrowing crabs on habitat use and foraging activity of migratory shorebirds. Estuaries, **23**: 208-215.

BRADSHAW, C. & T. P. SCOFFIN, 1999. Factors limiting distribution and activity pattern of the soldier crab *Dotilla myctiroides* in Phuket, South Thailand. Mar. Biol., Berlin, **135**: 83-87.

BUCHANAN, J. B., M. SHEADER & P. F. KINGSTON, 1978. Sources of variability in the benthic macrofauna off the south Northumberland coast, 1971-1976. Journ. mar. biol. Assoc. U.K., **58**: 191-209.

BUTLER, S. & F. L. BIRD, 2007. Estimating density of intertidal ghost shrimps using counts of burrow openings. Is the method reliable? Hydrobiol., **589**: 303-314.

CHHAPGAR, B. F., 1957. On the marine crabs (Decapoda Brachyura) of Bombay State. Journ. Bombay nat. Hist. Soc., **54**: 399-439.

CHHAPGAR, B. F. & T. MUNDKUR, 1995. Occurrence of the crab *Euxanthus exsculptus* (Herbst) in Gujarat. Journ. Bombay nat. Hist. Soc., **92**: 286.

CHHAPGAR, B. F., S. H. PATEL & B. S. DESAI, 2004. On two interesting marine crabs (Decapoda: Brachyura) from Mandvi, Kutch. Journ. Bombay nat. Hist. Soc., **101**: 184-186.

DITTEL, A. I., A. H. HINES, G. M. RUIZ & K. K. RUFFIN, 1995. Effect of shallow water refuge on behavior and density-dependent mortality of juvenile blue crabs in Chespaeake Bay. Bull. mar. Sci., **57**: 902-916.

FLINT, R. W., 1981. Gulf of Mexico outer continental shelf benthos macrofaunal-environmental relationships. Biol. Ocean., **1**: 135-155.

FLORES, A. V., G. K. ABRANTES & J. PAULA, 2005. Estimating abundance and spatial distribution patterns of the bubble crab *Dotilla fenestrate* (Crustacea: Brachyura). Australian Ecol., **30**: 14-23.

FOLK, R. L. & W. C. WARD, 1957. Brazos River Bar: a study in the significance of grain size parameters: Journ. Sediment Petrol., **27**: 3-26.

FRUSHER, S. D., R. L. GIDDINS & T. J. SMITH, 1994. Distribution and abundance of grapsid crabs (Grapsidae) in a mangrove estuary: effects of sediment characteristics, salinity tolerances, and osmoregulatory ability. Estuaries and Coasts, **17**: 647-654.

GLÉMAREC, M., 1973. The benthic communities of the European North Atlantic continental shelf. Oceanogr. mar. Biol. annu. Rev., **11**: 263-289.

KHAN, A. S., S. M. RAFFI & P. S. LYLA, 2005. Brachyuran crab diversity in natural (Pitchavaram) and artificially developed mangroves (Vellar estuary). Curr. Sci., **88**: 1316-1324.

LEME, M. H. A., 2002. A comparative analysis of the population biology of the mangrove crabs *Aratus pisonii* and *Sesarma rectum* (Brachyura, Grapsidae) from the north coast of São Paulo State. Brazilian Journ. Crust. Biol., **22**: 553-557.

MORRISEY, D. J., S. J. TURNER & A. B. MACDIARMID, 1998. Subtidal assemblages of soft substrata. In: M. KINGSFORD & C. BATTERSHILL (eds.), Studying temperate marine environments: a handbook for ecologists: 194-226. (Canterbury University Press, Canterbury, New Zealand).

NOBILI, G., 1906. Diagnoses préliminaires de Crustacés, Décapodes et Isopodes nouveaux recueillis par M. le Dr. G. Seurat aux îles Touamotou. Bull. Mus. Hist. nat. Paris, **12**: 256-270.

ORTMANN, A., 1897. Carcinologische Studien. Zoologische Jahrbücher, (Syst.) **10**: 258-372.

PETER, M. J., J. J. MIDDELBURG & H. R. HEIP, 2001. Benthic community structure and sediment processes on an intertidal flat: results from the ECOFLAT project. Cont. Shelf Res., **21**: 2055-2071.

RAMANANDAN, R., 1966. On the occurrence of *Porcellanella picta* Stimpson (Decopoda: Anomura) in the Gulf of Kutch. Journ. Bombay nat. Hist. Soc., **63**: 770-771.

RIBEIRO, P. D., O. O. IRIBARNE & P. DALEO, 2005. The relative importance of substratum characteristics and recruitment in determining the spatial distribution of the fiddler crab *Uca uruguayensis* Nobili. Journ. exp. mar. Biol. Ecol., **314**: 99-111.

SAKAI, T., 1965. The crabs of Sagami Bay collected by His Majesty the Emperor of Japan: 1-206. (Maruzen Co. Ltd., Tokyo).

SANDERS, H. L., 1958. Benthic studies in Buzzards Bay. I. Animal sediment relationships. Limnol. Oceanogr., **3**: 245-258.

SETHURAMALINGAM, S. & S. A. KHAN, 1991. Brachyuran crabs of Parangipettai: 1-93. (Annamalai University, city?).

SHERIDAN, P. F., 1992. Comparative habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, Florida. Bull. mar. Sci., **50**: 21-39.

SNELGROVE, P. V. R. & C. A. BUTMAN, 1994. Animal sediment relationship revisited: cause versus effect. Oceanogr. mar. Biol. annu. Rev., **32**: 111-177.

SOUTHWELL, T., 1909. Report on the Anomura collected by Mr. James Hornell at Okhamandal in Kathiawar in 1905-6. Mar. Zool. of Okhamandal, **1**: 105-123.

TRAVIS, J., 1996. The significance of geographical variation in species interactions. American Natural., **148**: S1-S8.

VIRNSTEIN, R. W., 1987. Sea grass-associated invertebrate communities of the southeastern USA: a review. In: M. J. DURAKO, R. C. PHILLIPS & R. R. LEWIS (eds.), Proceedings of the Symposium on Subtropical-Tropical Sea Grasses of the Southeastern United States: 89-116. (Florida Marine Research Publications, Florida Department of Natural Resources Bureau of Marine Research, city?).

WARREN, J. H., 1990. The use of open burrow to estimate abundance of intertidal estuarine crabs. Australian Journ. Ecol., **15**: 27-280.

WEISSBURG, M., 1992. Functional analysis of fiddler crab foraging: sex specific mechanics and constraints in *Uca pugnax* (Smith). Journ. exp. mar. Biol. Ecol., **156**: 105-124.

ZINGDE, M. D., P. SHARMA & M. M. SABNIS, 1985. Physico-chemical investigations in Auranga River estuary. Mahasagar, **18**: 307-321.

First received 7 April 2009.
Final version accepted 31 May 2010.

Birds of Mahi River estuary, Gujarat, India

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The Mahi River is one of the major rivers of Gujarat. The estuarine stretch extending up to 50km was considered for the present study. The vast and complex ravines of the Mahi River make the habitat more suitable for terrestrial birds just in the vicinity of the river channel. The salinity flux, a typical estuarine character, also provides a freshwater habitat upstream while the estuarine mouth downstream can be considered as a high marine influenced zone. These eventually may result in changes in the inhabitant water fowl community. Sparse studies have been carried out and documented so far for the Mahi Estuary. The estuary has been studied previously by Jadhav & Parasharya (2004) who detailed the distribution of flamingoes at Khambhat and Dhuvaran (downstream of the Mahi). Work has been done on the avian diversity of Vadodara District which covers some part of the present study area (Padate et al. 2001). Moreover, literature surveys of a few years show notes of some important sightings like Black-necked Stork and Blue-tailed Bee-eater (Patel 2008). Unusual sightings of Crab Plovers (*Dromas ardeola)* have been reported by Parasharya (2008) on Dhadhar Estuary, Gulf of Khambhat; whereas it is well reported in Gulf of Kutch (Palmes & Briggs 1986). In the present study the same was sighted at the mouth of the Mahi Estuary which could be the supportive observation and new for the upper part of Gulf of Khambhat. The present study provides a comprehensive checklist of birds of the Mahi Estuary by covering more than 15 sites along the estuarine stretch.

Date of publication (online): 26 June 2010
Date of publication (print): 26 June 2010
ISSN 0974-7907 (online) | 0974-7893 (print)

Editor: Nishith Dharaiya

Manuscript details:
Ms # o2316
Received 17 September 2009
Final received 12 January 2010
Finally accepted 06 April 2010

Citation: Pandya, P.J. & K.D. Vachhrajani (2010). Birds of Mahi River estuary, Gujarat, India. *Journal of Threatened Taxa* 2(6): 994-1000.

Acknowledgements: The authors are thankful to the Department of Science and Technology, New Delhi, India, for financial assistance. PJP is thankful for the award of fellowship under the scheme.

Study Area

The Mahi estuarine stretch extends up to 50km, from Kamboi (22°12'52.38"N & 72°37'17.89"E) to Fajalpur (22°26'08.95"N & 73°04'26.98"E) (Fig. 1). The estuarine belt covers around 50km passing through Anand, Vadodara and Bharuch districts. The uppermost reaches (Fajalpur and Vasad) typically serve as freshwater habitat with floating and emergent vegetation, very rarely having saline flux; while the lowest reaches (Kamboi and Khambhat) reflect marine habitat with daily tidal cycles. The estuarine part also provides the isolated islands in the channel and the ravines and cliffs on the adjacent banks at many sites which serve as good habitat for the terrestrial birds. Aquatic pollution due to industrial effluents is the major cause of the degradation of the habitat.

Materials and Methods

The study was conducted from August 2006 to July 2009. Salinity was measured from different sites using handheld refractometer (ERMA made) with salinity range of 1-100 ppt. Salinity less than 1ppt from upstream reaches was measured using titrimetric method ($AgNO_3$) (Eaton et al. 1995). For the sake of convenience, easy understanding of estuarine dynamics and to check variations in avian distribution, the estuary was divided into upstream (Fresh water condition: 0.05-0.1 ppt), midstream (Oligohaline condition: 0.09-1.6 ppt) and downstream (Euhaline condition: 9.6-39.3 ppt) based on the monitored salinity status and range. The study area was covered by delineating 15 different stations along the estuary covering all different parts. Birds were observed libitum using binoculars and identified using standard field guides (Ali 1996; Grimmett et al. 1998). Aquatic birds of the Mahi Estuary as well as the birds of the adjacent ravines/banks within the vicinity of 50m were recorded. In case of complications in identification, especially of gulls and terns, photographs were taken when possible and later identified. Data were divided into upstream, midstream and downstream and was further compiled and subjected to similarity (Jaccards and Sorenson indices) and diversity indices (Shannon-Wiener, Simpson and Berger Parker) using PAST statistical software.

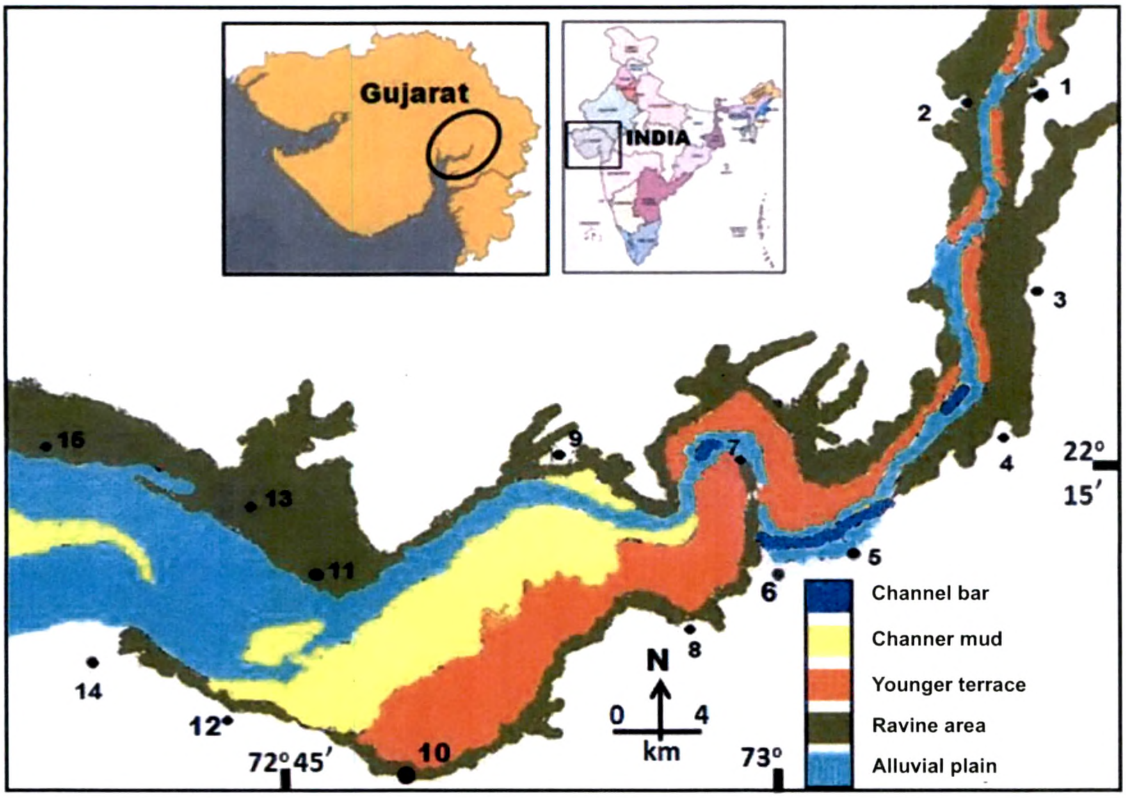

Figure 1. Study site Mahi River Estuary from Fajalpur (Vasad – Upstream) to downstream (Kamboi). Spots showing the locations of the different observation points along the river. (1-3 Upstream, 4-9 Midstream, 10-15 Downstream)
1 - Fazalpur; 2 - Vasad; 3 - Umeta; 4 - Gambhira; 5-Mujpur; 6 - Dabka; 7 - Mohammadpura; 8 - Chokari; 9 - Badalpur; 10 - Sarod; 11 - Dhuvaran; 12 - Nahar; 13 - Bajipur; 14 - Kamboi; 15 - Khambhat.

Results and Discussion

A total of 118 species were reported belonging to 42 families during the study period (Appendix 1). Although, some of the families were represented by one or two species, family Scolopidae dominated with 10 representatives (Table 1) and was mainly confined to the lower reaches of the estuary. Species richness was higher upstream with 68 species contributing 37% of the total number followed by midstream 63 species (33%) and downstream 57 species (30%) (Fig. 2). However, no significant difference in diversities among the three zones was noted (Table 2). Jaccard's and Sorenson's similarity indices depicted higher similarity between upstream and midstream followed by midstream and downstream. The higher diversity in upstream and midstream can probably be attributed to the appropriate feeding landscape available for aquatic birds and the adjacent bushy habitat in the gorges and ravines for terrestrial birds.

Conclusively, it can be stated that the Mahi Estuary and the adjacent ravines/gorges and bushy habitat within provides excellent environment for a variety of birds. As the present investigation did not include a detailed study of interior ravines, further surveys in the ravines and adjacent terrestrial region can certainly make a good addition to the present checklist.

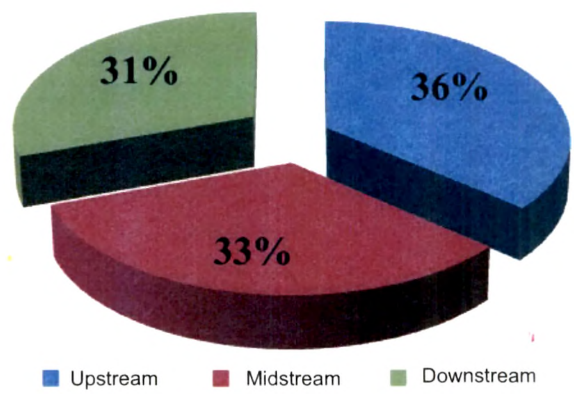

Figure 2. Percentage species richness along the three estuarine gradations.

The upstream estuarine region is closer to the Vadodara industrial zone dominated by petrochemical and other organic industries. However, the effluent discharges of these industries are released in the lower estuarine region through Asia's longest effluent channel. Therefore, the animal diversity and density in certain polluted pockets of the lower estuarine region is very low leading to lesser diversity of dependent avifauna. The freshwater upstream site has religious importance

Table 1. Species richness of the reported families from the study area.

	Family	No. species		Family	No. species
1	Phasianidae	2	22	Podicipedidae	1
2	Anatidae	5	23	Ardeidae	9
3	Upupidae	1	24	Phoenicopteridae	1
4	Alcedinidae	2	25	Threskiornithidae	4
5	Meropidae	2	26	Pelecanidae	1
6	Cuculidae	3	27	Ciconiidae	3
7	Psittacidae	1	28	Laniidae	1
8	Apodidae	1	29	Corvidae	3
9	Strigidae	1	30	Oriolidae	1
10	Columbidae	5	31	Dicruridae	1
11	Gruidae	1	32	Thurdinae	4
12	Rallidae	3	33	Sturnidae	3
13	Rostratulidae	1	34	Hirundinidae	4
14	Scolopacidae	10	35	Pycnonotidae	2
15	Burhinidae	1	36	Cisticolidae	2
16	Recurvirostridae	1	37	Sylviidae	7
17	Charadriidae	3	38	Alaudidae	1
18	Jacanidae	2	39	Nectariniidae	1
19	Dromadidae	1	40	Passeridae	1
20	Laridae	8	41	Montacillidae	7
21	Accipitridae	6	42	Phalacrocoracidae	1

resulting in high pilgrim pressure. However, since the long term quantitative data on pilgrim inflow is not available, it cannot be correlated with present avifaunal diversity. Further, the analysis of biomagnifications of pollutants and their influences on avifauna require a long term study; it is not possible to establish direct relationship between these factors and the present avifauna. It can be suggested that the increased human interventions in the upstream areas and the pollution stress on the downstream habitat may pressurize the estuarine complex and, if not mitigated, can eventually result in decrease in avifaunal diversity.

Table 2. Similarity and diversity index at different estuarine zones

Study Site	Similarity Index		Study Site	Diversity Index		
	Jaccard Index SC_J	Sorrenson Index SC_s		Shannon Index	Simpson Index	Berger-Parker Index
Upstream-Midstream	0.28	0.56	Upstream	4.22	0.985	0.01
Upstream - Downstream	0.17	0.35	Midstream	4.14	0.984	0.01
Midstream - Downstream	0.26	0.53	Downstream	4.06	0.982	0.01

REFERENCES

Ali, S. (1996). *The Book of Indian Birds.* Bombay Natural History Society, Bombay, 354pp.

Eaton, A.D., L.S. Clesceri & A.E. Greenberg (1995). *Standard Methods for the Examination of Water and Waste Water (19th edition).* United Books Press Inc. Batimore, Maryland, U.S.A., 1126pp

Grimmett, R., C. Inskipp & T. Inskipp (1998). *Birds of the Indian Subcontinent.* Oxford University Press, Delhi, 888pp.

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

Padate, G.S., S. Sapna & R.V. Devkar (2001). Status of birds in Vadodara District (Central Gujarat). *Pavo* 39: 83-94.

Palmes, P. & C. Briggs (1986). Crab Plovers *Dromas ardeola* in the Gulf of Kutch. *Forktail* 1: 21-22.

Parasharya, B.M., C.K. Borad & D.N. Rank (2004). *A Checklist of the Birds of Gujarat.* Bird Conservation Society, Gujarat, 185pp.

Parasharya, D. (2008). Crab Plover at Dhadhar Estuary in Bharuch District. *Flamingo* 6(3&4): 10.

Patel, P. (2008). Breeding record of Blue-tailed Bee-eater near Vadodara. *Flamingo* 6(3&4): 10.

Appendix 1. Checklist of birds with their location distribution.

	Family/Common name	Scientific name	Status	Up stream	Mid stream	Down stream
	Phasianidae					
1	Grey Francolin	*Francolinus pondicerianus*	RB	-	-	+
2	Indian Peafowl	*Pavo cristatus*	RB	-	-	+
	Anatidae					
3	Lesser Whistling Duck	*Dendrocygna javanica*	RB	+	+	-
4	Greylag Goose	*Anser anser*	M	+	+	-
5	Brahminy Duck	*Tadorna ferruginea*	M	+	+	-
6	Spot-billed Duck	*Anas poecilorhyncha*	RB	+	-	-
7	Comb Duck	*Sarkidiornis melanotos*	RB	+	-	-
	Upupidae					
8	Common Hoopoe	*Upupa epops*	M	-	-	+
	Alcedinidae					
9	White-throated Kingfisher	*Halcyon smyrnensis*	RB	+	+	+
10	Lesser Pied Kingfisher	*Ceryle rudis*	RB	+	+	-
	Meropidae					
11	Small Green Bee-eater	*Merops orientalis*	R	+	+	+
12	Blue-tailed Bee-eater	*Merops phillippinis*	RB	+	-	+
	Cuculidae					
13	Pied Cuckoo	*Clamator jacobinus*	rS	+	-	-
14	Asian Koel	*Eudynamys scolopacea*	RB	+	+	+
15	Greater Coucal	*Centropus sinensis*	RB	+	+	+
	Psittacidae					
16	Rose-ringed Parakeet	*Psittacula krameri*	RB	+	+	+
	Apodidae					
17	House Swift	*Apus affinis*	RB	+	-	-
	Strigidae					
18	Spotted Owlet	*Athene brama*	RB	-	+	+
	Columbidae					
19	Blue Rock Pigeon	*Columba livia*	RB	+	+	+
20	Oriental Turtle Dove	*Streptopelia orientalis*	M	-	+	+
21	Spotted Dove	*Streptopelia chinensis*	RB	-	+	+
22	Eurasian Collared Dove	*Streptopelia decaocto*	RB	-	+	-
23	Yellow-footed Green Pigeon	*Treron phoenicoptera*	RB			
	Gruidae					
24	Common Crane	*Grus grus*	M	-	+	-
	Rallidae					
25	White-breasted Waterhen	*Amaurornis phoenicurus*	RB	+	-	-
26	Purple Swamphen	*Porphyrio porphyrio*	RB	+	-	-
27	Common Coot	*Fulica atra*	RB,M	+	-	-
	Rostratulidae					
28	Fantail Snipe	*Gallinago gallinago*	M	+	-	-
	Scolopacidae					
29	Black-tailed Godwit	*Limosa limosa*	M	-	-	+
30	Eurasian Curlew	*Numenius arquata*	M	-	-	+
31	Common Redshank	*Tringa totanus*	M	-	-	+
32	Marsh Sandpiper	*Tringa stagnatilis*	M	+	+	-
33	Common Greenshank	*Tringa nebularia*	M	-	-	+
34	Green Sandpiper	*Tringa ochropus*	M	-	+	-
35	Common Sandpiper	*Actitis hypoleucos*	M	+	+	-

	Family/Common name	Scientific name	Status	Up stream	Mid stream	Down stream
36	Sanderling	*Calidris alba*	M	-	-	+
37	Little Stint	*Calidris minuta*	M	+	+	-
38	Curlew Sandpiper	*Calidris ferruginea*	M	-	-	+
	Burhinidae					
39	Great Thick-knee	*Esacus recurvirostris*	RB	+	-	-
	Recurvirostridae					
40	Black-winged Stilt	*Himantopus himantopus*	RB	+	+	-
	Charadriidae					
41	Red-wattled Lapwing	*Vanellus indicus*		+	+	+
42	Little-ringed Plover	*Charadrius dubius*	M	+	-	+
43	Kentish Plover	*Charadrius alexandrinus*	RB	-	-	+
	Jacanidae					
44	Phesant-tailed Jacana	*Hydrophasianus chirurgus*	RB	+	-	-
45	Bronze-winged Jacana	*Metopidius indicus*	RB	+	-	-
	Dromadidae					
46	Crab Plover	*Dromas ardeola*	M	-	-	+
	Laridae					
47	Brown-headed Gull	*Larus brunnicephalus*	M	-	-	+
48	Black-headed Gull	*Larus ridibundus*	M	-	-	+
49	Slender-billed Gull	*Larus genei*	M	-	+	-
50	Yellow-legged Gull	*Larus cachinnans*	M	-	+	-
51	Gull-billed Tern	*Gelochelidon nilotica*	M	-	+	+
52	Caspian Tern	*Sterna caspia*	RB,M	-	+	+
53	River Tern	*Sterna aurantia*	RB	+	+	+
54	Common Tern	*Sterna hirundo*	M	-	+	-
	Accipitridae					
55	Black-shouldered Kite	*Elanus caeruleus*	RB	-	-	+
56	Black Kite	*Milvus migrans*	RB	+	-	-
57	Brahminy Kite	*Haliastur indus*	RB	-	+	-
58	Western Marsh Harrier	*Circus aeruginosus*	M	-	+	+
59	Montagu's Harrier	*Circus pygargus*	M	-	-	+
60	Shikra	*Accipiter badius*	RB	-	+	+
	Podicipedidae					
61	Little Grebe	*Tachybaptus ruficollis*	RB	+	-	-
	Phalacrocoracidae					
62	Little Cormorant	*Phalacrocorax niger*	RB	+	+	-
	Ardeidae					
63	Little Egret	*Egretta garzetta*	RB	+	+	-
64	Western Reef Egret	*Egretta gularis*	RB	-	+	+
65	Grey Heron	*Ardea cinerea*	RB	+	+	-
66	Purple Heron	*Ardea purpurea*	RB	+	-	-
67	Great Egret	*Casmerodius albus*	RB	-	+	+
68	Intermediate Egret	*Mesophoyx intermedia*	RB	+	+	+
69	Cattle Egret	*Bubulcus ibis*	RB	+	-	+
70	Indian Pond Heron	*Ardeola grayii*	RB	+	+	+
71	Black-crowned Night Heron	*Nycticorax nycticorax*	RB	+	-	-
	Phoenicopteridae					
72	Lesser Flamingo	*Phoenicopterus minor*	RB,M	-	+	+
	Threskiornithidae					
73	Glossy Ibis	*Plegadis falcinellus*	RB,M	+	-	-

	Family/Common name	Scientific name	Status	Up stream	Mid stream	Down stream
74	Black-headed Ibis	*Threskiornis melanocephalus*	RB	+	+	-
75	Black Ibis	*Pseudibis papillosa*	RB	+	+	-
76	Eurasian Spoonbill	*Platalea leucorodia*	RB,M	-	+	-
	Pelecanidae					
77	Great White Pelican	*Pelecanus onocrotalus*	RB,M	-	+	-
	Ciconiidae					
78	Painted Stork	*Mycteria leucocephala*	RB	+	+	+
79	Asian Openbill	*Anastomus oscitans*	RB	+	+	+
80	White-necked Stork	*Ciconia episcopus*	RB	-	+	-
	Laniidae					
81	Bay-backed Shrike	*Lanius vittatus*	RB	-	-	+
	Corvidae					
82	Indian Treepie	*Dendrocitta vagabunda*	RB	+	+	+
83	House Crow	*Corvus splendens*	RB	+	+	+
84	Jungle Crow	*Corvus macrorhynchos*	RB	+	+	-
	Oriolidae					
85	Eurasian Golden Oriole	*Oriolus oriolus*	M	-	-	+
	Dicruridae					
86	Black Drongo	*Dicrurus macrocerus*	RB	+	+	+
	Turdinae					
87	Oriental Magpie Robin	*Copsychus saularis*	RB	+	+	+
88	Indian Robin	*Saxicoloides fulicata*	RB	+	+	-
89	Common Stonechat	*Saxicola torquata*	M	-	+	-
90	Pied Bushchat	*Saxicola caprata*	M	-	+	-
	Sturnidae					
91	Rosy Starling	*Sturnus roseus*	M	-	-	+
92	Common Myna	*Acridotheres tristis*	RB	+	+	+
93	Bank Myna	*Acridotheres ginginianus*	RB	+	+	+
	Hirundinidae					
94	Dusky Crag Martin	*Hirundo concolor*	RB	+	-	-
95	Common Swallow	*Hirundo rustica*	M	-	-	+
96	Wire-tailed Swallow	*Hirundo smithii*	RB	+	-	-
97	Red-rumped Swallow	*Hirundo daurica*	M	+	-	-
	Pycnonotidae					
98	White-eared Bulbul	*Pycnonotus leucotis*	RB	-	-	+
99	Red-vented Bulbul	*Pycnonotus cafer*	RB	+	+	+
	Cisticolidae					
100	Ashy Prinia	*Prinia socialis*		+	-	-
101	Plain Prinia	*Prinia inornata*		+	+	-
	Sylviidae					
102	Thick-billed Warbler	*Acrocephalus aedon*	V	-	-	+
103	Indian Great Reed Warbler	*Acrocephalus stentoreus*	RB,M	+	-	-
104	Booted Warbler	*Hippolais caligata*	M	+	-	-
105	Common Tailorbird	*Orthotomus sutorius*	RB	-	+	+
106	Common Babbler	*Turdoides caudatus*	RB	-	+	+
107	Large Grey Babbler	*Turdoides malcolmi*	RB	-	+	-
108	Jungle Babbler	*Turdoides striatus*	RB	+	+	-
	Alaudidae					
109	Black-crowned Sparrow-Lark	*Eremopterix nigriceps*	R	-	-	+

	Family/Common name	Scientific name	Status	Up stream	Mid stream	Down stream
	Nectariniidae					
110	Purple Sunbird	*Nectarinia asiatica*	RB	+	-	-
	Passeridae					
111	House Sparrow	*Passer domesticus*	RB	-	+	+
	Motacillidae					
112	White Wagtail	*Motacilla alba*	M	+	-	-
113	Large Pied Wagtail	*Motacilla maderaspatensis*	RB	+	-	-
114	Yellow Wagtail	*Motacilla flava*	M	+	-	-
115	Grey Wagtail	*Motacilla cinerea*	M	+	-	-
116	Tawny Pipit	*Anthus campestris*	M	-	-	+
117	Baya Weaver	*Ploceus philippinus*	RB	+	-	-
118	White-throated munia	*Lonchura malabarica*	RB	+	+	-

R - Residents; RB - Resident Breeding (breeding recorded in Gujarat); M - Migratory; S - Summer visitor; V - Vagrant
+ - Present, - - Absent

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Original Scientific Photographs

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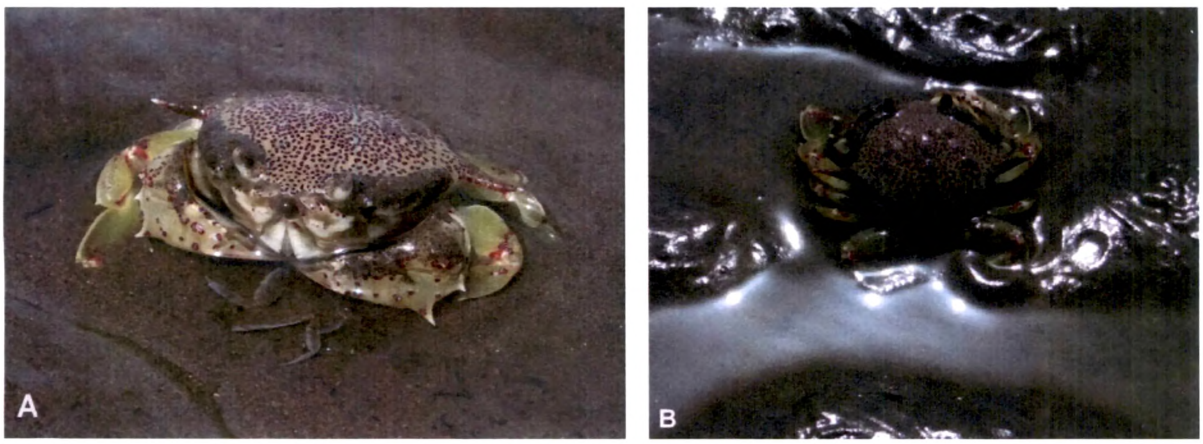

The Decapoda crab *Matuta planipes* (*Fabricius*, 1798) is usually found in marine reaches as well as mouth of estuaries. It belongs to family Calappidae. It is distributed from Southeast Asia to Australia and westward to India. This crab is known and reported as predator of flounder fishes. Mostly found in sandy zones and showed typical predatory behavior. On 27th July 2008 we observed adult M. *planipes* (Carapace width = 8 cm including lateral spines) predating on other crab *Macrophthalmsus dilatatus* (Lancheser, 1900), on the intertidal reach of Mahi river estuary (22º12'52.38" N - 72º37'17.89" E), Gujarat, India. The crab partially buries itself under the sandy substrata and predates on the other inhabitant *M. dilatatus* abundant in sandy zone. Also, observation and sampling of the area from 2006 to 2008 illustrated that both the predator and prey species were specific in substratum preference and habitat utility (90 -94% sand and 6-10% silt-clay). Picture characteristics: Canon PowerShot S70; Resolution of 4 megapixels; autofocus; automatic regulation; Image cropped.

References

Ng, P. K. L., Guinot D. and Davie P. J. F., 2008. Systema Brachyurorum: Part 1: An annotated checklist of extant brachyuran crabs of the world. **The Raffles Bulletin of Zoology**., 17: 1-286.

Hossain, M. A. R and Tanaka, M. 2002. Predator-prey interaction between hatchery-reared Japanese flounder juvenile, *Paralichthys olivaceus* and sandy shore crab, *Matuta lunaris*: daily rhythms, anti-predator conditioning and starvation. **J. Exp. Mar. Biol. And Ecol**. 26: 1-14.

Fatima, M. 2003. Length weight study of two species of crabs *Matuta planipes* and *Matuta lunaris* from Karachi, Pakistan. **Pakistan Journal of Biological Science**, 6(4):397-398.

BENTHIC COMMUNITY STRUCTURE OF MAHI RIVER ESTUARY WITH SPECIAL REFERENCE TO ANIMAL SEDIMENT RELATIONSHIP

Thesis submitted to

The Maharaja Sayajirao University of Baroda

For the award of

सत्यं शिवं सुन्दरम्

Doctor of Philosophy

in

Zoology

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JANUARY 2011

SUMMARY

An ecosystem is a complex matrix in which biotic and abiotic components interact and influence each other directly or indirectly. Estuaries are amongst the critical zones that form an ecotone which serve as buffer; linking land, freshwater habitat and the marine habitat. Estuaries have been studied with reference to hydrodynamics, oceanographic influences, migratory bird supporting wetlands and biotic diversity by researchers of different disciplines. During last couple of decades the anthropogenic activities have induced changes in varied aspects of estuarine ecosystem. Several reports demonstrated dependence of estuarine faunal diversity and distribution of physical and physico-chemical features. The hydrodynamic fluctuations result in surge in temperature, salinity, hardness and water column and some other parameters thus restricting the animal diversity in the harsh environment. The complexity of estuarine ecosystem thus creates dynamic critical mosaics which are challenges to understanding

Estuaries are important natural places. Since histories, estuaries have been of importance to humans and civilizations. Mankind has preferred to be settled on the river banks or near estuaries. An estuary provides settlements, food and transport to humans. Thus they have always been esthetically important. They provide goods and services that are economically and ecologically indispensable.

Estuaries harbor unique faunal and floral biota due to the constant water flux in terms of salinity and other water quality parameters. They are often called nurseries of the sea where they provide breeding, feeding and nesting ground for many of the faunal groups. Estuaries produce very high amount of organic matter as well as provide variety of habitats and microhabitats which is the cause of attraction for many of the marine animals. Many of the organisms make estuaries their permanent home while some of them pass only a part of their lifecycle in estuaries. Benthic fauna are the vital component of the estuarine food chain. Most of the benthos feed on either

detritus or the organic matter thus controlling the ecological functioning. In estuary, these organisms work as a super creatures adapting to the harshness of the environment. On the estuarine intertidal mudflats, they are acted upon by variety of environmental factors like desiccation stress, temperature, predation and change in salinity etc. Moreover, the daily tidal fluctuations imply flux in water quality and sediment depositions.

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, hydrodynamics and high tidal amplitude. 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,

Mahi River (583 km long and 34,842 km in drainage surface) is one of the major rivers of Gujarat. It originates from the Mahi Kanta hills in the Vindhyachal ranges of Madhya Pradesh. The Mahi River basin spreads over Rajasthan, Madhya Pradesh and Gujarat states. The estuarine stretch of Mahi river extends up to 50 km upstream (Vasad - 22° 26 'N and 73° 04 'E) and opens into Gulf of Khambhat at Kamboi (22° 12 N and 72° 36 °E).

For convenience of the study, the entire estuary was divided into 3 zones; Upstream, Midstream and Downstream based on salinity, total dissolved solids as well as area division. In general, the study area comprises of various geomorphic features, such as total freshwater region, freshwater and marine mixing zone, lagoon, small uplands, sand flats/dunes, tidal mudflats, ridge and runnel systems and fine sandy low intertidal areas. A total of 14 sites were considered for present studies of which 10 sites were located on the south bank and 4 sites were located on the north bank of Mahi estuary. The section wise distribution was; 4 sites in upstream, 5 sites in midstream and 5 sites in downstream. Since all the sites were not approachable throughout the year, particularly during monsoon, Fajalpur from upstream, Dabka from midstream and Sarod and Kamboi from downstream were considered as representative sites and visited frequently for studies.

Comparatively very sparse published data exists on the benthic diversity from estuaries of Gujarat. The Indian literature is very sparse on benthic fauna and their habitat association studies.

Fig. 1: The study area.

In order to apply overall justification to the study and for correlation, abiotic, biotic sampling was done with water and sediment assessment as part of abiotic study while benthic faunal study from various aspects as part of the biotic curriculum. The aim of the study was to integrate classical study in form of taxonomy, basic abiotic status and distribution with recent approaches like behaviour, animal-sediment relationship etc using newer methods like resin casting, Pipe core and X-ray study, Computer tomography (CT scan study). More or less the study rolled in following phases:

Understanding the study area (Habitat assessment – geomorphology)

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Baseline survey of abiotic condition (water and sediment study)

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Benthic faunal diversity assessment and proper identification

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Animal distribution and density (along the estuary and the intertidal area)

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Animal-sediment relationship

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Probable correlations

The preliminary survey and the prevalent hydrodynamics classify the Mahi estuary as a partially mixed kind wherein the marine influx mostly dominates the riverine output. The midstream and downstream shows high amount of churning of bed material during tides. Moreover, the estuary shows prominent meandering at several points which has caused prominent erosional and depositional sites. The generalized overview to the sedimentological features states that upstream site is dominated by sandy bed material and bank depositions. Interestingly, the lower estuarine part prominently shows a mudflat zone on the intertidal side adjoining the younger terrace. These mudflats, distinctively seen at Kamboi and adjoining lower estuarine sites are one of the vital parts of the Mahi estuary serving as an important habitat for benthic fauna. Furthermore, as an anthropogenic addition, the common industrial effluent channel running 55km from the industrial belt of Vadodara opens into the downstream site of Mahi estuary (Sarod) and releases treated effluent at an average rate of 145 million liters per day into the Mahi estuary. A beach slope was seen from upper intertidal zone to lower intertidal area at Kamboi. Overall, an elevation difference of 8 m was found over the study area, from the upper surf zone to the lower intertidal mark. Based on sediment analysis, five distinct zones were identified from upper to lower intertidal line respectively. Each zone represented a specific nature in terms of sedimentology or topographic features. Zone 3 and 4 dominated with silt and clay making them a muddy habitat. The lowermost intertidal area Zone-5, was mostly dominated by fine sand.

Various water quality parameters like pH, total alkalinity, acidity, phosphate, salinity, total hardness and total and dissolved solids (TS and TDS) were analyzed individually for upstream, midstream and downstream as well as compared. One way ANOVA was used to compare the parameters at three estuarine grades (upstream, midstream and downstream). Salinity, total hardness, TS and TDS were the governing factors which defined the estuarine gradient and their peak values were observed towards downstream while opposite was the case with upstream.

Data were analyzed and represented at 3 levels in following fashion;

- At estuarine gradient (upstream, midstream, downstream)
- Comparison among different zones at Kamboi
- Depth wise comparison for selected zones in Kamboi.

Sediment composition, organic matter, bulk density and water holding capacity were the main aspects wherein upstream had sandy composition, midstream and downstream had silty-clayey composition. Pertaining to varied sedimentological aspect, variation was seen in total carbon and sediment organic matter among different zones at Kamboi. Zone-3 appeared as an organic matter rich zone (SOM 3.26 ± 0.86) followed by Zone-4 (1.38 ± 1.14), Zone-5 (1.0 ± 0.83) and Zone-2 (0.84 ± 0.66). High amount of organic matter in Zone 3 and 4 can be one of the strong reasons of high density of crabs in respective zones. Overall, a very small variation was seen between upstream and downstream values, while midstream showed lower values.

Animal Collection and Preservation: Benthic animals were collected on field and carried to the laboratory for further preservation. The macrofauna like crabs, mollusks, polychetes were collected, narcotized with either menthol crystals or adding freshwater in case of crabs to avoid shrinking of appendages.

Foraminiferan sampling: During the course of study sediment samples for foraminiferan analysis were collected to in different ways depending on the site of collection. A core of nearly 1.5m was taken from downstream Kamboi mudflat for depthwise analysis. Regular cores of 36cm were also used for the purpose. In midstream site where coring was not possible, a vertical trench was made on the exposed bank by removing superficial eroded sediment. In case of upstream, in order to obtain a marine clay traces (having foraminifera), a trench was dug which showed different layers of sediments which were collected for analysis.

Quantitative Faunal Studies (Transects, Quadrates and Biomass): In order to reveal the brachyuran crab distribution on the estuarine intertidal area, transect sampling method was employed. A total 16 line transects, extending up to 175 m perpendicular to the shore line (surf zone to lower intertidal area) and covering all specified regions, were laid, spreading nearly 5 km of the length of the estuary. A burrow count technique involving counting of open burrows falling on transects line was employed to analyse the density and distribution pattern, keeping in mind both efficiency and reliability of the method. Quadrate sampling (0.25 X 0.25 m) was done for each zone randomly and amplified to density per sq. m. Multiple quadrates were taken from each zone to study the distribution pattern, as well as to minimize the error and support the transect data. Biomass samples were taken by digging 25 cubic cm of the sediments. The sediments were sieved and after their separation the wet weight was recorded.

Burrow Casting: Species specific burrow architecture pattern exists in different macrofaunal groups. Burrows of crabs and mudskippers were casted in present study. Initially, paraffin wax (congealing point 58-60°C) was used. A clear cast epoxy resin was used and poured in burrows. Resin was allowed to stand and harden and was dug out finely to get a burrow model (Plate 4a). After reaching laboratory, the casts of different species were subjected to morphometric studies like burrow cast length, diameter at different levels (opening, trunk diameter, neck diameter, resting chamber diameter etc.), number of bending points, number of resting chambers etc. in order to get the detailed subsurface structure of the burrow.

Radiological Studies: In instances to check the subsurface biogenic structures, radiological tools were used. Pipe cores after sealing at the ends were carefully taken to the radiological laboratory. Digital X-ray of pipe cores were taken to see the inner burrow structure other fine structures. In case of finer biogenic structures produced by smaller benthos like amphipods, isopods and few polychetes, resin or wax casting was not possible and moreover, X-ray did not give substantial results. In such cases, sediments blocks were directly taken to the radiological laboratory and were studied using Computed Tomography Scan (CT Scan). The result generates a 3D view and was even able to slice the sediment block at required levels to see the complex burrow structure virtually.

Behavioural Studies: Cryptic activities of benthos on exposed intertidal area can be well studied by their behavioral displays. The track and trail marks, burrowing patterns, feeding and burrowing expels by crabs and other benthic forms are some of the indirect evidence which mark the presence of the species in the ecosystem and provides clues to habitat interactions. Track and trail marks of different species were visually and photographically documented and standardized. The burrowing pattern of different crabs, mudskipper and few arthropods were documented with their marking specificity and dimensions. The feeding range and pattern of crab species was studied by taking a scaled photograph and measuring the area covered by crab using Bersoft Image measure software.

In present studies, of the total 292 benthic faunal **species** obtained, 241 species were identified while 51 were unidentified while of these species were identified to family or genus level. The details of the obtained species is as under:

Category	Sub category		No. identified species	No. of unidentified species	Total no. of species
Benthic microfauna	Foraminiferans		22	09	31
	Ostracods		-	05	05
	Mollusca		-	05	05
	Total		22	25	41
Benthic macrofauna	Nemaotda		-	02	02
	Mollusca		24	-	24
	Sipuncula		-	01	01
	Annelida		-	03	03
	Arthropoda	Spider	-	01	01
		Crab	11	03	13
		Amphipod	01	00	01
		Isopod	-	01	01
		Barnacle	-	01	01
		Insect larvae	01	01	02
		Ant	01	-	01
	Chordata: Mudskipper		01	-	01
	Total		38	14	51
Associated fauna	Planktonic		60	15	65
	Avifauna		118	-	118
	Fishes		15	-	15
	Reptiles		01	-	01
	Mammals (Dolphin)		01	-	01
	Total		185	15	200
Grand Total			238	54	292

DISTRIBUTION PROFILE OF BENTHIC FAUNA

The distribution of obtained benthic faunal species followed an estuarine gradient as per their individual tolerance level and habitat/microhabitat availability. Traces of foraminiferans were found from slight upstream sediments which showed past marine evidences or rather occasional marine intrusion. Though the detailed qunatitative survey of foraminiferans was not possible during the study phase, the priliminary observations and sample analysis strongly suggests that the diversity and density of foraminiferans increased gradually as moving towards downstream. Mollusca remained predominantly distributed from upstream to downstream no matter the density varied from sparse to abundant. Rich molluscan assemblage was seen in upstream sites.

Crabs and mudskippers showed their presence staring from midstream sites to downstream, though on less occasions at midstream. Larval stages of crabs were mostly seen seetling at the midstream site instead of adult ones with exeptional case of few larger species like *scylla serrata* which intruded midstream and upstream occassionally along with high tides. *Neries sp.* showed occassional sightings between midstream and downstream which increased ultimately towards downstream. In case of arthropods, most of them viz. amphipods, isopods, spider, insect larva, ant sp. were reported only from the downstream sites. Distribution of Sipuncula sp. was restricted to downstream especially in the calcritized hard sediments of Kamboi.

Distribution of brachyuran crabs at Kamboi: Brachyuran crabs showed a heterogeneous distribution pattern on the estuarine intertidal area of Kamboi. Different crab species showed a zonal distribution starting from zone 2 to zone 5 respectively depending on the general beach profiling and sedimentological features. In case of brachyuran crab community, an increase in diversity of brachyuran species was noted as going from Zone 2 to Zone 5. Though, many of the species remained restricted to specific zone, few of the species even shared a common habitat/microhabitat and exhibited community overlapping. Zone 3 and 4 were the most comfort zone harbouring many common species like *Uca lactea*, *Cardisoma carnifex* and *Macrophthalmus depressus*.

Zone wise distribution/ habitat/ microhabitat preference: Zone 2 was predominantly covered by coastal grass and silty in composition. The area was only preferred by *Uca lactea annulipes*. Moreover, few arthropods like ants, beetles also inhabited the area as the area remained dry most of the time. Zone 3 with more silt and clay was the best preferred zone in terms of density of crabs. Even, zone 4 showed two distinct microhabitats; a gentle beach slope and a runnel system with pools and patches of hard substratum. In case of *mudskipper sp.* they mostly preferred a more watery condition within the zone and hence forth use to create depression in surrounding of their burrow to facilitate water logging. Moreover, the shallow water pools were occupied by mudskipper young ones and at some instances nemertine worm. A higher affinity to watery (loose) substratum was seen by polychete, *Neries sp.* which also inhibited sandy substratum at zone 5 in higher density, though the encounter rate of their juvenile form was more frequent. In many cases, in the exposed ends a fine layering of sediment was seen indicative of regular tidal deposition. *D.clepsydrodactyla* mostly preferred a gentle slope within Zone 4 mosaic with fine sandy plaster mixed with silt. In Zone 5, the hydrodynamics and the bed structures formed various types of rippels ranging from large to very small ones which provided a distinct microhabitat to animals. The same species distinctly used two different microhabitats and made a niche selection.

Burrowing pattern: *Uca lactea* was one of the prominent burrower found at Kamboi mudflat. The species showed no external sculpture in terms of dome or a chimney over the burrow opening. The expelled burrowing sediments were usually dumped on one side which later on formed a small bulge. The burrowing pellets were usually oblong in case of females and large balls in case of males with well developed chela. The species usually prepared two types of burrows viz. 'S' and 'J' shaped. The burrows were simple, with single entrance and unbranched with distinct features like burrow opening, burrow neck, main shaft and different chambers. As a peculiar character of fiddler crab, *U. lactea* showed a waving display using larger chela.

M.depressus was the dominant species at downstream mudflat. After a specific interval of low tide, the species actively starts burrowing. The second phase follows is a feeding phase, wherein the species starts actively feeing on the adjacent area surrounding the burrow. Further, the species was one of the most sensitive species which swiftly entered the nearest burrow even at very slight disturbance/movement at few meters. After entering the burrow, the species passed sometime in the burrow allowing the predatory risk to pass on.

D. crepsyrodactyla was one of the dominant crab on the lower intertidal mudflats of Kamboi. Even in terms of density the species showed its higher abundance. The species was distributed mostly from Zone 4 and 5 preferring fine sandy substratum. The species used to build a chimney over the burrow opening. This type of sculpture was seen mostly in Zone 5. The chimneys were made up of small mudballs excavated from the burrow. The species arranged excavated/burrowing pellets on the edge of the burrow entrance subsequently by carrying them between their legs. The pellets were piled up on each other to giving a structure of chimney.

Bioturbation: It is a process of upwelling of the aquatic sediments aided by the benthic animals. It is one of the vital processes taking place at any aquatic/marine ecosystem. During the present study, the bioturbatory potential of few of the macorfaunal species was studied to understand their contribution to the prevailing habitat/environment. Burrowing was the most common and cost efficient activity reported by many of the crab species which was followed by feeding. The burrow excavation done by different species was the main assessment tool to calculate their bioturbatory potential. Three brachyuran species mainly taken in account were *Uca lactea, M.depressus* and *D. crepsydrodactyla*. Bioturbation done by single species annually and by community per sq.m was calculated derived from their density (Table 4.6). Individually, *Uca lactea* was showed highest turnover with a rate of 11.43kg/crab/year followed by *D. crepsydrodactyla* 7.2kg and *M.depressus* 3.9kg per year (Fig. 4.9). A different picture emerged on calculating the data with their population (density) as bioturbation per square meter by members of same species. As a whole, *D. crespydrodactyla* contributed with highest level of bioturbation of 1526 kg/sq.m/year followed by *M.depressus* (329kg) and *U. lactea* (327 kg) (Fig. 4.10). Additionally an impressive figure of surface processing was seen by *Dotilla crepsydrodactyla* through feeding area exploration. A single species explored an average of 124 sq.cm of area during a single tide giving 248sq.cm per two low tides a day, yielding 90520sq.cm i.e. 0.9 sq.km annually.

Interestingly, during the course of study one of the hypotheses was to check whether selected benthic species follow any specific rule of distribution. A species specific habitat preference was seen. Sediment type and strata formation are some of the important features of habitat selection by different animals. Studies suggest habitat specific distribution/occupancy by different crab species along the intertidal area. The extent and type of burrowing by crabs reflects their adaptation to the habitat and prevailing habitat conditions. The extent of habitat exploration by crabs is influenced by ecological factors, salinity being one of the major controlling factors. The distribution and abundance of crabs depend on their ability to make and maintain their burrows in a given habitat. Other important physical factors are tidal variations, slope, sorting, composition, and compactness of the sediments and the ease of excavation. At present, no information is available for mahi estuary on the larval recruitment, preferences of juveniles or adults, predation pressure, or factors determining community composition and, therefore, it is difficult to interpret the heterogeneity of the distribution of *M. depressus*. During the present investigation, only a single species *Dotilla crepsydrodactyla* was seen forming a chimney over the burrow. Based on the field observations and data available few of the possible hypothesis can be proposed and discussed regarding chimney formation by *Dotilla crepsydrodactyla* as i) The sexual attraction hypothesis, ii) Protection from abiotic factors, iii) Hypotheses of Ventilation and aeration, iv) Hypotheses of territoriality.

Mudskipper sp. tends to be one of the important macrofauna on Kamboi mudflat and one of the foremost bioturbator and forager. Few of the species confined to the hard substratum like amphipod, isopod, Sipuncula etc. showed a very restricted distribution and remained confined to their niche.

These animals highly perforated the sediment block which were soft and organic matter rich. The CT scan study has revealed that these animals preferred boring the sediment with less density and avoided an intermediate places in the block where there was a compaction and calcrete formation.

Overall it can be said that most of the benthic forms tend to overcome the harsh environment and roll on their bodily processes. The Uca species by forming the simple burrow instead of branched one tends to minimize the energy needs. Similar case is seen in isopods and amphipods also wherein by sharing a common microhabitat and selecting a soft part of the sediment the species tries to overcome and save the energy inputs.