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# Ecological role of fiddler crabs (*Uca* spp.) through bioturbatory activities in the coastal belt of East Midnapore, West Bengal, India

**Subhasish Chatterjee, Debasis Mazumdar[1] and Susanta Kumar Chakraborty***

Department of Zoology, Vidyasagar University, Midnapore-721102, West Bengal, India

[1]Department of Agriculture and Statistics, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India.

*Correspondence e-mail: susantachakraborty@yahoo.com

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## Abstract

The fiddler crabs, being a dominant intertidal macrobenthic faunal components' contribute significantly to ecosystem functioning by their repeated burrowing and re-burrowing activities which enhance the aeration of soil, reshuffle textural components of different layers of sediments and promote nutrient recycling. These biogenic processes collectively termed as 'bioturbation', is the disturbance of sediment layers, act as major modulators of microbial activities and accelerate biogeochemical processes in the land-water interface. The present paper has attempted to study the structural diversity of different biogenic structures formed by 3 species of fiddler crabs in the temporal and spatial scales and also to assess their functional roles towards bio-geo-physico-chemical cycling in the ecosystem by virtue of their survival strategies vis-à-vis feeding, territory protection, aggression, female attraction, courtship signaling etc. in the coastal belts of Midnapore (East), West-Bengal, India. The fiddler crab species, the *Uca acuta acuta* exhibited maximum bioturbatory activities followed by *U. lactea annulipes* and *U. triangularis bengali* mostly during pre-monsoon at high-tide-level. Statistical analyses such as ANOVA, Duncan Tests have been computed to establish the level of significance of variabilities among different tidal levels in the studied intertidal belts in different seasons of two consecutive years.

***Keywords:*** *Biogenic structure, nutrient cycling, survival strategy, fiddler crabs, coastal belt.*

## Introduction

The coastal belt of Midnapore district, West Bengal, India sharing 27% (60 km) of coastal tract of West Bengal, is a contiguous part of deltaic Sundarbans Mangrove Ecosystem a world Heritage site (Chakraborty, 2013). The intertidal belt of this coast harbours diversified benthic fauna of which the fiddler crabs represents a bioenergetically significant macrobenthic faunal group of ecological and economic importance (Chatterjee *et al.*, 2004; Chakraborty, 2013). Fiddler crabs (*Uca* spp., Ocypodidae) are best known for their remarkable sexual dimorphism: males have highly asymmetrical claws (chelipeds), with the major claw greatly enlarged (up to five times in length) relative to both the male's own minor claw and the female's two symmetrical minor claws (Rosenberg, 2002). The major cheliped may constitute up to 48% of an adult male's body mass and is considered a classic example of sexual selection (Pope, 2005).

Species composition and functional diversity of benthic fauna are known as major regulators of sediment biogeochemistry and microbial dynamics, with major implications on ecosystem functioning. Marine-estuarine macrobenthos through their burrowing, feeding, mobility, respiratory and excretory activities play considerable functional roles in altering the physical and chemical properties of sediments. Ecological functions of bioturbation in ecosystems have received increasing attention over the recent decades, and coastal bioturbatory activities by intertidal brachyuran crabs are being considered as one of the major contributors governing the physical and chemical processes in salt marshes (Chatterjee *et al.*, 2008). Burrowing activities of crabs increase soil water content and the turnover of carbon and nitrogen but decreased bulk soil density. Vertical movement of materials, and nutrient cycling driven by crab's burrowing might be obstructed by vegetation. The amount of soils excavated by crab's burrowing was higher than that deposited into burrow mimics. Bioturbation is defined as biological reworking of soils and sediments through animal activities like burrowing and feeding (Meysman *et al.*, 2006).

While the important ecological role of fiddler crabs is evident, few studies have focused on population dynamics (e.g. zonation, growth, community structure and recruitment rates) (Chakraborty *et al.*, 1986; 2012, Chakraborty, 2013) and feeding habits (Chatterjee and Chakraborty, 2014). Previous studies on secondary production of fiddler crabs show that they have high turnover and production rates (Koch and Wolff, 2002). But there is very little information on the bioturbatory activities from India that determines their survival strategies in respect of different ecological gradients (Chatterjee *et al.*, 2008).

The present investigation was undertaken to identify the different bioturbatory structures during different seasons among different tidal levels viz. Low Tidal level (LTL), Mid Tidal level (MTL) and High Tidal level (HTL) in relation to prevailing ecological condition to understand the survival strategies (aggression, burrowing, feeding, female attraction, territory protection and courtship signaling) of fiddler crabs in a subtropical coastal belt of Midnapore (East), West- Bengal, India. The present paper has also elucidated the structural diversity of bioturbatory structures formed by decapod brachyuran crabs and their functional role in the ecosystem through geochemical cycling in one hand and ensuring their survival strategy vis-à-vis feeding, territory protection, aggression, female attraction and courtship signaling on the other.

## Material and methods

### *Physiography of study sites*

The present study was conducted during March, 2008 to February, 2010 at an ecotone, named Talsari located at the confluence of Bay of Bengal and Subarnarekha estuary in the coastal tract of Orissa- West Bengal, India in between 21°35'48" N and 87°27'17" E (Fig.1). This site is characterized in having both sandflats and mudflats endowed with a tract of mangrove swamp around the estuarine link of Talsari tidal channel and an extensive salt marsh tract extends on the more saline flats of eastward tidal basin.

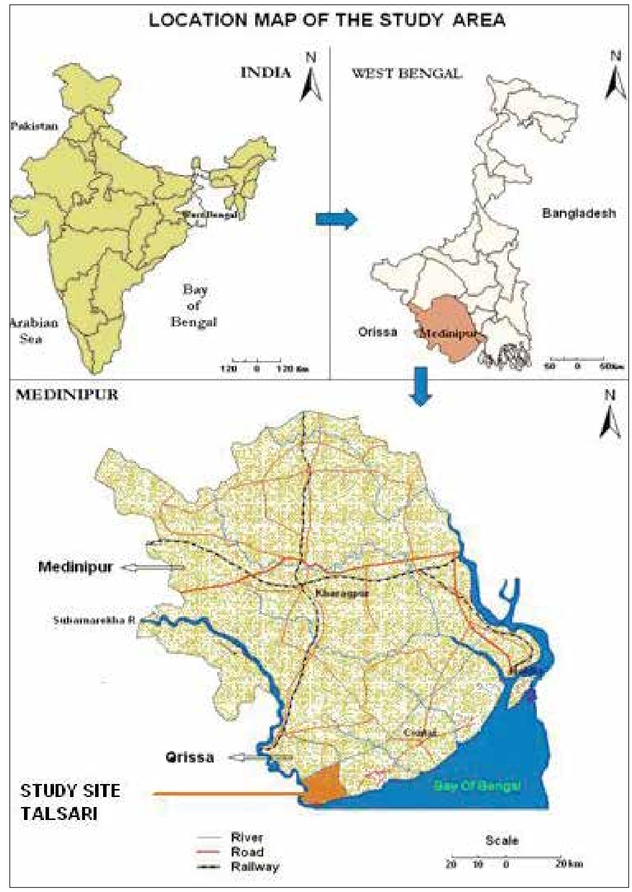


Fig. 1. Map of coastal tract of Midnapore district showing the location of study site.

### *Carapace width of crabs*

The carapace width (CW) of studied crabs were measured using a vernier caliper (± 0.05 mm accuracy) or, with the aid of a stereomicroscope (CW<10.0mm). Based on carapace width, each crab of the studied species was grouped in size classes with 2.0 mm of amplitude. The CW range of male *U. acuta acuta* was 6.5 to 16.5 mm, average larger than ovigerous females (CW 5.5 to 14.5 mm) which were in turn equal to non ovigerous females (of CW 5.5 to 14.5). The range of CW of male *U. lactea annulipes* was 7.5 to 14.5 mm, average larger than ovigerous females (CW 5.5 to14.5 mm) which were in turn larger than non ovigerous females (CW 4.5 to 13.5 mm). The CW range of male *U. triangularis bengali* was 6.5 to 13.5, not larger than ovigerous females (CW 5.5 to

12.5) which were in turn larger than non ovigerous females (CW=3.5 to 12.5).

### *Study of bioturbatory structures*

Burrow morphology of each species of fiddler crabs was examined by pouring and excavating casts of plaster of paris to determine burrow lengths at different distances from the lowest tidal levels. Individual crab trapped within the burrow casts were removed carefully and the length and diameter of burrows were measured. Seasonal variation of burrow depth and diameter (m), number of mudballs from the burrow openings, quantification of excavated sediments and distance (m) of placement of mudballs and the degree of biogenic activities vis-a-vis various bioturbatory structures such as chimney, semidom etc. were recorded during low tide at day time in each season at different tidal levels during the study period. All data after being collected monthly have been expressed as seasonal.

### *Assessment of bioturbation by scoring*

In order to estimate the scores and grade of bioturbation, the methods as proposed by Swift (1993) has been followed for classifying bioturbatory activities of different species of fiddler crabs. Photography and manual estimation were made as and when required.

### *Statistical analysis*

Different statistical analyses have been computed by following standard literatures (Zar, 2009) and utilizing 'STATISTICA' (STATSOFT, 2001) and 'SPSS (10.0)' packages with the help of a P-4 computer. Factorial ANOVA analysis was used to compare the main effects of seasons and tidal levels on species' bioturbatory activities. Main effects of means of different bioturbatory parameters were further subjected to Duncan's test at 5% level of significance to test the homogeneity among respective means of each factor. Significance of all main and interaction effects were also tested by F tests at each ANOVA. Significant main effects for factors having more than two levels were subjected to Duncan's test by using alphabets. Here similar alphabets denote homogenous means at 5% level of significance.

## Results

Three species of fiddler crabs have been recorded in the study site viz. *Uca acuta acuta*, *Uca lactea annulipes* and *Uca triangularis bengali* (Chakraborty *et al.*, 2012). Almost all intertidal fiddler crabs construct their own burrows for taking shelter, to escape from the predator's attack, to undertake courtship and also to experience feeding. Plaster casts of fiddler crab's burrows have been successfully recovered over the full lengths especially at HTL and MTL while at the LTL, such success was partially achieved because of clayey soil, minimum duration of exposure and accumulation of water at the bottom of the burrows. The burrow also serves as central hub from where the crabs used to venture out on their feeding excursions (Hemmi and Zeil, 2003).

### *Structural aspects of burrows and seasonal variation*

The burrows of *U. acuta acuta* displayed uniformity with regard to shape in most of the cases. The upper part of their burrows remained straight up to 0.15 m in length, after which it takes a bend of nearly 45° and the reaming part ends to a chamber. During high tide, the burrow entrance remained totally closed with mud. The maximum depths of their burrows have been found to be maximum (1.03±0.12 m) during pre-monsoon 2009 at HTL and that of minimum depths were recorded (0.359 ±0.21 m) during monsoon 2008 at LTL (Fig.2). The maximum burrow diameter was found (0.048±0.009 m) during monsoon 2008 at MTL and that of minimum was noticed (0.009±0.001 m) during post-monsoon, 2009-2010 at HTL (Fig.3). Out of 3 species of fiddler crabs recorded from mangrove estuarine complex of Sundarbans, India (Chakraborty *et al.*, 1986), *U. lactea annulipes* was found to be the most abundant in the studied coastal belt and their burrows initially remained straight upto 0.01 m after which taking bend, they ultimately ended to a chamber. All burrows contained air in the upper two-third part and water was found only in the lower one third part, which appeared to assume J- shaped burrows. During high tide, the burrow entrances remained totally closed with mud. The maximum depth of the burrow was exhibited (0.941±0.21

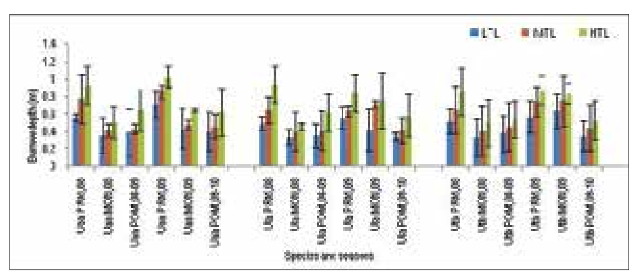

Fig. 2. Seasonal variation of burrow depths (m) with standard error of different species of fiddler crabs.

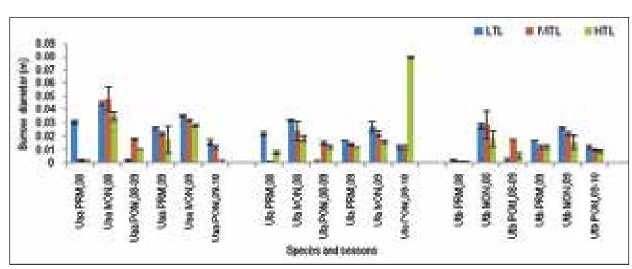

Fig. 3. Seasonal variation of burrow diameter (m) with standard error of different species of fiddler crabs.

m) during pre-monsoon, 2008 at HTL and the minimum depth was recorded (0.340±0.09 m) during monsoon, 2008 at LTL (Fig.2). The maximum burrow diameter was found (0.027±0.004 m) during monsoon 2009 at LTL and that of minimum was found (0.004 ±0.001 m) during post-monsoon, 2009-2010 at HTL (Fig.3). The maximum depth of the burrow of *U. triangularis bengali* was recorded (0.873±0.17 m) during pre-monsoon 2009 at HTL and the minimum depth was recorded (0.338±0.22 m) during monsoon 2008 at LTL (Fig.2). The maximum burrow diameter was observed (0.029±0.04 m) during monsoon 2008 at MTL and that of minimum was observed (0.006±0.002 m) during post-monsoon, 2008-2009 at HTL (Fig.3). The maximum depth and diameter of the burrows of each species were noticed during pre-monsoon and monsoon.

## *Mudballs- type, number and seasonal variability*

The number of slightly rounded excavated mud of *U. acuta acuta*, around the burrow openings varied from 12.00±0.79 at HTL during post-monsoon, 2009-2010 to 65.00±2.30 at LTL during monsoon, 2008. The number of oval shaped excavated mud around the burrow openings of *U. lactea annulipes* ranged from 9.00±0.05 at LTL during pre-monsoon, 2008 to 22.00 ±5.93 at HTL during post-monsoon, 2009-2010. Although both sexes of *U. triangularis bengali* could make mud balls, but significant differences between the sexes have been found with regard to sizes and placement of mudballs. Males used to make more mud balls of larger diameter and placed them comparatively at long distant places of their burrow entrance than females. The number of mud balls around the burrow openings fluctuated from 1.00±0.39 at LTL during post-monsoon, 2008-2009 to 11.00±0.87 at MTL during monsoon, 2009 (Fig.4).

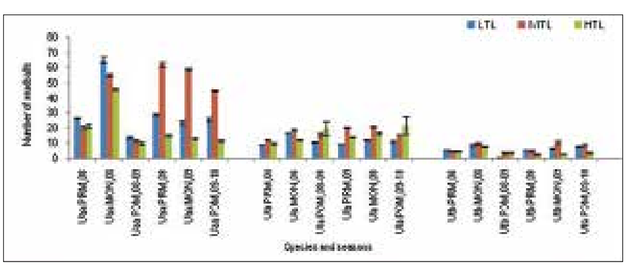


Fig. 4. Seasonal variation in the quantity of number of mudballs with standard error (in terms of number) of different species of fiddler crabs.

## *Different categories of bioturbatory structures*

### Chimney

Literally chimney is a vertical shaft that provides a path through which smoke from a fire is carried away through the wall or roof of a building. *U. acuta acuta* made chimney like structure which was composed of large wet soil pellets i.e., mud balls. The silty-clay soils for the construction of chimney of *U. acuta acuta* deposited after being excavated within the burrow, not from soils of the near the burrows. Therefore, the color of the chimney and the substrates composing these structures generally differed from the surface soil. Tower like cylindrical chimney structure was made by only male *U. acuta acuta* and the height of such chimney ranged from 0.064±0.002 m at LTL during monsoon, 2008 to 0.005±0.002 m at HTL during post-monsoon, 2009-2010 (Fig.5).

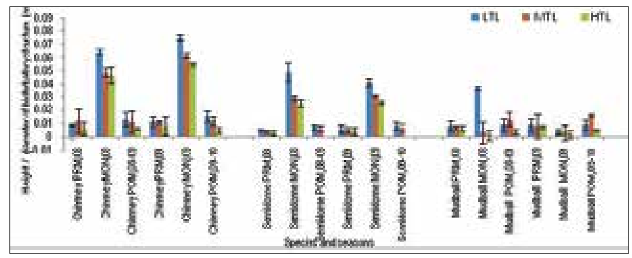


Fig. 5. Seasonal variation in height / diameter (m) of different bioturbatory structures with standard error of different species of fiddler crabs.

### Semidome

Semidome is a roof covering a semicircular space i.e. half a dome. Only male *U. lactea annulipes* could construct semidomes by scrapping up bits of sediment from the surface with their first four walking legs on the side with the major claw, and depositing the sediment materials around the burrow entrance in triangular shaped semidomes more frequently during monsoon. The maximum height of semidome (0.049±0.007 m) was recorded during monsoon, 2008 at LTL and the minimum height (0.003 ± 0.002 m) was exhibited during pre-monsoon, 2008 at HTL (Fig.5).

### Mudball

Males of *U. triangularis bengali* made mudballs which were composed of large wet soil pellets and the diameter of mudballs ranged from 0.016±0.001 m at MTL during post-monsoon, 2009-2010 to 0.001±0.004 m at HTL during monsoon, 2008 (Fig.5).

## *Quantification of excavated sediment*

The weight of the excavated muds from the burrows of *U. acuta acuta* ranged from a minimum of 0.101±0.01 kg at HTL during post-monsoon, 2009-2010 to a maximum of 0.254±0.01 kg at LTL during monsoon, 2009. In *U. lactea annulipes*, the weight of the excavated sediments varied from a minimum of 0.062±0.02 kg at MTL during pre-monsoon, 2008 to a maximum of 0.186±0.04 kg at LTL during monsoon, 2009 and the weight of the excavated soils of *U. triangularis bengali* varied from 0.055±0.01 kg at MTL during post-monsoon, 2008-2009 to 0.166±0.03 kg at MTL during monsoon, 2009 (Fig.6).

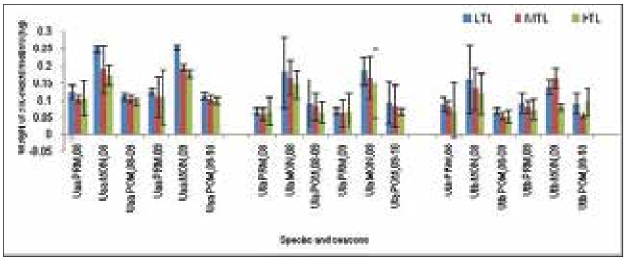


Fig. 6. Seasonal variation in quantity of excavated matters (in respect of weight-kg) with standard error of different species of fiddler crabs.

## *Distance of placement of excavated matters*

The seasonal variation in distance of placement of excavated matters from their burrow openings varied widely in different fiddler crabs. The distance of mudballs placement of *U. acuta acuta* ranged from 0.070±0.22 m at HTL during post-monsoon, 2009-2010 to 0.247±0.38 m at LTL during monsoon, 2009 from their respective burrows. The distance of placement of mudballs of *U. lactea annulipes* varied from 0.056±0.05 m at HTL during pre-monsoon, 2008 to 0.188±0.36 m at LTL during monsoon, 2009. The mudballs prepared by *U. triangularis bengali* have been found to be placed at a distance ranged from 0.039±0.32 m at HTL during post-monsoon, 2008-2009 to 0.101±0.08 m at LTL during pre-monsoon, 2009 (Fig.7).

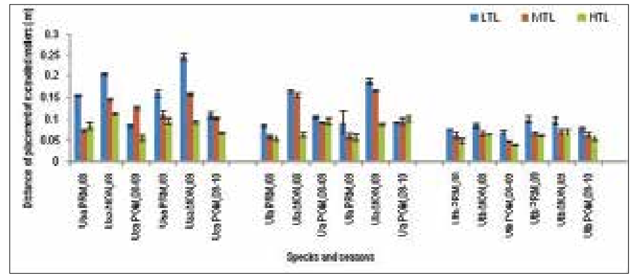


Fig. 7. Seasonal variation in distance (m) of placement of excavated matters with standard error from the burrow opening of different species of fiddler crabs.

Different bioturbatory structures of studied fiddler crabs in different seasons and tidal zones were recorded and statistical evaluation on it through ANOVA analysis and Duncan's test were performed, the results of which are presented in Tables 1-6.

## *Bioturbatory scores*

Deduction and analysis of bioturbatory scores of three intertidal fiddler crabs have been calculated on the basis of mobility, feeding and burrowing performance. The maximum score was shown by *U. lactea annulipes* (7) followed by *U.*

Table 1. Results of ANOVA analysis of different bioturbatory structures of *Uca acuta acuta* between seasons and tidal levels.

| Source | Variable | SS | df | MS | F | Sig. |
|---|---|---|---|---|---|---|
| SEASONS | Burrow Depth | 4283.48 | 2 | 2141.74 | 53.62 | 0.000** |
| | Burrow Diameter | 15.05 | 2 | 7.53 | 24.41 | 0.000** |
| | Number of mud balls | 1729.69 | 2 | 864.84 | 2.67 | 0.123 |
| | Chimney | 95.11 | 2 | 47.55 | 229.41 | 0.000** |
| | Weight of Excavated matters | 37843.75 | 2 | 18921.87 | 2751.67 | 0.000** |
| | Distance of placement | 174.07 | 2 | 87.04 | 18.87 | 0.001** |
| TIDAL LEVELS | Burrow Depth | 2008.22 | 2 | 1004.11 | 25.14 | 0.000** |
| | Burrow Diameter | 2.29 | 2 | 1.15 | 3.71 | 0.067 |
| | Number of mud balls | 1526.86 | 2 | 763.43 | 2.36 | 0.15 |
| | Chimney | 2.94 | 2 | 1.47 | 7.09 | 0.014* |
| | Weight of Excavated matters | 4109.86 | 2 | 2054.93 | 298.83 | 0.000** |
| | Distance of placement | 189.24 | 2 | 94.62 | 20.52 | 0.000** |
| SEASONS * TIDAL LEVELS | Burrow Depth | 172.23 | 4 | 43.06 | 1.08 | 0.422 |
| | Burrow Diameter | 0.13 | 4 | 0.03 | 0.1 | 0.979 |
| | Number of mud balls | 61.42 | 4 | 15.35 | 0.05 | 0.995 |
| | Chimney | 1.55 | 4 | 0.39 | 1.87 | 0.201 |
| | Weight of Excavated matters | 2664.41 | 4 | 666.1 | 96.87 | 0.000** |
| | Distance of placement | 86.79 | 4 | 21.7 | 4.71 | 0.025* |

SS=sums of squares, df=degrees of freedom, MS= SS/df, F=MS group/MS within group

* Significant at the 0.05 level ** Significant at the 0.01 level

Table 2. The mean effect of different bioturbatory structures of *U. acuta acuta* between seasons and tidal levels with Duncan's test result.

| Seasons/ Tidal levels | Tidal levels | Bioturbatory structures | | | | | |
|---|---|---|---|---|---|---|---|
| | | Burrow depth | Burrow diameter | Number of mud balls | Chimney | Weight of excavated matters | Distance of placement excavated matters |
| Seasons | | | | | | | |
| Pre monsoon | TOTAL | 81.30a | 2.45b | 29.78a | 1.02b | 115.66b | 11.45b |
| Monsoon | TOTAL | 47.69b | 3.72a | 44.16a | 5.93a | 208.13a | 16.65a |
| Post monsoon | TOTAL | 49.53b | 1.48c | 20.32a | 1.08b | 106.68c | 9.23b |
| Tidal levels | | | | | | | |
| Total | LTL | 47.79z | 2.92x | 31.44x | 3.18x | 164.36x | 16.59x |
| | MTL | 57.34y | 2.67xy | 42.69x | 2.67xy | 137.05y | 12.08y |
| | HTL | 73.39x | 2.07y | 20.13x | 2.19y | 129.06x | 8.67z |

Table 3. Results of ANOVA analysis of different bioturbatory structures of *Uca lactea* annulipes between seasons and tidal levels.

| Source | Variable | SS | df | MS | F | Sig. |
|---|---|---|---|---|---|---|
| SEASONS | Burrow Depth | 1712.37 | 2 | 856.18 | 7.34 | 0.013* |
| | Burrow Diameter | 3.84 | 2 | 1.92 | 35.1 | 0.000** |
| | Number of mud balls | 59.5 | 2 | 29.75 | 3.48 | 0.076 |
| | Semidome | 33.54 | 2 | 16.77 | 406.42 | 0.000** |
| | Weight of Excavated matter | 33621.5 | 2 | 16810.75 | 8865.7 | 0.000** |
| | Distance of placement | 143.61 | 2 | 71.8 | 86.37 | 0.000** |
| TIDAL LEVELS | Burrow Depth | 2391.68 | 2 | 1195.84 | 10.25 | 0.005** |
| | Burrow Diameter | 2.1 | 2 | 1.05 | 19.2 | 0.001** |
| | Number of mud balls | 107.23 | 2 | 53.61 | 6.27 | 0.020* |
| | Semidome | 3 | 2 | 1.5 | 36.29 | 0.000** |
| | Weight of Excavated matter | 1323.2 | 2 | 661.6 | 348.92 | 0.000** |
| | Distance of placement | 59.34 | 2 | 29.67 | 35.69 | 0.000** |
| SEASONS TIDAL LEVELS | Burrow Depth | 241.93 | 4 | 60.48 | 0.52 | 0.725 |
| | Burrow Diameter | 0.55 | 4 | 0.14 | 2.5 | 0.117 |
| | Number of mud balls | 83 | 4 | 20.75 | 2.43 | 0.124 |
| | Semidome | 2.18 | 4 | 0.55 | 13.22 | 0.001** |
| | Weight of Excavated matter | 797.3 | 4 | 199.33 | 105.12 | 0.000** |
| | Distance of placement | 69.86 | 4 | 17.46 | 21.01 | 0.000** |

* Significant at the 0.05 level ** Significant at the 0.01 level

Table 4. The mean effect of different bioturbatory structures of *U. lactea* annulipes between seasons and tidal levels with Duncan's test result.

| Seasons/ Tidal levels | Tidal levels | Bioturbatory structures | | | | | |
|---|---|---|---|---|---|---|---|
| | | Burrow depth | Burrow diameter | Number of mud balls | Chimney | Weight of excavated matters | Distance of placement excavated matters |
| Seasons | | | | | | | |
| Pre monsoon | TOTAL | 68.63a | 1.50b | 12.87a | 0.51b | 68.85c | 6.94c |
| Monsoon | TOTAL | 51.70b | 2.33a | 16.81a | 3.40a | 166.61a | 13.81a |
| Post monsoon | TOTAL | 45.57b | 1.24b | 16.64a | 0.50b | 82.54b | 9.71b |
| Tidal levels | | | | | | | |
| Total | LTL | 41.96y | 2.08x | 12.10y | 1.99x | 116.82x | 12.15x |
| | MTL | 53.86y | 1.73y | 17.87x | 1.42y | 105.33y | 10.55y |
| | HTL | 70.08x | 1.25z | 16.35x | 1.00z | 95.85z | 7.76z |

 

Table 5. Results of ANOVA analysis of different bioturbatory structures of *U. triangularis bengali* between seasons and tidal levels.

| Source | Variable | SS | df | MS | F | Sig. |
|---|---|---|---|---|---|---|
| SEASONS | Burrow Depth | 1886.711 | 2 | 943.356 | 5.019 | 0.034* |
| | Burrow Diameter | 3.447 | 2 | 1.723 | 9.856 | 0.005** |
| | Number of mud balls | 31.322 | 2 | 15.661 | 2.663 | 0.123 |
| | Mudball | 1.314 | 2 | 0.657 | 103.572 | 0.000** |
| | Weight of Excavated matters | 13788.107 | 2 | 6894.054 | 25.258 | 0.000** |
| | Distance of placement | 8.21 | 2 | 4.105 | 4.946 | 0.036* |
| TIDAL LEVELS | Burrow Depth | 1523.918 | 2 | 761.959 | 4.054 | 0.056 |
| | Burrow Diameter | 2.656 | 2 | 1.328 | 7.595 | 0.012* |
| | Number of mud balls | 23.198 | 2 | 11.599 | 1.972 | 0.195 |
| | Mudball | 0.548 | 2 | 0.274 | 43.225 | 0.000** |
| | Weight of Excavated matters | 1658.014 | 2 | 829.007 | 3.037 | 0.098 |
| | Distance of placement | 26.103 | 2 | 13.052 | 15.727 | 0.001** |
| SEASONS TIDAL LEVELS | Burrow Depth | 137.695 | 4 | 34.424 | 0.183 | 0.941 |
| | Burrow Diameter | 0.211 | 4 | 0.053 | 0.301 | 0.87 |
| | Number of mud balls | 9.942 | 4 | 2.485 | 0.423 | 0.789 |
| | Mudball | 0.457 | 4 | 0.114 | 18.023 | 0.000** |
| | Weight of Excavated matters | 2484.798 | 4 | 621.2 | 2.276 | 0.141 |
| | Distance of placement | 0.897 | 4 | 0.224 | 0.27 | 0.89 |

* Significant at the 0.05 level ** Significant at the 0.01 level

Table 6. The mean effect of different bioturbatory structures of *U. triangularis bengali* between seasons and tidal levels with Duncan's test result.

| Seasons/ Tidal levels | Tidal levels | Bioturbatory structures | | | | | |
|---|---|---|---|---|---|---|---|
| | | Burrow depth | Burrow diameter | Number of mud balls | Chimney | Weight of excavated matters | Distance of placement excavated matters |
| Seasons | | | | | | | |
| Pre monsoon | TOTAL | 70.32a | 1.64b | 5.72a | 0.81b | 82.99b | 7.10ab |
| Monsoon | TOTAL | 58.00ab | 2.33a | 8.46a | 0.34c | 135.53a | 7.62a |
| Post monsoon | TOTAL | 45.25b | 1.28b | 5.61a | 0.98a | 72.16b | 6.00b |
| Tidal levels | | | | | | | |
| Total | LTL | 46.64y | 2.18x | 6.73x | 0.77y | 108.70x | 8.55x |
| | MTL | 57.75xy | 1.82x | 7.91x | 0.89x | 96.80x | 6.45y |
| | HTL | 69.18x | 1.25y | 5.14x | 0.47z | 85.19y | 5.71y |

*acuta acuta* (6) while *U. triangularis bengali* (4) displayed least bioturbatory scores respectively (Table 7).

## Discussion

The term 'bioturbation' is frequently used to describe how living organisms affect the substratum in which they live. A closer look at the literature reveals, however, an inconsistent usage of the term with increasing perplexity in recent years. As significant biotic components of aquatic and terrestrial ecosystems, soil animals are multipurpose workers, for example, consumers, litter decomposers, and habitat modifiers, which passively or actively disturb the substrate (Meysman *et al*., 2006).

Animal bioturbation and its ecological roles in shaping soil ecosystem processes were first appreciated by Darwin (1881) and were described in great details in his last book *On the*

Table 7. Bioturbatory score of different species of fiddler crabs during the study period.

| Sl. No. | Brachyuran crabs | Scores | | | |
|---|---|---|---|---|---|
| | | Mobility | Feeding | Burrowing | Total |
| 1. | *Uca acuta acuta* (Stimpson) | 2 | 2 | 2 | 6 |
| 2. | *Uca lactea annulipes* (H. Milne Edwards) | 3 | 2 | 2 | 7 |
| 3. | *Uca triangularis bengali* (Nobili) | 1 | 1 | 2 | 4 |

*Formation of Vegetable Mounds through the Action of Worms with Observations on their Habits*. Invertebrates feeding on resources in the sediments evidently affect key processes, such as organic carbon mineralization (Otani *et al*., 2010), nutrient dynamics (McHenga and Tsuchiya, 2008), sediment texture modification and particle mixing. The altered soil characteristics might further impact microbial activities (Bertics and Ziebis, 2009) and other biotic components (Canepuccia *et al*., 2008).

The concept of 'ecosystem engineering' refers to a modification of the physical environment that strongly affects other organisms. All organisms affect their immediate abiotic environment in some way, but true ecosystem engineers reveal themselves when their presence or absence has a disproportionately large impact on the ecosystem. In artistic language, one could say that ecosystem engineers effectively function as authoritarian scenic designers, which not only set the stage, but also decide on the play to be performed, and select the potential players that enter the stage (Meysman *et al*., 2006).

From an ecological perspective, bioturbation is coupled to physical processes and associated chemical changes related to movement of particles or water. The important biological and biogeochemical consequences of bioturbation must be considered in a larger context, such as within the framework of ecosystem engineering as pointed out by (Meysman *et al*., 2006).

Fiddler crabs are among the most conspicuous group of bioturbating animals in intertidal belt (Emmerson, 1994). They have been shown to dramatically alter the environment in which they live (Robertson, 1986). Fiddler crabs by their sheer abundance constitute a rich food source for birds (Zeil *et al*., 2006). They form important links between the primary detritus at the base of the food web and consumers of higher trophic levels (Koch and Wolff, 2002). The fiddler crabs *U. acuta acuta, U. lactea annulipes* and *U. triangularis bengali* have a widespread distribution (Crane, 1975). Like most other deposit feeders, the species of fiddler crabs under study dwells in burrows which are dug to a depth of up to 0.9 m depending on the slope of the shore level. These species are diurnally active and emerge out as the tide recedes (Skov and Hartnoll, 2001). Surface activities terminate when burrows are re-entered and plugged. Burrow plugging also prevails at night and on hot days when sediment is dry (Crane, 1975). They are often present in large numbers; and their burrowing activities can directly break and transport sediments, decrease the hardness of the soil (Botto *et al*., 2005), modify microtopography, and increase the density of coarse particles on the soil surface. Crab's burrowing also affects soil chemistry and associated microbial processes, increases soil oxygenation, and alters pore water salinity (Fanjul *et al*., 2007). Burrowing activities by crabs significantly affect belowground processes that can impact marsh plants (Smith *et al*. 2009) in at least three ways. First, burrowing by crab increases the passage of liquid and gas between the soil and environment (that is, increase drainage), increasing soil oxidation (Weissberger *et al*., 2009) and the decomposition rate of organic debris (Fanjul *et al*., 2007). Second, burrows of crabs can selectively trap sediments that have high organic matter concentrations, finer grain size and low density through the interactions of the burrow openings with tidal water, which facilitate organic matter decomposition, which in turn increase nutrient availability and thus, promote their growth (Botto *et al*., 2005). Third, excavation by crabs transport soils and nutrients from deep layers to the marsh surface (Fanjul *et al*., 2007; 2008, Mermillod-Blondin, 2011), which might accelerate the turnover of soils and nutrients. Soil properties and plant assemblage characteristics influenced by crab's excavation and burrow deposition can in turn affect burrowing processes.

Sediment biogeochemical processes play important roles in the metabolism and nutrient cycling of salt marshes (Webb and Eyre, 2004). These processes could stimulate ecosystem C and N cyclings. Excavated soil was characterized by higher water content and lower bulk density. Excavated and deposited soils had higher nutrient concentrations compared to the surrounding background soil. Crab's burrowing significantly affect the functions of salt marshes and the nutrient balance between the marshes and estuarine waters by transporting soil rich in nutrients to marsh surfaces for aerobic decomposition and export to adjacent waters. Therefore, crabs directly and indirectly affect ecosystem processes and functioning of the salt marshes, and their roles in the conservation and restoration of coastal wetlands (Wang *et al*., 2010). Bioturbation is such a denominator and acts as an 'umbrella' term that covers all faunal transport activities physically disturbing the substratum. It is separated into activities by animals that directly move and mix particles by the process of reworking or directly move water through burrows by the process of ventilation (Meysman *et al*., 2006).

Many species of intertidal fiddler crabs build mud or sand structures on the surface of the sediment near or at their burrow entrances, in the form of hoods, pyramids, mounds, chimneys and mudballs. The fiddler crabs are well known for the behaviour of building various structures from moist mud sand at the entrance of their burrows. Different bioturbatory structures have been shown to function for sexual attraction, e.g., pillars (Christy, 1988), hoods (Christy *et al*., 2003), mudballs (Oliveira *et al*., 1998); some are related to aggression (fighting or invasion to others burrows occupation), e.g., hoods (Zucker, 1974), chimneys (Wada and Murata, 2000); and some are related to environmental regulation, e.g., hoods (Powers and Cole, 1976), chimneys (Crane, 1975). Some bioturbatory structures like low semidomes (Christy, 1988) are built on one edge of the burrow entrance by *U. pugilator* (Christy, 1988), *U. pugnax* and *U. minax* (Bason and Frey, 1977), rims are built around the edge of the burrow by *U. panacea*, tall wide hoods are built by *U. musica* (Zucker, 1974), *U. cumulanta* (Crane, 1975) and tall narrow pillars are built besides burrows by *U. beebei* (Christy, 1988), *U. lactea* (Yamaguchi, 1971), *U. latimanus* (Zucker, 1981). The bioturbatory structures observed in the coastal tract of East Midnapore have been found to experience temporal and spatial changes with respect to their structural features and intensity of occurrences.

Copulations of *U. acuta acuta* are much seen on the surface of the intertidal flat. Males without a burrow never mated. The *U. acuta acuta* species mated on the surface too, but most copulation took place after a male made a female follow it to the burrow. Chimney is supposed to contribute for microhabitat regulation and burrow protection against wandering crabs. If the chimney is destroyed by the tides, the builders i.e., males repair chimney immediately after it is damaged or broken. Semidomes are built more often by males of *U. lactea annulipes* in presence of females. Like U. lactea, semidome is related to courtship signaling but not for aggression between males in *U. lactea* annulipes. Kim *et al*., (2004) considered semidomes to be an indicator of courtship activity in *U. lactea*. Hence, a semidome around the burrow seems to be a prerequisite for successful mating by males. It seems it is the normal courtship behaviour of *U. lactea annulipes*, where the male waving allures the females to follow them into the burrow for copulation. The possible function of semidome building behavior is either a reduces aggression or attracting females. Mudballs formed by the male of *U. triangularis bengali* are supposed to be functioning as territory markings or for the attraction of females.

It seems that above mentioned different unique structures of different species have diverse functional roles, but more intensive study is required to understand their functional as well as ecological significance.

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