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Coastal Tourism Induced Alterations in Red Ghost Crab (*Ocypode macrocera*) Burrow Distribution and Burrow Parameters in Dakshin Purushottampur Beach, West Bengal, India

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Abstract: Coastal areas all over the globe are being threatened by anthropogenic impacts due to tourism and associated construction, which alter the landscape and pose a serious threat to the local biodiversity. Ghost crabs are often considered potential bioindicators as their abundance and spatial distribution are highly sensitive to anthropogenic impacts. In the current study, the impact of land use patterns and the extent of tourism-induced urbanization on the abundances, spatial distribution and other parameters of burrows of Red Ghost Crab *Ocypode macrocera* were studied in Dakshin Purushottampur Beach, West Bengal, India. The beach area was divided into three zones for this study. The presence of artificial embankments, entry points for tourists and vehicles on the beach and lack of natural vegetation with built-up areas were the major contributing factors to the low abundance of crab burrows in Zone 2. Although Zone 1 was nearest to the tourist hub, however, the lack of ingress points to the beach along with the undisturbed beach feature contributed towards the higher abundance of red ghost crabs. Zone 3 was the most pristine area around the eastern flank with undisturbed natural vegetation and showed the maximum abundance of crab burrows. In conclusion, the presence of urbanized structures, pedestrian trampling, vehicular activity and alteration of land use are the probable factors that significantly induce alteration in the abundance of Red Ghost Crabs in Dakshin Purushottampur Beach.

Keywords: *Ocypode macrocera*, Coastal tourism, Urbanization Index, Burrow parameters, Land-use

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Introduction

The coastal areas, especially with sandy beaches, are a major point of concern due to their degradation with enhanced human interferences and impacts with growing tourism and associated constructions (Beatley, 1991; Habibullah *et al.*, 2016; Hernández *et al.*, 2023). The sandy beaches play a vital role by preventing coastal erosion and storm surges thereby protecting the inlands from extreme weather events. Along with that, sandy beaches provide a habitat for several animal species and play an important part in nutrient cycling and sediment transport thereby impacting the peripheral marine environment (Schlacher *et al*., 2008; Defeo *et al*., 2009; Hyndes *et al*., 2022). However, these areas are popular tourist spots for recreational activities resulting in the alterations of the landscape for the construction of hotels, resorts etc. Though tourism brings economic benefits and cultural exchanges, they have a huge effect on the sustainability of the ecological condition of the beach environment (Davenport and Davenport, 2006; Otrachshenko and Bosello, 2017).

Researchers have turned their attention for the past few decades to the study of the anthropogenic pressure in these coastal dunes which requires serious attention for conservation efforts (Gormsen, 1997). For this purpose, mostly invertebrates from the habitats are selected as bioindicators since they are the most sensitive towards anthropogenic stresses than any vertebrate taxa (Gerlach *et al*., 2013). *Ocypode* spp. commonly known as ghost crabs are one of the preferential bioindicators for the study of sandy beaches (Gül and Griffen, 2019). The genus *Ocypode* comprises a diverse group of crabs that are found circumglobally in the tropics and subtropics. The burrowing activity of the ghost crabs is seen in the supratidal and intertidal zones which leads to bioturbation and aeration of the coastal sand (Branco *et al*., 2010; Chatterjee and Chakraborty, 2014). Ghost crabs are detritivores and opportunistic feeders rendering them as scavengers of the beach. They consume a variety of organic matter including carrion, algae, decaying matter etc. facilitating nutrient cycling and organic matter decomposition (Chatterjee and Chakraborty, 2014). Ghost crabs burrow during the day which provides them shelter and protection from predators, environmental extremes etc. and also act as their breeding grounds. The burrow opens up in the top sand and the size of the entrance hole is known to be proportional to the size of the carapace of the occupant (Lucrezi *et al*.,2009b). These holes are easily visible and thus provide a potent tool for population status estimation of ghost crabs in a beach landscape (Dubey *et al*., 2014a). In natural habitats, mid-sized burrows are found mainly in the intertidal zones and larger burrows with more complex burrow structures belonging to adults are mainly located in the supratidal zone (Gül and Griffen, 2019). However, shifts in their burrowing habit and burrow morphology in the presence of anthropogenic pressure have been reported and monitoring ghost crabs for the assessment of anthropogenic pressure on a beach landscape is done by several researchers globally (Chan *et al*., 2006; Noriega *et al*.,2012; Costa *et al*., 2022; Schlender *et al*., 2023). Several species of *Ocypode* revealed a lowering of population density in active beaches which are regularly visited by tourists and drastic population reduction was reported in the areas with vehicular movements (Neves and Bemvenuti, 2006; Lucrezi *et al*., 2009a). Burrow counts and spatial distribution become highly altered for the ghost crabs due to habitat alterations like shore armouring along with tourist visits and trampling (Lucrezi *et al*., 2009a, 2014). Pedestrian trampling on the beaches alters the burrow count in a significant manner and thus causes substantial sampling bias and low population density estimation (Lucrezi *et al*., 2009a). The effect of human impact has been studied on several species of *Ocypode* around the globe including *O. quadrata* (Neves and Bemvenuti, 2006; Costa and Zalmon, 2019; Machado *et al*.,2019; Barboza *et al*., 2021), *O. ceratophthalmus* (Lucrezi *et al*.,2009b; Yong and Lim, 2009) and *O. macrocera* (Dubey *et al*., 2014a, b, Naskar, 2018). In India, *O. macrocera* is found along the entire mainland coastline as well as the Andaman and Nicobar Islands. Several studies have been conducted to analyze the habitat and behavioural pattern of the red ghost crabs from the coastal regions to the mangrove regions of India (Ravichandran *et al*., 2001; Soundarapandian *et al*., 2008; Varadharajan and Soundarapandian, 2012; Dubey *et al*., 2014b; Haque and Choudhury, 2014; Naskar, 2018). However, data regarding the effect of tourism-related impact and the effect of disturbed CRZ (Coastal Regulatory Zone) in the Indian coastal region on the population and distribution of crabs is scarce. Several researchers have already proposed Urbanization indexing to provide an estimation of the anthropogenic pressure over a habitat (Elmqvist *et al*., 2013; McDonald *et al*., 2013). These indexes are useful in correlating the degree of urbanization with the distribution and abundance of bioindicator species (Kohsaka *et al*., 2013; Tripathi and Tewari, 2023). Concomitantly, Remote sensing (RS) techniques and indexes like NDVI (normalized difference vegetation index) and NDBI (normalized difference built-up index) are also being used to assess environmental pressures such as deforestation or urbanization along the coastline (Samsuri *et al*.,2019; Zhang *et al*.,2020; Martorell *et al*., 2023).

The current study is placed on the coastal landscape in the south of West Bengal, India. The long coastline which includes places like Tajpur, Mandarmani and Digha attracts millions of tourists each year which has led to altered land use patterns impacting the local biodiversity (Saha and Paul, 2021; Ghosh and Chakravarty, 2023). The particular landscape under the current study is the natural habitat of *O. macrocera* locally known as “Lal Kakra” (in Bengali) or Red Ghost crab. The occurrences of the red ghost crabs in the major tourism spots in West Bengal are progressively becoming rare, however, a tiny stretch of the coastline named after the red ghost crabs “Lal Kakra Beach” in Dakshin Purushottampur (East Midnapur, West Bengal, India) remains as one of the final refuges in the Mandarmani- Purushottampur coastal stretch. The objectives of the study were to assess the red crab habitat degradation along the entire stretch of Dakshin Purushottampur Beach and to assess the distribution and abundance of the red ghost crab burrows as a proxy of their population in the presence of tourism-induced urbanization and degradation of the adjoining CRZ.

Materials and Methods

Description of the study sites

The study was done on a narrow strip of beach known as Dakshin Purushottampur Beach, locally known as “Lal–Kakra” or the Red-crab beach in Mandarmani, East Midnapur, West Bengal, India. It is a part of 12.9 km long stretch extending from the Jalda Mohona (Estuary) in the west to the Pichaboni inlet in the east, of which the major portion has been highly intruded with constructions related to tourism and barely resembles the natural habitat. Thus, the study site was restricted to the Dakshin Purushottampur beach which spans approximately only 4 km, starting just 400 metres from the Dadanpatrabar khoti (Fish Landing Centre) near Mandarmani to the West and the Pichaboni River to the East (Lat: 21°40'13.54"N long: 87°43'15.50"E to Lat: 21°41'7.88"N, long: 87°45'8.52"E) (Figs. 1a, b).

The beach has a varying width and a gentle slope and extends in a nearly east-western direction and a series of wavy dunes demarcate the backshore. These coastal dunes are covered with salt-tolerant creeper plants and shrubs. Sampling in the study site was done in three zones (1, 2 and 3) from West to East. Each zone is approximately 1 km in length. Zone 1 is closest to the highly urbanized tourist site, Mandarmani (approximately within 2 Km from Zone 1) and closest to the Dandapatrabar Khoti (Figs. 2a, b). A large area of Zone 2 is barren and devoid of any significant vegetation and probably used as a boat anchorage site. This zone is protected from the sea by a manmade embankment (Fig. 2c). Zone 2 is the

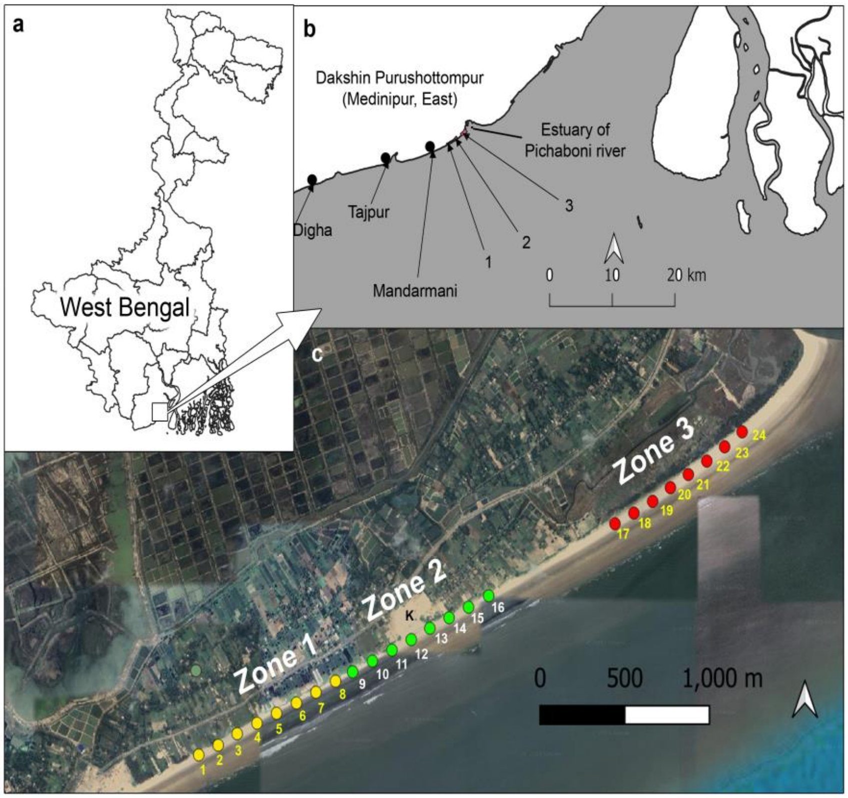

Fig. 1: Map of West Bengal showing the location of study sites (a). Location of Zone 1, 2 and 3 in Dakshin Purushottampur, Medinipur East, near prominent tourist sites like Digha, Tajpur and Mandarmani (b). Location of 24 sampling sites (1 to 24) within Zone 1, 2 and 3. K denotes a barren land in Zone 2 possibly used as a boatyard (c).

most important access point, connected to the main road (Mandarmani-Pichaboni Estuary Road) by unpaved roads (Fig. 2d). Zone 3 is nearest to the estuary and has minimal tourist activity along with very nominal encroachment by the residents (Figs. 2e, f, g). The dunes are covered and well-protected by larger trees and no permanent road connects this zone directly to the main road in the north. Compared to Mandarmani Beach, till the time of the study, the selected sites have relatively fewer man-made structures near the beach and recreational activities also occur at very low intensity in the selected sites. Hence, the study site was selected due to its partial urbanization, with preserved sand dunes and vegetation and a meagre human and tourist presence. As September is known for the moderate to high amount of domestic tourist influx in the aligned beach of Mandarmani (Mondal and Sen, 2017), the study was conducted from 2nd September 2023 to 5th September 2023.

Land Use Analysis:

To assess the land use pattern and foredune vegetation condition around the sampling areas, multispectral images were acquired from the online data portal of the European Space Agency through the Copernicus browser supplying Sentinel-2 data (Instrument**:** MSI, Image date**:** 2023-05-29, S2MSI1C product). The workflow of the analysis is depicted in Figure 3. A bundle of Sentinel-2 imagery consisting of 13 multispectral bands with varying resolutions of 10 m, 20 m, and 60 m. were used to generate a Multiband Raster. Green band (B3), Red band (B4), and Near-infrared band (B8), having a spatial resolution of 10 m, were used for the false colour image generation (Band: 8, 4, 3) (Joko Prasetyo *et al.*,

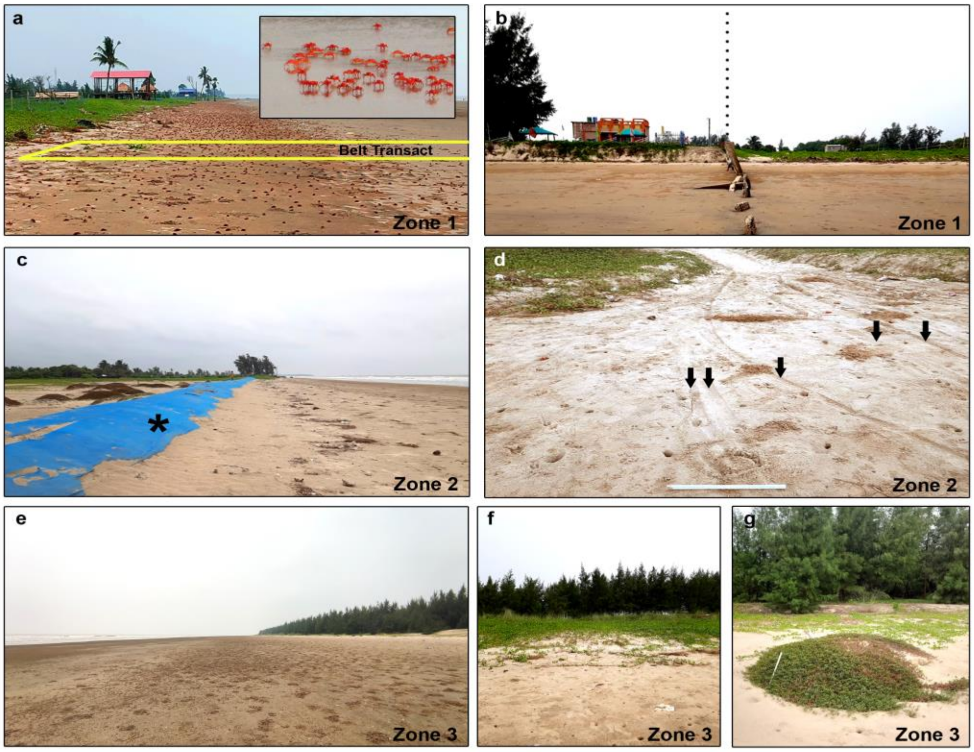

Fig. 2: Study sites on Dakshin Purushottampur beach. Zone 1 with the virtual marking of the belt transect (inset: *Ocypode macrocera* crabs on the shore) (a), dotted line showing the boundary between Mandarmani Beach and Dakshin Purushottampur Beach at Zone 1 (b), picture of Zone 2. (* denotes artificial banking to protect the boatyard and fallow lowland behind it) (c), tyre marks of vehicular movement (arrows) in Zone 2 (d), Zone 3 near the Pichaboni River Estuary (e), undisturbed natural vegetation at the backshore of Zone 3 (f), embryo dune supported by *Sesuvium sp*. at Zone 3 (g).

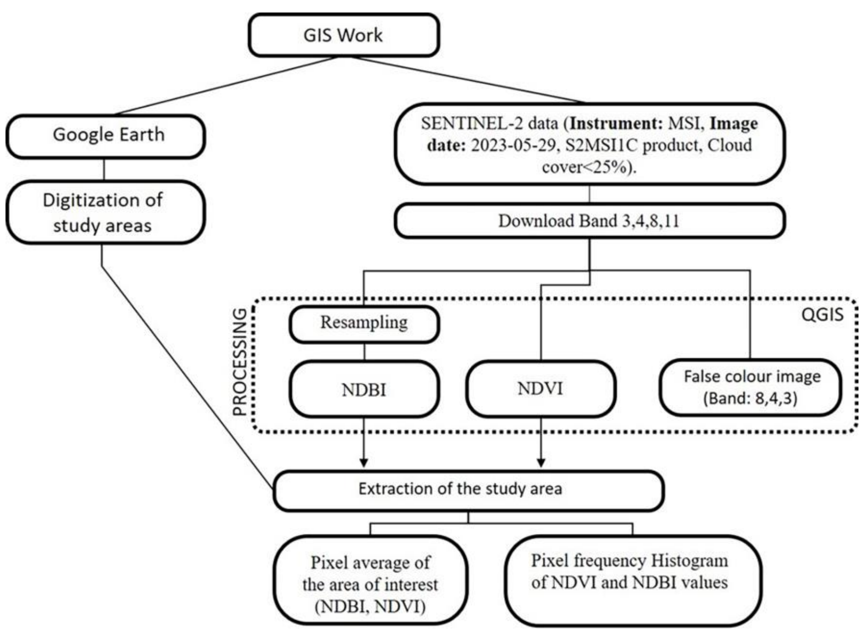

Fig. 3: Methodological framework for the assessment of NDVI and NDBI in the region of interest.

2021; Alcaras *et al.*,2022; Saleh, 2022; Lekhak *et al.*, 2023).

The most commonly used index of vegetation cover is NDVI (Normalized Difference Vegetation Index) which is based on the difference in absorbance and reflectance trends of red (RED) and near-infrared (NIR) lights. NDVI value depends on the absorbance of NIR by leaf pigments (e.g., chlorophyll) and reflectance of RED by the mesophyll layer of healthy leaves. NDVI is widely used in assessing the green biomass of a selected area. To qualitatively assess the vegetation quality near the sampled area, three 150×100 metre areas (which fall within the CRZ or Coastal Regulatory Zone) were extracted and aligned with the sampled zones from the vegetation line at the beach. The average NDVI was calculated for each Zone using the raster calculator in QGIS and using the formula:

$$NDVI = (NIR - Red) / (NIR + Red),$$

Where, NIR (Band 8 in Sentinel-2, resolution 10 m, 842 nm) and Red (Band 4 in Sentinel-2, resolution 10 m, 665 nm) are near-infrared band and red band reflectance, respectively.

NDVI scale goes from -1 to +1, with higher values indicating more plant growth and biomass and where values closer to −1 generally represent non-vegetated areas.

Similarly, NDBI (normalized difference built-up index) was also calculated for the same area using the formula: NDBI = (SWIR − NIR)/ (SWIR + NIR), where SWIR is Band 11 (resolution 20 m, 1610 nm) and NIR is Band 8 (resolution 10 m, 842 nm) in Sentinel-2. The NDBI index focuses on urbanised areas or human construction or built-up areas that bounce Shortwave Infrared or SWIR. Like, NDVI, the NDBI value falls between +1 and -1. The higher the NDBI value, the higher the portion of built-up areas in the area under study. However, as in the case of Sentinel-2, Band 11 has 20 m resolution, and Band 8 has 10 m resolution, resampling of data to lower resolution was performed before calculation. Frequency histograms of NDVI and NDBI for the selected 150 ×100-metre extracted areas were created for comparison. A sampling of the beach vegetation was also performed to estimate the number of plant species in the vicinity of the backshore. These plant species aid in sand compaction and prevent erosion during high tides, thereby, acting as an indicator of the robustness of the CRZ.

Urbanization Index (UI) assessment of the study sites:

Urbanization level or Urbanization Index (UI) was estimated for the selected three sites by calculating an index devised by González *et al.* (2014) and later modified by Schlender *et al.* (2023). The UI indicates the human interference in the study sites using six variables: (1) linear distance of the centre of the study site from the nearest urban centre (Here nearest hub of fishing and tourist activity in km, (2) Structures erected /buildings on the sand or the dunes, (3) Presence of solid man-made waste on the sand, (4) vehicle movement on sand evident from direct observation or presence of tyre tracks, (5) Quality of Night Sky graded visually by assessing the glow of artificial lights nearby, and (6) visitor frequency determined by direct observation or by observation of footprint on sand (Schlender *et al.*,2023). In the current study, the protocol is modified, the "beach cleaning activity" is omitted, and only 6 variables were used for calculation. The scoring criteria selected for the study are shown in Table 1.

Urbanization index calculation was done using the method mentioned by González *et al.* (2014) by calculating $X' = ((X - X_{min})/(X_{max} - X_{min}))$ (Legendre, 1998) which ranges from "0" indicating lowest human intervention or anthropogenic effect (X_{min}) to "1", indicating sites with highest human activity (X_{max}). where X designates the value assigned to each variable and $X_{min} - X_{max}$ is the difference between the extreme values of the range, i.e. (0-5) = 5 in the present scenario where 5 is the maximum possible score that can be assigned to a particular variable. X' was obtained for all belt transects used for the crab burrow

Table 1: Scoring criteria for qualitative indicators of human intervention used for the determination of Urbanization Index of the Dakshin Purushottampur Beach. Scoring criteria modified from González *et al.* (2014)

	Beach urbanization indicator levels		
	Low (0-1)	Medium (2-3)	High (4-5)
Proximity to nearest Urbanized area (nearest tourist hubs or fishing harbour in Mandarmani)	Several kilometers away from the sampling site and no direct influence	Within 1 km. with effects on the beach, such as noise, artificial lighting and near vehicular movement	Within meters, the beach is next to vehicular traffic, with evident noise and urban lighting
Buildings or structures on the sand	No nearby buildings	Buildings or structures erected close to the beach but not on the sand or the dunes	Buildings occupying some area on the beach or in the dunes
Solid man-made waste in the sand (Solid waste was counted for each transect and scored. Includes plastic cups, wrappers, earthen pots, fragments of fishing nets etc.	No or negligible waste	A moderate amount of Solid Waste	high frequency of solid waste
Vehicle movement on the sand (bicycle/bike and motorized vehicle tracks)	No tracks were observed	Limited vehicular activity	Recurring vehicular traffic with full access to the beach
Quality of the night or the severity of skyglow or light pollution (Scored based on visible stars in night sky)	The sky appearing black with stars (in absence of moon or fog)	Moderate presence of artificial light and moderately reduced conditions for stargazing due to skyglow.	High brightness of the artificial lighting making stargazing difficult. Only the occasional brightest stars can be seen
Frequency of visitors (based on counting presence/absence throughout the study time)	Visited by very few tourists/passers-by and local fisherman	Moderate demand for use by tourists/passers-by and local fisherman	High demand from passers-by/tourists/local fisherman

survey by averaging all the scores from the selected variables. The Urbanization index was calculated for each belt transect separately and averaged for Zone 1, Zone 2 and Zone 3.

Burrow surveys and Spatial distribution patterns of Crab Burrow:

To assess the abundance of ghost crabs, the protocol given by Schlender *et al.* (2023) was used with some modifications. Eight belt transects (6 m × 30 m) were employed symmetrically in each zone (transect number 1 to 8 in Zone 1, 9 to 16 in Zone 2 and 17 to 24 in Zone 3) perpendicular to the shore and extending from the vegetation line to the swash zone (Total n = 24, Fig. 1c). Within each transect, the number, depth, width, and distance from the vegetation line of ghost crab burrows were recorded. Surveys were conducted at low tide and mainly during the hours when tourist activity was low to minimize sampling biases.

In the present study, the following parameters were investigated (1) diameter of burrow entrances, (2) spatial distributions of burrows and (3) vertical depth of burrows. Burrow diameter was measured using a Vernier caliper (Freeman's FDC 150, India). The maximum vertical depth accessible by a weight tied with a string was taken as an approximation of the actual depth of the burrows (Shinoda *et al*., 2019). Crab burrow count was taken as a proxy for crab abundance as per previous researchers (Costa *et al*., 2019, 2022; Schlender *et al*.,2023). Distance from the vegetation and the transect lengths were measured using a laser distance meter (Bosch GLM 40, Germany). GPS coordinates were recorded using Garmin etrex10 (Garmin, USA).

The nearest neighbour distance (NND) analysis was performed to study the spatial distribution patterns of crab burrows following the methods given by various sources with modifications as stated (Clark and Evans, 1954, Sinha and Pati, 2008). For spatial distribution analysis, a camera mounted in an extension was used to take photographs of burrow openings from each study area with active burrows marked by fresh sand or fresh traces. The photographs were processed, distance calibrated and the distance from a specific burrow to its nearest neighbour irrespective of direction was measured using a built-in function of ImageJ software. Nearest Neighbour Ratio (Rn) was calculated by using the formula $\bar{D}_o/\bar{D}_e$, where $\bar{D}_e$ is the mean distance to the nearest neighbour expected in an infinitely large random distribution of crab burrow with density rho(ρ) and $\bar{D}_o$ is the mean of the series of distances to nearest neighbour (Clark and Evans, 1954). The Rn values indicate the type of spatial distribution. In a random distribution, Rn equals 1, while in an aggregated distribution, Rn equals 0. For a uniform distribution, the maximum Rn value is 2.1491, as stated by Clark and Evans (1954).

Statistical Analysis:

All data are represented as Mean±SD. Data collected on burrow count and UI was subjected to nonparametric Kruskal-Wallis tests followed by post hoc "Dunn's Multiple Comparison Test" to compare variables among sites. Spearman's rank correlation was used to assess the relationships between UI and crab burrow parameters such as burrow number, burrow diameter and burrow depth of ghost crabs.

A Matrix of Spearman's correlation coefficients between the Urbanization Index (UI) and other urbanization factors (Proximity to downtown, buildings on sand, solid waste, vehicle activity, visitor demand, quality of night sky and distance from nearest road) was also performed.

To compare the number of burrows, burrow diameter and burrow depth across the study sites, Kruskal-Wallis followed by Dunn Post Hoc tests or One Way ANOVA followed by Tukey's Multiple Comparison Test were used and plotted using R. nMDS ordination plot using Bray-Curtis distance matrix based on number, diameter and depth of crab burrows were performed using PAST. All statistical analyses were done in R and R Studio (v4.0) and PAST v4.16c (Hammer and Harper, 2001).

Results

Land use analysis:

The study revealed that Zone 2 consists of the most anthropogenic structures including a large fallow land (Denoted K) with an artificial embankment towards the sea (Fig. 4a). The embankment is devoid of any vegetation. Zone 1 being nearest to the Mandarmani beach incorporates several built-up areas mostly resorts and lodging facilities for the tourists. However, despite having multiple structures, the beach in front of Zone 1 is less visited by tourists due to the lack of entry points. Zone 3 is the most pristine location on the eastern flank of the beach which is covered with natural vegetation and lacks built-up structures as well as any links to the main road at the north of the beach.

The False colour composite (Fig. 4b) indicates a highly fragmented coastline on the Western end of the beach with several constructions within the CRZ. In the Eastern part of the beach, the vegetation is more continuous and the beach profile is not fragmented. The NDBI values ranged from -0.143 to 0.108 in Zone 1, -0.126 to 0.163 in Zone 2 and - 0.124 to 0.09 in Zone 3. The average NDBI for Zone 1, Zone 2 and Zone 3 are -0.026, 0.048 and -0.001, respectively (Fig. 5 b). The

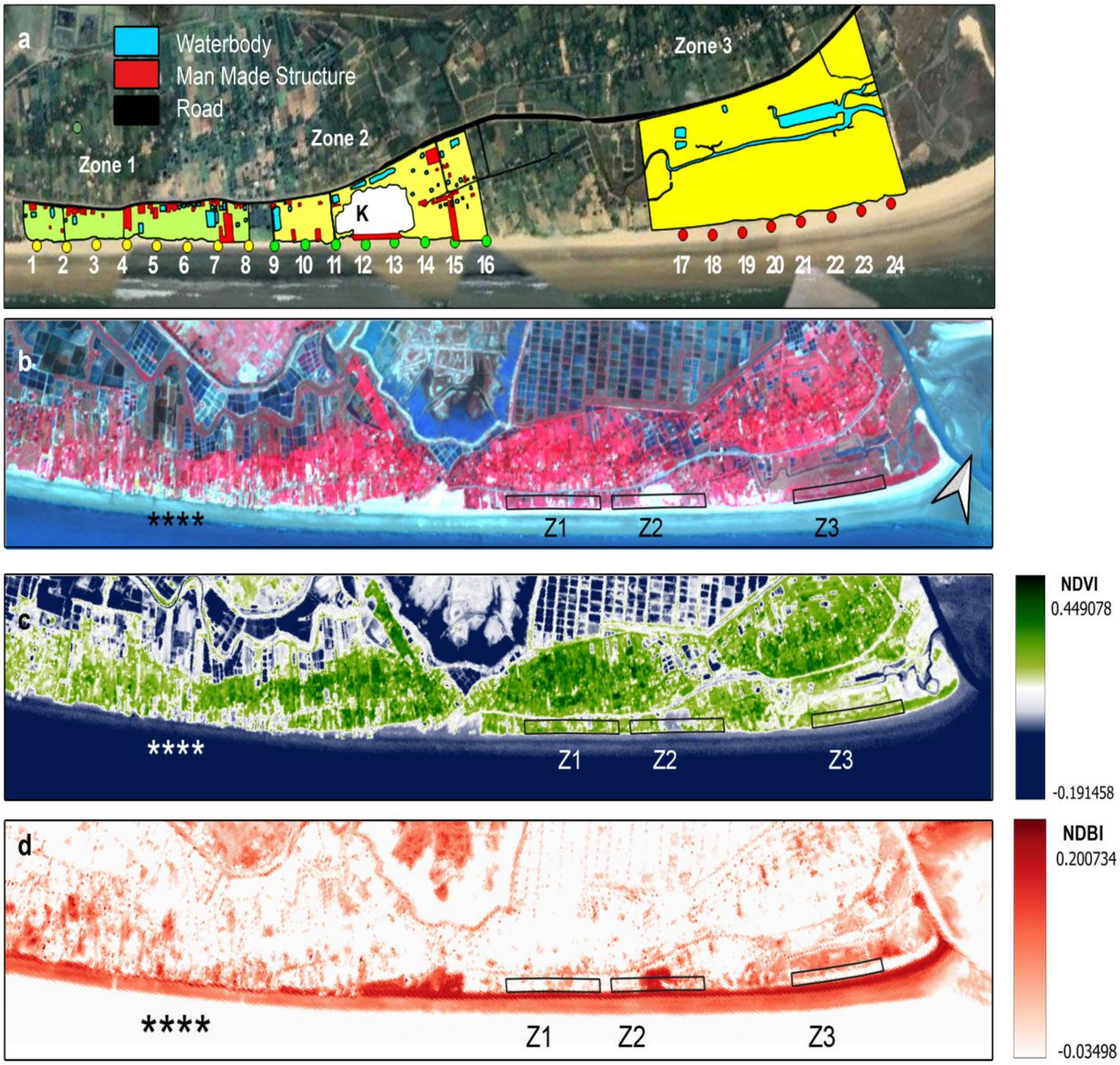

Fig. 4: Major Land use pattern in the study sites. K denotes a fallow lowland, completely devoid of vegetation and probably used for boat anchorage in past and isolated from the coastal belt with a man-made embankment. The numbers denote location of each belt transect (a), false colour composite image showing the highly fragmented coastal landscape in the Mandarmani region (****) in comparison to the study sites (Z1, Z2 and Z3) (b), NDVI (c) and NDBI (d) analysis of the study sites.

higher NDBI in Zone 2 is due to the presence of the fallow land or boat anchoring site and lack of vegetation. The NDVI value ranged from 0.044 to 0.307 in Zone 1, 0.021 to 0.314 in Zone 2 and 0.0877 to 0.264 in Zone 3 (Fig. 4c). The Average NDVI is lowest in Zone 2 (0.139) and highest in Zone 1 (0.185). The NDBI and NDVI pixel value histograms in Figure 5 show the difference between the three Zones. NDVI pixels of Zone 1 and Zone 3 are concentrated around the value 0.2 (Fig. 5a). On the other hand, 82% of total NDVI pixels are found to be below the value of 0.2 in Zone 2 which indicates the lack of vegetation cover.

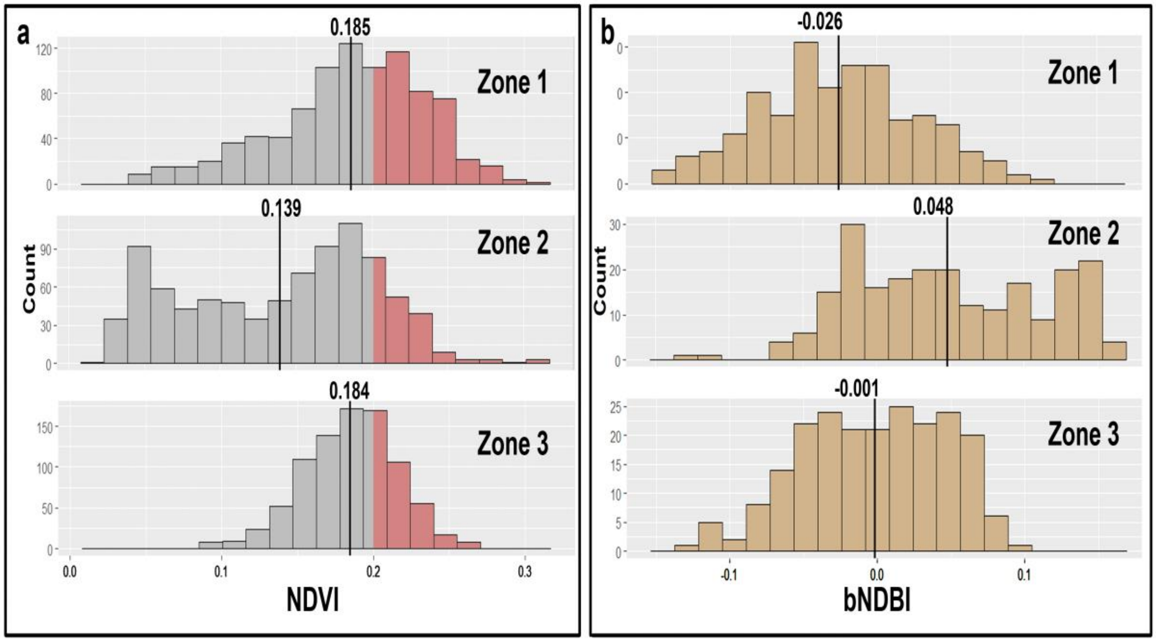

Fig. 5: Pixel value histogram of NDVI (a) and NDBI (b) of the study sites with the mean values for each zone.

Larger NDBI values are concentrated in Zone 2. 27.43% of the NDBI pixels of Zone 2 are above the value of 0.1 which designates barren land or built-up areas. On the other hand, 0% and 0.44% pixels are above 0.1 in Zone 3 and Zone 1, respectively. Zone 1 showed the highest percentage (67.41%) of negative NDBI pixels corresponding to small freshwater bodies and associated vegetation found in this region. Whereas, Zone 2 and Zone 3 have 27.43% and 50.23% of the same, respectively. The higher NDBI and lower NDVI areas in Zone 2 correspond to the absence of primary and secondary vegetation zones (Fig. 5b) which are visually shown in the NDVI and NDBI pictures (Figs. 4c, d).

The vegetation profiling around the study sites resulted in a total of 16 species of plants which includes large trees, herbs and creepers. Table 2 shows the list of plant species found in the study site along with their abundance. It was observed that as many as 9 species of herbs were found cumulatively in the three zones that act as sand binders and help in embryo dune formation. *Ipomoea pes-caprae* was the major creeper found to be consistent in all three zones with major abundances in Zone 1. *Sesuvium potrulacastrum* was found mainly in the immaculate location of Zone 3 and was observed to form embryo dunes (Fig. 2g). *Ipomoea pes-caprae* patches were fragmented in Zone 2 mainly to facilitate the entry routes to the beach and ingress-egress point for the boats which now appears as an empty area located at Zone 2. Moreover, it was observed that plastic barricades have been used in the region to create an artificial embankment leading to the complete removal of the *Ipomoea* patch in that region. Trees like *Casuarina equisetifolia*, *Cocos nucifera* and *Acacia auriculiformis* were most abundant in zone 3 and the backshore in that region is protected by a natural layer of *Casuarina equisetifolia* plants (Fig. 2f) which is also evident from the high and continuous pixel NDVI value of the region (Fig. 4).

Urbanization Index:

The findings of the urbanization index as per the data obtained from the study sites is depicted in

Table 2: Zone-wise list of plants found on the backshore of Dakshin Purushottampur beach. +, ++ and +++ roughly indicate the abundance of the species in the study sites as low, moderate and high respectively, - denotes an absence of the species

Plant Species	Zone 1	Zone 2	Zone 3
Borassus flabellifer	+	-	-
Acacia auriculiformis	-	-	++
Bulbostylis barbata	-	-	++
Casuarina equisetifolia	++	+	+++
Cocos nucifera	++	-	+++
Cyperus sp.	+	-	-
Desmodium gangeticum	+	-	-
Gisekia pharnaceoides	-	-	+
Hydrophylax maritima	-	-	++
Ipomoea pes-caprae	+++	+	++
Launaea sarmentosa	-	-	+
Pandanus tectorius	-	-	++
Panicum repens	-	++	-
Phoenix sylvestris	++	+	-
Saccharum spontaneum	-	+	-
Sesuvium potrulacastrum	-	-	+++

Table 3: Urbanization Index estimation: BT stands for the location of the belt transects performed in each zone

	Proximity to downtown	Buildings and other structures on the sand	Solid waste in the Sand	Vehicle/human traffic	Demands of Visitor	Quality of night sky	Urbanization index value	Average UI
BT1-Zone1	5	3	2	3	1	4	0.56	0.405±0.078
BT2-Zone1	4	0	2	2	1	3	0.36	
BT3-Zone1	3	0	2	2	1	2	0.32	
BT4-Zone1	3	0	3	2	1	2	0.36	
BT5-Zone1	3	2	2	2	1	2	0.4	
BT6-Zone1	3	0	3	2	2	4	0.4	
BT7-Zone1	3	4	2	2	1	5	0.48	
BT8-Zone1	3	0	2	3	1	4	0.36	
BT9-Zone2	3	1	5	5	5	2	0.76	0.585±0.2004
BT10-Zone2	3	0	5	4	5	2	0.68	
BT11-Zone2	3	0	4	5	4	2	0.64	
BT12-Zone2	3	5	5	3	4	2	0.8	
BT13-Zone2	2	5	5	2	4	1	0.72	
BT14-Zone2	2	0	5	1	3	1	0.44	
BT15-Zone2	1	2	4	1	2	1	0.4	
BT16-Zone2	1	0	2	1	2	1	0.24	
BT17-Zone2	1	0	3	2	2	1	0.32	0.135±0.036
BT18-Zone3	1	0	2	1	2	1	0.24	
BT19-Zone3	1	0	1	1	1	1	0.16	
BT20-Zone3	1	0	2	0	0	0	0.12	
BT21-Zone3	0	0	2	0	0	0	0.12	
BT22-Zone3	0	0	1	0	0	0	0.04	
BT23 -Zone3	0	0	1	0	0	0	0.04	
BT24 -Zone3	0	0	1	0	0	0	0.04	

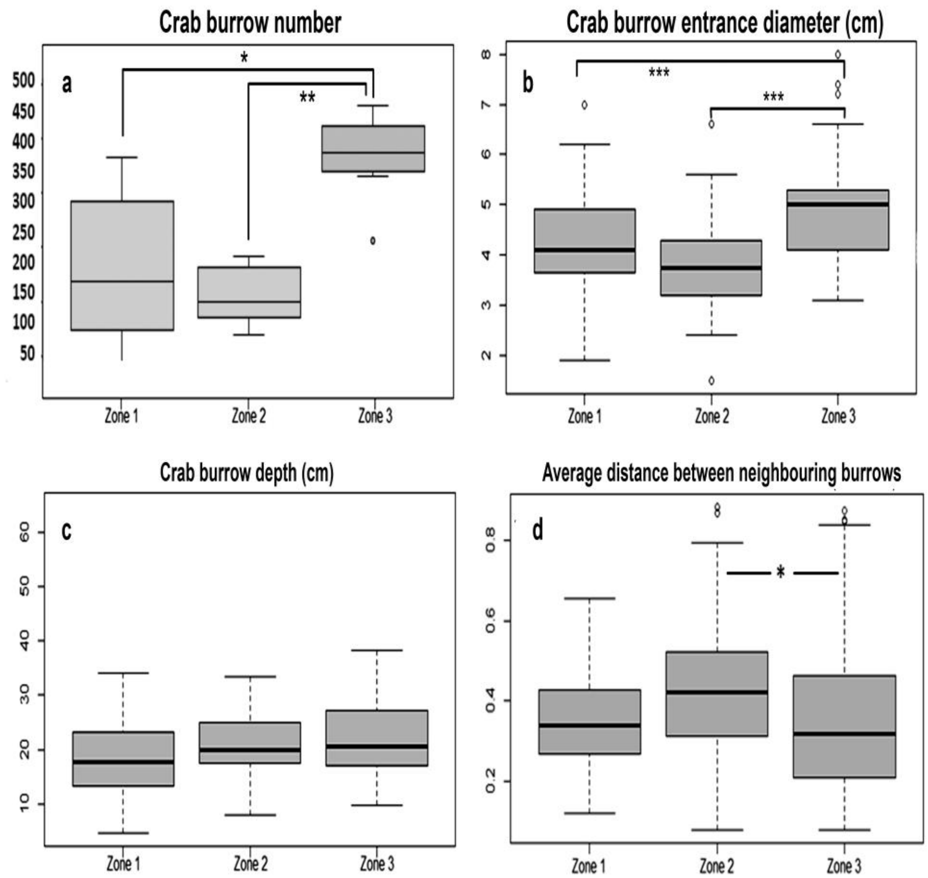

Fig. 6: Burrow survey results obtained from the study sites. Crab burrow number varies significantly in the three study sites (a), Variation in crab burrow entrance diameter in three zones (b), Crab burrow depth (c), Average distance between neighbouring burrows in three zones (d). (* p< 0.05, ** p<0.01 and *** p<0.001).

Table 3. The Urbanization Index (UI) ranged from 0.04 to 0.8 in the study sites where the lowest average UI value was obtained by Zone 3 (UI=0.135±0.036) and the highest average belonged to Zone 2 (0.585±0.2004). The UI of Zone 2 is high due to the higher anthropogenic factors contributing to its index (especially due to the impact of solid waste present on the beach and the higher demand of visitors). The lowest UI was obtained by Zone 3 (0.135±0.036).

Burrow Survey of O. macrocera:

A total of 5594 burrows were counted over the three study sites. Ghost Crab burrow count (hence density) significantly differed among zones (Kruskal-Wallis statistics=13.67, p< 0.001). The average burrow number in Zone 3 (373±67.48) is higher than in Zone 1 (148.8±118.0) and Zone 2 (140.8±45.82) (Dunn's Multiple Comparison Test) as seen in the bar diagram (Fig. 6a). It was found that the density of *Ocypode* burrows is higher in low-impact sites (Zone 3, 2.03 burrows per m^2) than high high-impact sites (Zone 2 and Zone 1, 0.78 and 1.026 burrows per m^2, respectively). A significant difference in crab hole entrance diameter was also found between the Zones (One-way analysis of variance, F=12.77, p<0.0001). The average entrance diameter of sampled crab burrows from Zone 1, Zone 2 and Zone 3 were 4.181±1.039 cm, 3.863±0.911cm and 5.030±0.2039 cm, respectively. A significant difference in crab burrow diameter was found between Zone 3 and Zone 1 and between Zone 3 and Zone 2 (Tukey's Multiple Comparison Test, P<0.0001). Zone 2 has the lowest average ghost crab burrow diameter (Fig. 6 b). However, no

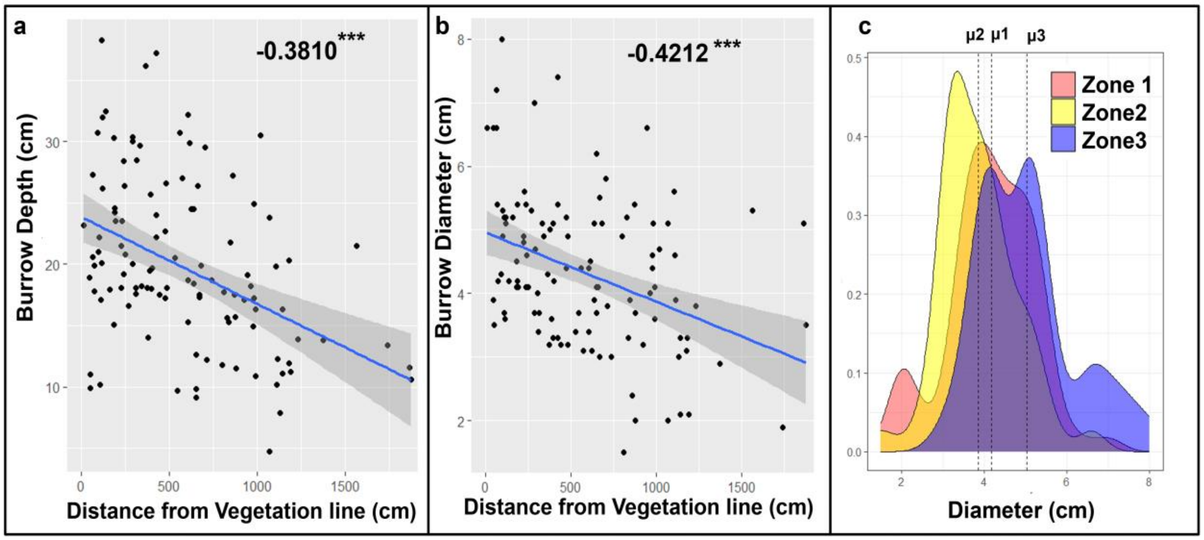

Fig. 7: Spearman's rank correlation showing the relationship between distance of a burrow from vegetation line and burrow depth (a), and relationship between distance of a burrow from vegetation line and burrow diameter (b). The density plot of the crab burrow entrance diameter shows a higher number of smaller burrows in the Zone 2 (c). (* p< 0.05, ** p<0.01 and *** p<0.001).

significant difference in crab hole depth was found among the sampling sites in the post hoc test (Fig. 6c).

From the nearest neighbour distance (NND) analysis for examining spatial distribution patterns of crab burrow, it was found that the mean value of Nearest Neighbour Ratio (Rn) for Zone 1, 2 and 3 were 0.43, 0.46 and 0.36, respectively that indicates burrow distribution is between aggregated and random in all three sites. The average distance between the two neighbouring burrows in Zone 1, Zone 2 and Zone 3 are 0.3845±0.019 m, 0.423±0.0142 m and 0.3601±0.0186 m, respectively. Difference between the average distance between two neighbouring burrow openings differed between the three zones. A feeble significant difference was noticed (Fig. 6d) between Zone 2 and Zone 3 (One-way ANOVA, F=5.083, P<0.0068 and Tukey's Multiple Comparison Test).

Ocypode burrow diameter and burrow depth showed a negative correlation (-0.3810, p<0.001 and -0.4212, p<0.0001, respectively) with the distance from the vegetation line with larger burrows towards the beach dune and smaller burrows towards the foreshore (Figs. 7a, b). Zone 2 has a higher frequency of smaller burrows in contrast with Zone 3 which can be seen in the density plot (Fig. 7c).

Non-metric multidimensional scaling (nMDS) of all 24 transects was done using burrow number, burrow diameter and burrow depth which showed the similarity (Similarity index: Bray-Curtis, Stress: 0.07112) of the 3 Zones based on burrow parameters. The plot reveals that as per the parameters studied, the burrows in Zone 3 were different from those of Zone 1 and 2 as manifested by the separate clustering (Fig. 8). Zone 1 shows much variability in the burrow parameters obtained from the belt transects and the nature of burrows is similar to those found in Zone 2. However, the variability in the parameters of the crab burrows is much less in Zone 2 as compared to Zone 1.

Spearman's rank correlation matrix was constructed between UI and crab burrow parameters such as burrow number, burrow

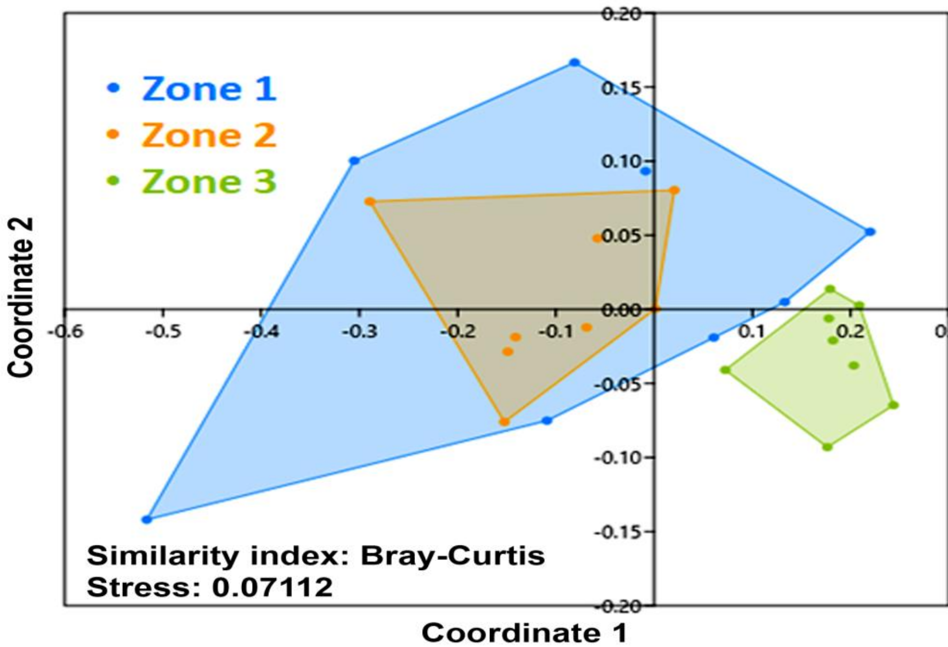

Fig. 8: nMDS analysis using the burrow parameters for the three zones under study using Bray-Curtis Similarity index.

diameter and burrow depth of ghost crabs. Burrow diameter and burrow depth were averaged for each sampling site. UI vs. crab burrows number counted in 24 sampling sites show a strong negative correlation (Spearman's r, -0.690, p<0.001) whereas, UI vs average burrow entrance diameter showed a negative correlation (Spearman's r, -0.50, p<0.05) and very weak negative correlation (Spearman's r, -0.22, not significant) were found between average burrow depth and UI (Fig. 9). The matrix also showed a weak positive correlation between the burrow number and burrow diameter and the distance of the burrow from the open road (Spearman's r, 0.18 and 0.30, respectively).

Discussion

Coastal tourism is well known for fragmenting the homogeneity of beaches and is often associated with the higher built-up area indices and lower value of the vegetated land indices (Saha and Paul, 2021; Sunarta and Saifulloh, 2022). In the current study, the 4 km stretch of Dakshin Purushottampur beach was also found to be partially heterogeneous and fragmented. In a previously done study on the same stretch of the beach, it was found that a surge in tourism and associated development partially altered the protected CRZ (Coastal Regulatory Zone), fragmented the landscape, degraded vegetation cover, and fragmented dune ecology in the Western part of the beach (Saha and Paul, 2021). The study reveals that the 3 zones differ considerably in both NBVI and NDBI values as well as in Urbanization Index. Among the three zones, Zone 2 scored highest in UI. One of the major contributing factors is the direct access of tourists through unpaved roads into the beach. The direct connection of the beach with the main road through the unpaved roads allows two-wheelers to enter the beach unrestricted as evidenced by the frequent tyre marks on the sand. These access

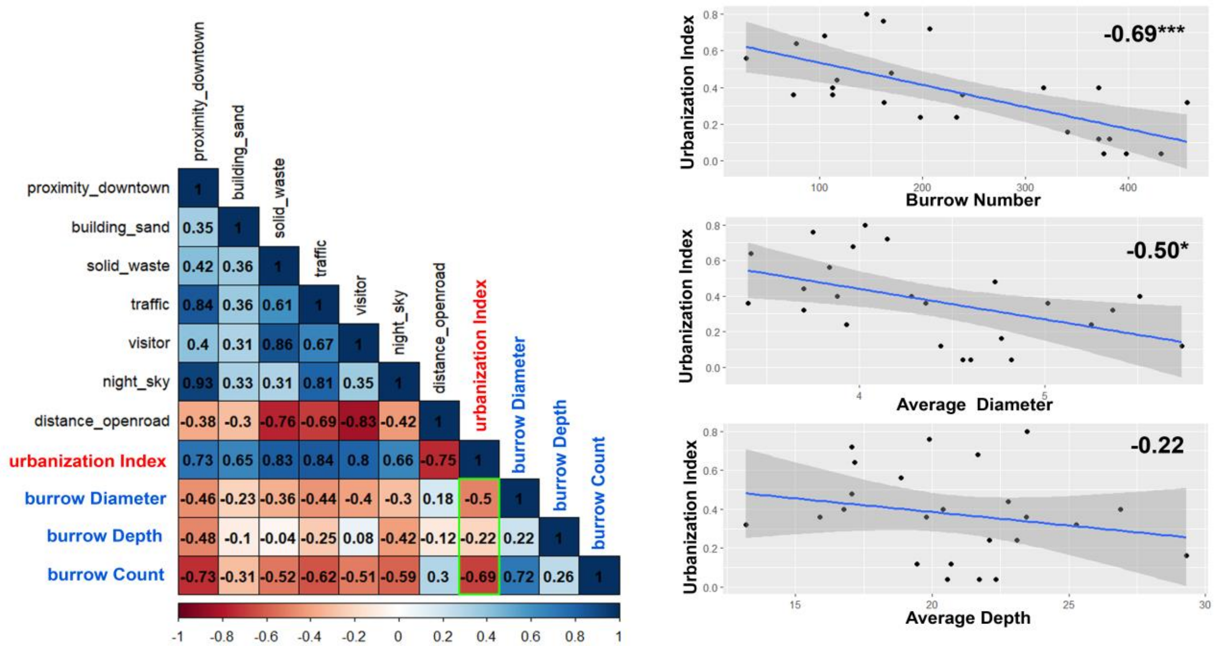

Fig. 9: Spearman's rank correlation matrix showing the relationship between Urbanization index and the burrow statistics in the study sites (a). Burrow number, average burrow diameter and depth shows negative correlation with UI (b).

points increase visitor demand and vehicle/tourist activity and solid waste around Zone 2. The NDVI and NDBI features also show fragmentation and heterogeneity in Zone 2 due to the presence of a huge barren land protected by an artificial embankment. On the other hand, Zone 1 is nearest to the Mandarmani tourist hub and with relatively higher built-up/prospective resort sites which often use artificial lights for beautification. All these factors escalate the UI of the concerned area. However, the waterbodies and beach-associated primary and secondary vegetation in the backshore Zone 1 are still relatively unaffected and the same is reflected in the higher NDVI values. On the contrary, Zone 3 is relatively secluded, without any direct connection with the main road in the north and restricted by the Pichaboni River in the East. Negligible tourist activity was seen in Zone 3 during the sampling period. The beach dune of Zone 3 is covered with continuous strips of vegetation populated by plants like *Casuarina equisetifolia, Acacia auriculiformis, Bulbostylis sp., Gisekia pharnaceoides, Hydrophylax maritima, Ipomoea pes-caprae, Sesuvium potrulacastrum* and *Pandanus sp*. (Table 2). The fore dunes, when present, were found to be covered with a layer of *Ipomoea pes-caprae* in all the studied zones except areas with high disturbance (Zone 2). The beach-vegetation boundary was maintained chiefly by creepers like *Ipomoea pes-caprae* in all three zones. It was also recorded that active crab burrows were scarcely present within the creepers probably due to the presence of dense root zone and compact sand which is harder for burrowing. A similar trend of the burrow distribution was also observed in Zone 3, in embryo dunes supported by the *Sesuvium* root zone.

Though the study was limited to a 4 km stretch, UI and GIS study revealed admissible differences in the extent of urbanization and land use patterns that affect the distribution of ghost crabs. The outcome of the current study illustrates that higher UI and degraded coastal features adversely affect *Ocypode* burrow distribution and number. Larger crabs with a bigger gill area and larger carapace size can tolerate longer times out of moisture and tend to stay within their burrow in the daytime (Costa *et al*., 2019). As a result, larger burrow openings and deeper burrows can be found towards the backshore. A similar trend was found with *Ocypode macrocera*, where the distance of a burrow from dune vegetation is inversely proportional to the burrow diameter and burrow depth. It was found that the density of *Ocypode* burrows is higher in low-impact sites (Zone 3) than the high-impact sites (Zone 2 and Zone 1). Anthropogenic pressure not only reduces the burrow density but also affects the average burrow diameter. Average burrow diameter was found to be significantly lower in high-impact areas (Zone 2). This finding resonates with the previous reports of declining *Ocypode* burrow density and reducing burrow diameter with increasing urbanization or increasing tourist and vehicular activity in other parts of the world in other species (Noriega *et al*., 2012; Gül and Griffen, 2019; Costa *et al*., 2021; 2022, Schlender *et al*., 2023). Ghost crab burrow opening diameter is a key indicator of crab size and alteration of the distribution of burrow diameter might severely affect ghost crab population structure (Lucrezi *et al*.,2014).

Zone 2 is accessible by several entry points and thus faces significant anthropogenic disturbance. Vehicular activity was highest in that area along with other usage like picnic spots and playground during low tide. These human activities might contribute significantly to the density and other parameters of the crab burrow (Lucrezi *et al*.,2014). However, reduction in burrow number is not a suitable indicator for population decline but it signifies the degradation of the habitat for ghost crabs (Silva and Calado, 2013). The result from the nearest neighbour distance study was indicative of the non-random distribution of crab holes in all three sampling zones as the average Rn value ranges between 0.46 and 0.36 (Clark and Evans, 1954; Sinha and Pati, 2008). In the current study, an interesting fact emerged from NND analysis that crab holes are much more crowded in relatively undisturbed zones. However, the exact cause of this observation could not be identified and further investigation is necessary. Furthermore, the UI of all the 24 transect found to be negatively correlated with the burrow count, average diameter and average depth of the *Ocypode* burrow. This finding corroborates with the previous works with other crab species and emphasizes the role of tourism-induced alteration of crab burrowing habit and habitat (Noriega *et al*., 2012; Lucrezi *et al*., 2014; Schlender *et al*., 2023).

Ironically, red crabs act as a part of tourist attraction at the Mandarmani-Tajpur tourism belt (Saha and Paul, 2021) which has developed from a fishing village to a tourist attraction (Mondal and Sen, 2017; Saha and Paul, 2021; Ghosh and Chakravarty, 2023). Due to booming tourism from the Western end (towards the Jaldah Mohona tidal inlet), the beach has undergone a significant shift in land use in the last 30 years. This shift is primarily characterized by the conversion of agricultural land, fallowed fields, sand dunes, beaches, and vegetation cover into areas dedicated to tourism activities. It must be noted that Purushottampur of Ramnagar-II block is under CRZ–IA (Ecologically Sensitive Areas) status which prohibits construction within High Tide Line (HTL) to 200 m (The Coastal Zone Regulation Notification, 2011; later amendment-2019) on the landward side along the seafront (Report of the Expert Committee, 2021; Ghosh and Chakravarty, 2023). There are multiple instances of violation of CRZ in past within the Mandarmani tourism belt which drew the attention of authorities and proper steps are being taken. In the present study, Zone 2 is found to be the most affected zone even with lesser tourism-related construction. Zone 1, though having a few constructions within and just outside the CRZ, has a moderate amount of burrow activity as it has an unaltered beach feature, no direct access to the zone through road and higher primary and secondary vegetation with waterbodies that ensures the future wellbeing of this particular zone. It is evident that as long as Zone 3 is protected from tourism-related construction, the area will remain ideal for the crabs in the near future. However, the implementation of the law could delay further damage to the coastline within the CRZ, but it may not ensure reduced anthropogenic pressure on the *Ocypode* habitat that inadvertently comes with the expansion of the tourism industry.

Conclusion

In the present study, it was found that areas of beach with fragmented beach landscape (with high NDBI and low NDVI features, higher built-up, disturbed vegetation zone etc.) or higher UI components caused by tourists from nearby tourist spots and associated vehicular activity, affect the burrowing behaviour of *O. macrocera*. Similarly, burrowing activity which increases with the robustness of dune health and acts as a bioindicator of Coastal integrity. It was also observed that higher burrow density and average burrow diameter prevailed in the sampling zones devoid of direct access to the beach. In conclusion, it can be proposed that restriction of unauthorized built-up areas within CRZ will prevent further degradation of the beach. Alongside this, restraint in vehicular and recreational activity within the present habitat is also necessary for the sustenance of *Ocypode macrocera* habitat in the Dakshin Purushottampur beach.

Ethical Statement

In this study, no live specimens were harmed or collected. Observations and measurements were limited to burrow characteristics and spatial distribution; all activities were non-invasive and minimized disturbance to the natural habitat. The study did not involve any endangered or protected species. All data were collected and reported with integrity, ensuring transparency and respect for the local ecosystem.

Author Contributions

De Arijit: Conceptualization, Methodology, Investigation, Writing and original draft preparation: *Chowdhury Saheli*: Vegetation Analysis; *Bhuiya Krishnendu*: GIS-based Analysis; *Chatterjee Rupsa*, *Mandal Kritibandhu*, *Sinha Samparna*, *Dey Chayanika*, *Naskar Sumona* and *Parveen Shagufta*: Field Work and Sampling; *Dasgupta Mandakranta* and *Sen Debrup*: Field Work supervision and Sampling; *Bhowal Ankur*: Conceptualization, Data Analysis, Writing, Review and Editing, and Project administration. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflicts of interest.

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