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Effect of Anthropogenic Pressure on Distribution and Burrow Morphology of the Brachyuran Crab, *Dotilla blanfordi* Alcock, 1900 (Decapoda: Brachyura) Inhabiting Mudflats of North Western India

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Abstract: Coastal regions are one of the most crucial ecosystems as they support biology of numerous vertebrate and invertebrate taxa which provide economic aid to mankind. Monitoring of the natural resources of the coasts and to test the ecological impact of human disturbance therefore becomes necessary. The present study was conducted from 26th January to 18th February 2019 to investigate the effect of anthropogenic impacts on the population (burrow density, distribution and size) and burrow characteristics (burrow length, depth, inclination angle, weight and volume) of *Dotilla blanfordi* Alcock, 1900*.* Total eight sandy beaches of Gujarat and Maharashtra states of India were examined. The beaches were categorised into pristine, moderately impacted or heavily impacted sites on the basis of various levels of anthropogenic pressures. It was found that the burrow density was observed maximum at the low impacted sites (Tithal --21.11±13.53; Dandi site-2 --20.66±11.23), as compared to the moderately impacted sites (Umargam-- 16.11±21.62; Gorai-- 20±10.77; Uran-- 7.11±10.99) and heavily impacted sites (Kuda-- 5.11±14.24; Koliyak-- 1.56±2.01; Dandi site 1-- 11.78±8.27). The crabs built simple burrows in heavily impacted sites as compared to the complex burrows in the moderately affected and pristine sites. Burrow weight and burrow volume showed significant variation across all study sites as compared to other morphological traits. The results inferred that anthropogenic stress can directly influence the distribution and burrow morphology of *Dotilla blanfordi*. The results also suggested utility of *D. blanfordi* as an indicator species for effective coastal management but the outcomes would benefit with a comprehensive study of environmental as well as ecological characters.

Keywords: Burrow characteristics, Ecology, Gujarat, Human disturbance, *Dotilla blanfordi*

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Introduction

Human population has flourished a lot in the past century and generously relied on natural resources for their sustainment (Gul and Griffen, 2018). The impacts have greatly influenced the condition of ecosystems (Wolcott and Wolcott, 1984). Rapid and widespread infrastructure development and rise in coastal populations has intensified human pressures on coastal ecosystems (Schlacher *et al.,* 2006). Use of beaches by public has ecological consequences that brings about environmental degradation (Brown and McLachlan, 2002; Dugan and Hubbard, 2006). The intensity of these impacts in different areas is highly associated with the size of human population and changes in land use dynamics (Ojima *et al.,* 1994). Coastal ecosystem is one of the most exploited ecosystems as humans turn to it for recreational purposes and tourism, while recreation and tourism boost the country's economy, they raise ecological issues too (Wolcott and Wolcott, 1984; Schlacher *et al*., 2007; Lucrezi and Schlacher, 2010) and hamper the biodiversity. Effects of tourism on environment shows that countries prioritize economic development over environmental sustainability (Zahedi, 2008).

Study of burrowing characteristics provides a low-cost and cogent monitoring technique for assessing health of the coastal environment (Pombo and Turra, 2013). Indicators can act as proxy for whole ecosystems (Niemeijer and de Groot, 2008). Ecological indicators are widely applied to assess nature, determine severity of human impacts and to evaluate the efficiency of management (Niemi and McDonald, 2004). Maximum studies of human impacts are concentrated on ghost crabs of the Ocypodidae family (Neves and Bemvenuti, 2006; Hobbs *et al*., 2008; Aheto *et al*., 2011; Pombo and Turra, 2013; Schlacher *et al*., 2016). It is conclusively found that crabs of the *Ocypode* species are reliable indicator species due to their strong responses to anthropogenic and natural impacts (Barros, 2001; Moss and McPhee, 2006; Neves and Bemvenuti, 2006; Hobbs *et al*., 2008; Lucrezi *et al*., 2008; 2009; Noriega and Smeuninx, 2008; Dubey *et al*., 2013; Gul and Griffen, 2018). Crabs of the genus *Dotilla* Stimpson, 1858 are commonly referred to as soldier crabs or sand bubbler crabs (Mitra *et al*., 2020). They play an important role in ecology of faunal community due to their burrowing and feeding behaviour (Manzoor *et al*., 2016). These crabs remain inside the burrows and come out to the surface during low tides when their habitat is exposed for various activities. The most effective way of determining the population of burrowing crabs is by simply counting the number of burrow entrances as the circular openings are easy to spot (Moss and McPhee, 2006). *Dotilla blanfordi* Alcock, 1900 is commonly found in the sandy and muddy shores of tropical Indo-Pacific region (Bradshaw and Scoffin, 1999) with higher abundance at the coastal regions of Gujarat and Maharashtra state. *Dotilla blanfordi* is an actively burrowing species of the family Dotillidae and no such study has been carried out so far. Therefore, the present study was conducted to assess the employment of *D. blanfordi* as an indicator species for anthropogenic activities.

The purpose of this study was to investigate how various levels of anthropogenic impacts could alter the population (burrow density, distribution and size) and burrow characteristics (burrow length, depth, inclination angle, weight and volume) of *D. blanfordi*, on the sandy beaches of North Western coast of India.

Materials and Methods

Study sites:

The present study was carried out at total eight sandy beaches of Gujarat and Maharashtra coast of India with various levels of anthropogenic pressures (Fig. 1). Sampling was carried out between 26th January and 18th February 2019 at afternoon period during low tide time.

These beaches were selected based upon primary investigation of distribution of *Dotilla blanfordi*. Sampling was carried out at six beaches of Gujarat state: (1) Kuda (21°37'31.2" N, 72°18'17.6" E), (2) Koliyak (21°36'02.4" N,

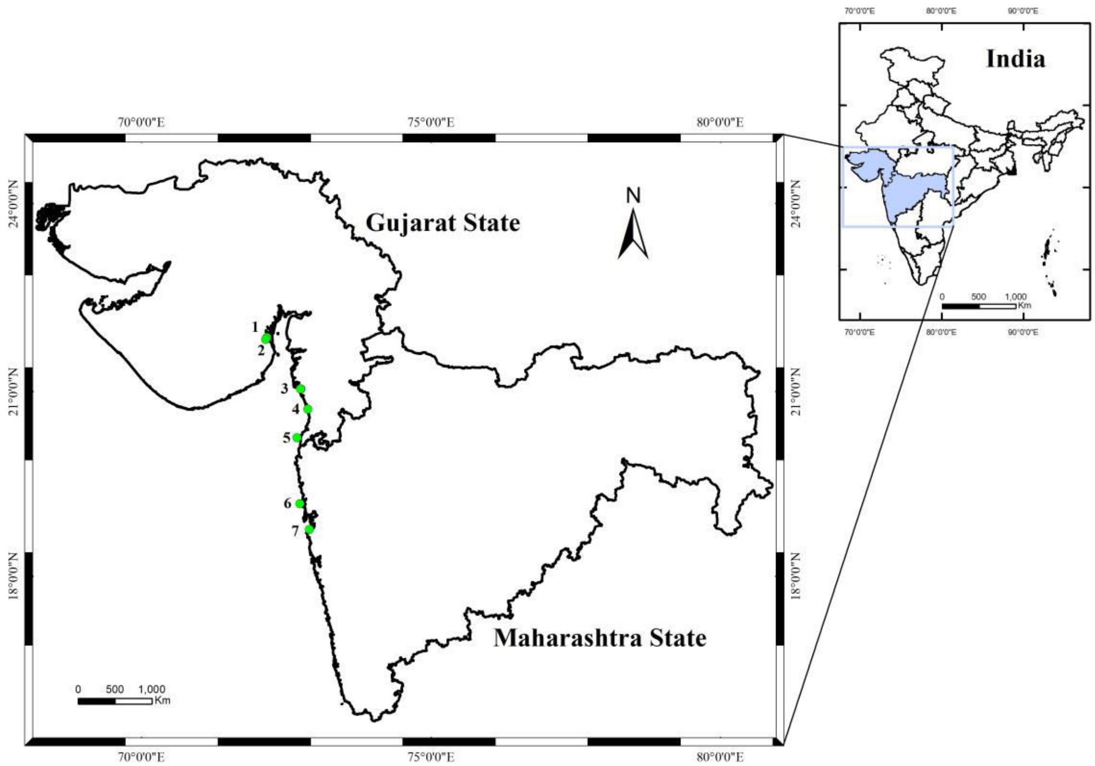

Fig. 1: Map of study area showing different sampling sites of Gujarat and Maharashtra states, India.1. Kuda, 2. Koliyak, 3. Dandi site 1, 4. Dandi site 2, 5. Tithal 6. Umargam, 7. Gorai, 8. Uran. (Source: QGIS version 3.6).

72°17’12.0” E), H (3) Dandi site 1 (20°53’15.6” N, 72°47’40.3” E), (4) Dandi site 2 (20°53’48.2” N, 72°47’15.0” E), (5) Tithal (20°35’52.3” N, 72°53’40.8” E) and (6) Umargam (20°11’18.6” N, 72°44’12.5” E) and two beaches of Maharashtra state: (1) Gorai (19°14’31.0” N, 72°46’50.5” E) and (2) Uran (18°52’20.9” N, 72°55’04.9” E) (Fig. 1). The total distance between the northernmost studied site (Kuda beach, Gujarat) and the southernmost studied site (Uran beach, Maharashtra) was about 600 km.

Anthropogenic activity:

The study sites were visually scanned to check for the intensity of visitors and presence or absence of vehicles. The number of people at each site were counted every hour over a three-hour period. Based on the observations, the sites were classified as pristine, moderately impacted or heavily impacted sites (Gul and Griffen, 2018). The sites with less than 30 people per hour were considered as pristine sites, sites with less than 50 people per hour were considered as moderately impacted sites, while sites with more than 50 people per hour were considered as heavily impacted sites (Gul and Griffen, 2018).

Burrow distribution:

Burrows of the sand bubbler crab *Dotilla blanfordi* were identified by examining the crab specimen and its mud-balling pattern. In order to determine if distribution patterns of *Dotilla blanfordi* are affected by human disturbance, the burrow density and the burrow opening diameter were observed. At each site, three line transects perpendicular to the shoreline, spaced 100 meters apart were laid. In each line transect, three quadrats (0.25 m^2) were laid starting from the upper intertidal to lower intertidal region (Trivedi and Vachhrajani, 2017). Total number of burrows were counted per quadrat and the burrow opening diameters were measured using digital vernier callipers (Mitutoyo 500-196-20; 150mm/6 inch model, ±0.01 mm accuracy). In each quadrat, only active crab burrows were examined. Fresh sand or traces left by crab individuals around the burrow

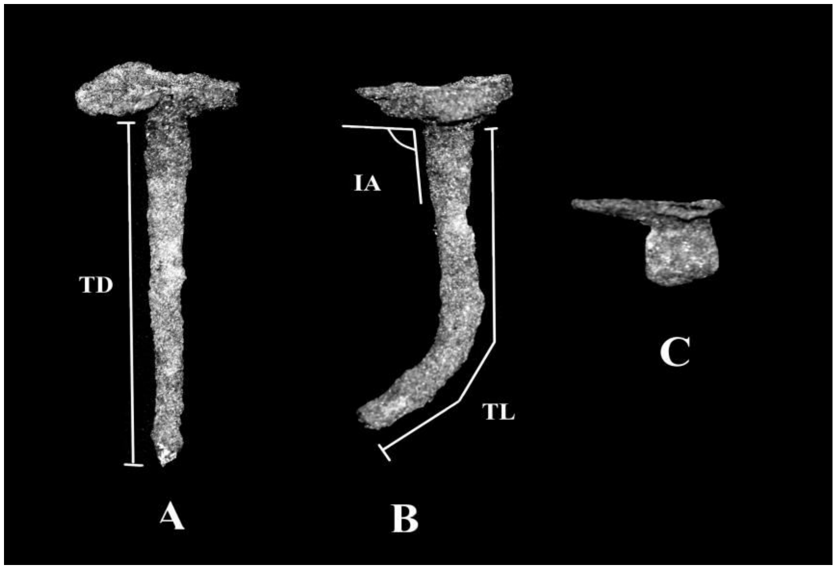

Fig. 2: Burrow architecture of *Dotilla blanfordi* Alcock, 1900 with measurements, (A) Straight burrow; (B), J-shaped burrow; (C), Bulbous burrow. TD: Total depth, IA: Inclination angle, TL: Total length.

mouths were observed to determine whether the burrow was active or not (Lucrezi *et al*., 2008; 2009).

Burrow morphology:

Burrows were randomly selected for obtaining burrow casts. At least two burrows from each quadrat level with various opening diameters were selected. The burrow opening diameter was measured using digital vernier callipers (± 0.01 mm accuracy). A 2:1 mixture of unsaturated resin and hardener compound was poured into the burrows until they were filled completely (Trivedi and Vachhrajani, 2016). The resin took around an hour to dry after which the burrow casts were excavated out using a shovel. Excess sand was brushed off and casts were tagged and brought back to the laboratory for further investigation. Only the intact burrows were used for the analysis.

In the laboratory, the burrow casts were classified according to their shape and various measurements including total length (TL) (along the mouth of the burrow at surface till the end point of the burrow), total depth (TD) (from the mouth of the burrow at surface till the deepest part of the burrow), burrow inclination angle (IA) (angle between the surface of the substratum and the main burrow tube) and weight (Trivedi and Vachhrajani, 2016) (Fig. 2). Burrow volume was calculated by dividing weight of the burrow with the density of the resin (0.9 gm/cm^3) (Trivedi and Vachhrajani, 2016).

Mean variation in all the attributes of burrow distribution, burrow morphology and anthropogenic pressure from all study sites was analysed by single factor ANOVA (Analysis of Variance). All the statistical analyses were performed using Microsoft Excel.

Results

Anthropogenic pressure:

On the basis of anthropogenic pressure Dandi site-1 (484 ± 331), Koliyak (92 ± 31) and Kuda (76 ± 7) were classified as highly impacted sites; Uran (53 ± 8), Umergam (43 ± 26) and Gorai (42 ±1 9) were classified as moderately impacted sites; Tithal (24 ± 18) and Dandi site-2 (14 ± 8) were classified as pristine sites (Fig. 3). A significant variation was observed in the number of people visiting each hour between the study sited sites (ANOVA; F: 6.912, $p<0.001$).

Burrow distribution:

In the present study, the burrows of *D. blanfordi* were examined for their size, density and

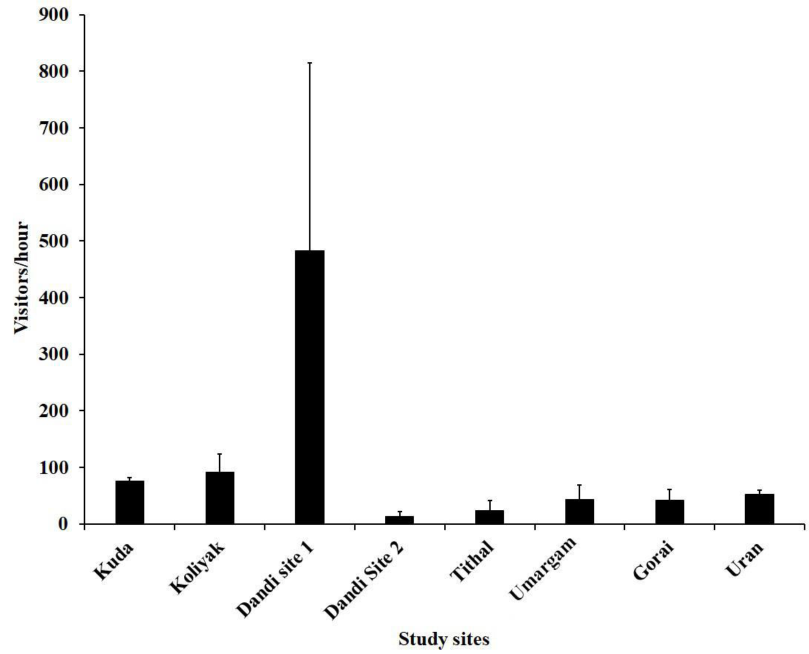

Fig. 3: Anthropogenic pressure at the study sites.

distribution. Burrow density varied significantly between the pristine, moderately impacted and heavily impacted sites (ANOVA; F: 3.291, $p<0.1$). The burrow density was observed maximum at the low impacted sites (Tithal 21.11 ± 13.53 and Dandi site-2 20.66 ± 11.23), as compared to the moderately impacted sites (Umargam 16.11±21.62; Gorai 20 ± 10.77, and Uran 7.11±10.99) and heavily impacted sites (Kuda 5.11±14.24; Koliyak 1.56 ± 2.01 and Dandi site 1 11.78±8.27) (Fig. 4A).

Significant variation was observed in the burrow opening diameter across study sites (ANOVA; F: 15.337, $p<0.001$) but no trend was noted in response to anthropogenic pressure. In the present study, maximum burrow opening diameter was recorded in Koliyak (7.15±2.98) followed by Kuda (5.48±1.20), Uran (3.75±0.67), Dandi site 1 (3.64±1.65), Tithal (3.53±1.61), Dandi site 2 (3.38±1.66), Gorai (3.36±1.13), and Umbergaon (3.15±1.29). (Fig. 4B).

Figure 5 illustrates that the density and burrow opening diameter differ between upper intertidal zone (0-100 meter), middle intertidal zone (100-200 meter) and lower intertidal zone (200-300 meter). The upper intertidal zone of highly impacted sites like Koliyak, Kuda and Dandi site 1 was having fewer burrows with smaller diameter as compared to moderately impacted and low impacted sites (Fig. 5)

Burrow morphology:

In all, 54 intact burrows were obtained from all study sites (Fig. 6) of three different shapes *viz*. I-shape (straight burrow), J-shape and bulbous burrow. Maximum number of obtained burrows were I-shape (41 burrows) followed by J-shape (11 burrows) and bulbous burrow (2 burrows). Site wise maximum number of burrows were obtained from Umbergaon (9 burrows) followed by Tithal (8 burrows), Dandi site 2 (7 burrows), Uran (7 burrows), Kuda (6 burrows), Koliyak (6 burrows), Dandi site 1 (6 burrows) and Gorai (5 burrows). A maximum number of I-shaped burrows were obtained from Umbergaon (8 burrows) followed by Tithal (6 burrows), Uran (6 burrows), Dandi 1 (6 burrows), Koliyak (5 burrows), Kuda (4 burrows), Gorai (4 burrows) and Dandi 2 (2 burrows). A maximum number of J-shaped burrows were obtained from Dandi 2 (5 burrows), Tithal (2 burrows), Kuda (2 burrows),

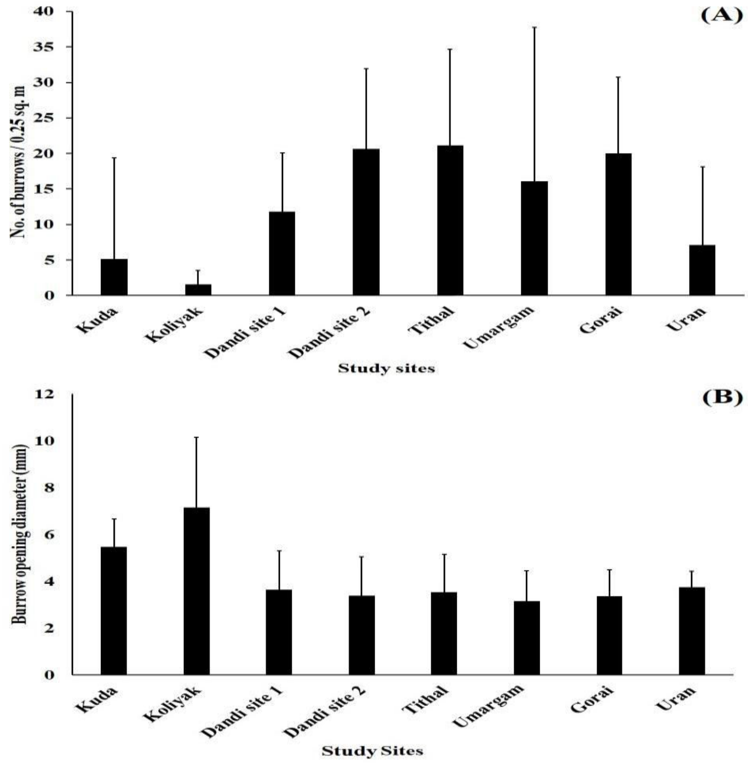

Fig. 4: Distribution of *Dotilla blanfordi* Alcock, 1900 across the study sites of Gujarat and Maharashtra state, India. (A) Burrow density, and (B) Burrow opening diameter.

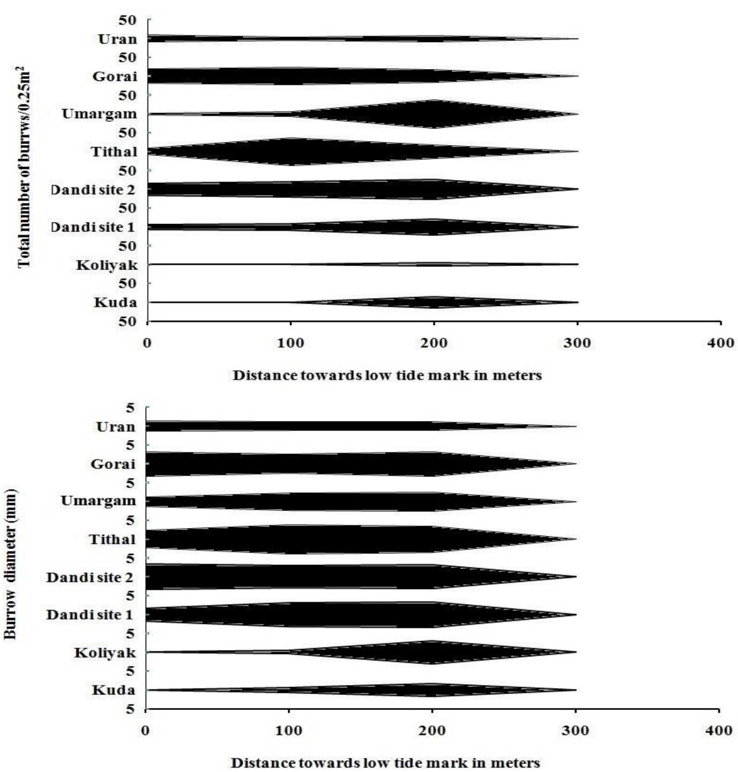

Fig. 5: Zonal distribution of *Dotilla blanfordi* across the study sites of Gujarat and Maharashtra state, India. (A) Burrow density, and (B) Burrow opening diameter.

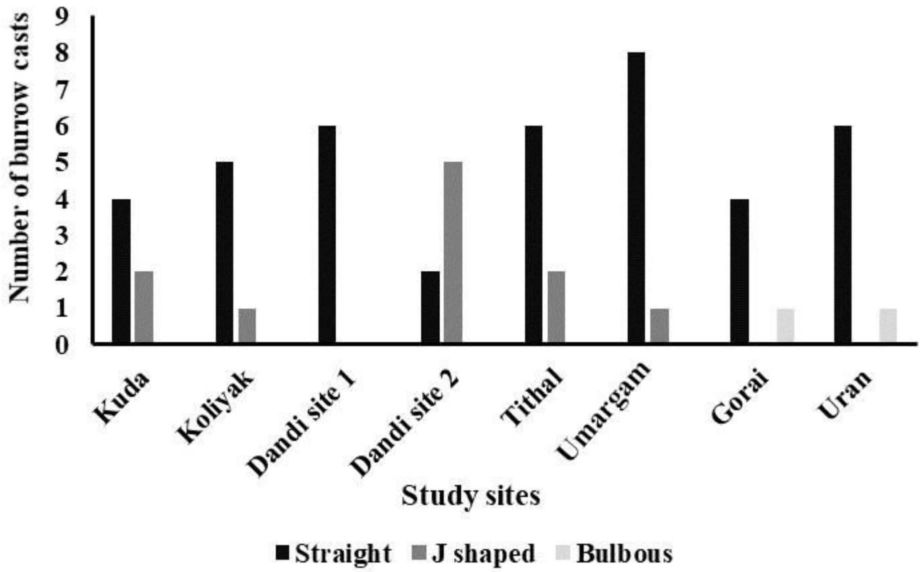

Fig. 6: Shape of burrow casts of *Dotilla blanfordi* Alcock, 1900 across the study sites.

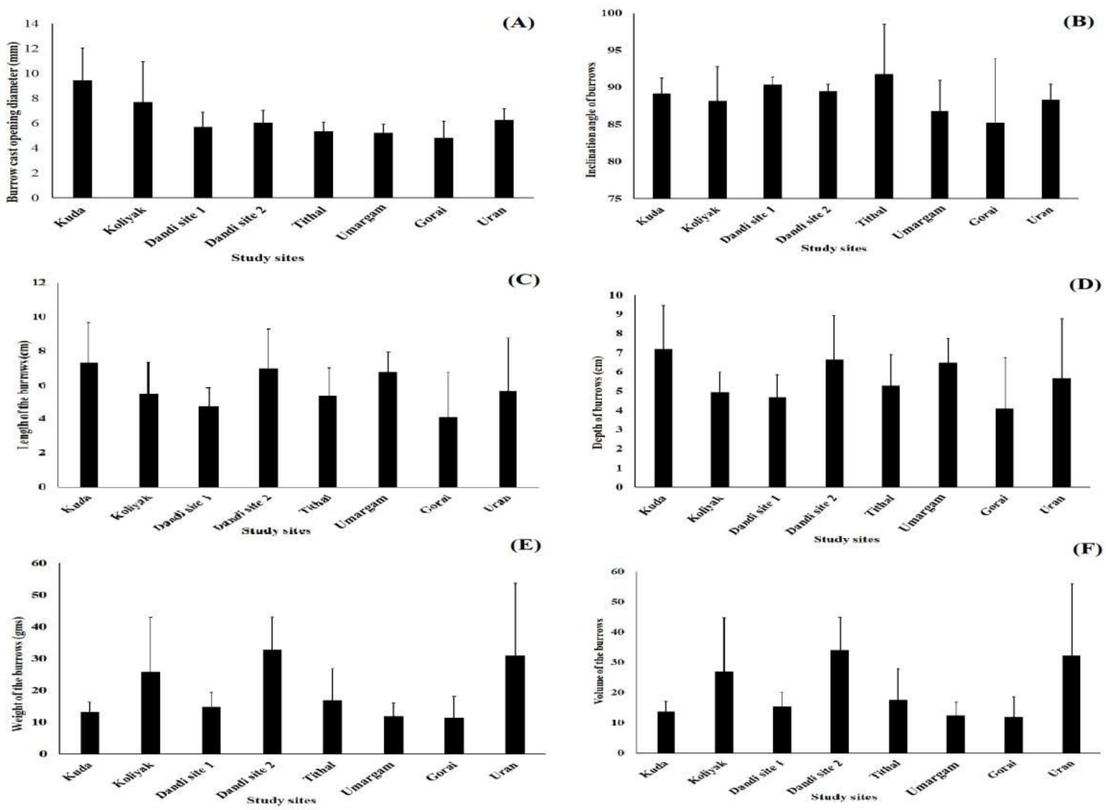

Fig. 7: Variation in *Dotilla blanfordi* Alcock, 1900 burrow morphometrics across the study sites. (A) Burrow opening diameter, (B) Inclination angle of burrows, (C) Length of burrows, (D) Depth of burrows, (E) Weight of the burrows, (F) Volume of the burrows.

Umbergaon (1 burrow) and Koliyak (1 burrow) while single-single bulb shaped burrows were obtained from Uran and Gorai. From the most highly impacted site, Dandi site 1, only straight burrows (I shaped) were obtained while maximum number of J-shaped burrows were obtained from the most pristine site Dandi site 2. Burrows with maximum weight (32.67±10.40) and volume (34.03±10.83) were noted from Dandi site 2 where human interference was the least.

Of the excavated burrow casts from all sites, no significant variation was observed in the burrow opening diameter (ANOVA; F: 0.965, p= 0.464), inclination angle (ANOVA; F: 1.371, p= 0.240), burrow length (ANOVA; F: 1.896, p= 0.084) and burrow depth (ANOVA; F: 1.740, p= 0.123) between the study sites. Whereas, weight (ANOVA; F: 3.772, p<0.01) and volume (ANOVA; F: 3.772, p<0.01) of the burrow casts showed significant variation between the study sites (Fig. 7).

Discussion

In the present study it was found that the burrow density varied significantly between the pristine, moderately impacted and heavily impacted sites. Some previous studies carried out on *Ocypode* spp. (Lucrezi *et al*., 2009), *Ocypode quadrata* (Neves and Bemvenuti, 2006) and *Ocypode cordimana* (Barros, 2001) found similar results. It has been suggested that the behaviour of Dotillid crabs is very flexible and complex (Barrass, 1963) and therefore any changes in the habitat, diet or any anthropogenic activities on the beach can affect their activity (Hughes, 1966). Some previous studies found that vehicular moments, intense pedestrian trampling and other anthropogenic activities cause significant decrease in the density and size of ghost crab population of *Ocypode* genus (Hobbs *et al*., 2008; Lucrezi *et al.*, 2009; Schlacher and Lucrezi, 2010).

A Significant variation was observed in the burrow opening diameter across the study sites but no trend was noted in response to anthropogenic pressure. The results are contrasting to a previous study carried out on the *Ocypode quadrata* (Fabricius, 1787) where the burrow diameter was higher in moderately impacted site as compared to heavily impacted sites (Gül and Griffen, 2018). Generally, the occurrence of smaller individuals in heavy impacted sites is due to direct crushing of the crabs under vehicles during night times since, the larger individuals locomote slowly as compared to the middle size ones as a result of which they might not escape vehicles during night (Gül and Griffen, 2018). Unavailability of preferred food like clams, mole crabs, sandy beach coleoptera, etc. in the impacted sites due to human disturbance could be one of the reasons affecting the energy intake of the ghost crabs which limits the growth rate of the individuals (Wolcott, 1978; Schlacher *et al*., 2008; Sheppard, 2008; Cardoso *et al*., 2016). Hence, it is possible that the smaller individuals in highly impacted sites might be of similar age as that of the larger individuals in pristine and moderately impacted sites as a result of limited food availability leading to lower growth rates (Gül and Griffen, 2018). Therefore, the reason for decreased size of ghost crab individuals at different sites cannot be explained clearly by using a single mechanism.

In the present study, a lower burrow density and smaller burrow opening diameter was observed in the upper intertidal region whereas high burrow density and larger burrow opening diameter was in the middle and lower intertidal regions of all the study sites. Similar results were noted by Lucrezi *et al*. (2008) where they found that *Ocypode quadrata* burrow density was greater in middle intertidal region than the other intertidal regions. Lucrezi *et al*. (2009) in their study on an *Ocypode* spp. found that the maximum burrow opening diameter decreased in the region with human trampling. Such variation in the burrow density and burrow opening diameter could be due to maximum human trampling and interference occurring in the upper intertidal region. Due to increased vehicle traffic, the survival of larger crabs is affected as in the heavy traffic region, the life expectancy of ghost crabs decreases drastically such that the smaller individuals may not reach maturity (Steiner and Leatherman, 1981). Since, the burrow opening diameter represents the size of resident crab, decreased burrow diameter in the upper intertidal region could be due to heavy anthropogenic activities including increased vehicle movements. Also, the lower intertidal region is affected by the waves and swash and due to prolonged immersion in seawater can cause osmotic stress (Vinagre *et* *al*., 2007).

In the present study, significant variation was observed for weight and volume of the burrow casts with the heaviest (32.67±10.40) and voluminous (34.03±10.83) burrow recorded from Dandi site 2 having human interference. Studies suggests that in the heavily impacted region the burrows are longer, deeper and less inclined as compared to the pristine regions since deeper burrows would provide lower risk of getting crushed under vehicular trampling (Lucrezi and Schlacher, 2010). Studies also suggest that individuals constructing burrows shallower than 25 cm are more likely to get crushed under passing vehicle (Schlacher *et al*., 2007). It is believed that constructing deeper burrows could be a behavioural adaptation to decrease the risk of getting crushed under vehicles (Schlacher and Lucrezi, 2010).

It was also found that in the most heavily impacted site, only straight burrows (I shaped) were obtained. Similar results were obtained in some previous studies carried out on *Ocypode ceratophthalma* (Pallas, 1772) and *Ocypode cordimana* Latreille, 1818 (Schlacher and Lucrezi, 2010) and *Ocypode* spp. (Lucrezi and Schlacher, 2010). It has been observed that the coastal region with heavy higher anthropogenic impact including vehicular movements were dominated by simple I-shaped burrows whereas complex burrows were observed in the regions without or moderate anthropogenic activities (Lucrezi and Schlacher, 2010; Schlacher and Lucrezi, 2010). Schlacher and Lucrezi (2010) found that the smaller ghost crabs generally constructed I, J, Y, and M type of burrows during low vehicular disturbance while during heavy vehicular disturbance they built only I, and Y type of burrows. In the heavily impacted region, due to frequent disarray of the sediment the burrow destruction occurs regularly and the residing crabs have to build or repair the burrows more oftenly as a result of which they build simple burrows (Lucrezi and Schlacher, 2010). In the present study, maximum number of J-shaped burrows were obtained from Dandi site 2. The complexity of burrows on this site could be a result of very low anthropogenic pressure on the beach. The style of burrow making also depends on the life stage of the crab, seasonal variation and characteristics of the sediment (Chan *et al*., 2006, Trivedi and Vachhrajani, 2017). Hence, an inclusive study of ecology of *Dotilla blanfordi* and human impact on it is necessary.

Conclusion

The present study investigated the effect of anthropogenic pressure on the population and burrow morphology of *D. blanfordi*. The study was carried out on eight sandy beaches of Gujarat and Maharashtra state, India. The burrow density varied significantly among the study sites with different level of anthropogenic pressures. The burrow density was observed maximum at the low impacted sites followed by moderately impacted sites and heavily impacted sites. It has been observed that the changes in habitat greatly affected the burrowing behaviour of *Dotilla* crabs which leads to variation in their burrowing behaviour. In terms of burrow morphology, significant variation was observed in the weight and volume of the burrow casts as the burrows in the heavily impacted sites would be longer, deeper and less inclined in order to protect from the vehicular trampling. The crabs built simple burrows in heavily impacted sites (I-shaped) as compared to the complex burrows in the moderately affected and pristine sites since the burrow destruction occurs regularly at the regions with higher anthropogenic activities. The present study also provided a baseline data on *D. blanfordi* which can be used as an indicator species for effective coast monitoring and management.

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