Chapter 4: Burrow Architecture of Brachyuran Crab *Ocypode ceratophthalma* (Pallas, 1772)

Introduction

The near shore sediments of marine environment are mostly perforated by burrow structure made by various burrowing macro fauna. The burrows may be found in various stages like excavation, construction, maintenance and disrepair. The burrows constructed by macro fauna are used for certain period of time after that they are modified by the inhabitant or abandoned in search of favourable location. The burrows are also abandoned by the inhabitant in the presence of dominant individual or predator (Diaz and Cutter, 2001). The morphology and function of burrows vary significantly between different groups of macro fauna. The burrow shapes differs from the simple unbranched single tube burrow with single opening on the surface to the complex and highly branched burrows with several opening on the surface inhabited by several generations of the species.

The burrow plays several functions in the survival and growth of the inhabitant species (Fig. 74). The burrow provides refuse to the soft bodied animals from predator and desiccation. The burrow also provides physical support to the digging, feeding and reproductive activities of the burrow inhabitant. The internal environment of the burrow is very harsh which can be counteracted by the active and passive flow of the tidal water. Many burrow dwelling animals have evolved special mechanism to cope up with latter mentioned problems in which they coat the burrow wall by various kind of chemical secretion. The burrow coating also helps attracting various meiofaunal and microbial communities which are adapted to the steep chemical gradient (Aller, 2001). Many of the macro faunal communities residing in the burrow change or modify the burrow by every tidal cycle. The alteration in the burrow structure significantly affects the surface topography and sediment property (Pandya and Vachhrajani, 2010). During the high tide, significant amount of water enter inside the burrow which serves several purposes essential for the animal like gaseous exchange, food transport, transport of environmental

stimuli and removal of metabolites. The water transport inside the burrow also controls the microbial process in the sediment by enhancing the exchange of solutes between the sediment and overlying tidal water (Aller, 2001). The decomposition of the organic matter is increased by the macro fauna by enhancing the metabolic activities of the microbes by facilitating them with the regular transport of the tidal water.

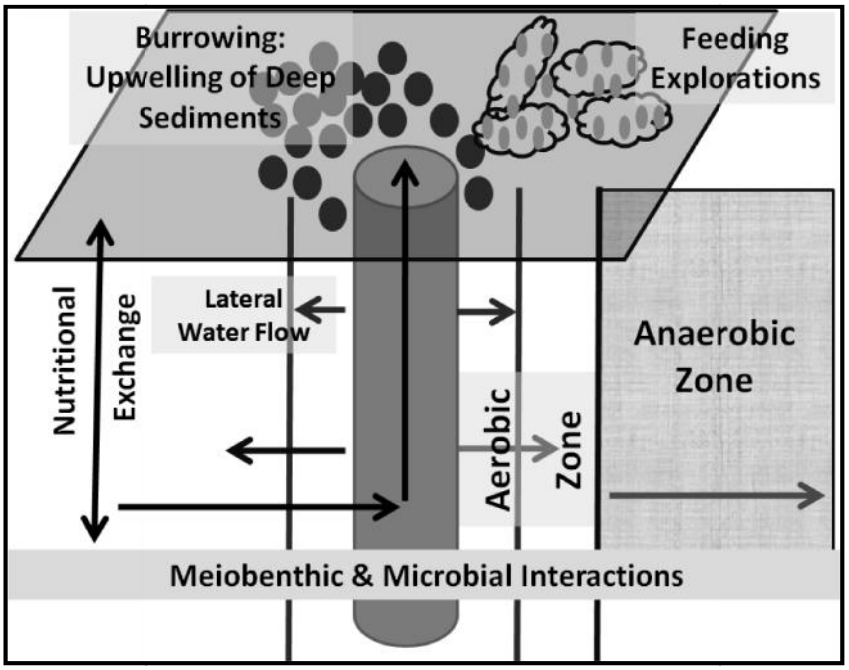

Figure 74: Biogenic structure and sub surface interactions of burrowing forms.

The complete understanding of the burrow function, biogeochemistry and burrow microbiology can be obtained by the detail characterization of these biogenic structures. Significant amount of information about the burrow structure is available for the larger burrowing species but smaller burrowing species are highly ignored. Knowledge gaps were also observed in the burrow structure of larger burrowing species because only few species are studied in sufficient detail. The seasonal variation in the different environment variable of water and sediment may affect the individuals of the species living in the same geographical regions to form different kinds of burrow structures. On the other hand, geographically separated populations of same species through time may evolve different burrowing which directly affect the biogeochemistry of the local sediment. The details of the burrow morphology of the species can be

interpreted by the feeding mode, activity level and size of the inhabitant along with the variation in the environmental condition and sediment composition.

Many invertebrate phyla living in marine environments have independently evolved classes, orders, genera, or species with a burrow-dwelling habit, including coelenterate, nemertea, nematoda, annelida (e.g. polychaetes and oligochaetes), mollusca (e.g. cockles and clams), arthropoda (e.g. insect larvae and crustaceans), pogonophora, sipuncula, echiura, priapulida, phoronida, echinodermata (e.g. brittle stars and sea urchins), and hemichordata. The three most successful burrowing classes in marine sediments are polychaeta, bivalvia, and crustacea. The physical dimensions of macro faunal burrows vary considerably, depending on the species and the environment. The depth distribution of burrows in sediments varies from a few centimeters for small species and juveniles to several decimetres for many adult polychaetes and more than 3 m for large crustaceans (e.g. mud lobsters) (Pemberton et al., 1976; Rhoads and Boyer, 1982).

The burrows constructed by larger species in the different environment showed strong relationship between the depth and diameter of the burrow. This kind of relationship is also dependant on the size of the individual residing in the burrow since the burrow diameter is closely related with the size of the individual residing in the burrow (Chakrabarty, 1981; Chan et al., 2006; Pandya and Vachhrajani, 2010). Esselink and Zwarts (1989) have studied the burrowing polychaete species *Nereis diversicolor* and established strong relationship between the size of the individuals and burrow depth. They have also stated that the relationship also varies with in the individuals of the same species living in different habitat; for e.g. individuals of *Nereis diversicolor* living in the sandy bottom make deeper burrow as compared to individuals living in the mudflat. The depth-diameter relationship reveals that the larger individuals of the species with good body conditions make larger burrows and they are also adapted to the harsh chemical conditions occurring in the water contained by the deep burrows. Several researchers have attempted to classify or model the architecture of the burrow in relation with the function of the burrow and the trophic mode of the inhabitant species (Griffis and Suchanek, 1991; Nickell and

Atkinson, 1995). However, different models have faced difficulties in placing all the burrowing species in one fixed framework because of variation in the feeding behavior. Furthermore intraspecific and inter specific differences in the burrow architecture of the species also creates problems in the viability of the model for all the species. Nickell and Atkinson (1995) have worked on the burrow morphology of thalassinidean species and classified variation in the burrow morphology of the species based on 12 burrow features which are indicators of the requirements or modes adapted by the species. The burrow features and its relation with the requirement of the species are listed below (Table 14).

Feature no.	**Description of the feature**
1	Surface mounds are indicative of sediment deposition at the surface via a deposit-feeding mode.
2	A tightly layered lattice suggests reworking by a subsurface deposit-feeder.
3	Burrow depth can be indicative of the relative importance of surface detritus in the food. Surface deposit-feeding dominates in shallow burrows and subsurface deposit-feeding dominates in deep burrows.
4	Sub circular tunnels develop as a result of animal movements in established, but not maintained, burrows. Suspension-feeding and subsurface deposit feeding is not likely.
5	Chambered burrows indicate deposit-feeding, and chambers are used as storage of surface or subsurface material.
6	The presence of large pieces of detritus may result from scavenging on the surface.
7	Oblique tunnels allow access to the sediment surface for movement of detritus or sediment and suggest a deposit-feeding trophic mode.
8	Numerous burrow openings to the surface suggests intimate contact with the surface and suggest a surface deposit-feeding mode.
9	Funnel-shaped openings enhance particle capture and suggest surface deposit-feeding mode.
10	A narrow exhalant shaft indicates a necessity for current generation

	to remove particles or capture particles and suggests a deposit-feeding or suspension-feeding mode.
11	U- or Y-shaped burrows allow rapid water movement and indicate a suspension-feeding mode.
12	Circular tunnel cross-sections facilitate efficient flow and allow close fit for filter mechanisms and indicate suspension-feeding mode.

Table 14: Burrow features indicative of certain trophic requirements of the inhabitant. Adopted from Nickel and Atkinson (1995).

Although Nickell and Atkinson (1995) have mostly used a particular trophic mode in relation to each feature, burrows may morphologically be related to more than one feature. The individual features of a burrow must be considered together with local environmental factors and animal anatomy, as well as activities other than feeding. Although the specific features given in table are based on observations from thalassinidean shrimps, they are also largely valid for and can be applied to burrow-dwelling animals of other taxonomic origin.

Crabs are very active burrowers in the intertidal soft sediment and greatly affect the surface sediment properties. The burrow morphology in brachyuran crabs is mostly species specific, however, in contrast to wide variety of environmental factors along with sediment and vegetation type, the crab species might change or modify the burrow structure to adjust the specific environmental condition in changing environment (Wolfrath, 1992). Brachyuran crabs are larger in size as compared to other burrowing macro fauna and in some species, intra specific variation is observed in burrow architecture with relation to sediment type, sediment hardness and vegetation root mass (Bertness and Miller, 1984). Brachyuran crabs belonging to genus *Ocypode*, commonly known as ghost crabs and are commonly distributed on the sub-tropical and tropical sandy beaches. *Ocypode* crabs are nocturnal feeders feeding on the animal and plant material and during the day time they remain hiding inside the burrows. The species of genus *Ocypode* exhibits various

behaviour patterns by making different biogenic structures and these biogenic structures are species specific. The burrow opening of the ghost crabs are circular in shape and often surrounded by sand mound along with redial feeding lines (Chakrabarti, 1981). Barros (2001) had proposed ghost crabs as an indicator species to predict the effect of anthropogenic activities on sandy shore. He suggested that the density of the burrows of the ghost crabs can be reduced by the anthropogenic and recreational activities on sandy shores. Different species of ghost crabs were studied extensively for their behaviour and physiology but information of burrow morphology for various species is scarce. In the previous studies carried out on burrow morphology of few species of ghost crabs, it was observed that the burrow architecture varies with the shore height and tidal period as well as with the sex and age of the individuals (Chan et al., 2006).

Ocypode ceratopththalma is the most common species of ghost crabs with wide distribution in Indo-Pacific region. In the coastal areas of Saurashtra coast, the species is mostly observed in the upper intertidal zone which is made up of sandy shore. The adults of the species are nocturnal and remain in the burrows during the day times while the juvenile regularly come out from the burrow to go to the water line during day time to renew their respiratory water (Morton and Morton, 1983). Chakrabarti (1981) had studied the burrow architecture of *Ocypode ceratopththalma* on the sandy shore of Bay of Bengal. He identified various shapes of burrows like J shape, U shape and Y shape and also reported that different shapes of the burrows occur at different tidal zones of sandy shores. In the present study, the burrow architecture of brachyuran crab *Ocypode ceratophthalma* is studied with relation to variation in environmental factors like sediment temperature and pH.

Figure 75: (a) Burrow of brachyuran crab *Ocypode ceratopththalma* (b) *Ocypode ceratopththalma* in life.

Material and method

The present study was conducted at two study sites *viz.* Sutrapada and Kodinar. These two sites were selected because the level of anthropogenic activities is observed low as compared to other two study sites. Both the sites face high temperature in the summer (42 °C) while in winter the lowest temperature recorded was (20 °C). The sandy shores of both the sites contain steep slope and the burrow distribution start 1 meter away from the water line. The tides at the study site are semi diurnal and maximum tidal range is 2 meter.

The burrows present in the transect area were selected randomly. The unsaturated resin mixed with catalyse poured in the burrows until the burrows were totally filled. Crab emerged from the burrows were collected and classified for sex and the carapace length and width were measured using digital vernier callipers. When the burrow cast were solidified (approximately after 1 hour), they were dug out and brought to the lab for further measurement.The casts were cleaned to remove as much sediment as possible from the surface. There was no upwelling of water when the casts were excavated, indicating that the burrows had not touched the water table. Only complete casts were used for analysis. The burrows were classified according to their shape and various measurements like Opening diameter (OD), burrow Inclination angle (IA), Total depth (TD), Total length (TL), Horizontal length (HL), length, diameter and depth of various branches of the burrows and length and width of burrow chambers were measured (Fig. 76). The burrow volume was measured by weighing the burrow (± 1gm) and dividing the burrow weight with the density of the unsaturated resin (0.96 gm/cm^3).

Variation in sediment temperature and pH was measured along the depth of the burrow in the afternoon low tides. The sediment temperature and pH was measured for the randomly selected burrow for casting. The temperature and pH were measured using digital thermometer and digital pH meter respectively. The temperature and pH of sediment were measured at every 5 cm depth interval up to the depth of 25 cm. Measurement could not be recorded beyond the depth of 25 cm because of the limited length of probe of the instruments.

Results

Burrow structure

A total of 55 intact burrow casts were obtained of which the host was captured for 38 times (28 males and 10 females). Total 7 different types of burrow shapes were recorded which include Single tube burrow (15 burrow cast), J shape with branch at the base (12 burrow cast), J shape (7 burrow cast), Bulb shape (6 burrow cast), Y shape burrow (4 burrow cast), Multi branched burrow (4 burrow cast), Y shape with double opening (4 burrow cast) and U shape burrow (3 burrow cast) (Fig. 76). The crab carapace width showed significant correlation with burrow opening diameter (Pearson's correlation coefficient = 0.89, $p < 0.001$) (Fig. 77a), burrow volume Pearson's correlation coefficient = 0.55, $p < 0.001$) (Fig. 77d) and burrow total length Pearson's correlation coefficient = 0.57, $p < 0.001$) (Fig. 77e). The crab carapace width did not show significant correlation with burrow depth (Pearson's correlation coefficient = 0.24, $p = 0.07$) (Fig. 77b) and burrow inclination angle (Pearson's correlation coefficient = 0.03, $p = 0.80$) (Fig. 77c).

Burrow type called Y shape with double opening (YDO) (n= 4) had largest volume (465.42 ± 266.93 cm^3) with average burrow opening diameter of 24.54 ± 4.80 mm. The YDO shaped burrows were made by the crabs with mean carapace width of 16.85 ± 5.67mm. The burrow was vertical with mean inclination angle of 90.25 ± 18.02°. The inclination angle of primary arm (90.25 ± 18.02°) was significantly smaller than the secondary arm (97.05 ± 17.76°; paired t test, $t = 2.35$, $df = 3$, $p<0.05$). The primary and secondary arm of the burrow joined together in the straight shaft and the straight shaft ended with small chamber at the base. Both the primary and secondary arms of the burrow opened on the surface and the burrow opening diameter of primary arm (24.54 ± 4.80 mm) was significantly larger than the secondary arm (19.08 ± 0.89 mm; paired t test, $t = 4.31$, $df = 3$, $p<0.05$). The total depth of the burrow was 36.22 ± 12.80 cm. Depth of primary arm (16.25 ± 9.25 cm) was slightly but significantly higher than depth of secondary arm (15.6 ± 9.42 cm; paired t test, $t = 2.91$, $df = 3$, $p<0.05$)

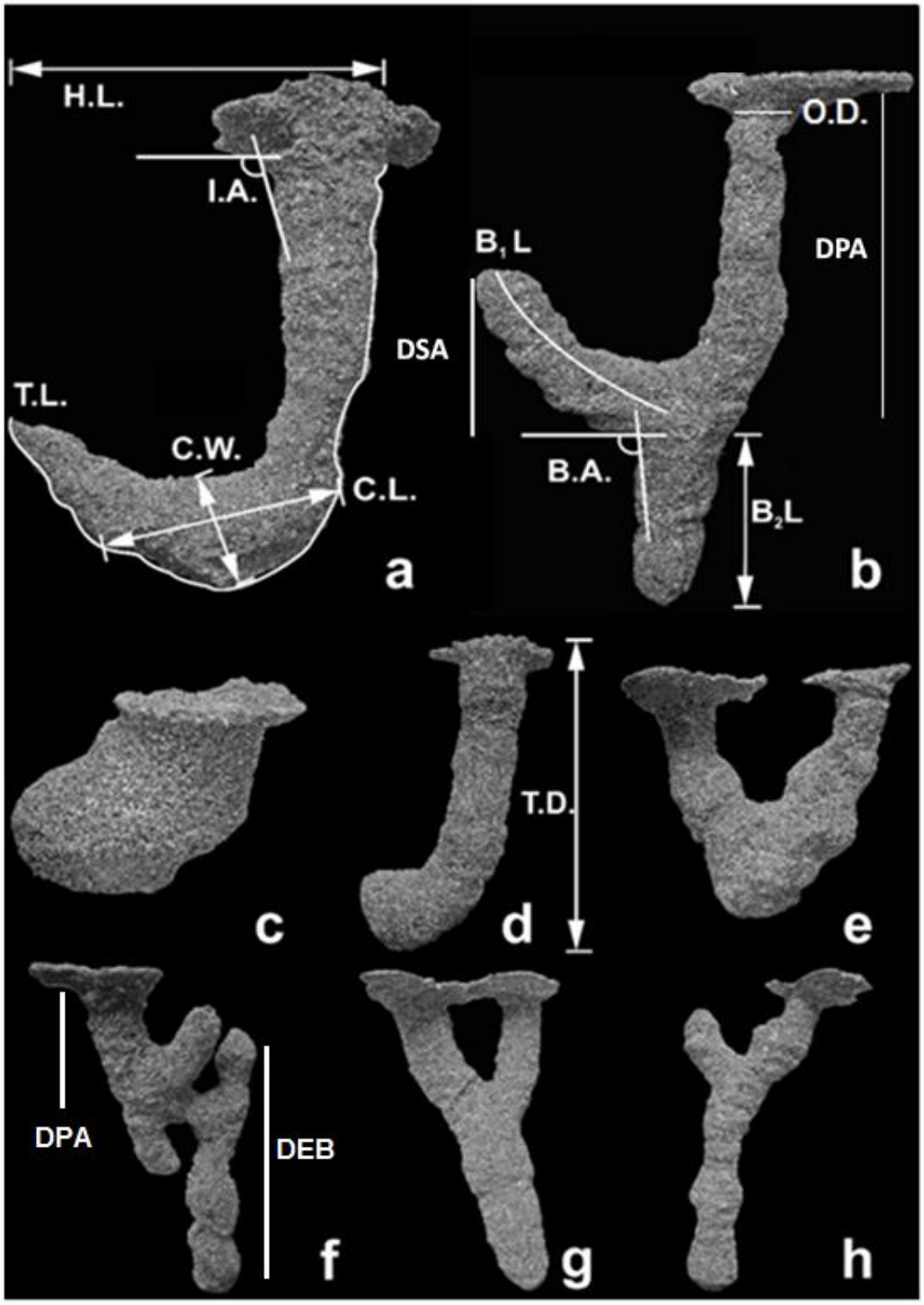

Figure 76: Burrow architecture of *Ocypode ceratophthalma* with various measurements of burrow cast. a. J shape, b. J shape with branch at the base, c. Bulb shape, d.Single tube burrow, e. U shape burrow, f. Multi branched burrow, g. Y shape with double opening, h. Y shape burrow. (O. D. - Burrow opening diameter; T. D. – Total depth; T. L. – Total length; I. A.: Burrow inclination angle; H. L. – Horizontal length; C. L. – Chamber length; C. W. – Chamber width; B_1L – Branch 1 length; B_2L – Branch 2 length; B. A. – Branch inclination angle; DPA – Depth of primary arm; DSA – Depth of secondary arm; DEB- Depth of extra branch)

Total mean length of the burrow was 42.1 ± 14.48 cm and the horizontal distance between burrow openings of both the arms was 13.77 ± 4.34 cm. The chamber situated on the base had length of 6.15 ± 2.14 cm and width of 4.12 ± 1.55 cm (Table 15; Fig. 76g).

U shape burrows (n= 3) had mean burrow volume of (399.39 ± 236.42 cm^3) with average burrow opening diameter of 22.47 ± 5.39 mm. The U shaped burrows were made by the crabs with mean carapace width of 14.02 ± 4.52 mm. The burrow was vertical with mean inclination angle of 98.00 ± 28.58°. The inclination angle of primary arm (98.00 ± 28.58°) was larger than the secondary arm (97.33 ± 5.85°; paired t test, t = 2.91, df = 2, p=0.48). Both the primary and secondary arms of the burrow opened on the surface and the burrow opening diameter of primary arm (22.47 ± 5.39 mm) was significantly larger than the secondary arm (16.86 ± 1.19 mm; paired t test, t = 2.91, df = 2, p<0.01). The total depth of the burrow was 20.26 ± 6.59 cm. The depth of primary and secondary arm was similar. Total mean length of the burrow was 33.63 ± 8.95 cm and the horizontal distance between burrow openings of both the arms was 16.52 ± 2.64 cm (Table 15; Fig. 76e).

J shape with branch at the base (JBB) (n= 12) had mean burrow volume of 386.40 ± 259.94 cm^3 with an average opening diameter of18.73 ± 5.40 mm. The burrows were excavated by the crabs with average carapace width of 12.37 ± 4.77 mm. The burrow was vertical in shape with mean inclination angle of 93.16 ± 18.58° and depth of 21.83 ± 7.82 cm. The main shaft takes turn towards the surface in the form of branch which does not extend to the surface and ends in the forms of spherical blind end. Second branch is formed from the base of the main shaft and ends making small chamber at the base. The mean length of the burrow was 25.81 ± 8.09 cm. The length of branch 1(11.31 ± 3.19 cm) (Side branch) was significantly higher than the branch 2 (8.07 ± 3.19 cm; paired t test, t = 1.79, df = 11, p<0.001) (Base branch). The depth of primary arm (14.3 ± 5.45 cm) was significantly higher than the depth of secondary arm 2 (7.55 ± 2.62 cm; paired t test, t = 1.80, df = 11, p<0.0001). The inclination angle of primary arm (109.41 ± 20.35°) was significantly higher than the main shaft (paired t test, t = 1.83, df = 11, p<0.001). In 70 percent burrows the primary arm faced the

seaward orientation. The horizontal distance between main arm and primary arm was 11.57 ± 5.14 cm (Table 15; Fig. 76b).

Bulb shaped (n= 6) were the smallest burrow in terms of depth with mean depth of 12.29 ± 3.47 cm. The burrows were vertical in shape with mean inclination angle of 95.08 ± 17.31° and mean burrow volume of 376.97 ± 240.80 cm^3. The mean burrow opening diameter was 19.07 ± 5.02 mm and they were excavated by the crabs with mean carapace width of 12.29 ± 3.45 mm. In the bulb shape burrows, the burrow opens directly in a large chamber. The mean length and width of the chamber were 6.43± 1.71 cm and 5.46 ± 1.78 cm, respectively. The mean total length of the burrow was 23.72 ± 9.37 cm (Table 15; Fig. 76c).

The single tube burrow (ST) (n=15) had mean volume of 366.22 ± 236.19 cm^3 with mean opening diameter of 18.14 ± 5.07 mm. The burrows were excavated by the crab having mean carapace width of 11.66 ± 3.69 mm. The burrow inclined vertically from the surface with the mean inclination angle of 93.11 ± 17.08° and ended with chamber (CL: 3.06 ± 0.59 cm CW: 4.48 ± 0.53 cm) at the base. The mean depth and length of the burrows were 19.22 ± 7.50 cm and 23.39 ± 8.85 cm, respectively. The mean horizontal distance of the burrow was 3.13 ± 0.60 cm (Table 15; Fig. 76d).

The multi branch burrows (MB) (n= 4) had mean volume of 365.06 ± 248.30 cm^3 with mean opening diameter of 19.50 ± 5.16 mm. In MB burrows the burrows looked similar to JBB shape but they all had extra branch attached to the base of the secondary branch. In MB burrow except primary arm no branch reach the surface and they all ended with spherical blind lobe. The extra branch attached with secondary branch base had multiple chambers. The burrows were excavated by the crab having mean carapace width of 12.82 ± 4.32 mm. The burrows inclined vertically with mean inclination angle of 96.63 ± 22.19°. The burrow had mean depth of 26.25 ± 7.99 cm in which the mean depth of extra branch (15± 4.10 cm) was significantly higher than the mean depth of primary arm (11.25 ± 4.03 cm; paired t test, $t = 2.35$, $df = 3$, $p<0.01$). The total mean length of the burrow was 31.08 ± 8.91 cm and the horizontal distance of the burrow was 8.09± 8.91 cm (Table 15; Fig. 76f).

The J shaped burrows (J) (n= 7) had mean burrow volume of 215.32 ± 110.08 cm^3 with an average burrow opening diameter of 14.43 ± 4.61 mm. The burrows were vertically inclined with mean inclination angle of 98.65 ± 15.88°. The J shaped burrows were excavated by crab with mean carapace width of 8.87 ± 3.41mm. The mean depth and length of the burrow were 14.11 ± 5.88 cm and 24.30 ± 8.03 cm respectively. The horizontal length of the burrow was 12.11 ± 2.22 cm. The mean length and width of the chamber situated on the base was 2.32 ± 1.04 cm and 6.24 ± 2.28 cm (Table 15; Fig. 76a).

The Y shaped burrows (Y) (n=4) had mean volume of 265.81 ± 101.20 cm^3 with an average opening diameter of 15.25 ± 3.93 mm. The burrows were excavated by crabs with mean carapace length of 9.69 ± 3.45 mm. The primary and secondary arm of the burrows joined the main shaft and ended with small chamber at the base. The burrows were inclined down with an average inclination angle of 88.64 ± 11.04°. In all the burrow casts obtained, the secondary branch did not reach the surface and ended up with blind spherical end. The mean depth of the burrow was 26.25 ± 7.21 cm. The depth of the primary arm (9.0 ± 2.68 cm) was significantly longer than the secondary arm (6.9 ± 2.14 cm; paired t test, $t = 2.38$, $df = 3$, $p<0.01$). The mean horizontal distance of the burrow was 4.82 ± 3.14 cm. Total mean length of the burrow was 24.67 ± 9.12 cm. The chamber attached at the base had length of 2.44 ± 1.16 cm and width of 3.82 ± 1.02 cm (Table 15; Fig. 76h).

Vertical temperature profile of burrows

The depth wise variation in burrow temperature was studied for various burrow shapes recorded in the present study. Results revealed similar pattern in temperature variation for all the burrow shapes. The sand surface temperature recorded was 42-45°C which remained similar for all the burrow types. The temperature declined to 33 °C at a depth of 5 cm. After the depth of 5 cm the rate of temperature drop decreased to 1 to 1.5°C at every 5 cm. The temperature recorded at the deepest part of the burrow that could be measured up to 25 cm was 28-29.5°C, which was 14-15.5°C cooler than the surface temperature (Fig. 78).

Vertical pH profile of burrows

The depth wise variation in burrow sediment pH was studied for various burrow shapes recorded in the present study. Results showed similar pattern in the sediment pH variation in all the burrow shapes except bulb shape and U shape burrows. The sediment surface pH recorded was 7.7 -7.9 which remained same for all the types of burrows. The sediment pH values did not vary much with reference to difference in depth. In case of U shape burrow, the sediment pH showed deceasing trend up to the depth of 20 cm but the pH values increased drastically at the deeper part of the burrow which could be measured up to 25 cm. In case of bulb shaped burrow, initially the sediment pH values showed decreasing trend up to the depth of 15 cm but after that the pH values increased slightly (Fig. 79).

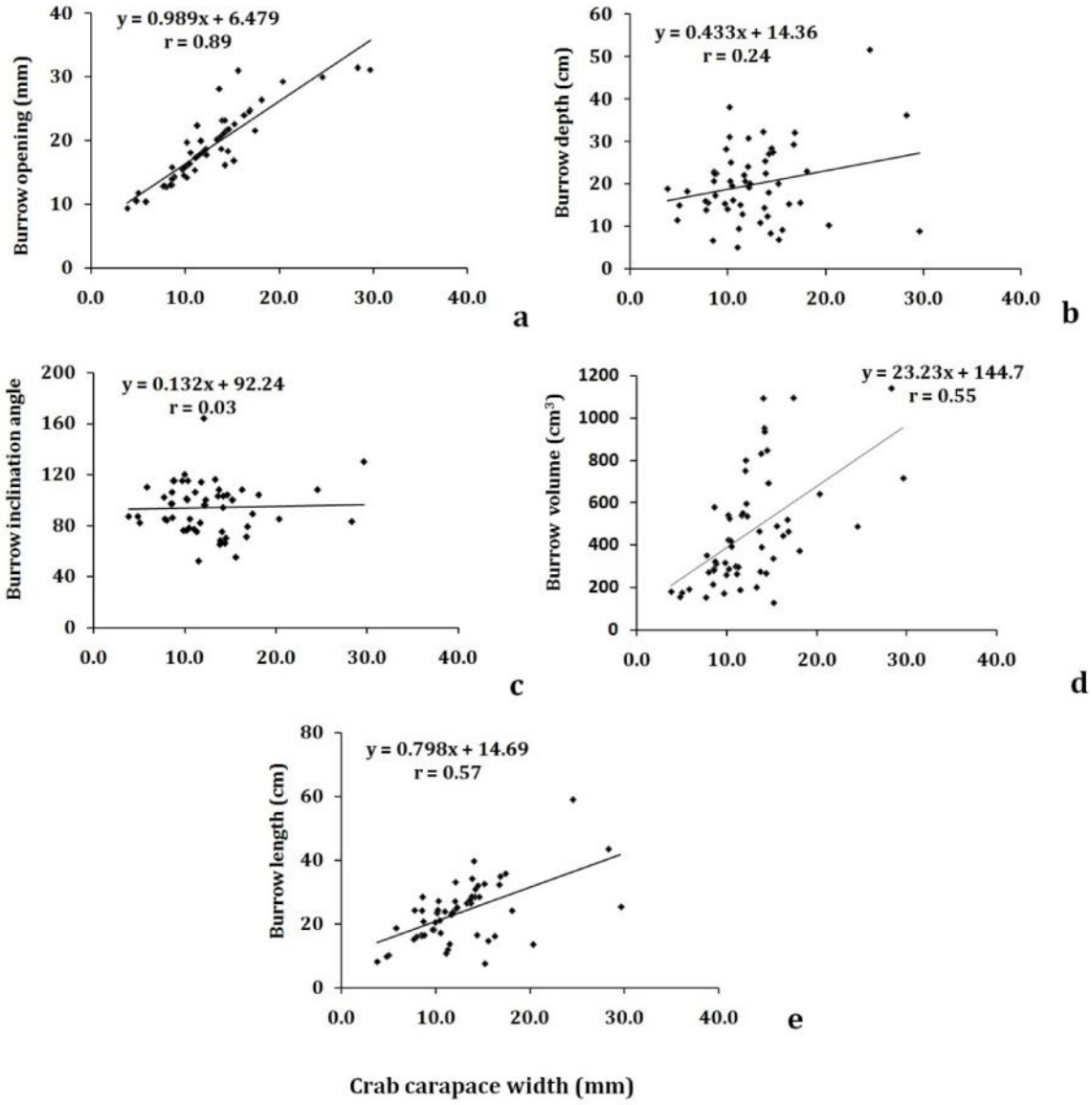

Figure 77: Pearson's correlation coefficient and regression values for the relationship between crab carapace width and burrow opening diameter (a) burrow depth (b) burrow inclination angle (c) burrow volume (d) burrow length (e).

Burrow shapes	**ST**	**JBB**	**J**	**Bulb**	**Y**	**MB**	**YDO**	**U**
No. of burrows	15	12	7	6	4	4	4	3
Crab carapace width (mm)	11.66 ± 3.69	12.37 ± 4.77	8.87 ± 3.41	12.29 ± 3.45	9.69 ± 3.45	12.82 ± 4.32	16.85 ± 5.67	14.02 ± 4.52
Burrow opening diameter (mm)	18.14 ± 5.07	18.73 ± 5.40	14.43 ± 4.61	19.07 ± 5.02	15.25 ± 3.93	19.50 ± 5.16	24.54 ± 4.80	22.47 ± 5.39
Burrow depth (cm)	19.22 ± 7.50	21.83 ± 7.82	14.11 ± 5.88	12.29 ± 3.47	26.25 ± 3.21	26.25 ± 7.99	36.22 ± 12.80	20.26 ± 6.59
Burrow inclination angle°	93.11 ± 17.08	93.16 ± 18.58	98.65 ± 15.88	95.08 ± 17.31	88.64 ± 11.04	96.63 ± 22.19	90.25 ± 18.02	98.00 ± 28.58
Burrow volume cm^3	366.22 ± 236.19	386.40 ± 259.94	215.32 ± 110.08	376.97 ± 240.80	265.81 ± 101.20	365.06 ± 248.30	465.42 ± 266.93	399.39 ± 236.42
Total length of burrow (cm)	23.39 ± 8.85	25.31 ± 8.09	24.30 ± 8.03	23.72 ± 9.37	24.67 ± 9.12	31.08 ± 8.91	42.1 ± 14.48	33.63 ± 8.95

Table 15: The variation in burrow cast numbers in sample, crab carapace width, burrows depth, burrow inclination, burrow volume, and total length of burrow for various shapes of burrow cast. (Single tube burrow (ST), J shape with branch at the base (JBB), J shape (J), Bulb shape, Y shape burrow (Y shape), Multi branched burrow (MB), Y shape with double opening (YDO), U shape burrow (U).

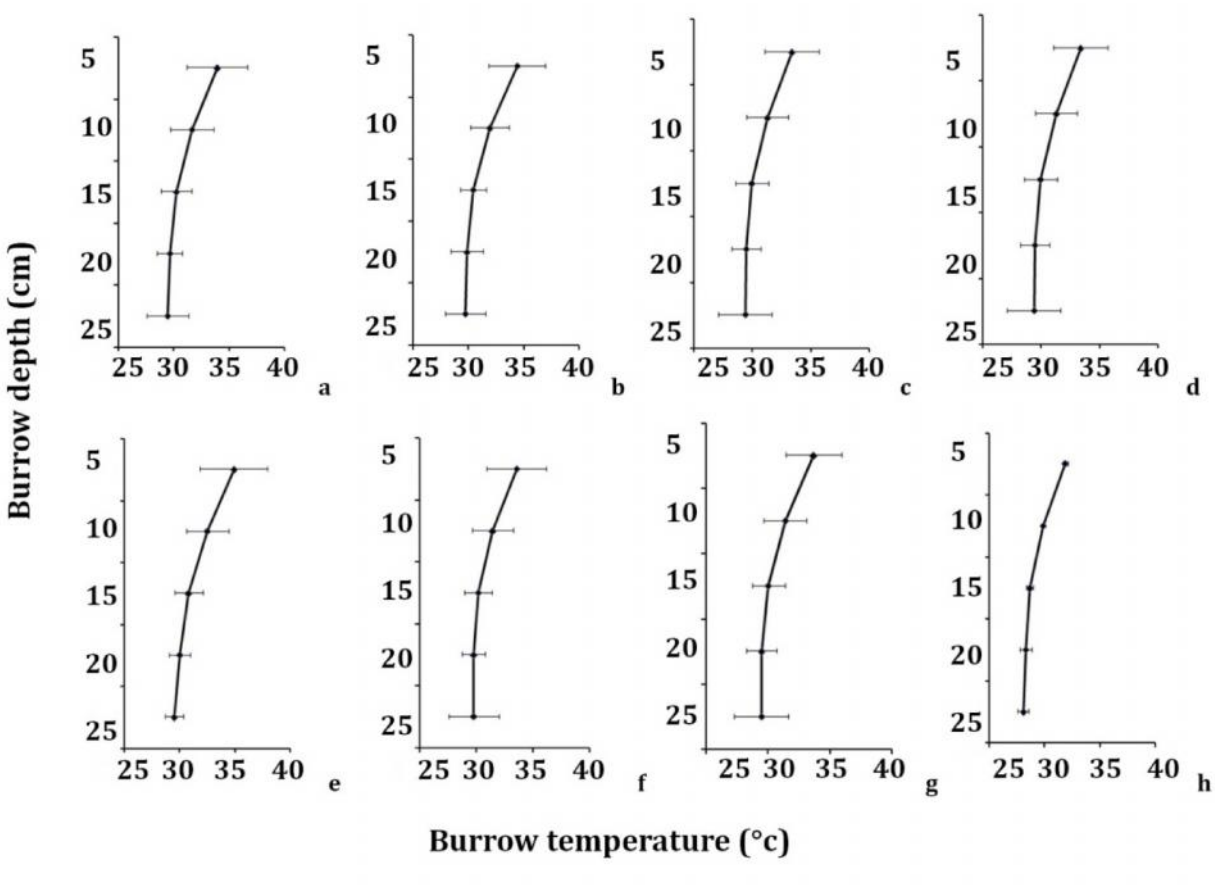

Figure 78: Vertical temperature profiles with the burrow depth for different shapes of the burrows. (Single tube burrow (a), J shape with branch at the base (b), J shape (c), Bulb shape (d), Y shape burrow (e), Multi branched burrow (f), Y shape with double opening (g), U shape burrow (h).

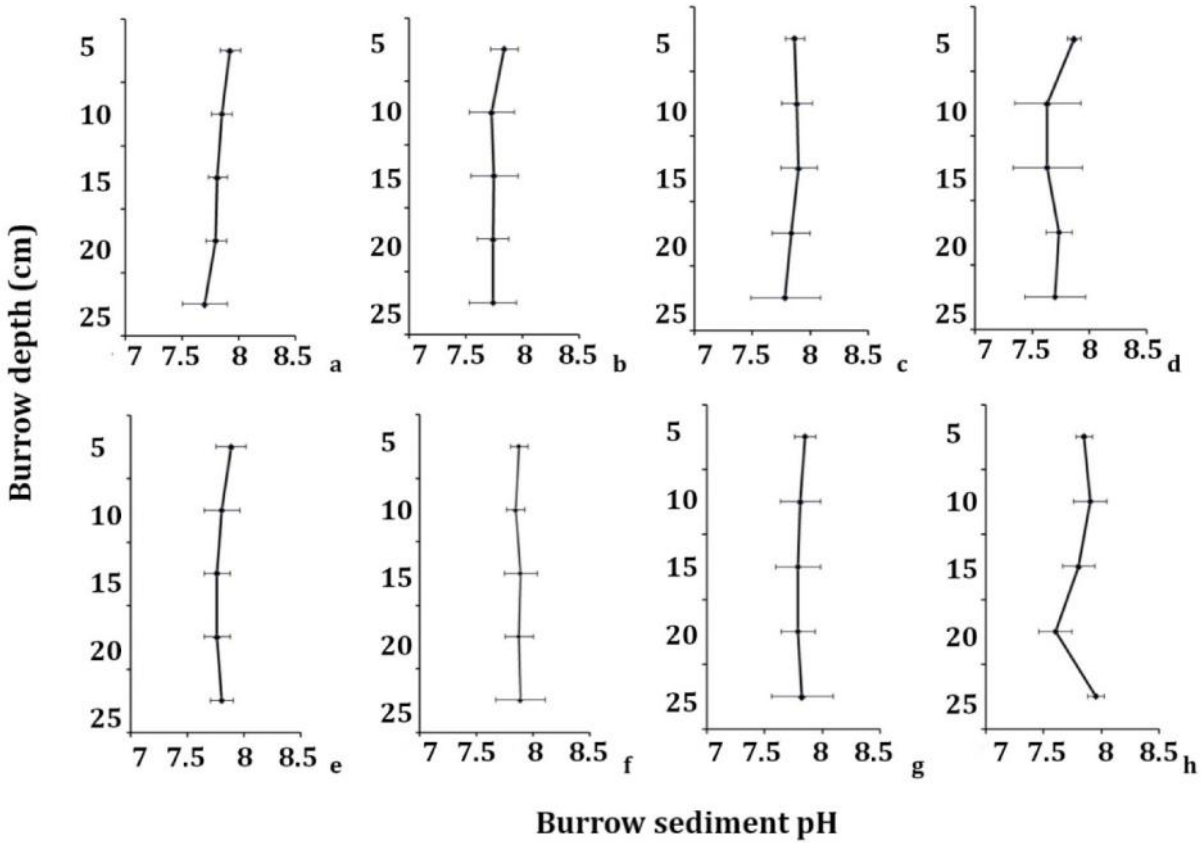

Figure 79: Vertical pH profiles with the burrow depth for different shapes of the burrows. (Single tube burrow (a), J shape with branch at the base (b), J shape (c), Bulb shape (d), Y shape burrow (e), Multi branched burrow (f), Y shape with double opening (g), U shape burrow (h)).

Discussion

In the present study, the morphology of brachyuran crab *Ocypode ceratophthalma* burrows showed variation in size, shape and complexity of structure ranging from single tube structure with single opening and no branches to multi branched burrows with multiple opening. Various parameters like tidal variation, sediment pH and temperature played important factors influencing the burrow structure. The size of the crab species is measured in terms of carapace width and length. The crab width affects the burrow opening size because crabs walk sideways direction. In the present study, the crab width showed strong correlation with burrow opening diameter, burrow volume and burrow length which showed that the larger crabs had greater burrow diameter, larger burrow volume and larger depth as compared to medium sized and juvenile crabs. Lim (2006) found similar kind of relationship of crab-carapace size with burrow opening in brachyuran crab *Uca annulipes* and *Uca vocans*. She suggested that the burrow of *U. vocans* were larger in size as compared to *U. annulipes* because *U. vocans* is larger species as compared to the other species and it requires larger burrow opening which enables the species to move comfortably inside the burrow.

In the present study, 7 different shapes like Single tube burrow, J shape with branch at the base, J shape, Bulb shape, Y shape burrow, Multi branched burrow, Y shape with double opening and U shape burrow were recorded for burrow architecture of *Ocypode ceratophthalma*. Chan et al., (2006) have studied the burrow architecture of *Ocypode ceratophthalma* on the sandy shores of Hong Kong and they have reported presence of five different shapes of burrow which includes J shape burrow, J shape with branch at the base burrow, Y shape burrow, spiral burrow and single tube burrow. In the present study, more complexity is recorded in the structure of *O. ceretophthalma* burrows as compared to previous studies (Chakrabarti, 1981). In the present study, differences in the burrow architecture were reported with the age and size of crab. Juvenile crab had made J shape, Y shape and single tube burrows, sub adult and adult crabs has created JBB shape, bulb shape, MB shape while older and large crab have made YDO and U shape burrows.

The burrow type like J shape, Y shape and single tube burrows made by juvenile crabs were shallow burrows with narrower opening diameter and lesser volume. Chakraborty (1981) and Chan et al., (2006) have studied that burrows structure and its role in the eco physiology of *O. ceretophthalma* on the sandy shores of Bay of Bengal and Hong King, respectively. They observed similar pattern in Juveniles of the species, as noted by us. They stated that the juveniles of the species have smaller gill area and because of that they cannot tolerate prolonged air or sunlight exposure without renewing their respiratory water. In this situation, the juveniles have to leave their burrow frequently to go to sea water to renew their respiratory water.

In the present study single tube burrows and bulb shaped burrows were created by adult and juvenile of the species. Similar kinds of burrows were also reported in other brachyuran crab species like *Uca pugilator, Cradisoma carnifex* and *Macrophthalmus parvimanus.* These kinds of burrows are believed to be temporary and made by the species to get refuge during the high tide time or get protection from the predator (Braithwaite and Talbot, 1972; Christy, 1982). In the present study, the juveniles of the species have created J shape burrows with mean depth of (14 cm to 19 cm) which are little shallower than juvenile J shape burrows reported for *O. ceratophthalma* and *O. quadrata* in India, Taiwan, America and Hong Kong. (Chakrabarti, 1981; Takahashi, 1932; Hill and Hunter; 1973; Chan et al., 2006). In Hong Kong, the juveniles of *O. ceretophthalma* make J shape burrow with branch at the base (Chan et al., 2006) but in the present study this particular burrow type was reported to be made by the adults of the species.

In Y shape burrows, two different types of burrows were reported. First type is the simple Y shape in which burrow opening is available on primary arm while second type is Y shape with double opening in which the opening is available on both arms. In both the type the orientation of the primary arm was reported towards seaward side while the orientation of the secondary arm was reported towards landward sides. Chan et al., (2006) and Chakrabarti (1981) have also reported similar kind of pattern in terms of arm orientation in Y shape burrow made by *O. ceratophthalma* on the sandy shore of Hong Kong and Bay of

Bengal of India. In the present study, the secondary arm of the Y shape burrow did not reach the surface but ended with spherical blunt end. Hill and Hunter (1973) have also reported similar pattern in Y shape burrows made by the individuals of *O. quadrata* on Texas coast. In the present study, the adults of *O. ceratophthalma* had created Y shape with double opening burrow type in which the secondary arm opens on the surface. The diameter of secondary arm was significantly smaller than the primary arm and inclination angle of primary arm was significantly smaller than the primary arm. YDO type of the burrow is first time reported for *O. ceratophthalma* in present study and it has not been reported even for other crab species.

The function of the secondary branch of Y shape burrows is still unknown but it has been proposed that the secondary arm may provide shelter to the crab individuals from the splash of the waves and predators (Chakrabarti, 1981). In the present study, the YDO burrows ended with small chamber at the base but the size of the chamber was smaller as compared to the chamber size reported in Y shape burrows made by individuals of *O. ceratophthalma* in Hong Kong (Chan et al., 2006). Such kind of chamber was not observed in the Y shape burrows of crab species in other studies (Takahashi, 1932; Hill and Hunter, 1973; Chakrabarti, 1981). In fiddler crab males of the species make such kind of chambers during the mating season (Lim, 2006; Christy, 1982) so it may be believed that presence of such chambers in *O. ceratophthalma* burrows may provide protection against predators or shelter during mating season. In the present study, multi branched burrows (MB) were also recorded. Such kinds of burrows were also recorded in same species studied in Bay of Bengal but not found in Hong Kong population (Chakrabarti, 1981; Chan et al., 2006). Chan et al., 2006 have quoted the reason behind the absence of multi branched burrow in *O. ceratophthalma* population in Hong Kong. They have stated that the study had been carried out in maximum population abundance zone of the species but not in the backshore zone where the individuals may have created multi branch burrows. In the present study U shape burrows had both the branches opening on the surface. Such kinds of burrows were created by large and older crabs. The U shaped burrows were not reported in previous studied on the species (Chakrabarti ,1981; Chan et al., 2006).

In the present study specific distribution pattern has been observed in terms of burrow shapes. Maximum number of J shape, Y shape, and single shaped burrows which are occupied by juveniles were recorded in the lower part of sandy shore near the water line while burrows containing other shapes like JBB shape, Bulb shaped, MB shape, YDO and U shape burrows occupied by adult and older individuals were located on the upper part of the sandy shore away from the water line. The adult individuals of the species have bigger gill surface area which helps them to tolerate the exposure of air or sunlight for longer period of time. Because of the above mentioned adaptation, the larger individuals of the species stay in the burrow for entire day as compared to juveniles and come out on the surface only in night time for feeding. This adaptation also helped them to reduce the risk of predators. It was also observed that in the burrow shapes made by adults, the lower part of the burrows contain moisture which help the individuals to respire without changing their respiratory water.

In the present study, specific pattern has been observed for the burrow temperature. During the study period the sediment surface temperature recorded was 42-45°C which could be lethal for the species but the sediment temperature dropped along with the depth of the burrow (sub surface). The temperature recorded in the deepest part of the of the burrow was near 29°C and the temperature reduced up to 14-15°C which suggests that the burrows can provide refuge or shelter to the crabs during the sunny days. In the case of sediment pH, such kind of pattern was not observed. The sediment pH remained more or less similar at the different depth interval of the burrows. Similar kind of pattern of temperature gradient was also observed in burrows of Hong Kong population of *O. ceratophthalma* (Chan et al., 2006). Ferrow (1971) had stated that Y shaped burrows are utilized by females while, males utilize spiral shape burrows but such kind of pattern of shape partition of burrows between male and females was not observed in the present study as well as in the other studies on burrows of *O. ceratophthalma* (Chakrabarti ,1981; Chan et al., 2006).

The individuals of *O. ceratophthalma* population living on the sandy shores of Saurashtra coast, Gujarat have created different shapes of burrows which are highly influenced by their body size and different life stages. The

burrows serve different functions in the life of an individual and further studies should be carried out to investigate the functional morphology of different shapes or burrows in the life of an individual.