5.1 INTRODUCTION

"Burrow is a hole or tunnel excavated into the ground by an animal to construct a space suitable for habitation or temporary refuge, or as a by-product of locomotion."

(Source: https://education.nationalgeographic.org/resource/burrow/)

Most marine sediments near the beach have burrow structures created by a variety of burrowing macro-organisms. There are different stages of the burrows, including excavation, building, maintenance, and disrepair. The burrows dug by macro-fauna are utilized for a while before being altered by the occupants or abandoned in search of a more advantageous position. In the presence of a dominant individual or a predator, the resident also leaves the burrow (Diaz and Cutter, 2001). The shape and purpose of burrows vary significantly among different macro-faunal groupings.

Numerous biologists have always been interested in the burrow architecture and how it affects the surrounding habitat. Burrow architectural studies are important because they offer a morphological window into an organism's life. It is simple to draw conclusions about the ecological differences between the subject individual and the biotic and abiotic elements of the surrounding habitat using comparison structures and distinct burrow patterns (Sinha, 2008). Atkinson and Taylor (1988) analysed a number of articles relating to the decapod's burrowing behaviour. Our understanding of burrow characteristics, biological complexity, and ecological significance is improved through studies on tunnel morphology. It goes into detail about the species' reproductive, behavioural, and physiological activity.

Burrow architecture is ecologically important phenomena specially to maintain semi-terrestrial mode of habit (Dubey et al., 2013). Burrow architecture is observed in many vertebrates (Moulton et al., 2006; Schwaibold and Pillay, 2005) and invertebrate fauna (Matsumasa et al., 1992; Lomovasky et al., 2006) especially in several benthic invertebrates inhabiting marine, estuarine and freshwater soft sediment habitats (Little, 2000; Huhta, 2007). These burrows serve as greatest example of adaptation on the exposed beaches (Brown and

McLachlan, 1990; Lee, 2008). Burrows constructed by the macrobenthic invertebrates serve for various activities like mating (Ribeiro et al., 2010), provide protection against harsh environmental conditions such as excessive heat exposure (Ansell, 1988), refuge during hightides, getting away from aerial and terrestrial predators (Kinoshita, 2002; Thongtham and Kristensen, 2003; Michaels and Zieman, 2013).

During low tide, water retains inside the burrows of benthic invertebrates which can be used by the resident invertebrates to fulfil their physiological needs like moistening the gills, courtship, reproduction and as a winter abode (Crane, 1975; Powers and Cole, 1976; Ringold, 1979; Robertson et al., 1980). A lot of aquatic burrowing decapods use their pleopods to irrigate their burrows. Burrows can also serve as a location for reproductive activity, egg incubation, and joint habitation by juveniles (Sinha, 2015). The burrows offer protection against tidal intrusions and increase porosity of the surrounding soil which helps to accelerate the regeneration of mangrove seedlings (Khan et al., 2005). Burrowing activity increases oxidization rate of sulphide that builds up due to high rate of organic decomposition in mangrove swamps (Diemont, 1975). Besides that, burrow density in the respective habitat improves aeration and aid of local transport of nutrients within coastal tidal flats (Kristensen and Alongi, 2006; Araujo et al., 2012).

Some of the intertidal organisms living in dry and exposed environment constructs burrow to face several environmental constraints during low tide (Chapman and Underwood, 1996; Thurman, 1998; Somero, 2002; Schneider, 2008; Miller et al., 2009; Allen et al., 2012). Brachyuran crabs are active burrower of intertidal soft sediment causing remarkable effect on organism present in the sediments (Iribarne et al., 1997; Herman et al., 1999) and shows significant intraspecific variation in the burrow architecture (Upadhyay et al., 2022). Burrow morphology varies from species to species (Griffis and Suchanek, 1991; Wolfrath, 1992) but sometimes variation in burrow morphology is observed within same species due to several physical and biological factors such as sediment composition, substratum hardness, vegetation type, root-mat density of the surrounding vegetation, shore height, tidal variation, sex and age of the individual etc. (Bertness and Miller, 1984; Takeda and Kurihara, 1987; Lee and Koh, 1994; Morrisey et al., 1999; Lim and Diong, 2003; Chan et al., 2006). Temperature is one of the physical factors and its fluctuation affects the feeding, physiology, growth and reproduction of the resident fauna (Weinstein, 1998; Ruscoe et al., 2004; Resgalla et al., 2007; Allen et al., 2012).

Depending on the animal, burrows can also vary in size, shape, and complexity, have a single opening or several branches. According to Nandi and Dev Roy (1991), the shapes of the burrows of *Scylla serrata* are J, U, or Y. Few scientists have studied effect of ecology and influence of varying environmental conditions on intra-specific variation on burrow architecture of various species (Dworschak, 1983; Suchanek, 1985; Griffis and Suchanek, 1991). Complex branched and multiple branched burrows are often found in thalassinids, living in marine and estuarine environments (Doworschak, 1983). Suchanek (1985) distinguished between the simple Y-shaped burrows of filter/suspension feeders and the deep-chambered burrows of rift catchers in the thalassinidean shrimp. According to Griffis and Suchanek (1991), the actions involved in burrow formation encourage the remobilization of sediment grains and nutrient cycling, which alters the physical and chemical characteristics of the immediate environment. Burrow morphology, general ecology, burrow types and nature, as well as the feeding habits of its occupants, are all reflected in the burrow traits. The form of the burrow in *Leptuca uruguayensis* (Nobili, 1901) significantly affects the sediment properties. The burrows are shown to be deeper, longer, and more numerous as sediment thickness increases (Ribeiro et al., 2005). Burrow morphology of *Ocypode ceratophthalma* (Pallas, 1772) was studied from Chandipur, on the eastern Indian coast and several morphological parameters of the burrows were recorded like burrow diameter, orientation, inclination, branching, and volume. From the study, the authors have concluded that burrow morphological features (e.g., I, J, Y) were not dependent on their positions with respect to the coastline (Paul et al., 2019).

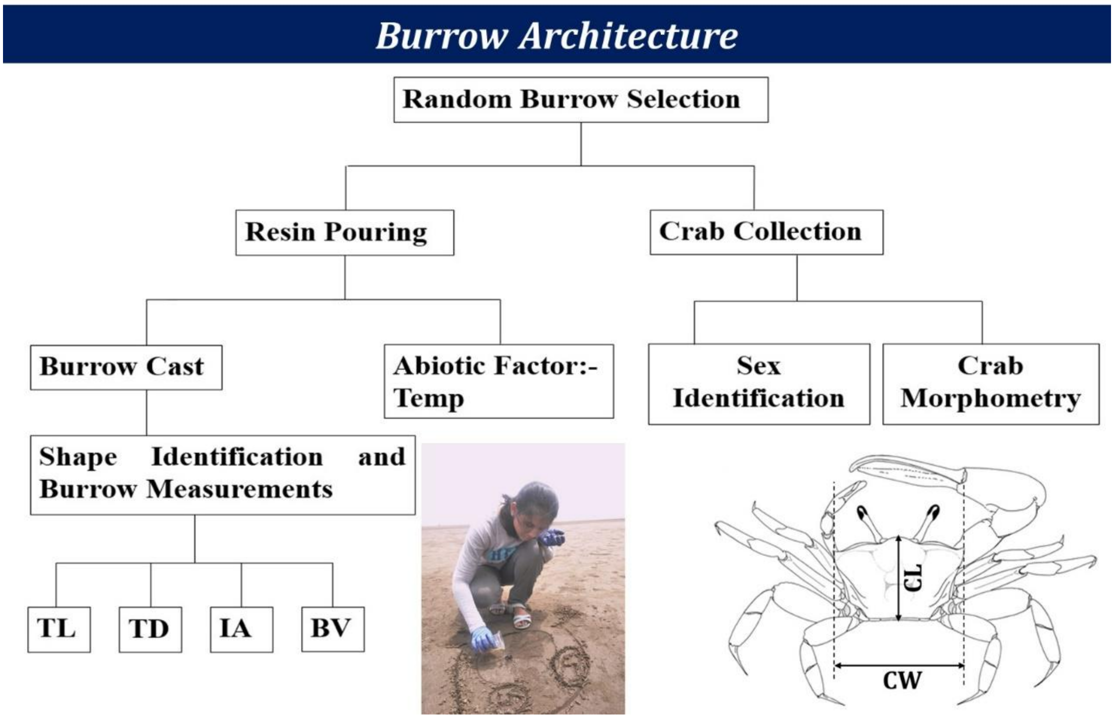
The scientists have employed a range of methods to identify the morphological patterns and other environmental influences on the architecture of the burrows. Previously, cement or plaster of Paris were used to create the moulds or casts of the burrows (Stevens, 1929). However, more recently, scientists have employed resins to create extremely accurate replicas of whole burrows (Shinn, 1968; Atkinson and Chapman, 1984; Dworschak, 2001). Burrow morphology and mating behaviour of thalassinidean *Upogebia noronhensis* Fausto-Filho, 1969 was studied using resin casting in the field and has been observed in the laboratory (Candisani et al., 2001). Vaugelas (1984) proposed the archaeological technique of burrow excavation, which requires careful removal of sediment layers one at a time and direct examination of burrow features, with or without cast.

Crabs, one of the dominant macrobenthos are acknowledged as the ecological engineers as they regulate the structure of estuarine communities (Dittel et al., 1995; Heck and Coen, 1995; Gutierrez et al., 2006) and affect the material cycles as well as energy flows of the mangroves and salt marshes (Lee, 1998). Burrowing behaviour is commonly reported in the genera *Macrophthalmus* Desmarest, 1823 and *Heloecius* Dana, 1851 (Griffin, 1965, 1968), *Uca* Leach, 1814 (Pearse, 1912; Crane, 1941a; Altevogt, 1955), *Ocypode* Weber, 1795 (Cott, 1929; Crane, 1941b; Tweedie, 1950; Barrass, 1963; George and Knott, 1965; Hughes, 1966), *Dotilla* Stimpson, 1858 (Tweedie, 1950) and *Scopimera* De Haan, 1833 (Tweedie, 1950; Fielder, 1970). Burrow morphology of crabs has been digitally characterised by measuring various parameters such as depth, width, length, and branch number (Lim and Diong, 2003; Chan et al., 2006; Lim, 2006; Trivedi and Vachhrajani, 2016; Maheta and Vachhrajani, 2023). Environmental characteristics like temperature and moisture fluctuation also studied previously with the burrow architecture (Chan et al., 2006; Trivedi and Vachhrajani, 2016; Maheta and Vachhrajani, 2023). Environmental characteristics affect the burrow morphology in various type of coastal beaches by influencing the burrow diameter, vertical depth, length and orientation of the burrows (Chakrabarti, 1981; De, 2000; Chan et al., 2006; Seike and Nara, 2008; Rodrigues et al., 2016).

Members of family Ocypodidae Rafinesque, 1815 and Dotillidae Stimpson, 1858 are the most common burrowers found in tropical and subtropical regions. The fiddler crabs belonging to family Ocypodidae are among the most common and best known for their burrowing behaviour (Crane, 1975; Lim, 2006). They abound along the shores of tropical and subtropical regions around the world where they excavate simple dwellings (burrows) in intertidal areas (Gilbert et al., 2013). In family Dotillidae, individuals of genus *Ilyoplax* Stimpson, 1858 are commonly distributed on the intertidal mudflats of temperate to tropical Indo-Western pacific region. Species belonging to this genus are smaller in size but occur in large numbers on the sandy and muddy shores and they play a significant role in the ecology of the habitat (Nishihira, 1984; Snowden et al., 1991). *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 (Trivedi et al., 2015c) is a newly discovered species of the members of Dotillidae, found to construct burrows in muddy intertidal area. These crabs are known to accommodate their burrowing exercise to a varying degree of conditions like substratum conditions, salinity, temperature, tidal periodicity, anthropogenic disturbances, predators etc (Dubey et al., 2013). During high tide crabs remain inside the burrow while emerging out during low tide for feeding or other surface activities (Gherardi et al., 1999). Such behavioural adaptation helps them to avoid the need of periodically return to a burrow to replenish its water supply (Hartnoll, 1973).

Now a days, ecological functions of burrowing behaviour in specific ecosystem have received increasing attention and crab burrowing has been considered as one of the major factors of bioturbation affecting the physical and chemical processes in ecosystems (Wang et al., 2010). Therefore, the present study was planned to understand the structural characteristics of burrows of the fiddler crab *Austruca sindensis* (Alcock, 1900) and recently discovered species *Ilyoplax sayajiraoi* which is commonly distributed on coastal region of Gulf of Khambhat.

The detail methodology for data collection has been described in materials and methodology chapter (Page No. 29). Following flow chart shows summary of the methodology used in present chapter.



5.2 RESULTS

5.2.1 Burrow Architecture of Austruca sindensis (Alcock, 1900)

A total of 94 burrow casts were obtained for *A. sindensis* form two different zone i.e., Zone I and Zone II which were designated as upper and lower margin of upper intertidal zone (Fig. 4.1). A total of 46 host crabs were captured from studied burrows from which 29 males and 17 females (Table 5.1). A total of 7 different shaped burrows were recorded including J-shaped burrow (28), Single tube burrow (27), S-shaped burrow (21), Spiral burrow (10), J-shaped burrow with branch (5), U-shaped burrow with single opening (2) and Multi-branched burrow (1) (Fig. 5.1, 5.2).

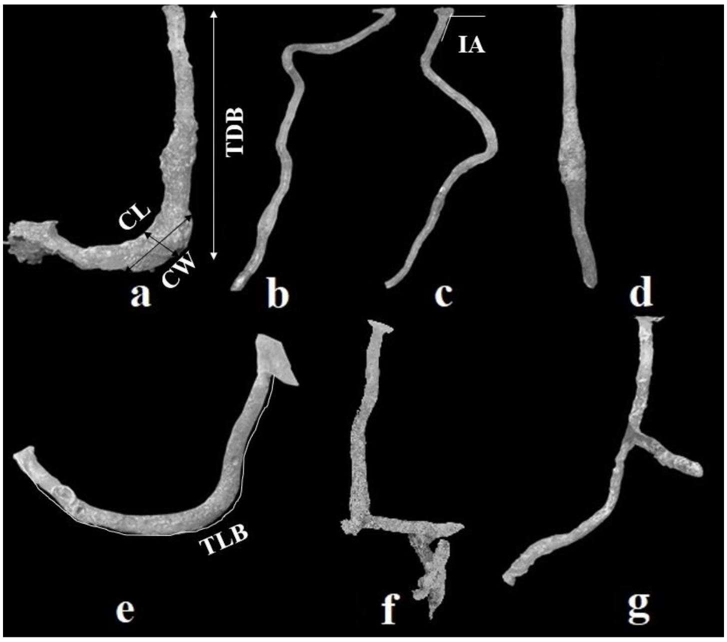


Figure 5.1: Burrow architecture of *Austruca sindensis* (Alcock, 1900) with various measurements of burrow cast. a. J-shaped burrow, b. Spiral burrow, c. S-shaped burrow, d. Single tube burrow, e. U-shaped burrow, f. Multi-branched burrow, g. J-shaped with Branch burrow. (TDB – Total depth of Burrow; TLB – Total length of burrow; IA– Burrow inclination angle; CL – Chamber length; CW – Chamber width)

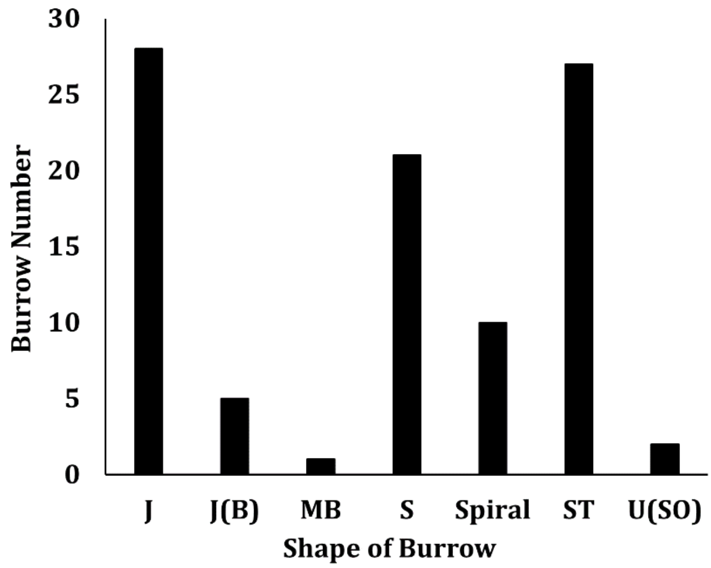


Figure 5.2: Indicates number of burrow count with respect to shape of the burrow in *Austruca sindensis* (Alcock, 1900)

J-shaped burrows (n = 28) had an average burrow opening diameter of 8.79±2.29 mm and a mean burrow volume of 44.59±32.76 cm^3. Burrows had a mean inclination angle of 120.2°±10.48°, which was vertical. Burrows were constructed by the crabs with mean carapace lengths of 7.87±1.96 mm (n = 10). The burrows' average length and depth were 27.08±10.12 cm and 22.43±6.29 cm, respectively. The centre and base chambers, respectively, had mean lengths of 2.45±0.99 cm and 2.47±0.50 cm. The middle and base chambers' respective mean widths were 4.37±1.99 cm and 4.82±1.39 cm.

The average volume of single tube burrows (ST) (n = 27) was 44.99±27.66 cm^3, and the average burrow diameter was 8.68±2.01 mm. The crabs that dug the burrows had an average carapace length of 8.34±2.01 mm (n = 12). Burrows ended with a chamber (CL: 3.2±0.58 cm CW: 9.02±1.8 cm) at the base and were inclined vertically from the surface with a mean inclination angle of 118.04±15.02°. Another chamber was built with dimensions of 6.22±2.05 cm in width and 3.08±0.84 cm in length on average. The burrows' average length and depth were 23.03±7.96 cm and 21.46±7.55 cm, respectively.

S-shaped burrows (n = 21) had the largest volume (47.12±26.80 cm^3) and an average burrow opening diameter of 8.71±2.20 mm. S-shaped burrows were constructed by the crabs with mean carapace length of 7.05±1.66 mm (n = 10). The mean inclination angle of the burrows was 117.47°±16.06°, which is a vertical position. The crabs built two small chambers in many S-shaped burrows, either at the bottom or in the centre. The average lengths of the terminal chambers and the central chamber were 2.52±0.63 cm and 2.6±0.58 cm, respectively. While The average width of the intermittent and terminal chambers was 5.53±2.58 cm and 5.34±1.64 cm, respectively. The burrows' average length and depth were 31.59±9.79 cm and 23.77±6.09 cm, respectively.

Spiral burrows (n = 10) had mean burrow volume of 37.35±22.46 cm^3 with a mean opening diameter of 7.91±1.80 mm and were dug by crabs with a mean carapace length of 6.33±1.19 mm (n = 4). With a mean inclination angle of 137.5°±17.05°, burrows were vertically inclined. The average depth and length of the burrows were 22.73±8.15 cm and 29.95±10.31 cm, respectively. The chamber measured 3.4±0.28 cm and 5.5±1.34 cm in length and width, respectively.

J-shaped branch burrows (JB) (n = 5) had an average opening diameter of 9.03±0.88 mm and a mean burrow volume of 21.09±11.38 cm^3. The crabs dug burrows with a mean carapace length of 7.27±0.16 mm (n=3). With a mean inclination angle of 128.8°±8.54° and a depth of 15.6±4.13 cm, the burrows were vertical in shape. The main shaft of the burrow turns in the direction of the surface in the shape of a branch that does not continue there, and it finishes in the shape of a spherical blind end. The main shaft's base forms the second branch, which terminates at the base with a small chamber. The burrows had an average length of 17.7±2.95 cm.

U-shaped burrows with a single opening (U with SO) (n = 2) had an average burrow opening diameter of 7.54±0.87 mm and a mean burrow volume of 40.63±0.11 cm^3. The crab with a carapace length of 7.55 mm (n = 1) constructed U-shaped burrows. Burrows had a mean inclination angle of 138°±2° and were vertical. The burrows had an average depth and length of 17.5±0.8 cm and 28.4±0.9 cm, respectively. The chamber's base measured an average of 2.9 cm and 8.3 cm in length and width.

The mean volume of the multi-branched burrow (MB) (n = 1) was 79.58 cm^3, and the aperture diameter was 10.53 mm. The only difference between the burrow and a J-shaped with branch burrow was an extra branch that was joined to the base of the secondary branch. Other than the central arm, there are no other branches in this burrow that reach the surface, and all of them end in a spherical blind lobe. The additional branch, which was joined to the secondary branch base, contained several chambers. The crab, which had a carapace length of 7.72 mm (n=1), built the burrow. The burrow has an 87° vertical angle of inclination.

5.2.1.1 Variation in burrow architecture in male and female crabs of Austruca sindensis (Alcock, 1900)

The carapace length (mm) of the male and female crabs were not significantly different (males: 7.94±1.8, females: 7.17±1.87). In the case of burrow characteristics, both sexes constructed 6 different shaped burrows and their burrow shapes were not different. However, the diameters of male crab burrows were larger compared to the diameters of female crab burrows, male crab burrows were longer and more voluminous than those of the female crabs (Table 5.1)

Table 5.1: Burrow characteristics of *Austruca sindensis* (Alcock, 1900)

Burrow Morphology	**Male**	**Female**
Total shape	6	6
Total burrow	29	17
carapace length (mm)	7.94±1.8	7.17±1.87
Burrow opening diameter (mm)	9.22±1.97	8.47±1.77
Burrow length (cm)	30.55±10.94	27.56±10.56
Burrow depth (cm)	21.81±6.34	21.18±5.04
Inclination angle °C	123.28±13.29	124.71±11.22
Volume (CM^3)	39.19±13.33	30.62±8.99

5.2.1.2 Burrow architecture of Austruca sindensis (Alcock, 1900) in winter season

A total of 32 burrow casts were obtained for *A. sindensis* during winter season form which 21 and 11 cast were obtained from upper and middle intertidal zone respectively.

5.2.1.2.1 Relationship between burrow parameters of Austruca sindensis (Alcock, 1900) in two different intertidal zones

During winter season, High Pearson correlation was recorded for the examined morphological parameters of the burrow (0.05 level of significance). Larger crabs preferred the Zone I and created a suitable burrow with all the necessary features there (Table 5.2). The burrow's proper length, width, and volume were noted. In middle intertidal zone, Pearson correlation was recorded high among the studied parameters. As smaller sized crabs are mainly observed in Zone II, there was little association between burrow metrics (Table 5.3).

Table 5.2: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for winter season in Zone I

	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.86	1					
CW	0.93	0.98	1				
TLB	0.90	0.80	0.97	1			
TDB	0.89	0.89	0.90	0.61	1		
BV	0.96	0.37	0.97	0.16	0.46	1	
IA	-0.50	-0.11	-0.14	-0.30	-0.10	0.67	1

Table 5.3: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for winter season in Zone II

	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.91	1					
CW	0.96	0.87	1				
TLB	0.93	0.79	0.95	1			
TDB	0.77	0.45	0.80	0.64	1		
BV	0.71	0.71	0.71	0.73	0.58	1	
IA	0.33	0.46	0.37	0.39	-0.05	0.34	1

5.2.1.2.2 Regression analysis burrow parameters and carapace length of Austruca sindensis (Alcock, 1900)

In winter, crab carapace length showed positive correlation with carapace width (R^2=0.90), burrow opening diameter (R^2=0.82), total burrow length (R^2=0.57), total burrow depth (R^2=0.56) and burrow volume (R^2=0.49). The crab carapace length did not show significant correlation with burrow inclination angle (R^2=0.06) (Fig. 5.3, 5.4, 5.5).

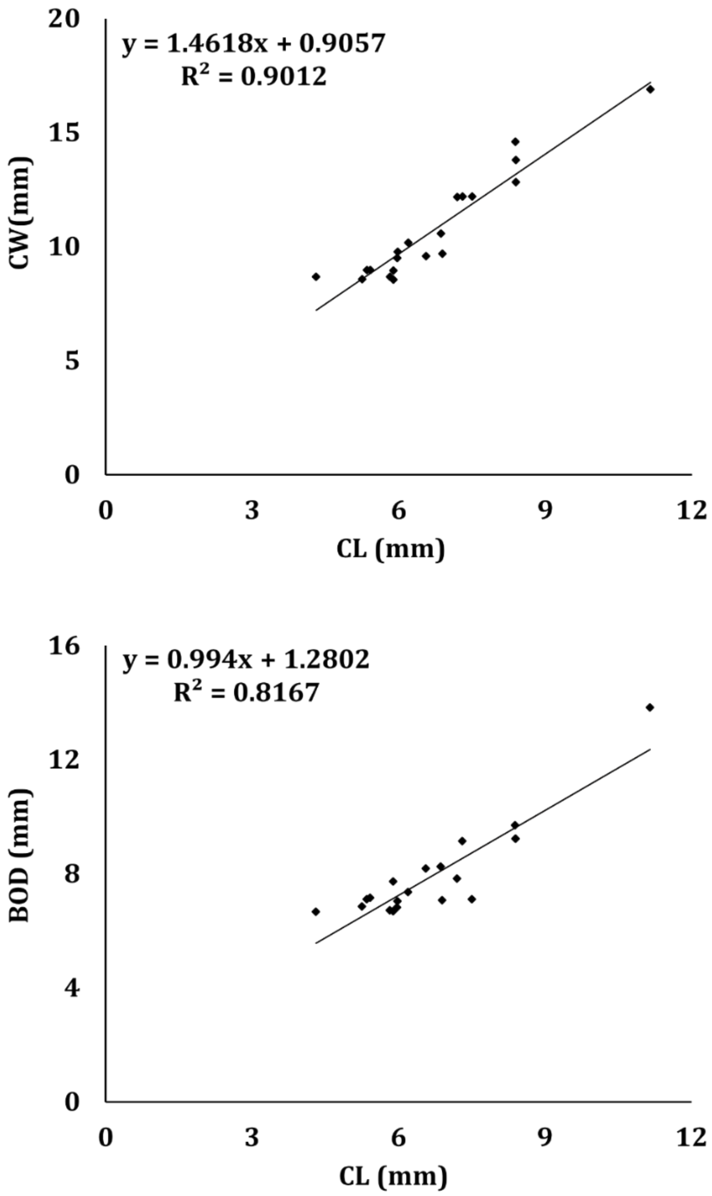


Figure 5.3: Regression analysis for the relationship between crab carapace length and crab carapace width (CW) and Burrow opening diameter (BOD) *Austruca sindensis* (Alcock, 1900) in winter season

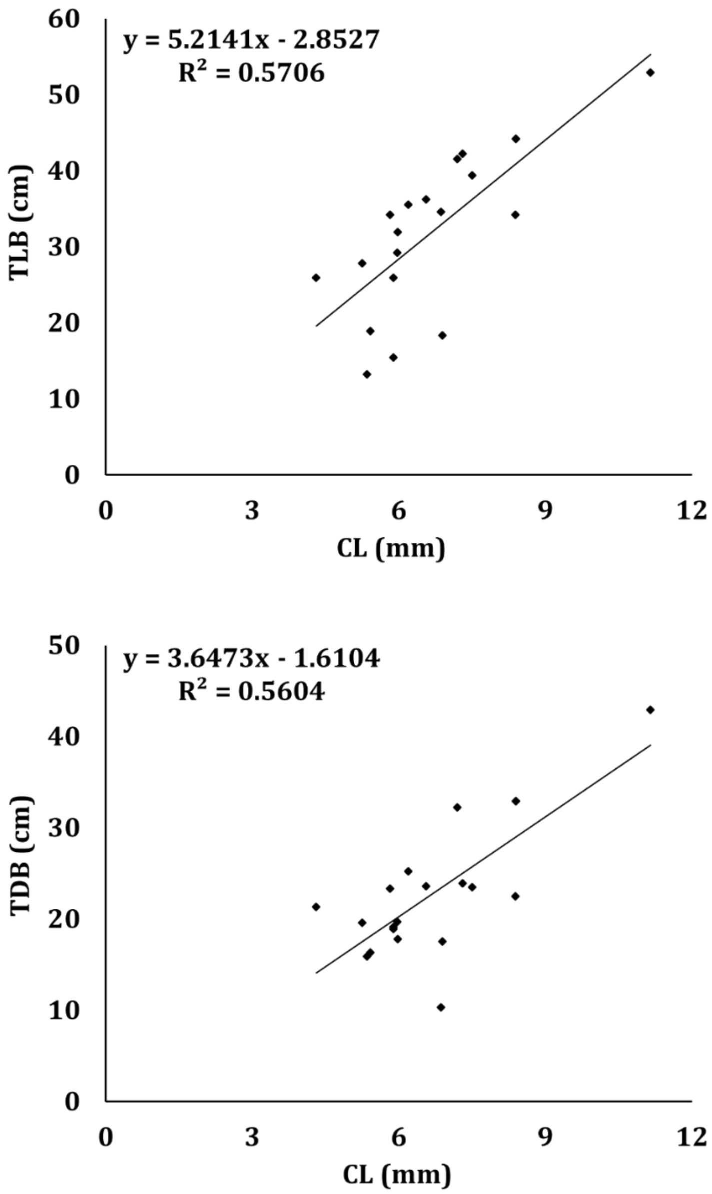
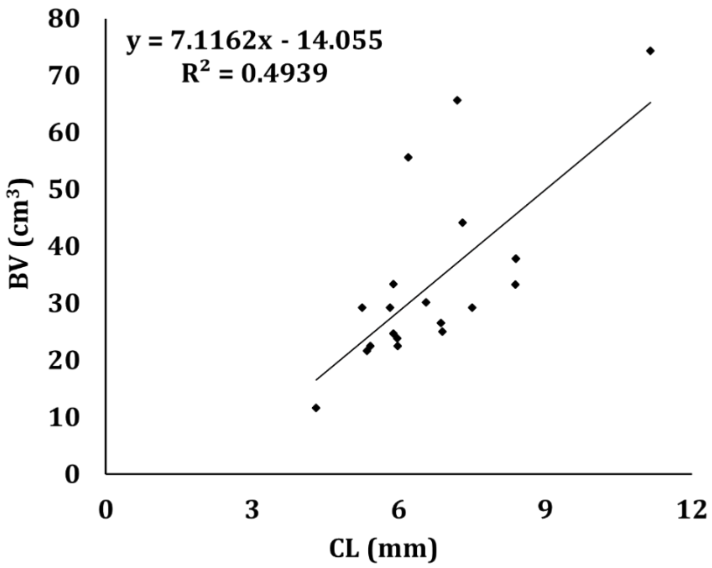


Figure 5.4: Regression analysis for the relationship between crab carapace length and Total length (TLB) and Total depth (TDB) of burrow burrows of *Austruca sindensis* (Alcock, 1900) in winter season



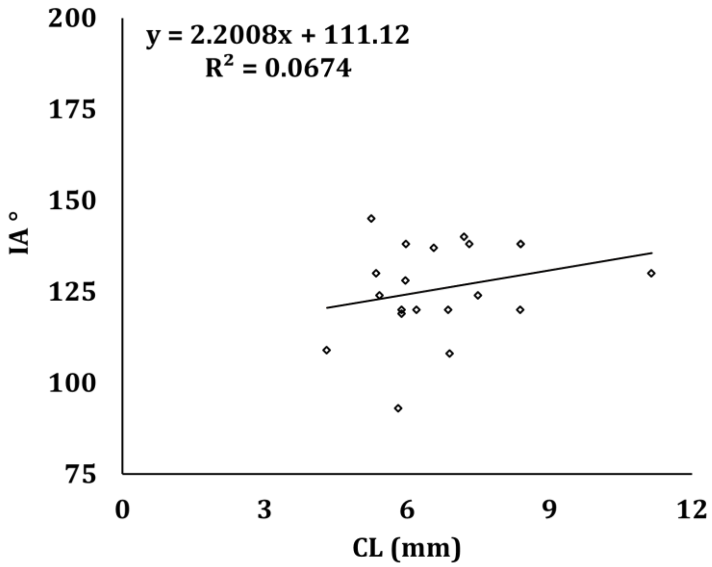


Figure 5.5: Regression analysis for the relationship between crab carapace length and Burrow volume (BV) and Inclination angle (IA) of burrows of *Austruca sindensis* (Alcock, 1900) in winter season

5.2.1.2.3 Vertical temperature profile of shaped burrows of Austruca sindensis (Alcock, 1900)

The depth wise variation in burrow temperature was studied for various burrow shapes like J- shaped, S- shaped, Spiral and ST burrows in the present study. Results revealed similar pattern in temperature variation for all the burrow shapes. In winter, the sand surface temperature recorded 26-30°C which remained similar for all the burrow types (Fig. 5.6, 5.7). 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 22-25 C, which was cooler than the surface temperature in all the season.

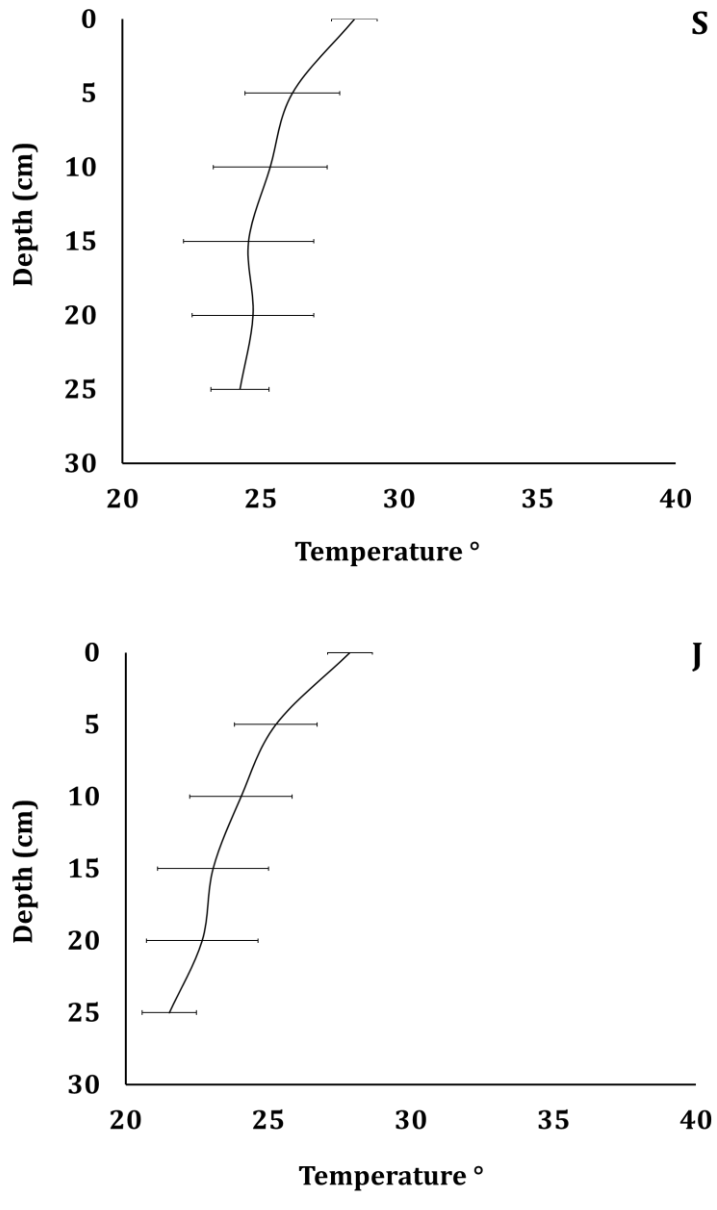
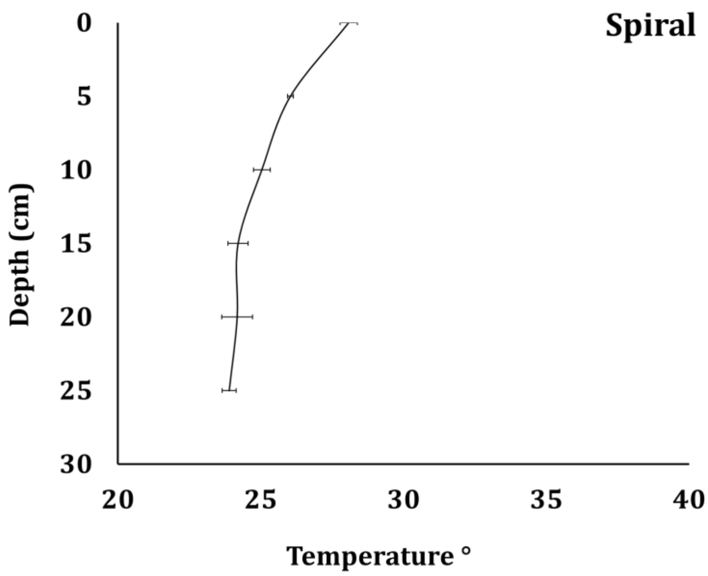


Figure 5.6: Vertical temperature profiles with the burrow depth in S-shaped and J-shaped burrows of *Austruca sindensis* (Alcock, 1900) during winter season



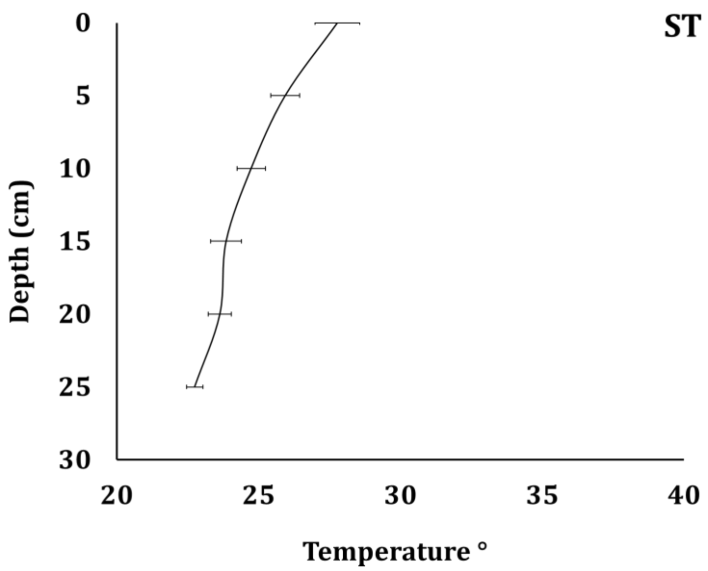


Figure 5.7: Vertical temperature profiles with the burrow depth in spiral and single tube (ST) burrows of *Austruca sindensis* (Alcock, 1900) during winter season

5.2.1.2.4 Principle Component Analysis of burrow morphology of Austruca sindensis (Alcock, 1900) between two different zone

In winter season number of variables in Zone I (U1 to U21) are twenty-one and Zone II (M1 to M11) are eleven. Per cent variance for component 1 is 77.837%, 2 is 17.369% and 3 is 4.795%. Cumulative percentage for component 1 is 77.837%, component 2 is 95.205% and component 3 is 100% shown in Table 5.4. Fig. 5.9 indicates most of the burrow are forming close clusters and giving out maximum correlation.

Table 5.4: Total Variance in winter season *Austruca sindensis* (Alcock, 1900)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	24.908	77.837	77.837	24.908	77.837	77.837
2	5.558	17.359	95.205	5.558	17.359	95.205
3	1.534	4.795	100	1.534	4.795	100

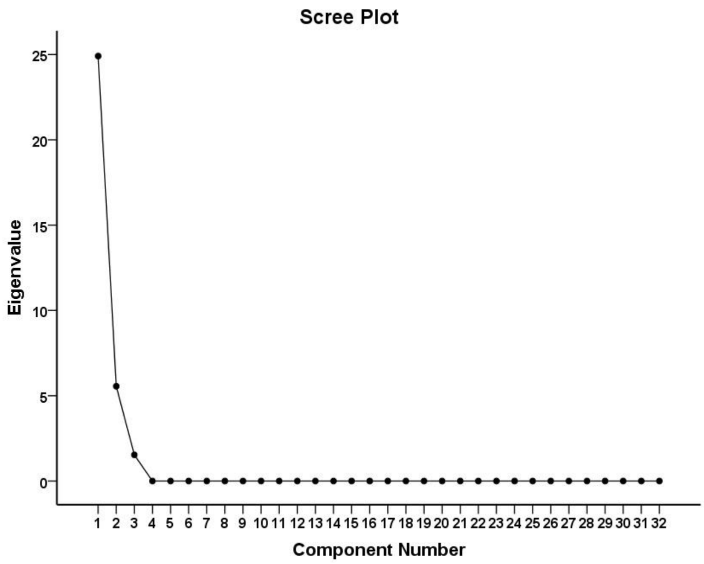


Figure 5.8: Scree plot indicating major 2 plots for winter season

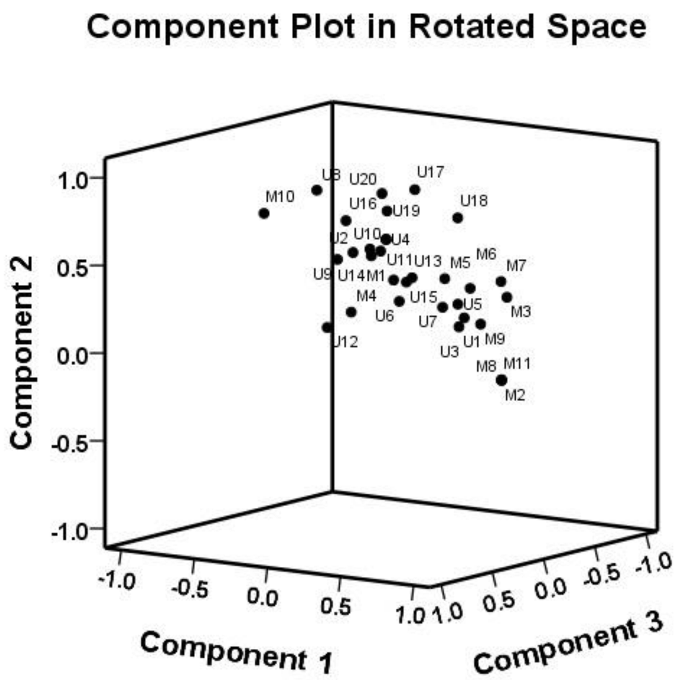


Figure 5.9: Component plot in rotated space for winter season

5.2.1.3 Burrow architecture of Austruca sindensis (Alcock, 1900) in summer season

A total of 32 burrow casts were obtained for *A. sindensis* during summer season form which 13 and 21 cast were obtained from upper and middle intertidal zone respectively.

5.2.1.3.1 Relationship between burrow parameters of Austruca sindensis (Alcock, 1900) in two different intertidal zones

Due to the accommodation of larger crabs in the Zone I, the summer season revealed a high Pearson correlation (0.05 level of significance). They created a suitable burrow to make their stay there more comfortable. The burrow's proper length, width, and volume were noted (Table 5.5). This season's burrows also included a resting chamber for ovigerous females. The middle intertidal zone, where crabs are smaller than those in the Zone I, had lower Pearson coefficient than the Zone I (Table 5.6).

Table 5.5: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for summer season in Zone I

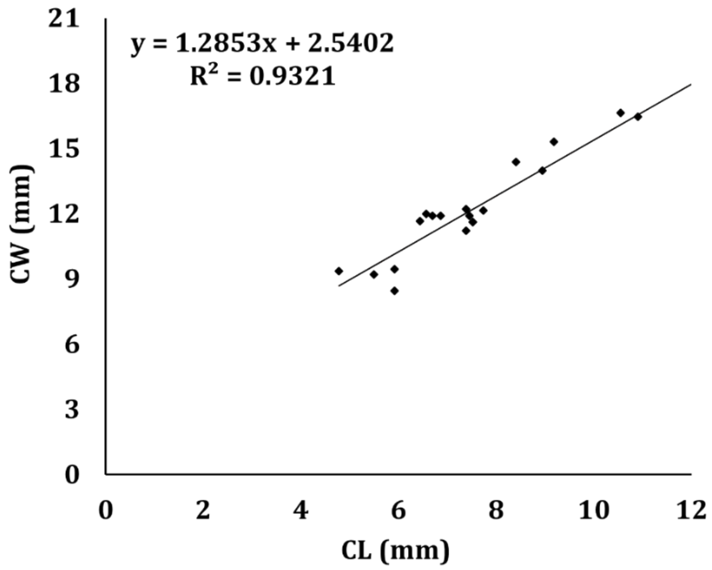
	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.99	1					
CW	0.99	0.98	1				
TLB	0.71	0.76	0.67	1			
TDB	0.44	0.39	0.41	0.46	1		
BV	0.72	0.65	0.70	0.71	0.04	1	
IA	-0.40	-0.12	-0.31	-0.11	-0.68	-0.19	1

Table 5.6: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for summer season in Zone II

	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.94	1					
CW	0.86	0.82	1				
TLB	0.26	-0.10	0.44	1			
TDB	0.40	0.23	0.41	0.17	1		
BV	0.15	-0.32	-0.02	0.40	-0.09	1	
IA	-0.30	-0.13	-0.32	0.16	0.25	-0.08	1

5.2.1.3.2 Regression analysis burrow parameters and carapace length of Austruca sindensis (Alcock, 1900)

In summer, carapace length showed strong positive correlation with the carapace width (R^2=0.93), burrow opening diameter (R^2=0.96), total burrow length (R^2=0.74), total burrow depth (R^2=0.57) and burrow volume (R^2=0.63). The crab carapace length did not show significant correlation with burrow inclination angle (R^2=0.01) (Fig. 5.10, 5.11, 5.12).



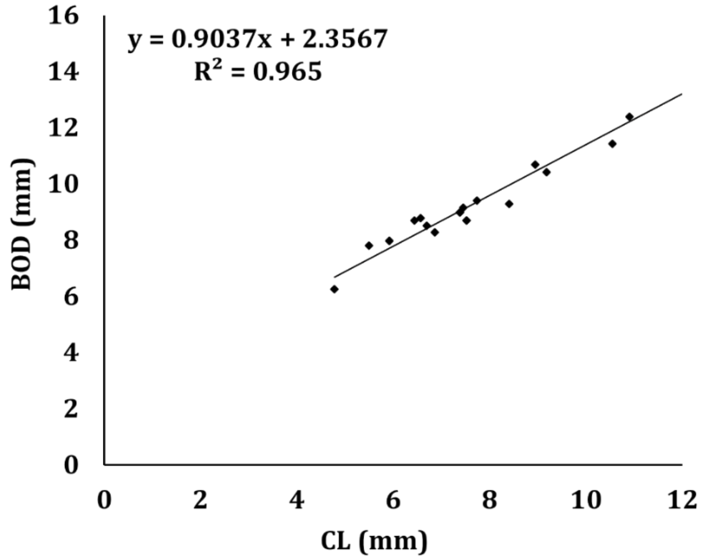


Figure 5.10: Regression analysis for the relationship between crab carapace length and crab carapace width (CW) and Burrow opening diameter (BOD) *Austruca sindensis* (Alcock, 1900) in summer season

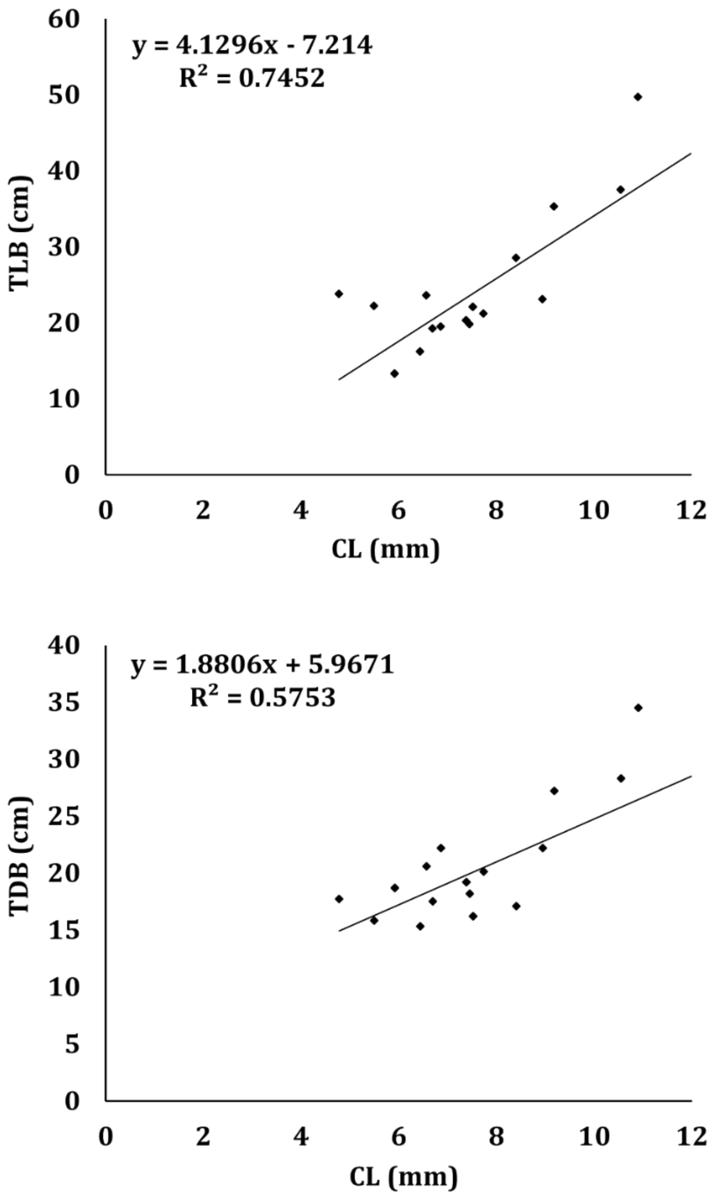


Figure 5.11: Regression analysis for the relationship between crab carapace length and Total length (TLB) and Total depth (TDB) of burrow burrows of *Austruca sindensis* (Alcock, 1900) in summer season

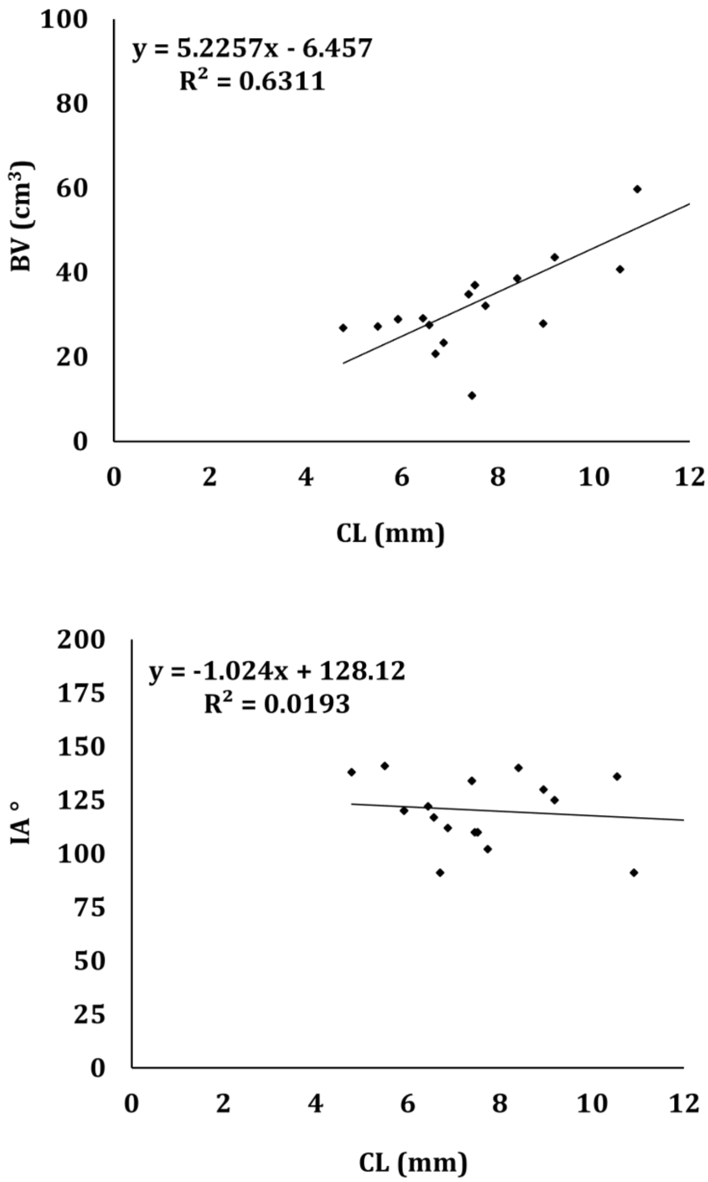


Figure 5.12: Regression analysis for the relationship between crab carapace length and Burrow volume (BV) and Inclination angle (IA) of burrows of *Austruca sindensis* (Alcock, 1900) in summer season

5.2.1.3.3 Vertical temperature profile of various shaped burrows of Austruca sindensis (Alcock, 1900)

The depth wise variation in burrow temperature was studied for various burrow shapes like J- shaped, S- shaped, and ST burrows in the present study. Results revealed similar pattern in temperature variation for all the burrow shapes. The sand surface temperature recorded 38-44°C which remained similar for all the burrow types (Fig. 5.13, 5.14). 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 27-28 C, which was cooler than the surface temperature.

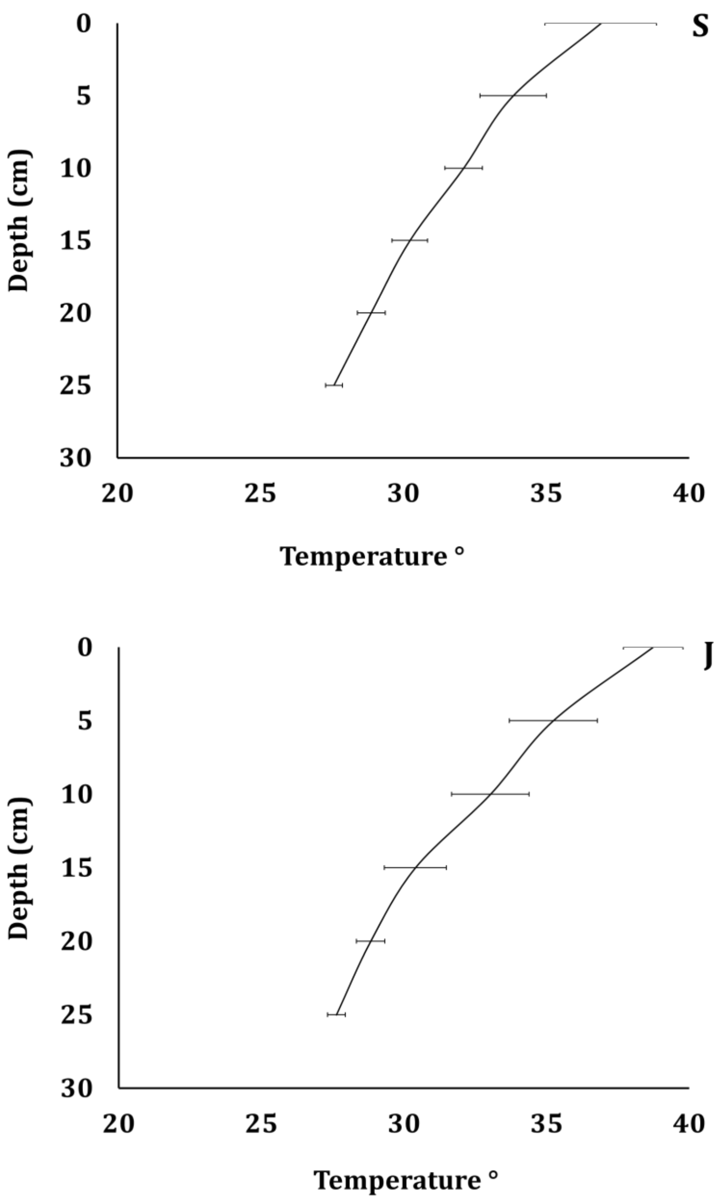


Figure 5.13: Vertical temperature profiles with the burrow depth in S-shaped and J-shaped burrows of *Austruca sindensis* (Alcock, 1900) during summer season

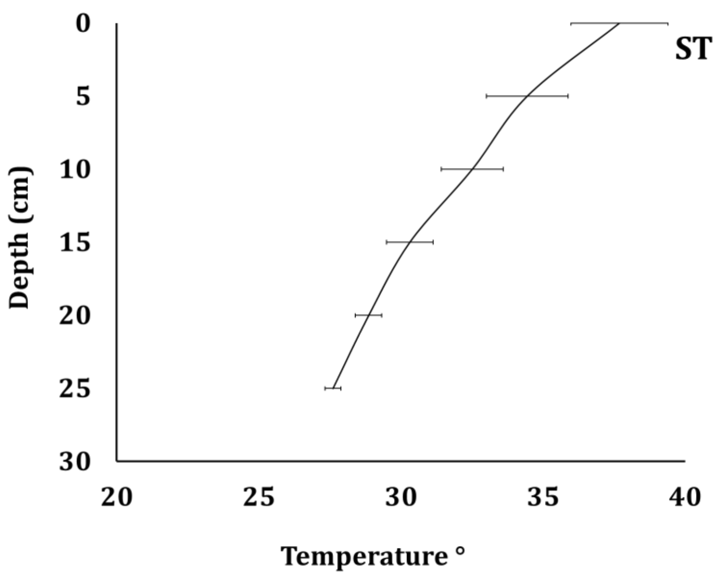


Figure 5.14: Vertical temperature profiles with the burrow depth in single tube (ST) burrows of *Austruca sindensis* (Alcock, 1900) during summer season

5.2.1.3.4 PCA of burrow morphology in summer season of Austruca sindensis (Alcock, 1900) between two different zone

In summer season number of variables in Zone I (U1 to U13) are thirteen and Zone II (M1 to M21) are twenty-one. Scree plot in fig. 5.15 shows data has two major components as shown in Table 5.7. Per cent variance for component 1 is 85.503% and 2 is 16.497%. Cumulative percentage for component 1 is 85.503% and component 2 is 100% shown in Table 5.7. Fig. 5.16 indicates most of the burrow forms close clusters in one compartment and only M9 and M11 are dispersed in another that suggests maximum correlation among burrow metrics.

Table 5.7: Total Variance in summer season *Austruca sindensis* (Alcock, 1900)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	28.391	83.503	83.503	28.391	83.503	83.503
2	5.609	16.497	100	5.609	16.497	100

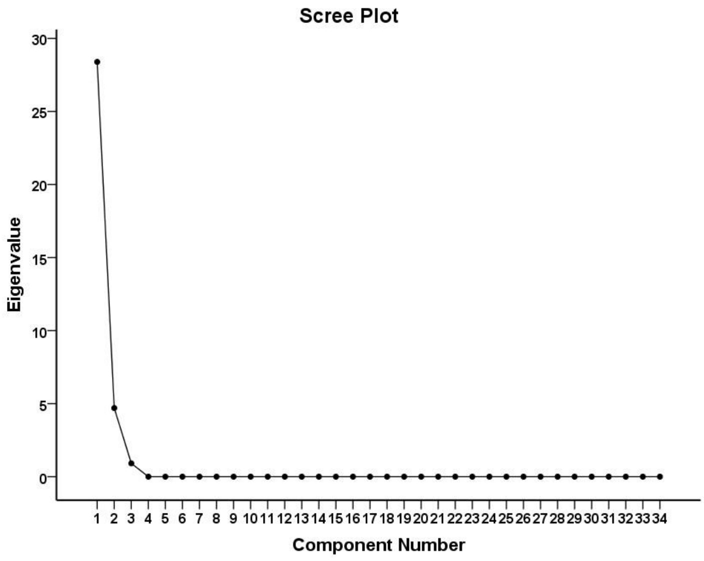


Figure 5.15: Scree plot indicating major 2 plots for summer season

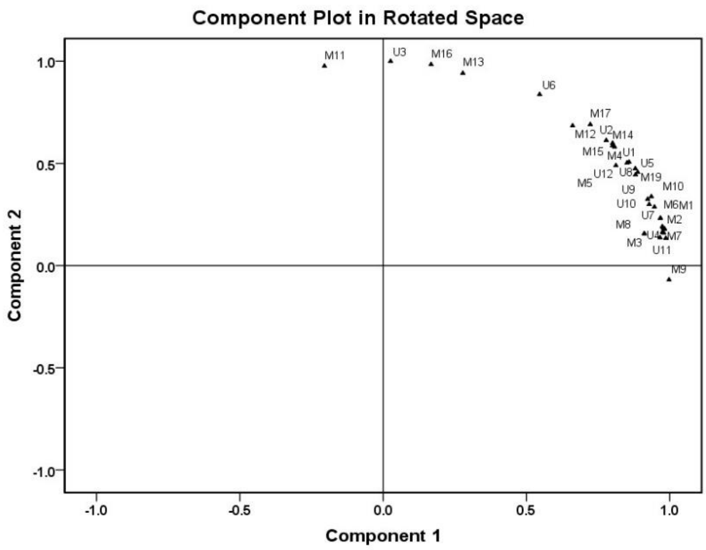


Figure 5.16: Component plot in rotated space for summer season

5.2.1.4 Burrow architecture of Austruca sindensis (Alcock, 1900) in monsoon season

A total of 28 burrow casts were obtained for *A. sindensis* during winter season form which 16 and 12 cast were obtained from upper and middle intertidal zone respectively.

5.2.1.4.1 Relationship between burrow parameters of Austruca sindensis (Alcock, 1900) in two different intertidal zones

The monsoon season showed a strong Pearson correlation (0.05 level of significance) in both the zone i.e. 1 and 2 (Table 5.8, 5.9). Less variation in burrow parameters was seen during this season in both upper and middle intertidal zone. Both adult and young crabs were distributed randomly during monsoon season, however the bulk of larger-sized crabs were seen in the upper intertidal zone.

Table 5.8: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for Monsoon season in Zone I

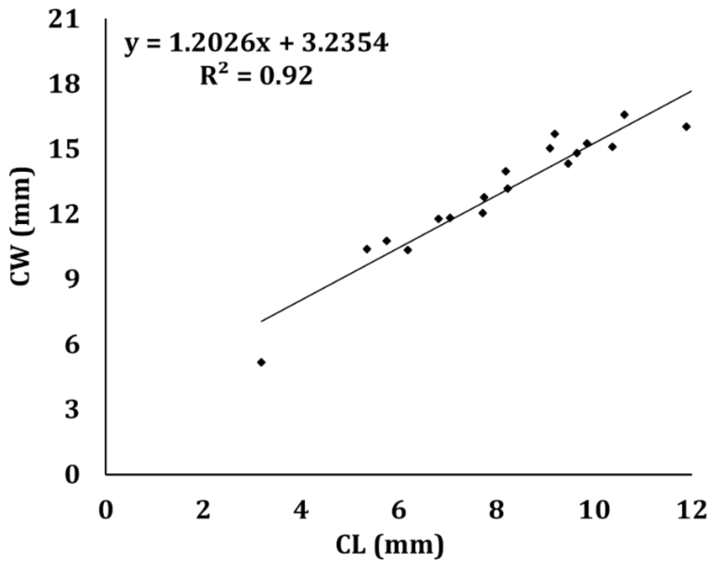
	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.93	1					
CW	0.87	0.82	1				
TLB	0.69	0.69	0.79	1			
TDB	0.720	0.17	0.81	-0.06	1		
BV	0.60	0.14	0.79	0.18	0.52	1	
IA	-0.41	-0.13	-0.56	-0.21	-0.33	-0.24	1

Table 5.9: Indicates Pearson correlation between various burrow parameters of *Austruca sindensis* (Alcock, 1900) for Monsoon season in Zone II

	CL	BOD	CW	TLB	TDB	BV	IA
CL	1						
BOD	0.95	1					
CW	0.98	0.88	1				
TLB	0.70	0.53	0.69	1			
TDB	0.58	0.51	0.59	0.72	1		
BV	0.49	0.42	0.42	0.66	0.89	1	
IA	0.06	0.04	0.11	-0.14	-0.32	-0.44	1

5.2.1.4.2 Regression analysis burrow parameters and Carapace length Austruca sindensis (Alcock, 1900)

Crab carapace length was positively correlated with the carapace width (R^2=0.92), burrow opening diameter (R^2=0.91), total burrow length (R^2=0.64), total burrow depth (R^2=0.57) and burrow volume (R^2=0.44) in monsoon season. The crab carapace length did not show significant correlation with burrow inclination angle (R^2=0.01) (Fig. 5.17, 5.18, 5.19).



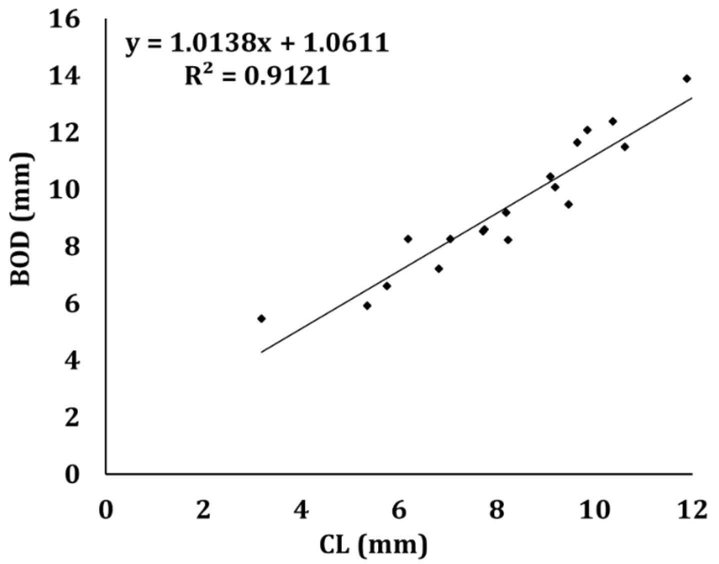


Figure 5.17: Regression analysis for the relationship between crab carapace length and crab carapace width (CW) and Burrow opening diameter (BOD) *Austruca sindensis* (Alcock, 1900) in monsoon season

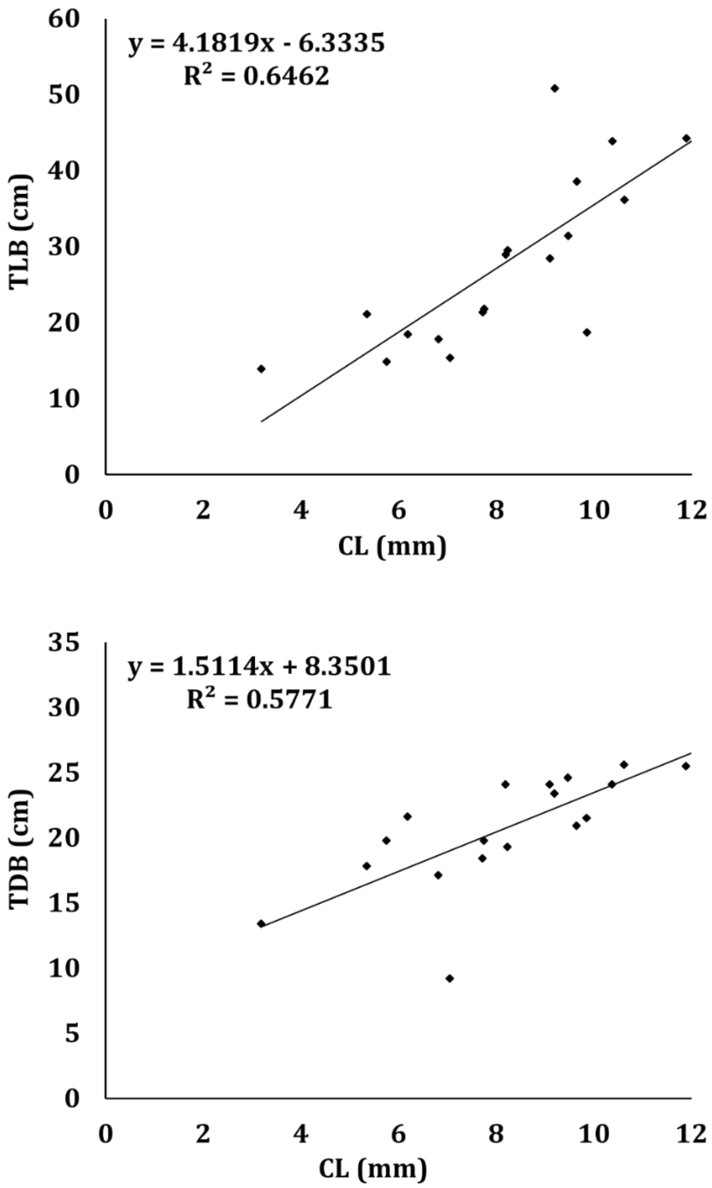
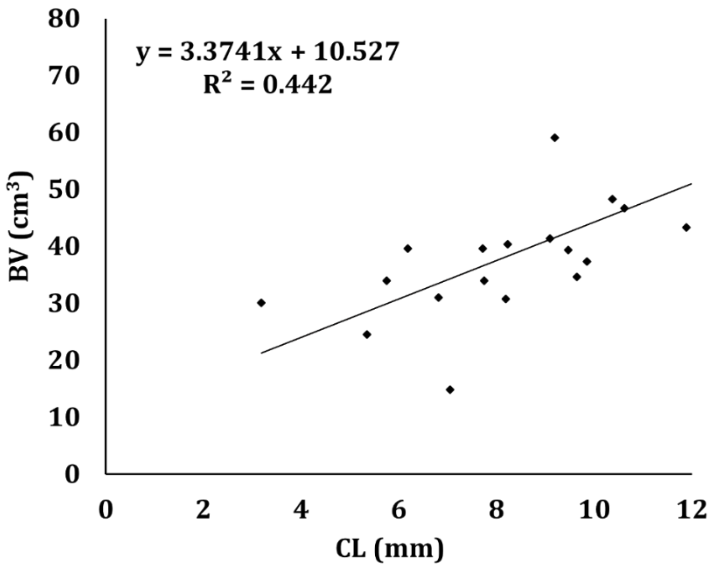


Figure 5.18: Regression analysis for the relationship between crab carapace length and Total length (TLB) and Total depth (TDB) of burrow burrows of *Austruca sindensis* (Alcock, 1900) in monsoon season



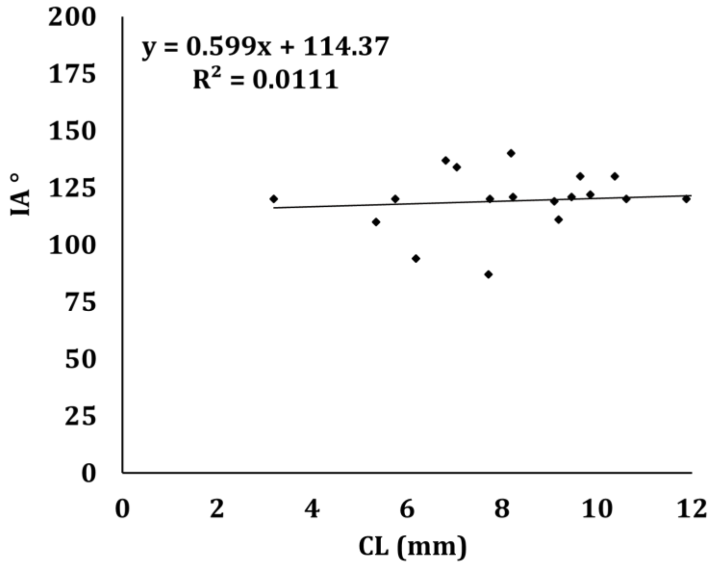


Figure 5.19: Regression analysis for the relationship between crab carapace length and Burrow volume (BV) and Inclination angle (IA) of burrows of *Austruca sindensis* (Alcock, 1900) in monsoon season

5.2.1.4.3 Vertical temperature profile of various shaped burrows of Austruca sindensis (Alcock, 1900)

The depth wise variation in burrow temperature was studied for various burrow shapes like J- shaped, S- shaped, and ST burrows in the present study. Results revealed similar pattern in temperature variation for all the burrow shapes. The sand surface temperature recorded 32-40°C which remained similar for all the burrow types (Fig. 5.20, 5.21). 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 25-26 C, which was cooler than the surface temperature.

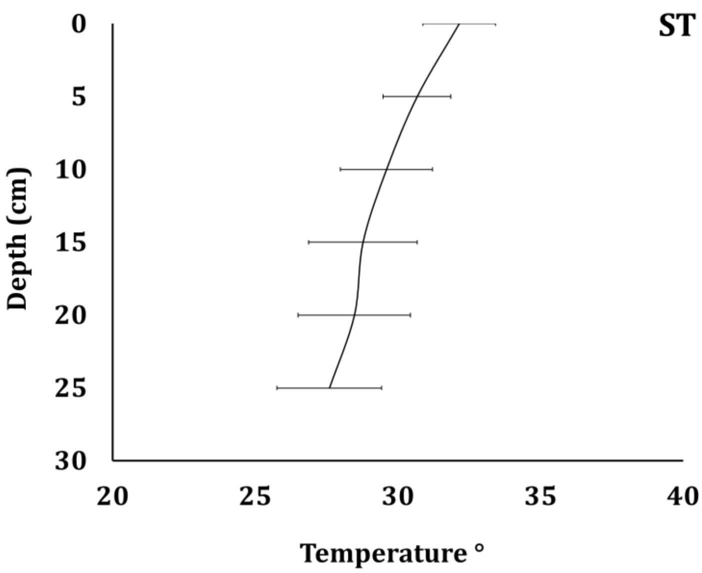


Figure 5.20: Vertical temperature profiles with the burrow depth in single tube (ST) burrows of *Austruca sindensis* (Alcock, 1900) during monsoon season

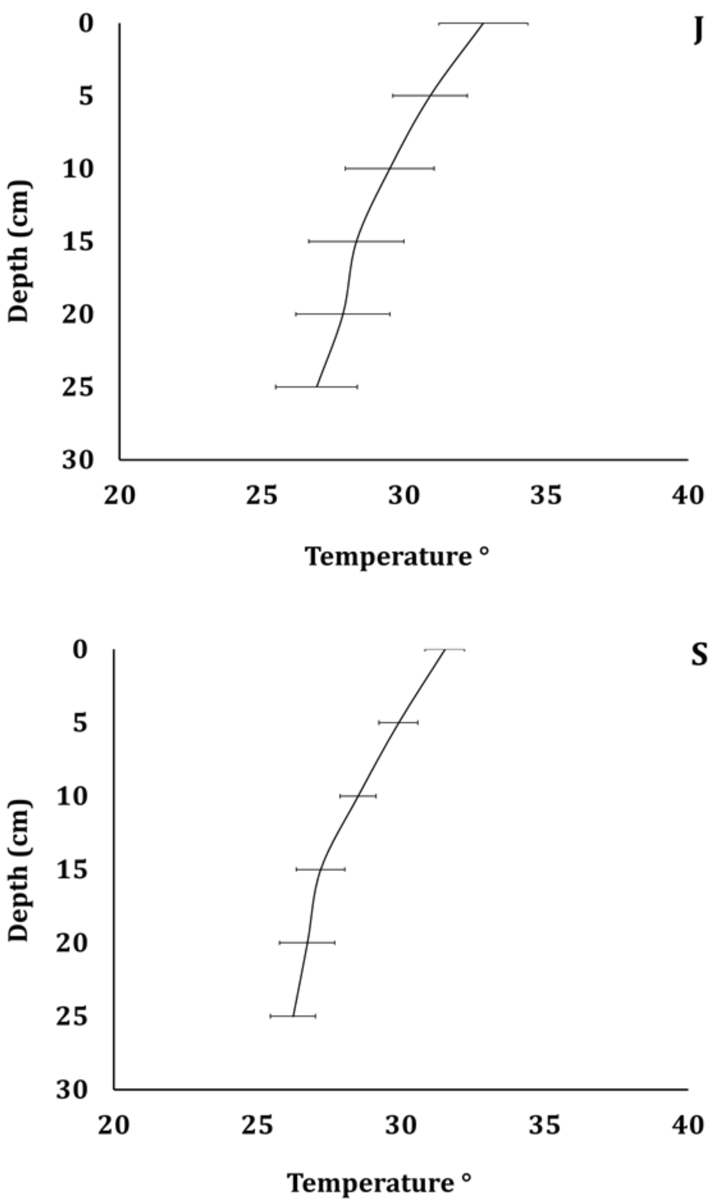


Figure 5.21: Vertical temperature profiles with the burrow depth in J-shaped and S-shaped burrows of *Austruca sindensis* (Alcock, 1900) during monsoon season

5.2.1.4.4 PCA of burrow morphology in monsoon season

In monsoon season number of variables in Zone I (U1 to U16) are sixteen and Zone II (M1 to M12) are twelve. Scree plot in Fig. 5.22 shows data has two major components as shown in Table 5.10. Per cent variance for component 1 is 91.679% and 2 is 8.322%. Cumulative percentage for component 1 is 91.679% and component 100% shown in Table 5.10. In monsoon season burrows forms close clusters which suggests that in both zone burrows have less variation in burrow metrics (Fig. 5.23).

Table 5.10: Total Variance in monsoon season *Austruca sindensis* (Alcock, 1900)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	25.670	91.679	91.679	25.670	91.679	91.679
2	2.33	8.322	100	2.33	8.322	100

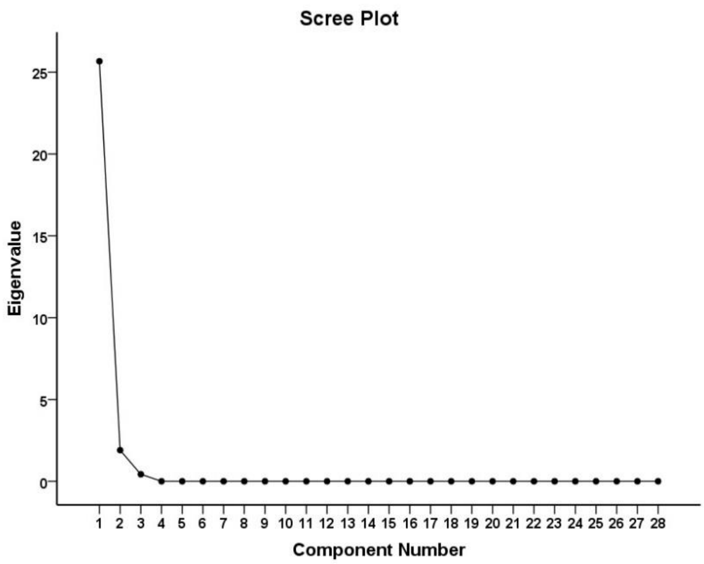


Figure 5.22: Scree plot indicating major 2 plots for monsoon season

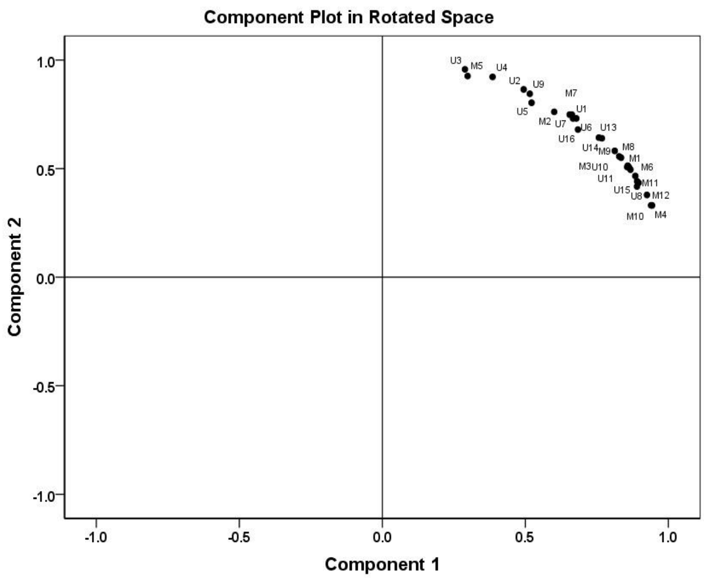


Figure 5.23: Component plot in rotated space for monsoon season

5.2.2 Burrow Architecture of Ilyoplax sayajiraoi JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015

5.2.2.1 Morphometrical analysis of the excavated burrow casts of I. sayajiraoi

During field study a total of 66 burrow cast were obtained and from which from which host crabs were captured. During pre-monsoon season, a total of 31 burrow cast were examined and six different shape of the burrow cast were identified viz., J-shaped burrows (15), J-shaped burrows with branch {J (B)} (2), Single tube burrows (ST) (6), S-shaped burrows (3), Spiral burrows (3) and C-shaped burrows (2). A total of 35 burrow cast were obtained during post-monsoon season and burrow cast were classified into six different shape such as J-shaped burrows (15), J-shaped burrows with branch (2), S-shaped burrows (7), Spiral burrows (5), Single tube burrows (3) and Irregular-shaped burrows (3).

During pre-monsoon, maximum burrow casts were of J-shaped burrows (n=15) with mean burrow volume of 15.24±4.42 cm^3 and average burrow opening diameter of 5.55±1.54 mm (Table 5.11). While during post-monsoon, J- shaped burrows (n=15) had mean burrow volume of 8.58±3.55 cm^3 with an average burrow opening diameter of 5.37±1.70 mm (Table 5.12). The burrows were constructed by the crabs with mean carapace length of 4.2±1.39 mm and

3.57±1.28 mm during pre-monsoon (Table 5.11) and post-monsoon (Table 5.12) respectively. During pre-monsoon, the burrows were inclined vertically with an average inclination angle (IA) of 122.22±11.06° (Table 5.11). While during post-monsoon, the burrows were inclined with an average inclination angle of 124.92±10.17° (Table 5.12). The mean of total length and mean of total depth of the burrow casts were 16.95±4.49 cm and 13.35±4.79 cm, respectively during pre-monsoon (Table 5.11). While, the mean of total length and mean of total depth of the burrow casts were 14.75±3.07 cm and 10.52±3.34 cm, respectively during post-monsoon (Table 5.12). Resident crabs were found to construct chamber at terminal part of the burrow casts. Mean length and mean width of the chamber was 5.77±1.25 cm and 2.6±0.69 cm, respectively during pre-monsoon season (Table 5.11).

During pre-monsoon, J-shaped burrows with branch (n=2) had mean burrow volume of 13.25±3.22 cm^3 (Table 5.11), while J-shaped burrows with branch (n=2) had mean burrow volume of 13.21±0.51 cm^3during post-monsoon (Table 5.12). Average opening diameter of the burrow casts was 4.63±1.32 mm and mean carapace length of the resident crabs was 3.85±1.42 mm during pre-monsoon (Table 5.11). Whereas, mean burrow opening diameter was 4.37±0.58 mm and mean carapace length of the resident crabs was 2.18±1.42 mm during post-monsoon (Table 5.12). Burrows inclined vertically with mean inclination angle of 130±12.25° and 120° respectively during pre-monsoon (Table 5.11) and post-monsoon (Table 5.12). The mean of total length of the burrow casts was 15.62±4.25 cm and branch length were 2.05±0.25 cm during pre-monsoon (Table 5.11). Whereas, the mean of total length of the burrow casts was 11.40±0.90 cm and branch length were 2.55±0.35 cm during post-monsoon (Table 5.12). The mean of total depth of the burrow casts was 13.18±4.25 cm and 9.99±1.21 cm respectively during pre-monsoon (Table 5.11) and post-monsoon (Table 5.12). Burrow chamber was constructed at the terminal end of the burrow cast with mean length of 3.3 cm and mean width of 2.4 cm during post-monsoon season (Table 5.12).

Single tube burrows had mean burrow volume of 15.25±4.29 cm^3 during pre-monsoon (n=6) (Table 5.11) and 8.77±4.85 cm^3 during post-monsoon (n=3)

(Table 5.12). Average burrow opening diameter was 5.42±1.55 mm and 4.92±2.63 mm during pre-monsoon and post-monsoon respectively with mean carapace length of the resident crabs of 4.10±1.41 mm and 3.82±2.38 mm (Table 5.11, 5.12). During pre-monsoon mean of total length and mean of total depth of the burrow casts was 16.56±4.59 cm and 12.96±4.95 cm, respectively (Table 5.11). While, mean of total length and mean of total depth of the burrow casts was 13.41±5.92 cm and 12.69±4.84 cm, respectively during post-monsoon (Table 5.12). Burrows were inclined vertically with mean inclination angle of 122.59±10.93° and 113.33±4.71° during pre-monsoon and post-monsoon respectively (Table 5.11, 5.12).

During pre-monsoon, S-shaped burrows (n=3) with mean burrow volume of 13.70±3.51 cm^3 and average burrow opening diameter of 4.49±1.30 mm (Table 5.11). While during post-monsoon, J- shaped burrows (n=7) had mean burrow volume of 8.94±6.06 cm^3 with an average burrow opening diameter of 5.41±2.61 mm (Table 5.12). The burrows were constructed by the crabs with mean carapace length of 3.41±1.48 mm and 3.66±2.18 mm during pre-monsoon (Table 5.11) and post-monsoon (Table 5.12) respectively. During pre-monsoon, the burrows were inclined vertically with an average inclination angle (IA) of 121.67±12.13° (Table 5.11). While during post-monsoon, the burrows were inclined with an average inclination angle of 117.71±5.06° (Table 5.12). The mean of total length and mean of total depth of the burrow casts were 14.05±3.47 cm and 10.78±4.19 cm, respectively during pre-monsoon (Table 5.11). While, the mean of total length and mean of total depth of the burrow casts were 13.98±4.32 cm and 11.85±3.27 cm, respectively during post-monsoon (Table 5.12).

Spiral shaped burrows had mean burrow volume of 15.92±4.12 cm^3 in pre-monsoon (n=3) and 10.18±4.59 cm^3 in post-monsoon (n=5) respectively (Table 5.11, 5.12). Burrow casts were inclined vertically with mean inclination angle of 122.45±8.73° and mean burrow opening diameter was 5.96±1.15 mm during pre-monsoon (Table 5.11). Whereas, mean inclination angle of the burrow casts was 138±22.05° with mean burrow opening diameter of 5.21±1.74 mm during post-monsoon (Table 5.12). The mean of total length and mean of total depth of the burrow casts were 18.15±4.38 cm and 13.9±4.89 cm, respectively during pre-monsoon (Table 5.11). While, the mean of total length and mean of total depth of the burrow casts were 16.50±0.81 cm and 13.01±1.98 cm, respectively during post-monsoon (Table 5.12). Mean carapace length of the resident crabs was 4.49±1.09 mm and 3.93±1.70 mm respectively during pre-monsoon and post-monsoon (Table 5.11, 5.12). Burrow chamber was constructed at the terminal end of the burrow cast with mean length of 4.1 cm and mean width of 1.7 cm during pre-monsoon season (Table 5.11).

C-shaped burrows were only obtained during pre-monsoon season (n=2) with mean burrow volume of 15.37±3.94 cm^3 and average opening diameter of 5.99±1.09 mm. Mean carapace length of the resident crabs was 4.45±1.1 mm and burrow were inclined vertically with mean inclination angle of 120.58±8.66°. The mean of total length and mean of total depth of the burrow casts were 17.68±4.15 cm and 13.77±4.56 cm, respectively (Table 5.11).

During post-monsoon, some of the burrows cast were not identified as any specific shaped burrow and named as irregularly shaped burrows (n=3) with mean burrow volume of 6.97±3.56 cm^3 and average opening diameter of 4.74±1.81 mm. Mean carapace length of the resident crabs was 3.43±1.90 mm and burrow were inclined vertically with mean inclination angle of 116±4.32°. The mean of total length and mean of total depth of the burrow casts were 13.43±1.43 cm and 10.23±2.49 cm, respectively (Table 5.12).

Table 5.11 Burrow parameters of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon. (CL: Carapace length; CW: Carapace width; BOD: Burrow opening diameter; TLB: Total length of burrow; TDB: Total depth of burrow; BV: Burrow volume; IA: Inclination angle; B1l: Branch 1 length; ChL: Chamber length; ChW: Chamber width)

Burrow shape	n	Host crab CW (mm)	Mean							
			BOD (mm)	TBL (cm)	TBD (cm)	IA	BV (cm^3)	B1L (cm)	ChL (cm)	ChW (cm)
J	15	4.2±1.39	5.55±1.54	16.95±4.49	13.35±4.79	122.22±11.06	15.24±4.42		5.77±1.25	2.6±0.69
ST	6	4.10±1.41	5.42±1.55	16.56±4.59	12.96±4.95	122.59±10.93	15.25±4.29			
S	3	3.41±1.48	4.49±1.30	14.05±3.47	10.78±4.19	121.67±12.13	13.70±3.51			
Spiral	3	4.49±1.09	5.96±1.15	18.15±4.38	13.9±4.89	122.45±8.73	15.92±4.12		4.1	1.7
J (B)	2	3.85±1.42	4.63±1.32	15.62±4.25	13.18±4.25	130±12.25	13.25±3.22	2.05±0.25		
C	2	4.45±1.1	5.99±1.09	17.68±4.15	13.77±4.56	120.58±8.66	15.37±3.94			

Table 5.12 Burrow parameters of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon. (CL: Carapace length; CW: Carapace width; BOD: Burrow opening diameter; TLB: Total length of burrow; TDB: Total depth of burrow; BV: Burrow volume; IA: Inclination angle; B1l: Branch 1 length; ChL: Chamber length; ChW: Chamber width)

Burrow shape	n	Host crab CW (mm)	Mean							
			BOD (mm)	TBL (cm)	TBD (cm)	IA	BV (cm^3)	B1L (cm)	ChL (cm)	ChW (cm)
J	15	3.57±1.28	5.37±1.70	14.75±3.07	10.52±3.34	124.92±10.17	8.58±3.55			
ST	7	3.66±2.18	5.41±2.61	13.98±4.32	11.85±3.27	117.71±5.06	8.94±6.06			
S	5	3.93±1.70	5.21±1.74	16.50±0.81	13.01±1.98	138±22.05	10.18±4.59			
Spiral	3	3.82±2.38	4.92±2.63	13.41±5.92	12.69±4.84	113.33±4.71	8.77±4.85			
J (B)	2	2.18±1.42	4.37±0.58	11.40±0.90	9.99±1.21	120	13.21±0.51	2.55±0.35	3.3	2.4
C	3	3.43±1.90	4.74±1.81	13.43±1.43	10.23±2.49	116±4.32	6.97±3.56			

5.2.2.2 Variation in burrow morphometry of Ilyoplax sayajiraoi JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon and post-monsoon period

During pre-monsoon, crab carapace length showed significant positive correlation burrow opening diameter (R^2=0.90, $p < 0.001$), burrow volume (R^2=0.54, $p < 0.001$), total burrow depth (R^2=0.43, $p < 0.001$) and total burrow length (R^2=0.46, $p < 0.001$) (Fig. 5.24, 5.25, 5.26). Whereas during post-monsoon, crab carapace length was significantly correlated with burrow opening diameter (R^2=0.89, $p < 0.001$), burrow volume (R^2=0.52, $p < 0.001$), total burrow depth (R^2=0.40, $p < 0.001$) and total burrow length (R^2=0.42, $p < 0.001$) (Fig. 5.27, 5.28). The crab carapace length did not show significant correlation with burrow inclination angle during pre-monsoon (R^2=0.06, $p = 0.2$) and post-monsoon (R^2=0.03, $p = 0.3$). (Fig. 5.26, 5.29). The significant variation was recorded in total depth, total length and volume of the burrow casts between pre-monsoon and post-monsoon (Fig. 5.31, 5.32), whereas carapace length of the resident crabs, opening diameter and inclination angle of burrow casts have not varied significantly between pre-monsoon and post-monsoon (Fig. 5.30, 5.32).

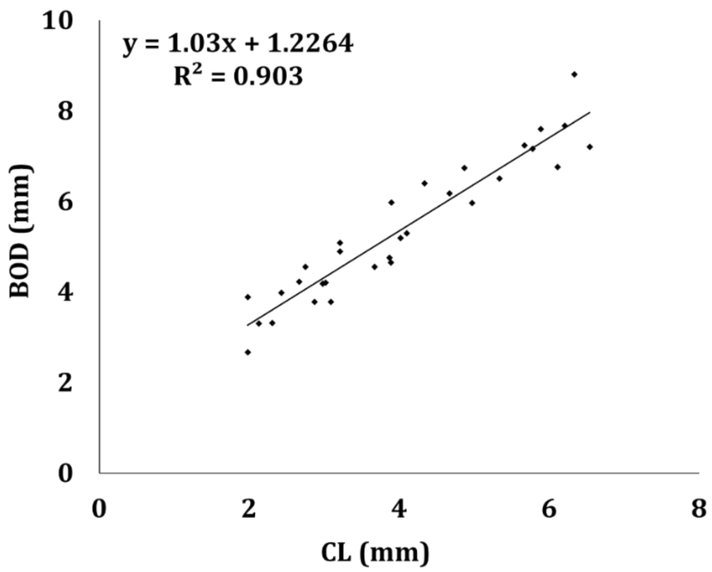


Figure 5.24: Regression analysis for the relationship status between crab carapace length (CL) and burrow opening diameter (BOD) of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 burrows during pre-monsoon season

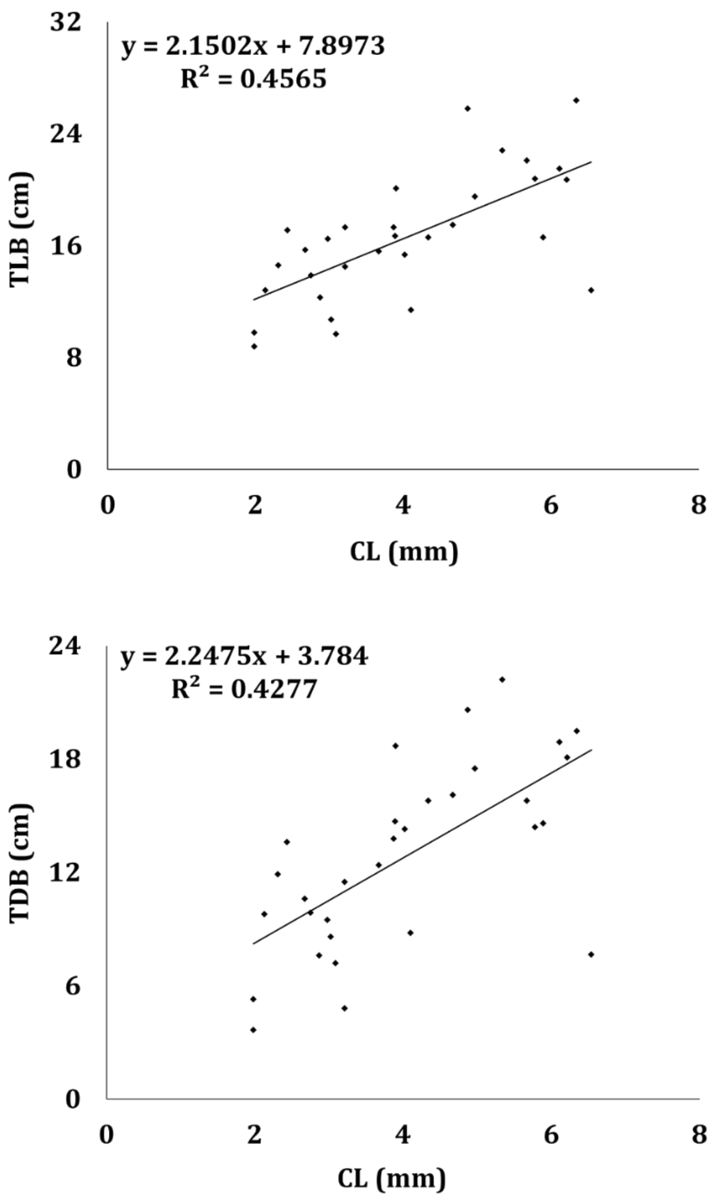
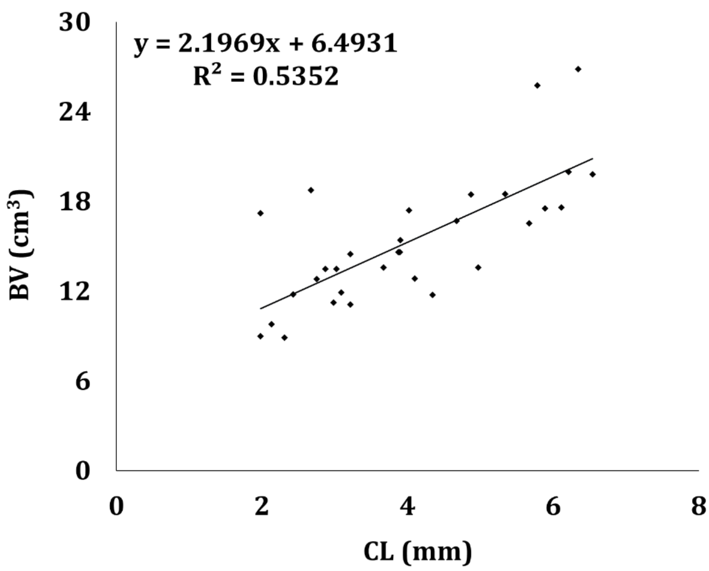


Figure 5.25: Regression analysis for the relationship between crab carapace length (CL) and total length (TLB) and total depth of burrow (TBD) of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon season



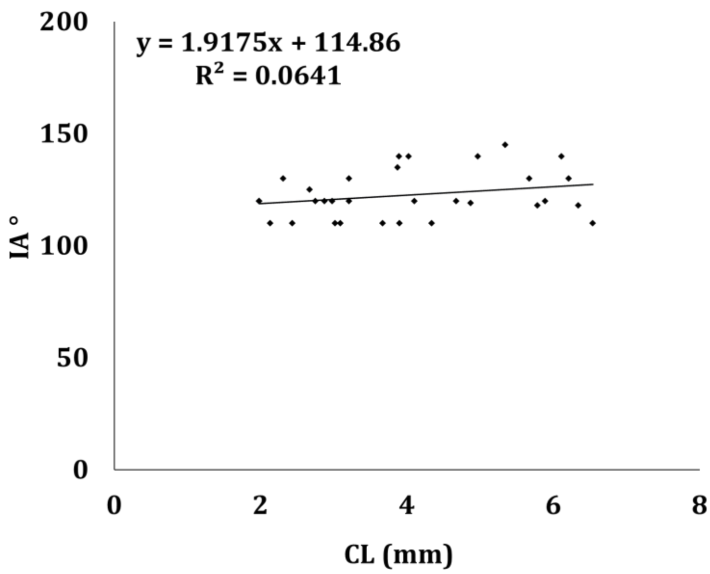


Figure 5.26: Regression analysis for the relationship between crab carapace length (CL) and burrow volume (BV) Inclination angle of burrow of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon season

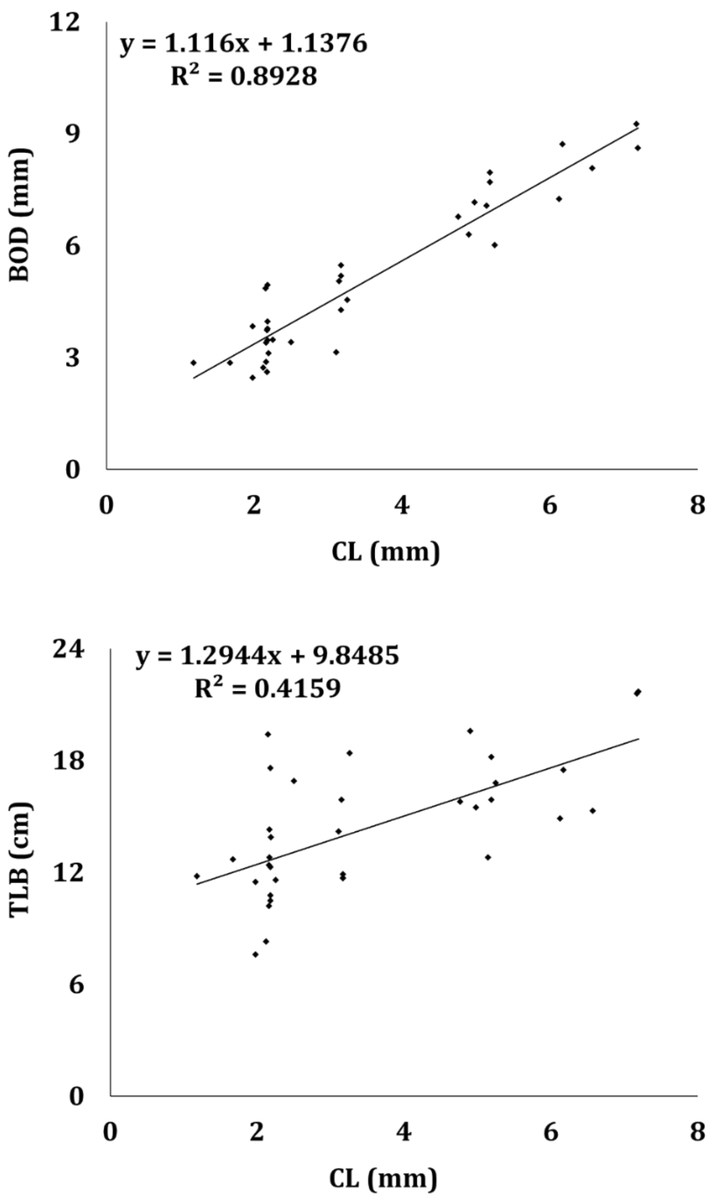
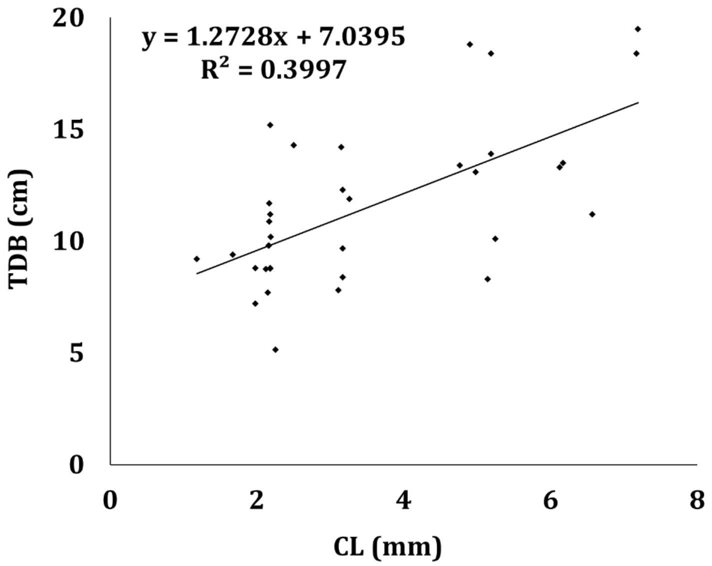


Figure 5.27: Regression analysis for the relationship status between crab carapace length and burrow opening diameter (BOD); total length of burrow (TLB) of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon season



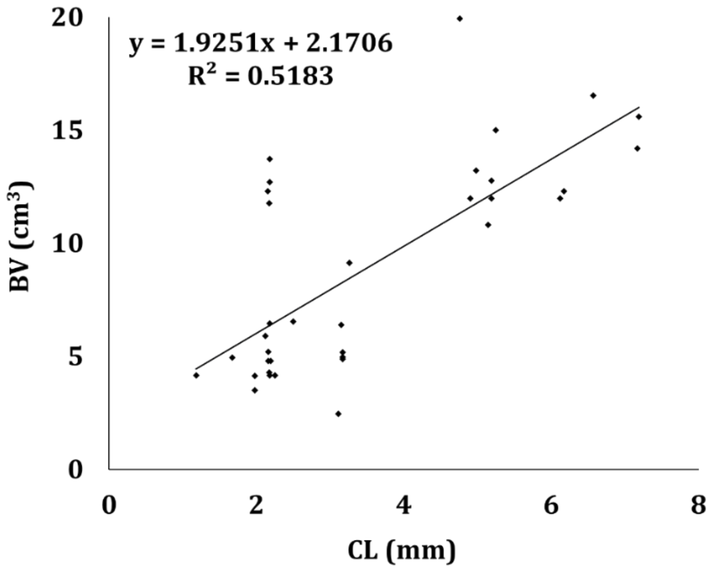


Figure 5.28: Regression analysis for the relationship status between crab carapace length and total depth of burrow (TDB); burrow volume of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon season

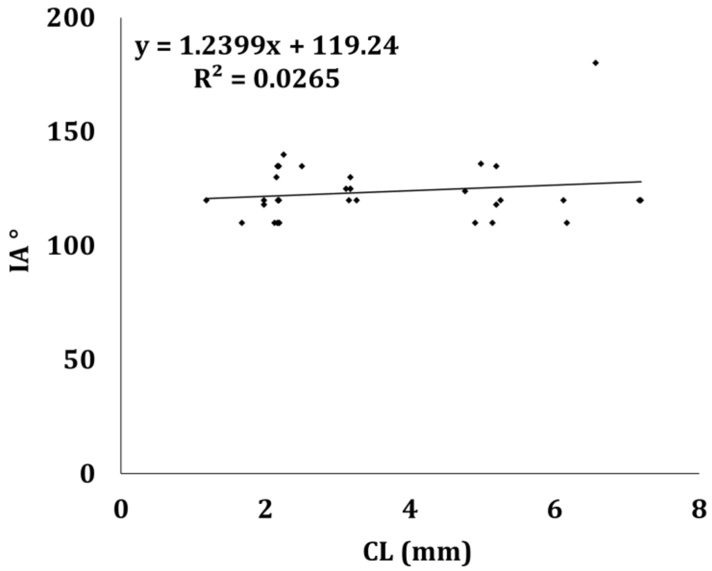


Figure 5.29: Regression analysis for the relationship status between crab carapace length and inclination angle of burrow of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon season

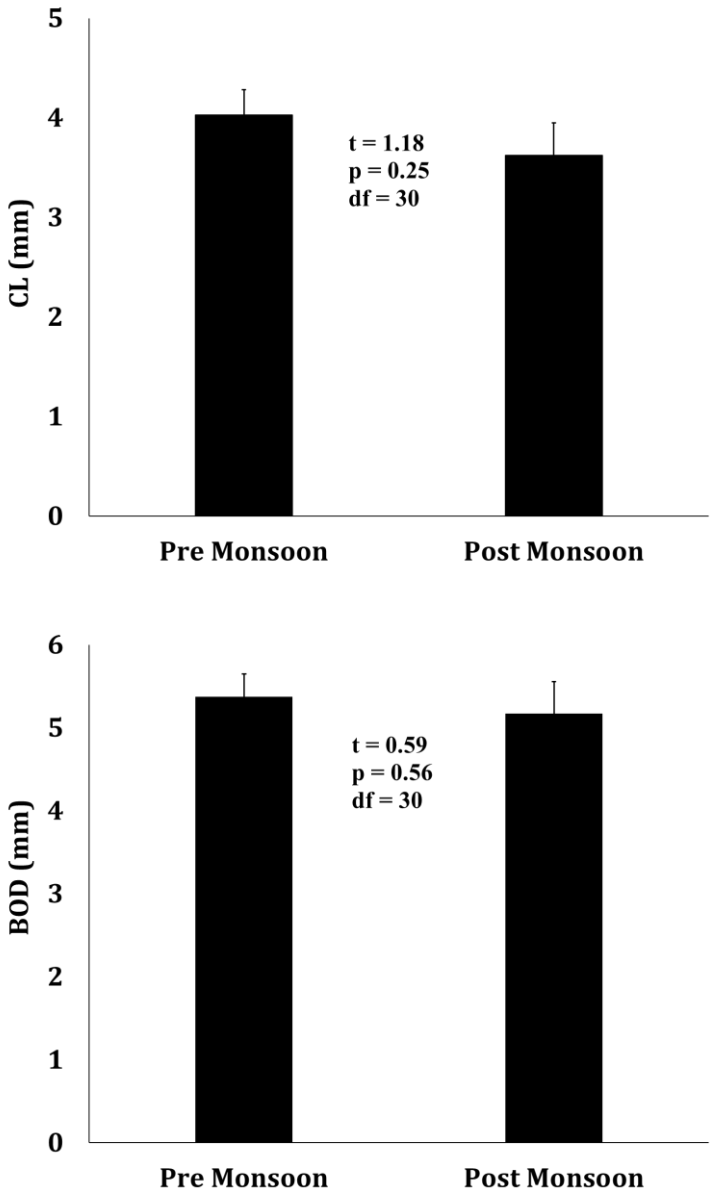


Figure 5.30: Mean variation in Carapace length and burrow opening diameter of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 between pre-monsoon and post-monsoon

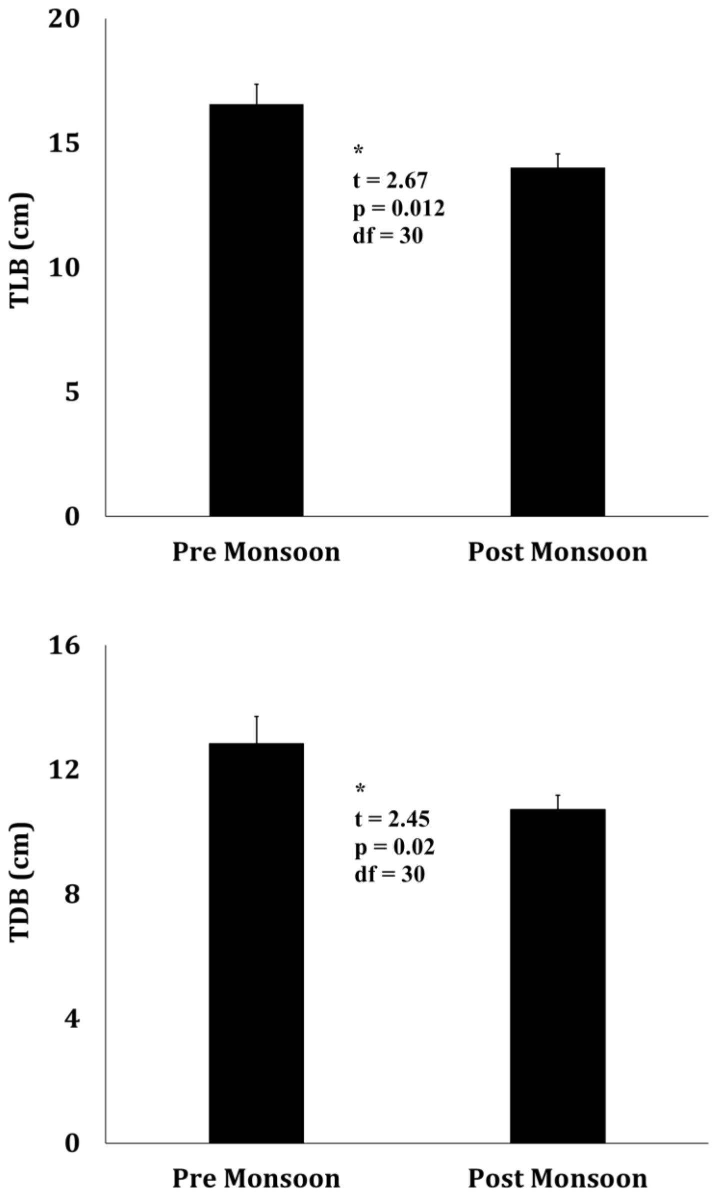


Figure 5.31: Mean variation in total length and total depth of burrow of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 between pre-monsoon and post-monsoon

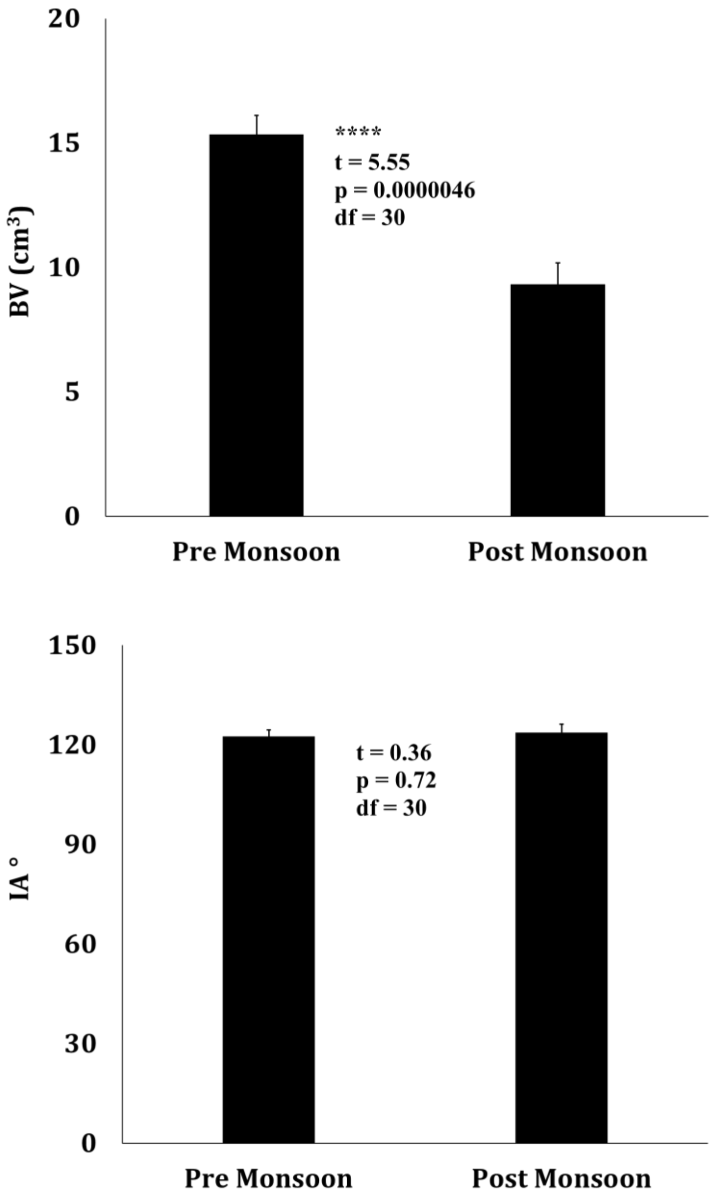


Figure 5.32: Mean variation in burrow volume and inclination angle of burrow of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 between pre-monsoon and post-monsoon

5.2.2.3 Variation in burrow architecture in male and female crabs of Ilyoplax sayajiraoi JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015

In present study a total of 31 burrow casts were excavated in pre-monsoon from which 17 burrow casts were of male crabs and 14 burrow casts were of female crabs. Whereas, 17 and 18 burrow casts were of male and female respectively out of 35 total excavated burrow casts in post-monsoon period. The carapace length (mm) of the male and female crabs were not significantly different during pre-monsoon and post-monsoon (Fig. 5.33, 5.36). In the case of burrow characteristics, males constructed seven different shaped burrows while females constructed six different shaped burrows. During post-monsoon, the diameters of female crab burrows were larger compared to the diameters of male crab burrows (Fig. 5.36), while male crab burrows were longer and deeper than those of the female crabs (Fig. 5.37) during both the studied seasons. Whereas, no significant variation was recorded between various morphometrical parameters of male and female burrow casts during pre-monsoon (Fig. 5.33, 5.34, 5.35).

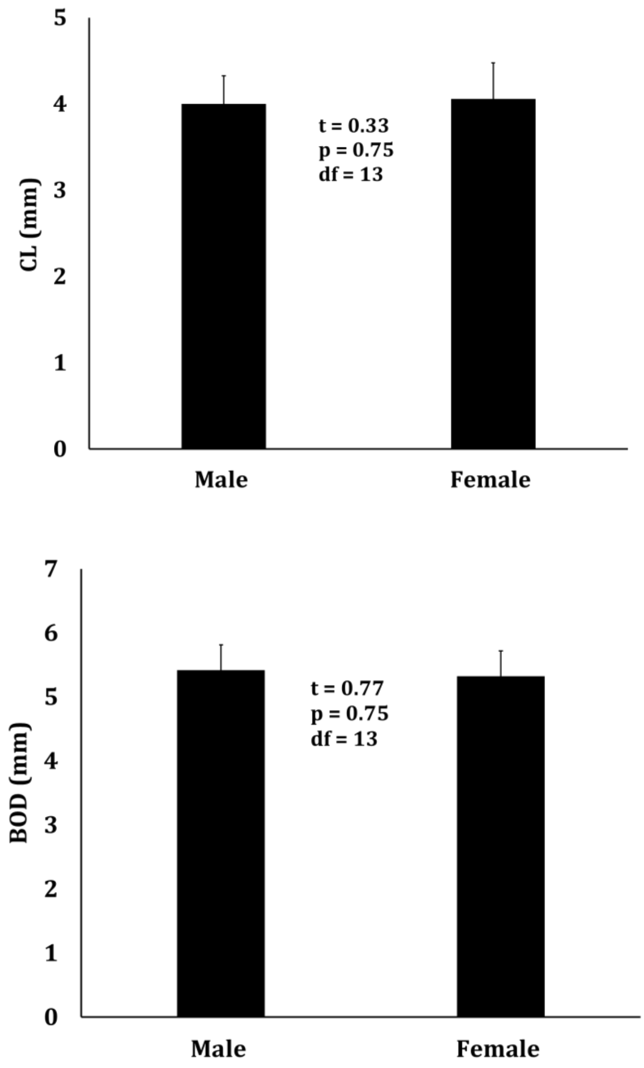


Figure 5.33: Mean variation in Carapace length and burrow opening diameter between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon

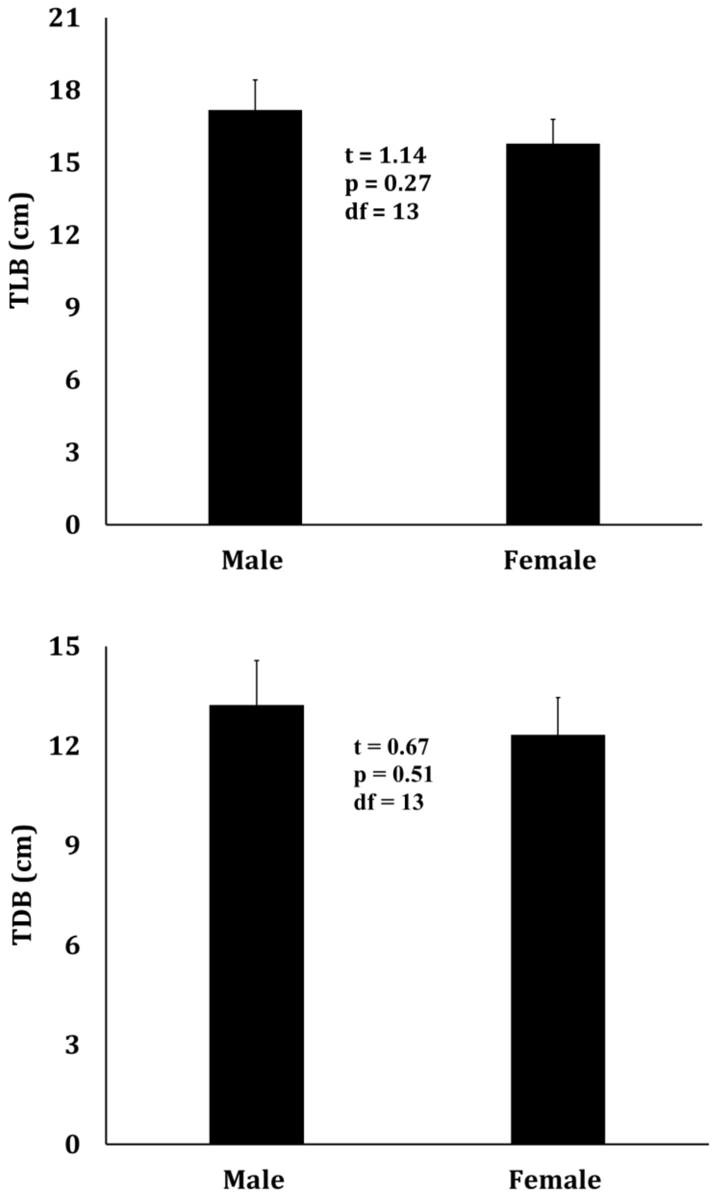


Figure 5.34: Mean variation in total length and total depth of burrow between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon

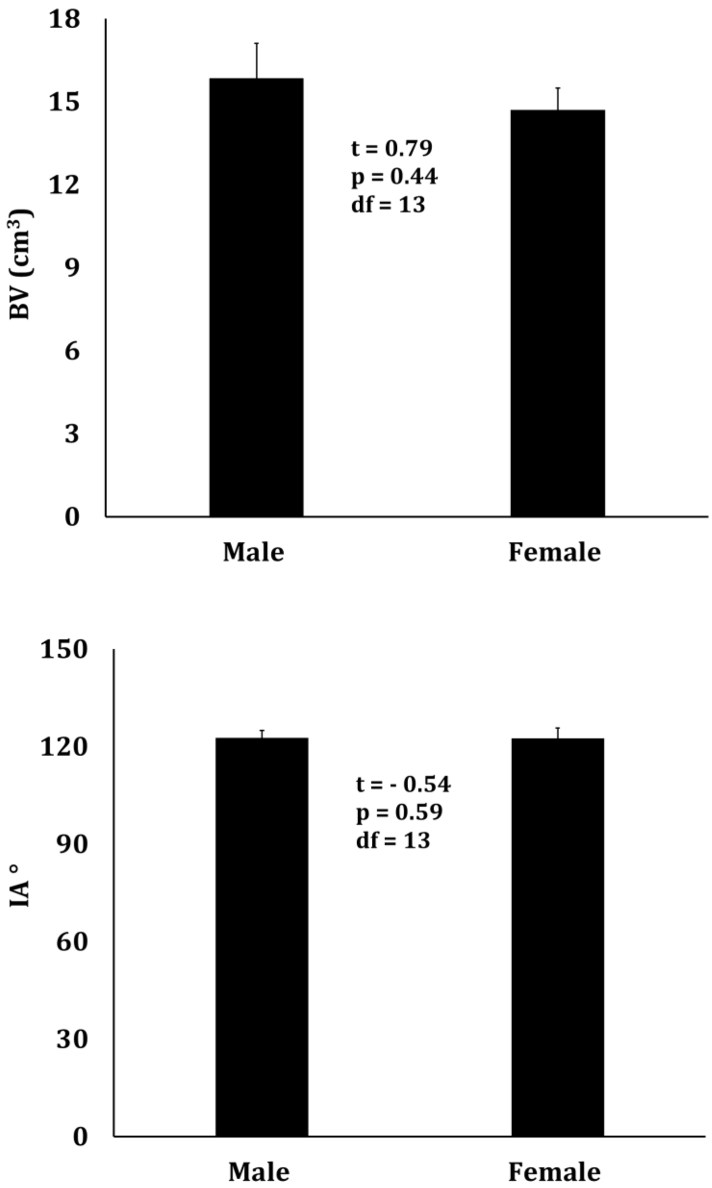


Figure 5.35: Mean variation in burrow volume and burrow inclination angle between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during pre-monsoon

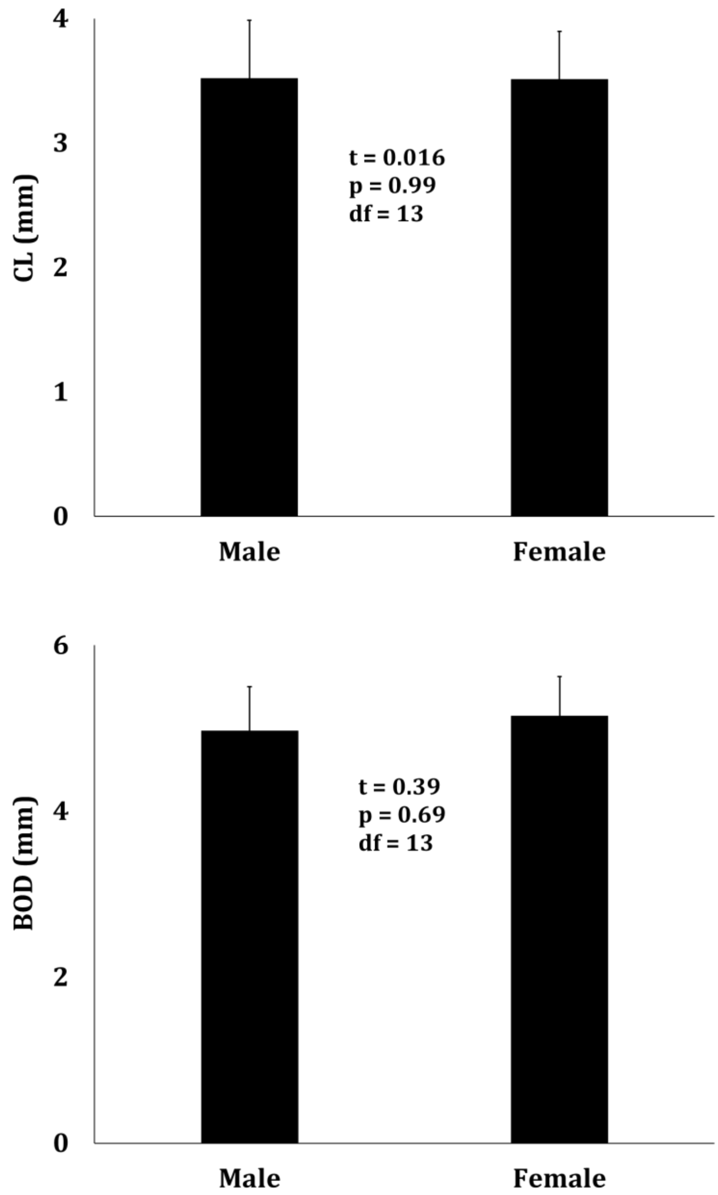


Figure 5.36: Mean variation in Carapace length and burrow opening diameter between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon

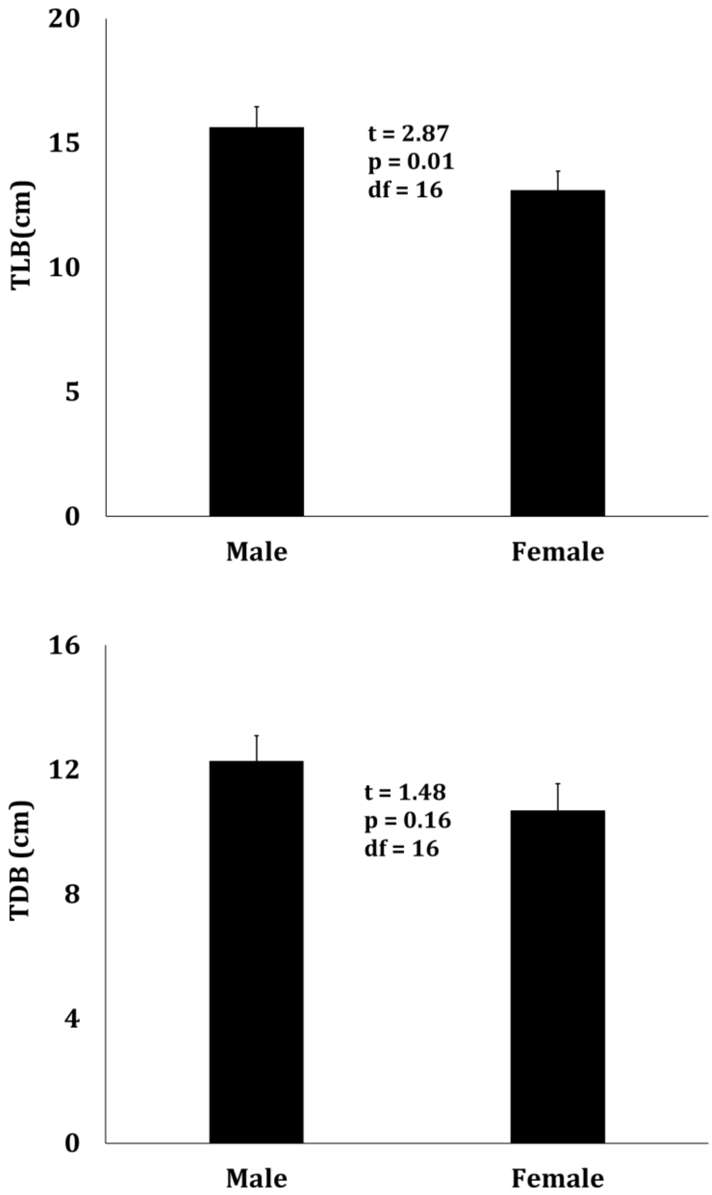


Figure 5.37: Mean variation in total length and total depth of burrow between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon

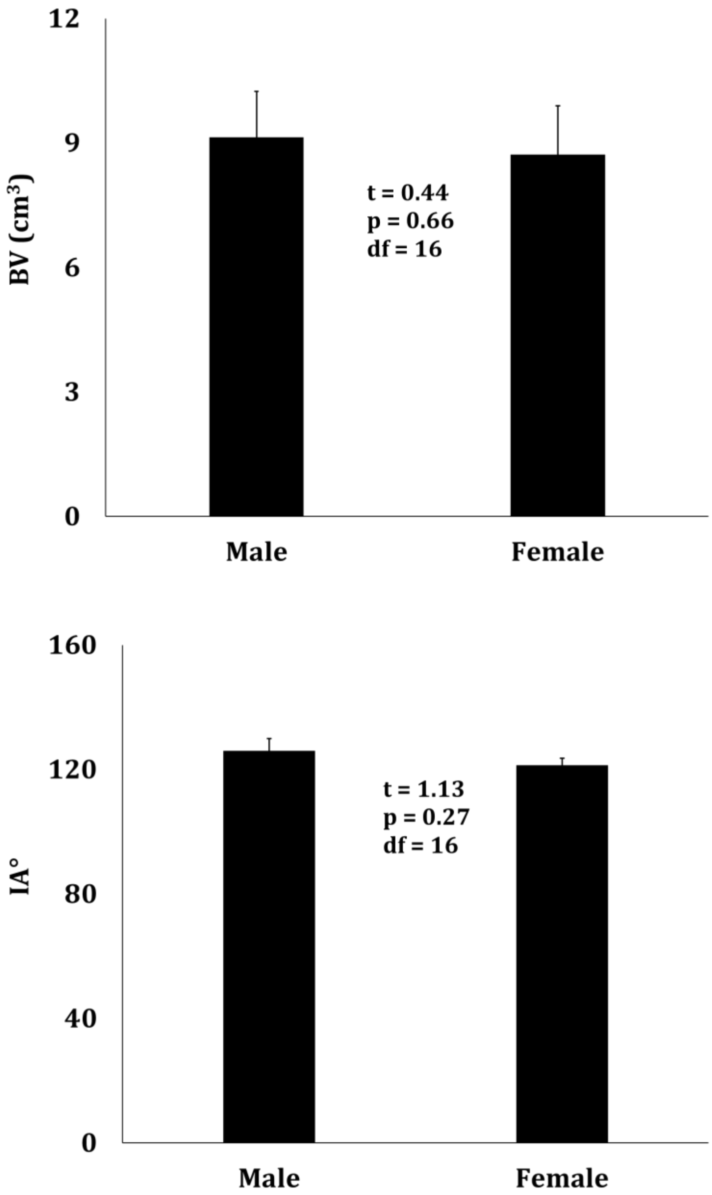


Figure 5.38: Mean variation in burrow volume and burrow inclination angle between male and female host crab individuals of *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 during post-monsoon

5.2.2.4 Vertical temperature gradient in burrows of Ilyoplax sayajiraoi JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 *during pre-monsoon and post-monsoon*

Variation in sediment temperature was measured along the depth of the burrow during low tides in both the seasons. During pre-monsoon, the sand surface temperature recorded around 32°C for the studied burrow casts. The temperature declined to 30 °C at a depth of 5 cm. After the depth of 5 cm the rate of temperature drop decreased to 0.5 to 1.0°C at every 5 cm (Fig. 5.39). Whereas during post-monsoon, the sand surface temperature was recorded 26°C around which declined to 23°C and 22°C at the depth of 5 cm and 10 cm respectively. Minimum temperature i.e., around 21°C was recorded in all the studied burrow cast at the depth of 15 cm. After the depth of 15 cm burrow pit temperature increases 0.1 to 0.5 at depth of 5 cm (Fig. 5.40).

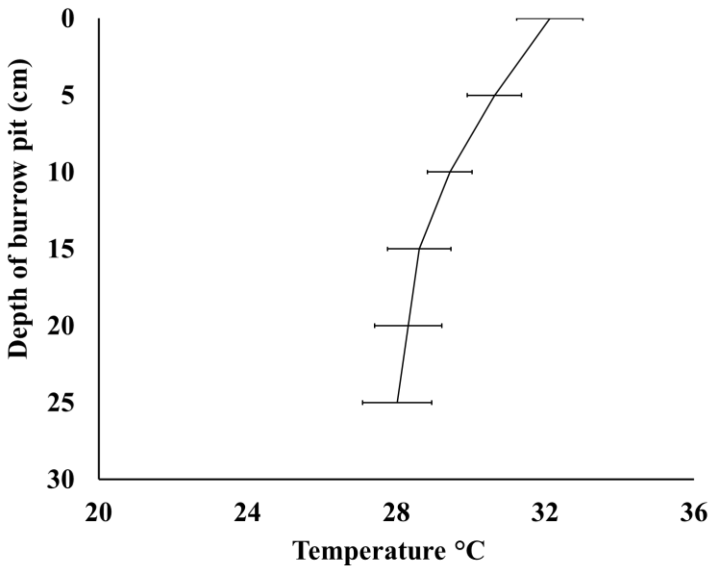


Figure 5.39: Vertical temperature profiles with the depth of burrow pit during pre-monsoon

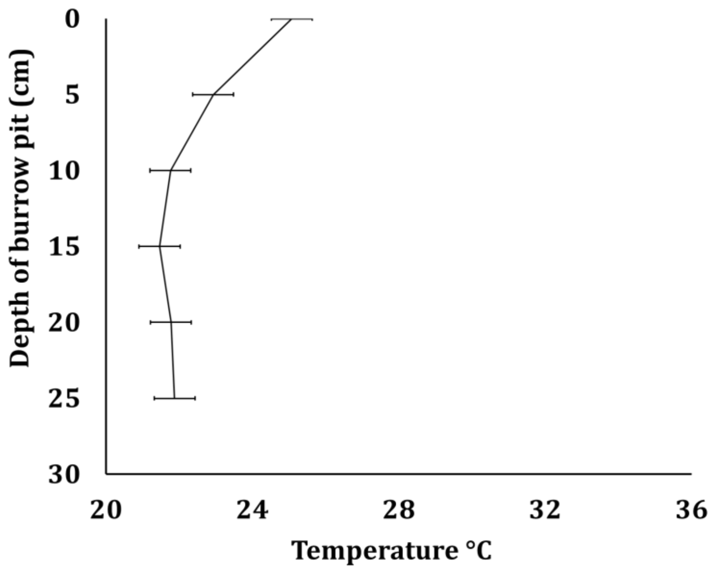


Figure 5.40: Vertical temperature profiles with the depth of burrow pit during post-monsoon

5.3 DISCUSSION

Burrows constructed in soft sediments play a significant role in the reproductive activity of the burrowing crabs of Ocypodidae and Dotillidae families (Lim, 2006). The morphology of *A. sindensis* and *I. sayajiraoi* burrows showed considerable variation in shape, size and complexity, ranging from single entrance shafts with no branches to multiple entrances. In the present study, total seven different burrow shapes were recorded like J-shaped, Single tube, S-shaped, Spiral, J-shaped with branch, U-shaped with single opening and Multi-branched burrow for *A. sindensis* whereas for *I. sayajiraoi* J-shaped, J-shaped with branch, Single tube, S-shaped, Spiral, C-shaped and Irregular-shaped burrows were excavated.

Previously, Chan et al. (2006) and Trivedi and Vachhrajani (2016) have studied burrow architecture of *O. ceratophthalma* on sandy shores of Hong Kong and India, respectively and identified various shapes of burrow casts like J-shaped, J-shaped with branch, Single tube, Bulb-shaped, Multibranched, U-shaped, Y-shaped and Y-shaped burrows with double opening. More studies have carried out on burrow architecture of various brachyuran crabs like *Dotilla blanfordi* Alcock, 1900 (7 shapes) (Upadhyay et al., 2022), *D. fenestrate* Hilgendorf, 1869 (4 shapes) (Gherardi and Russo, 2001), *Uca annulipes* (accepted name: *A. annulipes* (H. Milne Edwards, 1837), and *U. sindensis* (accepted name: *A. sindensis*) (six shapes) (Qureshi and Saher, 2012). Variation in burrow shapes is mainly species specific but sometimes it also gets affected by several physical and chemical differences in sediment type and vegetation (Griffis and Chavez, 1988).

Crabs with smaller carapace length had constructed single tube and J-shaped burrows, while larger sized crabs had created single tube, J-shaped, J-shaped with branch, multi-branched, U-shaped with single opening and spiral burrows. According to Chakrabarti (1981) and Chan et al. (2006), the burrows like J-shaped and single tube burrows of juvenile crabs were shallow in depth with narrower opening diameter and lesser volume. Temporary burrows of the adult crabs are often shallow and single tubular structures. In the present study, multi-branched and J-shaped with branched burrows were constructed by adult crab. The function of the branches of single tube and J-shaped burrows is still unknown but it has been assumed that the branch may provide shelter to the individual crab from the splash of the waves and predators (Chakrabarti, 1981). According to Chan et al. (2006), adult crabs can tolerate longer periods of exposure to air by digging deeper and more complex burrows. These crabs stay entirely in their burrows during daytime and as a result, their burrows were deeper and more complex as compared to the burrows of the juvenile crabs (Chan et al., 2006; Katrak et al., 2008, Gul and Griffen, 2018). More complex burrow provides greater underground surface area, which is favourable for increased gaseous exchange and microbial colonization. This also delivers greater access of resources to organisms inside the burrow (Thongtham and Kristensen, 2003). *U. pugilator* (Bosc), *Sesarma longipes* (Krauss), *Cardisoma carnifex* (Herbst) and *Macrophalmus parvimanus* (Guerin) has created temporary burrows like single tube and bulb shape for refuges during high tides or to get protection from the predator (Braithwaite and Talbot, 1972; Christy, 1982).

During investigation, adult carb excavated spiral burrow with end chamber. Previously, crabs of *O. ceratophthalmus* and *O. saratan* (Forskal, 1775) constructed spiral burrow with the sole purpose of providing a place for copulation (Hughes, 1973; Vannini, 1980). Nonetheless, simpler forms consisting of unbranched, subvertical to inclined, irregularly twisted to J-shaped shafts are very common among species of Macrophthalmidae, Myctiridae, Dotillidae, Gecarcinidae, Gecarcinucidae, and Portunidae (Chan et al., 2006).

In the present study, crab length showed significant positive relationship with burrow opening diameter, burrow length, burrow depth and burrow volume for *A. sindensis* as well as *I. sayajiraoi*. In *A. sindensis* burrows, mean burrow length and depth were recorded around 30.55±10.94 cm and 21.81±6.34 cm respectively for the crab with mean carapace length of 7.94±1.8 mm. Whereas, during present study, mean burrow length and depth of the *I. sayajiraoi* burrow were measured around 18.15±4.38 and 13.9±4.89 respectively. Qureshi and Saher (2012) have also studied the burrow architecture of *Uca sindensis* (synonym of *A. sindensis*). They excavated burrows with mean length and depth of 22.02±7.10 cm and 15.04±6.2 cm respectively for crab with the mean carapace length of 2.212 + 0.591 mm. The burrow morphology is species specific (Griffis and Suchanek, 1991;

Wolfrath, 1992; Griffis and Chavez, 1988) but variation in burrow morphology is observed within same species due to changes in physical and biochemical properties of the sediment (Lucrezi et al., 2009). Larger-sized crabs had greater burrow diameter, larger burrow volume and bigger chamber diameter than small and medium sized crabs (Upadhyay et al., 2022). Lim and Diong (2003) studied burrow morphology of the crab *U. annulipes* (H. Milne Edwards, 1837) and found that larger crabs generally excavated wider, more spacious burrows than small and medium-sized individuals.

Outcomes of present investigations represents that total length, total depth and volume of the burrow casts were varied seasonally. It may be because, burrow architecture gets affected by several environmental factor such as temperature, moisture level, wind (Lucrezi et al., 2009) and geomorphological properties of the sandy shores like sand compaction, beach slope and sand grain size (Pombo et al., 2017) and as well as erosion (Hobbs et al., 2008). Burrows provides protection and serves as a refuge during high external temperatures and environmental extremes (Atkinson and Taylor, 1988). Decrease in the temperature of the sand surface along the depths of the burrows were recorded in present investigation, which suggests that the burrows can provide the resident to the crab and helps to get refuges during the stressful period. According to Dubey et al. (2013), temperature and moisture levels in the substratum could influence the burrow depth. Temperature could be even lower when going further down the burrow. As burrows are important to get refuge from desiccation for intertidal crabs (Takeda and Kurihara, 1987; Thongtham and Kristensen, 2003), the depth of burrows will be influenced by the surrounding temperature and the water content of the sediment.

Burrow architecture also varies based on size and sex of the resident crab (Lim and Diong, 2003). Present study revealed that both male and female *A. sindensis* and *I. sayajiraoi* built six different shaped burrow and male crabs burrows were longer and voluminous than the female crab burrows. In present study, carapace width, carapace length, burrow opening diameter, inclination angle, burrow length, burrow depth and burrow volume were not varied significantly between male and female individuals during except total length, total depth of burrows. Similar results were observed in a study carried out on *O. ceratophthalma* where the burrow architecture did not differ between sexes (Chakrabarti, 1981). Male crabs build longer and deeper breeding burrows to attract females for mating purpose (Christy, 1982; Backwell and Passmore, 1996; Tina et al., 2018). Mate selection occurs mostly based on the quality of breeding burrows, because mating and egg incubation take place inside the male breeding burrows (Christy, 1982, 1987; Christy and Salmon, 1984; Christy and Schober, 1994; Ribeiro et al., 2010).

Vannini (1980) and Atkinson and Taylor (1988) discussed that burrow provides protection against high external temperatures and environmental extremes. Furthermore, Lim and Diong (2003) working upon fiddler crabs hypothesized that high intertidal areas might help to maintain lower burrow temperature during ebb tides. According to Dubey et al. (2013), temperature and moisture levels in the substratum could influence the burrow depth by playing an important ecological role in the life history and habitat dependency of *O. macrocera*. In the present study, the temperature of the sand surface dropped along the depths of the burrows which suggests that the burrows can provide the resident to the crab and helps to get refuges during the stressful period in summer. Temperature could be even lower when going further down the burrow, although measurement cannot be obtained at further depths. As burrows are important to get refuge from desiccation for intertidal crabs (Takeda and Kurihara 1987; Thongtham and Kristensen, 2003), the depth of burrows will be influenced by the water content of the sediment.

A few previous studies also observed that the burrows acted as refuge for fiddler crabs during very high or very low temperatures (Edney, 1961; Powers and Cole, 1976; Wolfrath, 1992). According to Wolfrath (1992), temperature variation inside the crab burrows was inversed with outside air temperature, and burrow temperature was lower during the day and higher during the night than the outside temperature. It was also concluded that temperatures higher than the optimal peak temperature reduces the ventilator and cardiac performance in crabs, resulting in a lesser supply of oxygen to the tissues and a reduced endurance capacity (Frederich and Portner, 2000; Allen et al., 2012). In PCA analysis for *A.*

sindensis, during summer and winter season less cluster formation was observed. While in monsoon season, PCA analysis demonstrated better cluster formation as all burrow parameters were closely correlated. This is may be because this season cab be a season for breeding and reproduction. Thus, burrows are highly developed for mating with appropriate breeding chambers and for an ovigerous female to stay inside the burrow for a longer time and with the least disturbance.