CHAPTER 3

BURROW MORPHOLOGY OF *ILYOPLAX SAYAJIRAOI*

- 3.1 • Burrows of crab and its morphology
- 3.2 • Methodology
- 3.3 • Result and observation
- 3.4 • Discussion

3.1 Burrows of crab and its morphology

Burrow is an excavation of soft sediment or soil by species to protect itself from the harsh environment and where it can stay for a long period time to complete its life cycle.

Burrow morphology is the study of its outer structure that includes length, width, volume, weight, angle, reproductive chamber, etc. The burrow morphology is species-specific. Species modify this structure to overcome the physical and biochemical stress of the environment (Griffis and Suchanek, 1991; Wolfrath, 1992; Griffis and Chavez, 1988). Crabs of family Dotillidae are the most common habitat of tropical and subtropical regions showing characteristic features of bioturbation. Burrows provide shelter from terrestrial predators and also from natural stress factors. It is the site for breeding, reproduction, and moulting. Bioturbation is common in mudflat areas of Kamboi; crustacean species show such activity at this zone. *Ilyoplax sayajiraoi* was a newly discovered species by Trivedi et al. in 2015 and members of this family formed morphologically diverse shapes of the burrow; S showing major two curves J and L having single curved structure and spiral grading to most complex structure which are also considered as abandoned burrows.

Present study deals with obtaining proper shape of the burrow to analyse the morphological burrows differences seasonally. In India, the ghost crab *Ocypode ceratophthalma* has several types of burrows, including J-, U- and Y-shaped burrows, and different types of burrows were reported to exist in different tidal zones on sandy shores (Chakrabarti, 1981). Similar patterns were also reported in the ghost crab *Ocypode quadrata* (Fabricus) in the Barrier Island, Texas coast, USA (Hull and Hunter, 1973). In Hong Kong study on burrow morphology of ghost crab, *Ocypode ceratophthalma* was carried out by Chan et al., 2004); it builts burrows of various shapes at different ages. Smaller crabs (Juveniles) (mean carapace length 11 mm) build shallow J-shaped burrows with zero branches and end straight into substratum (mean depth 160 mm). Larger crabs (17–25 mm carapace length) have Y-shaped and spiral burrows (mean depth 361 mm). The sand surface temperature at the burrow opening was 48°C, but temperatures inside the burrows can drop to 32°C at a depth of 250 mm. Large crabs have a big gill surface area that helps them to tolerate longer exposure periods to air. Crabs entirely stay in their respective burrows during daytime, and as a result, their burrows are deeper and more complex as compared with the juveniles. *Ocypode* created differently shaped burrows during their entire life span, and those burrows may serve different functions.

Burrow morphology of burrowing crab *Ocypode ceratophthalma,* including burrow diameter, orientation, inclination, branching, and volume, were studied from

Chandipur, on the eastern Indian coast. Burrow morphological features (e.g., *I*, *J*, *Y*) were not dependent on their positions with respect to the coastline. Also, no correlation between burrow morphology and burrow diameter was observed. Burrow diameter is smaller at the foreshore compared to that of backshore, indicating larger individuals reside at the backshore, where they can excavate deep into the sediment and large-diameter burrows to minimize chances of desiccation. Small burrows are straight with no branching. Large burrows are inclined towards the land to minimize the energy required to excavate sediments.

Trivedi and Vachhrajani in 2014 performed a similar analysis on Ghost crabs at two sandy shorelines of Gujarat, Sutrapada, and Kodinar. Intact 55 burrow casts were obtained with eight different types of burrow shapes. The crab carapace width showed a significant correlation with burrow opening diameter, burrow volume, and burrow total length. The juveniles utilized shallow burrows located near the foreshore. Adults utilized deep burrows with large diameters located on the upper part of the sandy shore. A specific pattern was observed in the burrow temperature in which the temperature dropped significantly at the greatest depth that provided a suitable environment for the crab to survive in the harsh environmental conditions.

3.2 Methodology

Burrows of *Ilyoplax sayajiraoi* was identified, and burrow diameter was measured along the transect. Resin mixed with cobalt and catalyst (1:2) was poured into burrows till it gets completely filled. Crabs that emerged from the burrows were collected, sexed and the carapace width and length were measured using vernier calipers (± 0.1mm). When the burrow cast had solidified (~2 h), they were dug up for subsequent measurement of burrow dimensions (Figure 3.1). The volume of the burrows was determined by weighing the burrow cast (± 0.1g).

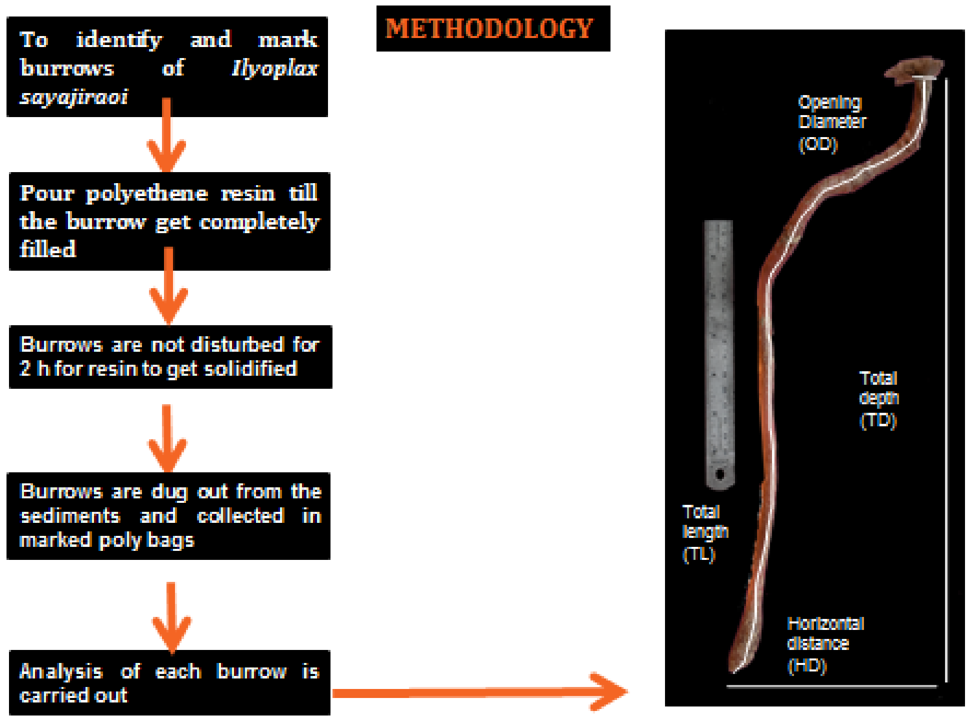

Figure 3.1 Burrow architecture of *Ilyoplax sayajiraoi* with different labels of burrow cast. O. D. - Opening diameter, H. L. - Horizontal length, V. D. - Vertical depth, C. L. - Chamber length, C. W. - Chamber width, T. L. - Total length

3.3 Results and observation

3.3.1 Shape and morphology of burrow

Relation between burrow diameter and distance from shore was analysed as shown in figure 3.6 Maximum burrows formed by larger crabs were at UTZ (Upper Tidal Zone), and maximum burrows with minimum diameter were observed at LTZ (Lower Tidal Zone). Shape vs. number of burrows showed; highest burrows of J-shape and least were spiral also known as abandoned burrows as shown in figure 3.7.

A total of 135 burrow casts were obtained, of which the 65 host crabs were captured (45 males and 20 females). Three types of burrow architecture were identified; they were J-Shaped (Figure 3.4), Spiral (Figure 3.4), and single tube burrow (Figure 3.3). The relationship between various parameters was studied in three seasons.

Burrows are the sole protector of brachyuran crab species. They form burrows in different shapes and size. Every species have specificity in burrow formation and that makes it different from other species. With such specificities crab species can also be identified. During high tide or just at the arrival of high tide crabs use these burrows to hide for few hours. Burrow diameter is also known as opening diameter which is the entry point for crabs to enter in and come out. Range of burrow diameter is from 0.5cm to 1.2cm with a depth of 15-40cm. Density ranges from 15 burrows/m^2 to 25. Various relations were studied to establish correlation between burrow diameter and crab morphology.

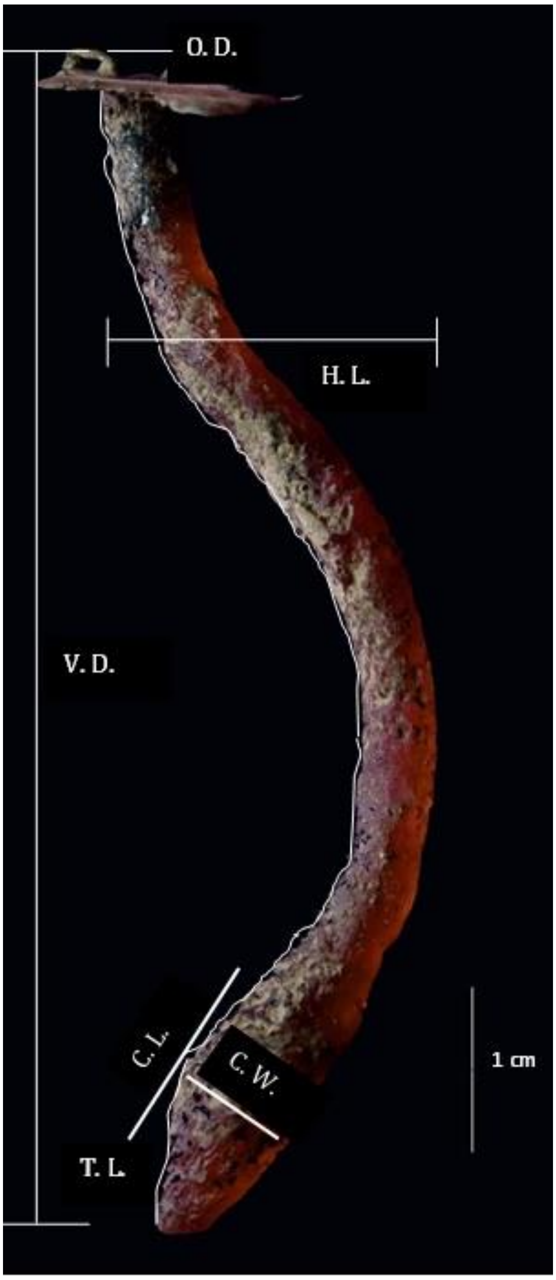

Figure 3.2 Burrow architecture of *Ilyoplax sayajiraoi* with different labels of burrow cast. O. D. - Opening diameter, H. L. - Horizontal length, V. D. - Vertical depth, C. L. - Chamber length, C. W. - Chamber width, T. L. - Total length

Figure 3.3 Winter burrows

Figure 3.4 Summer burrows

Figure 3.5 Monsoon burrows

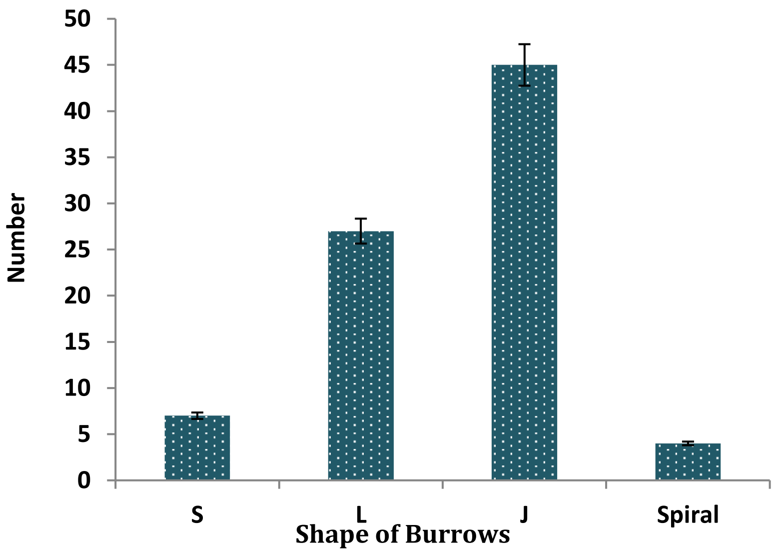

Figure 3.6 Indicates number of burrow count with respect to shape of the burrow

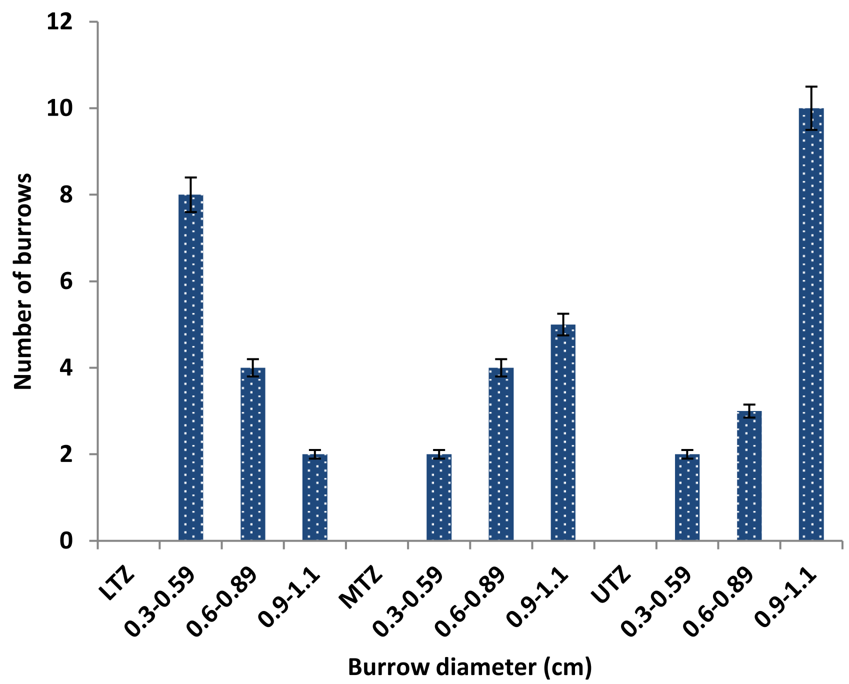

Figure 3.7 Indicates number of burrows in specific coastal zonation

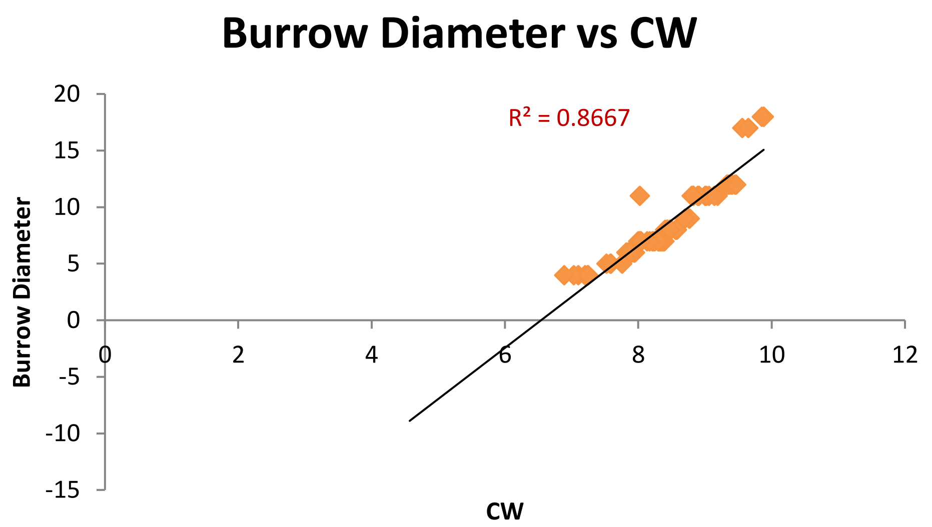

Figure 3.8 Relationship between burrow diameter and carapace width

3.3.2 Seasonal burrow measurements and statistical analysis

The study was carried out in May, July, and December of the year 2018. Burrows of *Ilyoplax sayajiraoi* were identified, and its diameter was measured along the transect during season-wise field visits. Resin mixed with cobalt and catalyst (1:2) was poured into burrows till it gets filled. Crabs that emerged from the burrows were collected, sexed and the carapace width and length were measured using vernier calipers (± 0.1mm). When the burrow cast solidified (~2 h), it was dug and cleaned thoroughly for subsequent measurements of burrow dimensions in the laboratory (Figure 2). The volumes of the burrows were determined by weighing the cast (± 0.1g). Gradient-wise (5 cm each), the temperature difference was studied on mudflats. Burrows with different opening sizes were selected randomly along the transect. Surface and gradient temperatures were measured using a digital thermocouple (±0.1^{o}C). Measurements could not be conducted for depth more than 30cm as the thermocouple could not pass vertically due to restrictions of the spiral turnings. We have variables as number of burrows in (Lower Tidal Zone (LTZ), Middle Tidal Zone (MTZ) and Upper Tidal Zone (UTZ). We have to establish whether there is any correlation between these burrows with respect to the zonation of mudflat area LTZ, MTZ, and UTZ. These correlations were conducted for each season winter, summer and monsoon.

Principle Component Analysis (PCA): In factor analysis univariate descriptives statistics was used and in correlation matrix two selected attributes were 'coefficient' and 'significance levels.' In 'factor analysis extraction' attribute display selected was 'unrotated factor' solution and 'scree plot.' Method of extraction was based on 'Eigen value > 1.

Multi-dimensional scaling (MDS) analysis was conducted to check if multi-colinearity exists between the parameters or variables.

- **Winter measurements and statistical analysis**

Table 3.1 Winter burrow morphology data						
Burrow number	**M/F**	**Shape**	**CW/CL**	**Length**	**Volume**	**Weight**
			cm	**cm**	**cm^3**	**gm**
Quadrate 1	**LOWER TIDAL ZONE**					
D 50	**F**	**S**	**0.7**	**15**	**2.94**	**10.73**
D 65	**M**	**L**	**0.5**	**17.5**	**2.19**	**7.93**
D 31	**M**	**L**	**0.6**	**23.6**	**9**	**17.7**
D 14	**M**	**J**	**0.8**	**23**	**14.62**	**29.61**
D 54	**M**	**S**	**0.9**	**35.6**	**25**	**31.71**
D13	**M**	**L**	**0.5**	**19.5**	**3.82**	**12.87**
D 09	**M**	**J**	**0.5**	**15.5**	**5.96**	**9.63**
D 50	**F**	**J**	**0.7**	**20.9**	**5.9**	**10.13**
D 34	**F**	**J**	**0.6**	**20.5**	**4.02**	**6.35**
S 60	**M**	**L**	**0.6**	**19.5**	**5.51**	**9.51**
D 17	**M**	**L**	**0.5**	**13**	**1.63**	**7.56**
D 58	**F**	**J**	**0.6**	**17**	**3.53**	**7.15**
Quadrate 2	**MIDDLE TIDAL ZONE**					
D 07	**M**	**J**	**0.84**	**16.5**	**10.49**	**15.36**
D 49	**M**	**J**	**0.84**	**21.5**	**16.09**	**15.86**
D 64	**M**	**J**	**0.95**	**34.5**	**23.93**	**30.17**
S 51	**F**	**Curved**	**0.6**	**37**	**29.04**	**34.31**

D 33	**M**	**J**	**0.5**	**24.5**	**23.27**	**41.04**
D 08	**M**	**L**	**0.94**	**41.5**	**26.38**	**52.73**
D 61	**M**	**S**	**1.3**	**45.5**	**62.92**	**71.33**
D 32	**F**	**J**	**0.7**	**32**	**25.12**	**25.81**
D 47	**M**	**L**	**0.9**	**32**	**9.04**	**15.8**
D 39	**F**	**J**	**0.79**	**21**	**4.12**	**12.22**
D 27	**M**	**J**	**0.85**	**22.9**	**17.97**	**23.17**
S 52	**F**	**J**	**0.7**	**25.5**	**7.2**	**10.56**
D 05	**F**	**J**	**0.8**	**23.5**	**4.61**	**12.75**
D 23	**M**	**L**	**0.92**	**31**	**15.57**	**32.61**
Quadrate 3	**UPPER TIDAL ZONE**					
D 42	**M**	**L**	**0.8**	**18.9**	**3.7**	**8.36**
D 11	**F**	**J**	**1.1**	**19.5**	**10.32**	**24.24**
D 38	**M**	**J**	**0.7**	**20**	**11.07**	**21.47**
S 53	**M**	**S**	**0.9**	**25.2**	**19.78**	**24.95**
D 10	**M**	**S**	**1**	**34.1**	**32.38**	**47.65**
D 53	**M**	**J**	**0.9**	**37.8**	**18.99**	**39.54**
S 59	**M**	**J**	**1**	**38.4**	**36.47**	**42.94**
D 40	**M**	**S**	**1.1**	**41.5**	**20.84**	**57.76**
D 44	**F**	**L**	**0.7**	**18.1**	**2.27**	**8.32**
D 20	**F**	**L**	**0.6**	**29.1**	**38.6**	**13.32**
D15	**M**	**S**	**1.2**	**42.5**	**33.36**	**43.19**
D51	**F**	**L**	**0.8**	**26**	**7.34**	**12.2**
***Blank cell in the table is because crabs were not captured in some case or were solidified along with the resin. So its measurement was not possible.**						

- **Relationship between burrow parameters of *Ilyoplax sayajiraoi* in three different intertidal zones.**

Winter season demonstrated high Pearson correlation (0.05 level of significance). Larger crabs preferred upper tidal zone (UTZ) and thus built a proper burrow with all requirements in this area. Appropriate length, width, volume of burrow was observed. Burrows had resting chamber to accommodate ovigerous females in it. Optimum Pearson coefficient was observed in middle tidal zone (MTZ) as crabs reduced in size compared to UTZ crabs. Lower LTZ showed least correlation between burrow parameters as maximum accommodation was of juveniles. They built burrows with lesser developed morphological structures.

Table 3.2 Indicates Pearson correlation between various burrow parameters for winter season in lower tidal zone (LTZ)

	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	.905**	1			
VOLUME	.929**	.915**	1		
CW	.748**	.756**	.802**	1	
LENGTH	.806**	.751**	.920**	.657*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.3 Indicates Pearson correlation between various burrow parameters for winter season in lower tidal zone (MTZ)

	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	.912**	1			
VOLUME	.681**	.874**	1		
CW	.805**	.523	.802**	1	
LENGTH	.806**	.456	.766**	.759**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.4 Indicates Pearson correlation between various burrow parameters for winter season in upper tidal zone (UTZ)					
	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	.664*	1			
VOLUME	.577*	.565	1		
CW	.792**	.787**	.564	1	
LENGTH	.857**	.431	.733**	.678*	1
*. Correlation is significant at the 0.05 level (2-tailed).					
**. Correlation is significant at the 0.01 level (2-tailed).					

- **Regression analysis**

In winter strong positive correlation was seen w.r.t. burrow between its length of burrow and volume (correlation coefficient R^2=0.6633) Figure 3.9; carapace width of crab and weight of burrow (R^2=0.66) Figure 3.10; volume and diameter of burrow (R^2=0.64) Figure 3.11; burrow diameter and carapace width of crab (R^2=0.635) Figure 3.12; length and weight of burrow (R^2=0.735) Figure 3.13.

Relationship between various burrow parameters

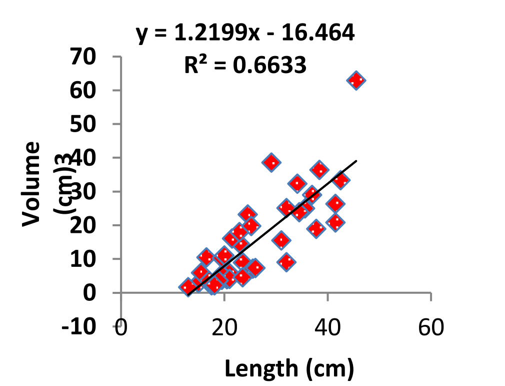

Figure 3.9 Length and Volume

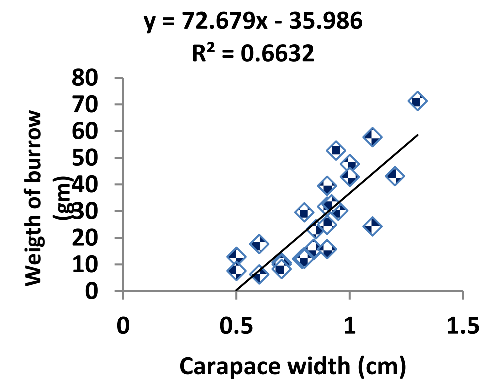

Figure 3.10 Carapace width and Weight of burrow

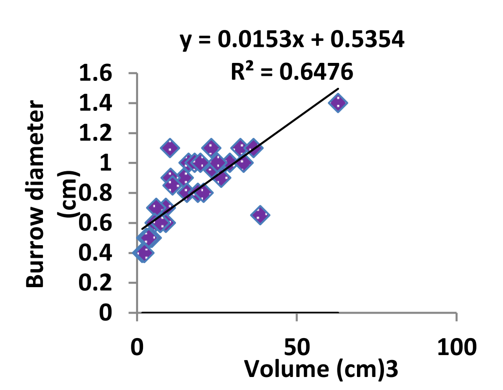

Figure 3.11 Volume and Burrow diameter

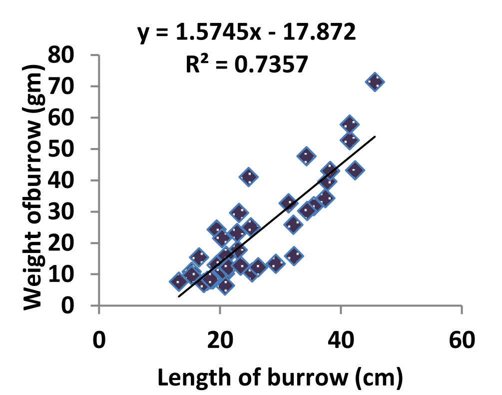

Figure 3.12 Length and weight of burrow

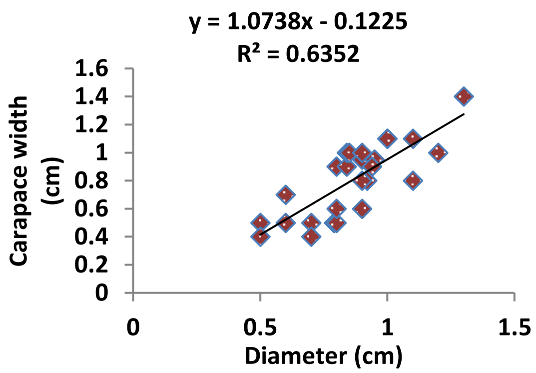

Figure 3.13 Diameter and Carapace width

- **Principle component analysis (PCA) of burrow morphology for winter season.**

In winter season number of variables in LTZ (L1 to L11) are eleven, in MTZ (M1 to M13) and in UTZ (U1 to U11), which means thirteen in MTZ and eleven in UTZ as shown in table 3.12.

Scree plot in figure 3.14 shows data has three major components as shown in table 3.12. Per cent variance for component 1 is 83.768%, 2 is 11.890% and 3 is 4.342%. Cumulative percentage for component 1 is 83.768%, component 2 is 95.658% and component 3 is 100% shown in table 3.13.

Figure 3.15 indicates all burrows of UTZ and MTZ are concentrated in one quadrate and burrows of LTZ are concentrated in one quadrate. Similar results can be seen in the summer season, but inn winter highest cluster formation is seen as compared to other seasons. All burrows are closely present giving out maximum correlation. Figure 3.16 gives 3D view of the PCA suggesting highest amount of cluster formation.

Table 3.5 Component Matrix[a] for winter season			
	Component		
	1	2	3
L1	.950	-.240	-.198
L2	.888	-.457	-.044
L3	.992	-.107	-.060
L4	.916	.331	-.225
L5	.973	.195	.124
L6	.949	-.276	-.152
L7	.976	-.212	.053
L8	.929	-.363	.078
L9	.841	-.521	.145
L10	.929	-.362	.075
L11	.916	-.371	-.152
M1	.986	.168	.019
M2	.943	.121	.310
M3	.975	.179	.131
M4	.950	.265	.166
M5	.802	.562	-.205
M6	.922	.327	-.209
M7	.720	.684	.120
M8	.941	.194	.277
M9	.935	-.348	.073
M10	.939	-.333	-.088
M11	.902	-.408	.143

M12	**.932**	**-.360**	**-.054**
M13	**.971**	**.157**	**-.181**
U1	**.899**	**-.436**	**.030**
U2	**.924**	**.251**	**-.287**
U3	**.968**	**.195**	**-.160**
U4	**.949**	**.295**	**.109**
U5	**.854**	**.517**	**-.056**
U6	**.972**	**.156**	**-.175**
U7	**.889**	**.436**	**.142**
U8	**.888**	**.293**	**-.355**
U9	**.891**	**-.452**	**-.049**
U10	**.531**	**.234**	**.814**
U11	**.947**	**.310**	**.090**

Table 3.6 Total Variance in winter season

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**30.1**	**83.768**	**83.768**	**30.1**	**83.768**	**83.768**
2	**4.28**	**11.890**	**95.658**	**4.28**	**11.890**	**95.658**
3	**1.56**	**4.342**	**100.000**	**1.56**	**4.342**	**100.000**

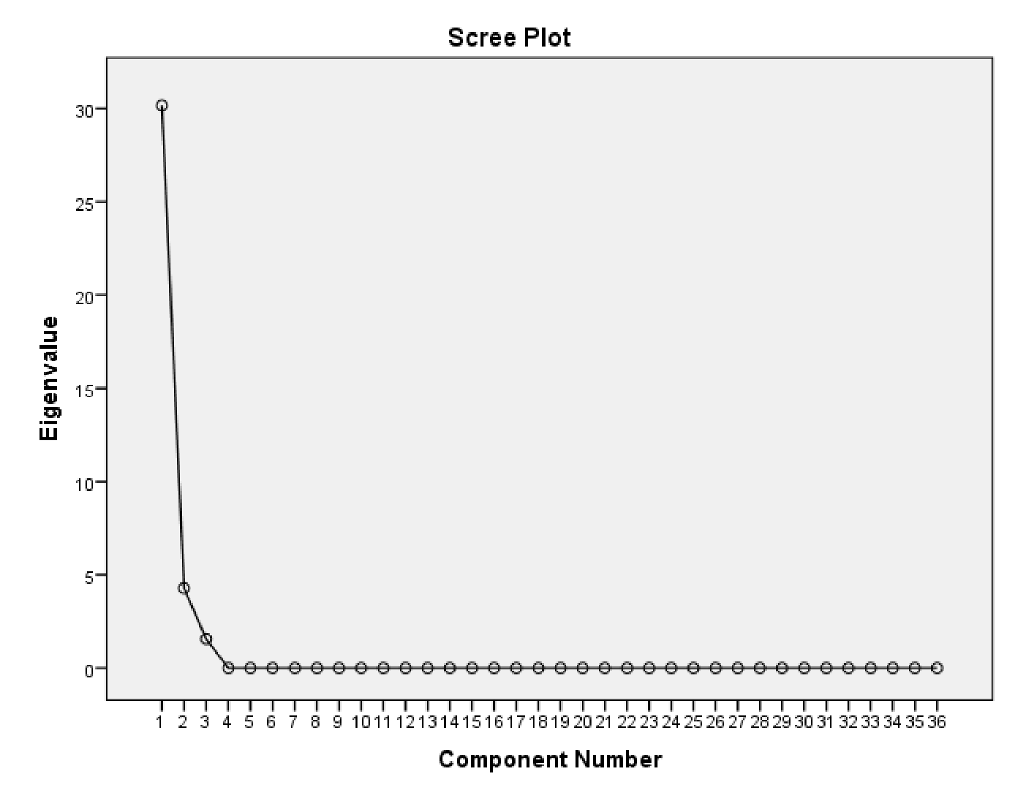

Figure 3.14 Scree plot indicating major 3 plots for winter season

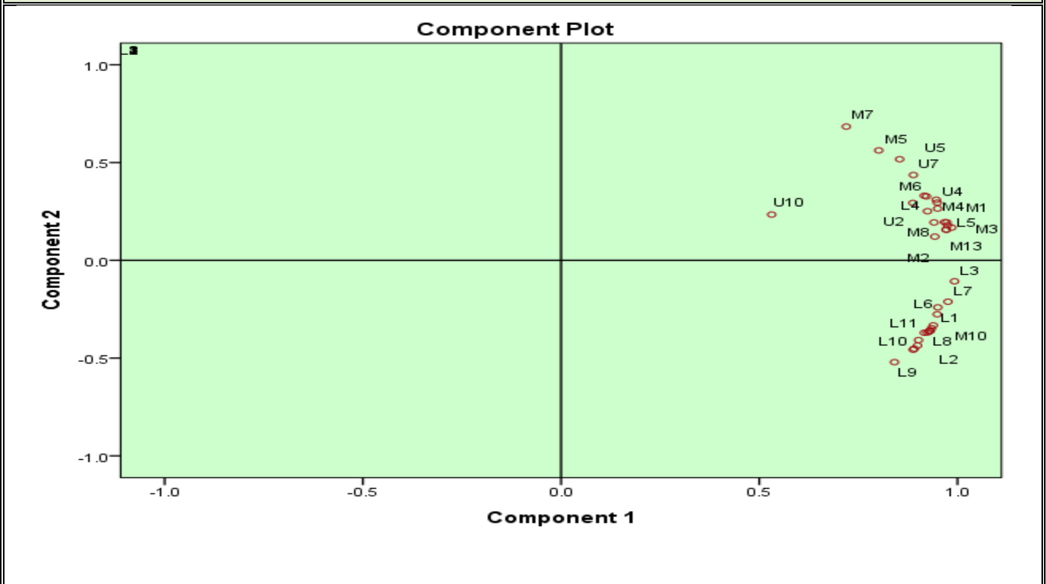

Figure 3.15 Score plots of PCA for winter season. L1-L11: Burrows at LTZ, M1-M13: Burrows at MTZ, U1-U11: Burrows at UTZ

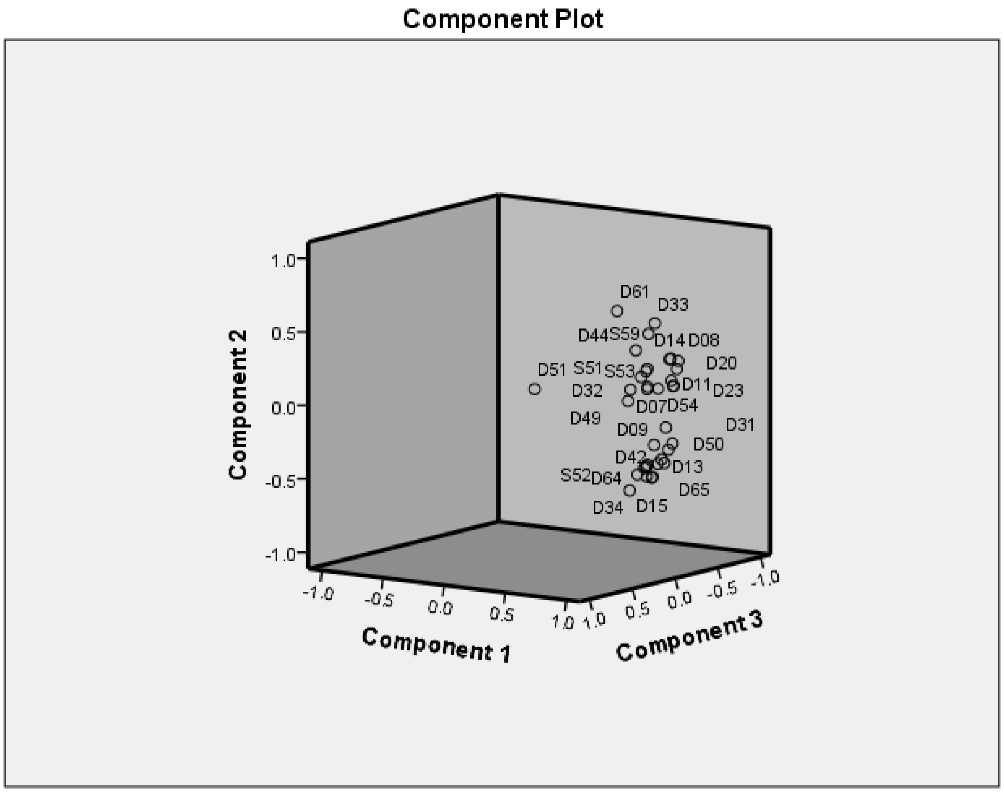

Figure 3.16 3 Dimensional Score plots of PCA for winter season. L1-L11: Burrows at LTZ, M1-M13: Burrows at MTZ, U1-U11: Burrows at UTZ

- **Multidimensional analysis (MDS) for winter season**

Multi-dimensional scaling (MDS) analysis with Euclidean distance model was used to highlight similarity among different burrow and crab parameters concerning seasonal variations. In winter, clustering between W-D (weight and diameter of burrow), W-V (weight and volume of burrow), V-L (volume and length of burrow), and D-C (opening diameter of burrow and carapace width of crab) was observed (Figure 3.17).

Table 3.7 Young's S-stress formula 1 used for Winter season

1	.38411	
2	.36301	.02109
3	.36087	.00215
4	.36108	-.00021

Stress and squared correlation (RSQ) in distances RSQ values are the proportion of variance of the scaled data (disparities) in the partition (row, matrix, or entire data) which is accounted for by their corresponding distances. Stress values are Kruskal's stress formula 1.

	Table 3.8 Stress and RSQ values for winter season							
Matrix	Stress	RSQ	Matrix	Stress	RSQ	Matrix	Stress	RSQ
1	0.25	0.481	2	0.202	0.663	3	0.35	0.92

Average (rms) over matrices

Stress = 0.27430 RSQ = 0.93

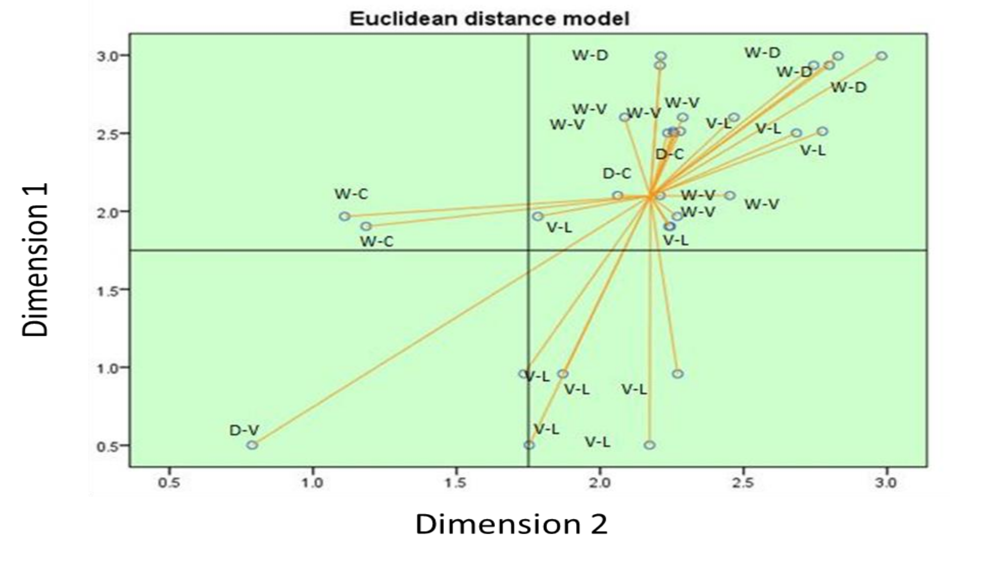

Figure 3.17 Multi-dimensional scaling (MDS) analysis between burrow parameters and crab parameters in the winter season. Labels in the above diagram represent W-D: Weight and diameter of the burrow, D-C: Opening diameter of burrow and carapace width of crab, D-V: Opening diameter and volume of the burrow, W-L: Weight and length of the burrow, V-L: Volume and length of the burrow, W-V: Weight and volume of the burrow, W-C: Weight and carapace width of crab

- **Summer measurements and statistical analysis**

Table 3.9 Summer burrow morphology data						
Burrow number	M/F	Shape	CW/CL	Length	Volume	Weight
			mm	cm	cm3	gm
Quadrate -1	LOWER TIDAL ZONE					
1	M	Spiral	5.5	7.5	2.88	4.77
2	F	L	6.02	7.9	2.23	8.31
3	M	L	8.26	7.6	4.8	6.33
4	M	L	7.1	8	3	8.68
5	F	L	6.5	8.5	2.4	4.77
6	M	J	7.5	2.8	4.2	6
7	M	J	6.25	8	3.07	8
8	M	Spiral	4.25	6.8	0.85	7.52
9	M	L	6.35	8	3.07	6.78
10	M	L	6.02	7.8	2.2	8.67
11	M	Spiral	8	12	3.39	7.18
Quadrate -2	MID TIDAL ZONE					
12	F	L	7.82	14.9	9.47	7.81
13	M	L	7.2	10	4.8	6.5
14	F	L	8	10	6.35	9.86
15	M	J	9.08	11.9	9.34	9.2
16	M	J	9.6	14.1	8.96	7.73
17	F	J	8.2	12.5	2.45	6.86
Quadrate -3	UPPER TIDAL ZONE					
18	M	J	7.2	11.5	7.31	7.5
19	M	J	9.23	13.5	15.26	12.04

20	**M**	**L**	**9.15**	**11.5**	**10.92**	**4.67**
21	**F**	**L**	**7.29**	**9**	**5.72**	**7**
22	**M**	**L**	**9.2**	**12.5**	**9.8**	**8.44**
23	**M**	**J**	**9.4**	**14.1**	**29.22**	**10.19**
24	**M**	**L**	**9.2**	**12.1**	**9.49**	**13.66**
25	**M**	**J**	**9.92**	**29.5**	**39.13**	**25.24**
26	**M**	**J**	**9.8**	**12.5**	**11.87**	**8.2**
27	**F**	**J**	**7.2**	**13**	**8.26**	**7.8**

- **Relationship between burrow parameters of *Ilyoplax sayajiraoi* in three different intertidal zones.**

Burrow analysis of crabs was performed using SPSS software (version 20). The Pearson correlation coefficient was analyzed to establish a relationship between differences in burrow morphology concerning season change. Multi-dimensional scaling (MDS) analysis was conducted to check if multi-colinearity exists between the parameters or variables. Pearson correlation was performed to analyze which burrow parameters have a strong correlation with each other and which are least correlated. The summer season demonstrated a high Pearson correlation (0.05 level of significance) in upper tidal zones (UTZ), as larger crabs accommodated in that area. They built a proper burrow to enhance their stay in it. Appropriate length, width, the volume of the burrow was observed. Burrows of this season also had a resting chamber to accommodate ovigerous females in it. Optimum Pearson coefficient was observed in the middle tidal zone (MTZ) as crabs reduced in size as compared to UTZ crabs. Lower LTZ showed the least correlation between burrow parameters as maximum accommodation was of juveniles. They built burrows with lesser developed morphological structures.

Table 3.10 Indicates Pearson correlation between various burrow parameters for summer season in lower tidal zone (LTZ)					
	CW	LENGTH	VOLUME	WEIGHT	DIAMETER
CW	1				
LENGTH	-.023	1			
VOLUME	.114	.585	1		
WEIGHT	-.374	.499	.246	1	
DIAMETER	.164	-.110	.706*	-.211	1
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 3.11 Indicates Pearson correlation between various burrow parameters for summer season in middle tidal zone (MTZ)					
	CW	LENGTH	VOLUME	WEIGHT	DIAMETER
CW	1				
LENGTH	.316	1			
VOLUME	.320	.499	1		
WEIGHT	-.096	-.135	.340	1	
DIAMETER	.012	-.192	.677	.186	1
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 3.12 Indicates Pearson correlation between various burrow parameters for summer season in upper tidal zone (UTZ)					
	CW	LENGTH	VOLUME	WEIGHT	DIAMETER
CW	1				
LENGTH	.570	1			
VOLUME	.525	.804**	1		
WEIGHT	.349	.868**	.788**	1	
DIAMETER	.518	.390	.200	.369	1
**. Correlation is significant at the 0.01 level (2-tailed).					

➢ **Regression analysis**

In summer, good correlation was obtained between volume and diameter of the burrow (R^2=0.599) Figure 3.18; length of burrow showed a positive correlation with volume and weight of burrow (R^2=0.757) Figure 3.19 and (R^2=0.671) Figure 3.20 respectively; Carapace width of crab and burrow diameter (R^2=0.858) (Figure 3.21) and weight (R^2=0.16) (Figure 3.22) show negligible correlation.

Regression graphs for summer season

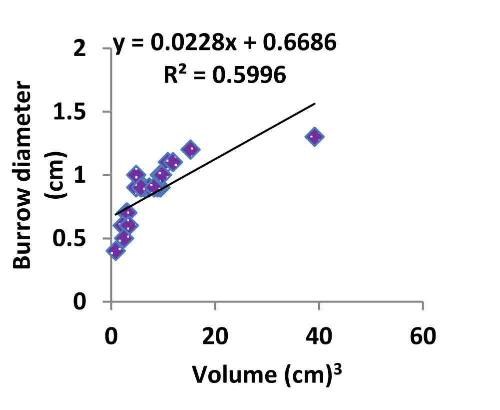

Figure 3.18 Volume and Burrow diameter

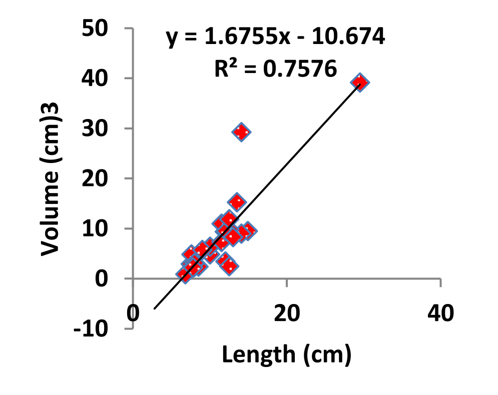

Figure 3.19 Length and Volume of burrow

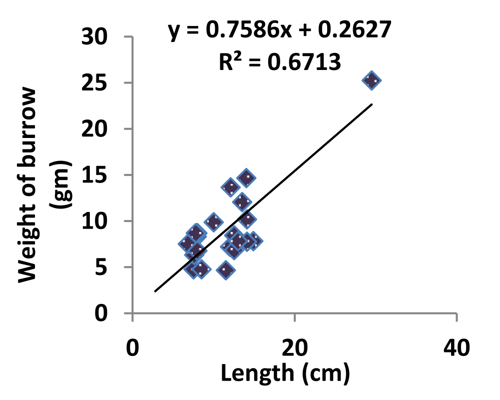

Figure 3.20 Length and Weight of burrow

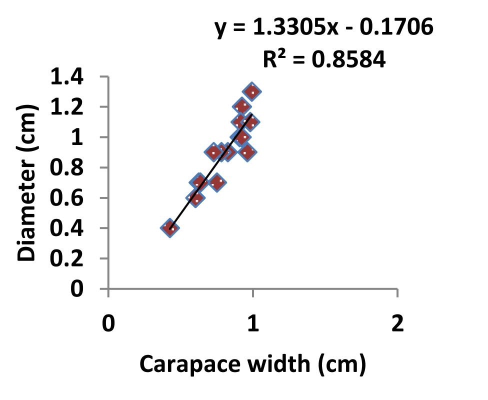

Figure 3.21 Carapace width and Diameter

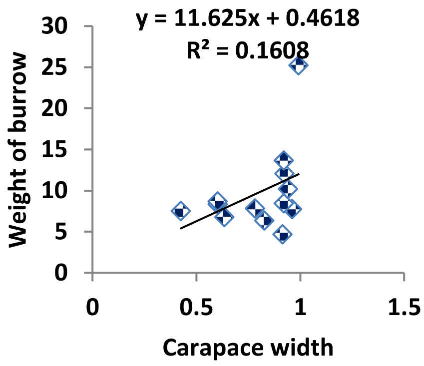

Figure 3.22 Carapace width and weight

- **Principle component analysis (PCA) of burrow morphology for summer season.**

In summer season number of variables in LTZ (L1 to L9) are nine, in MTZ (M1 to M6) and in UTZ (U1 to U9), which means six in MTZ and nine in UTZ as shown in table 3.20

Scree plot shown in figure 3.23 shows data has three major components as shown in table 3.20. Per cent variance for component 1 is 79.242%, 2 is 15.621% and 3 is 5.137%. Cumulative percentage for component 1 is 79.242%, component 2 is 94.863% and component 3 is 100% shown in table 3.21.

Figure 3.24 indicate all burrows of UTZ and MTZ are concentrated in one quadrate and burrows of LTZ are concentrated in one quadrate. But all burrows are closely present giving out maximum correlation. Figure 3.25 gives 3D view of the PCA suggesting high amount of cluster formation.

Table 3.13 Component Matrix[a] for summer season			
	Component		
	1	2	3
L1	0.961	-0.186	-0.203
L2	0.86	-0.494	0.131
L3	0.995	-0.048	0.085
L4	0.878	-0.44	0.188
L5	0.926	-0.234	-0.296
L6	0.792	-0.542	-0.282
L7	0.881	-0.433	0.191
L8	0.792	-0.6	0.112
L9	0.946	-0.324	0.006
M1	0.957	0.22	-0.189
M2	0.938	-0.309	0.157
M3	0.964	-0.141	0.224
M4	0.921	0.372	-0.113
M5	0.965	0.201	-0.168
M6	0.902	-0.299	-0.311
U1	0.9	0.307	-0.311
U2	0.85	0.432	0.302
U3	0.777	0.607	-0.165
U4	0.848	0.357	-0.39
U5	0.962	0.271	0.012
U6	0.455	0.845	0.282
U7	0.924	-0.07	0.376
U8	0.76	0.572	0.309
U9	0.895	0.44	0.073
U10	0.98	0.159	-0.12
U11	0.945	-0.2	0.259
*Blank cell in the table is because crabs were not captured in some case or were solidified along with the resin. So its measurement was not possible.			

Table 3.14 Total Variance in summer season						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	20.6	79.242	79.242	20.6	79.242	79.242
2	4.06	15.621	94.863	4.06	15.621	94.863
3	1.33	5.137	100.000	1.33	5.137	100.000

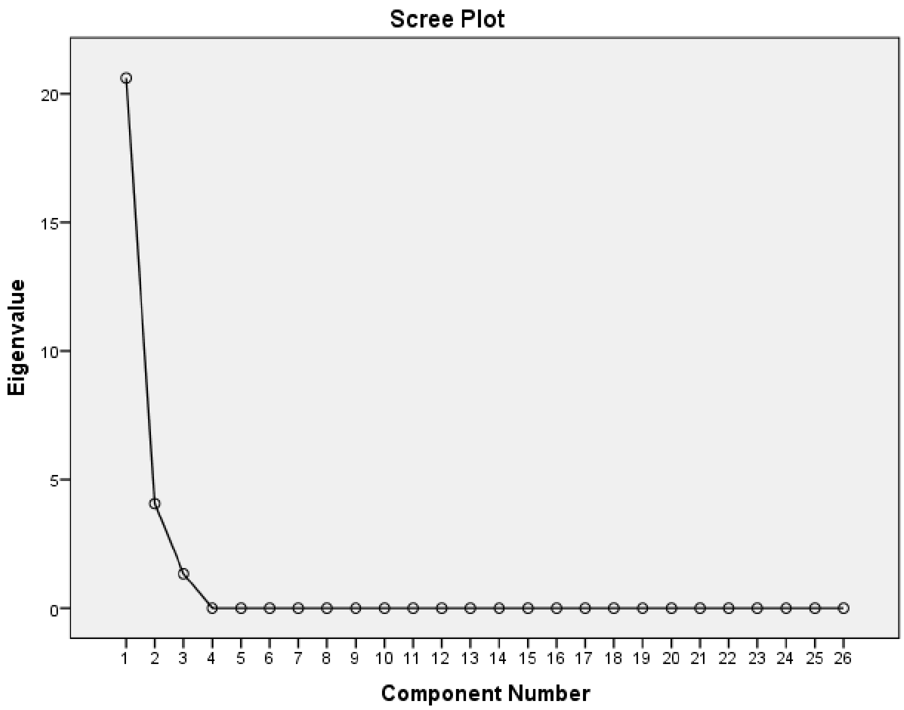

Figure 3.23 Scree plot indicating major 3 components for summer season

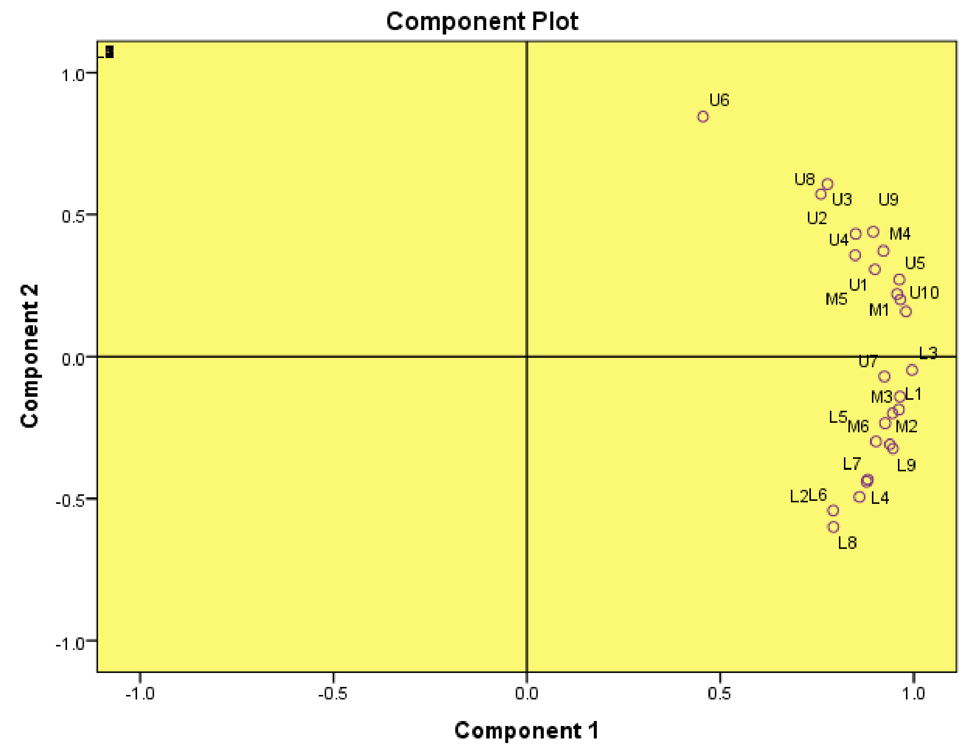

Figure 3.24 Score plots of PCA for summer season. L1-L9: Burrows at LTZ, M1-M6: Burrows at MTZ, U1-U11: Burrows at UTZ

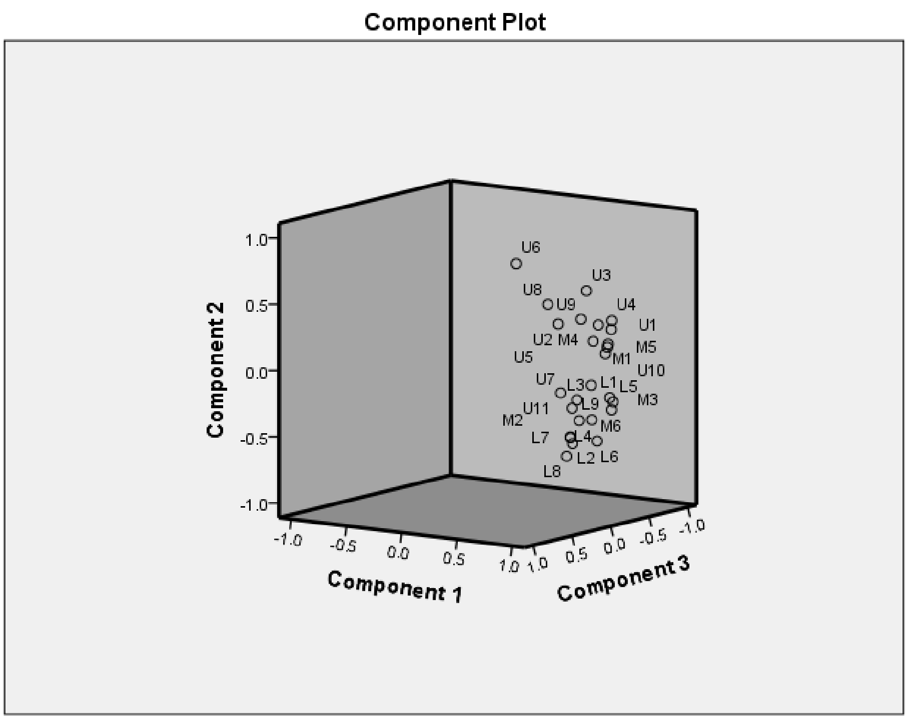

Figure 3.25 3 Dimensional Score plots of PCA for summer season. L1-L9: Burrows at LTZ, M1-M6: Burrows at MTZ, U1-U11: Burrows at UTZ

➢ Multidimensional analysis (MDS) for summer season

Multi-dimensional scaling (MDS) analysis with Euclidean distance model was used to highlight similarity among different burrow and crab parameters concerning seasonal variations. In summer, clustering between W-D (weight and diameter of burrow), W-V (weight and volume of burrow), V-L (volume and length of burrow), and C-L (carapace width of crab- length of burrow) was observed (Figure 3.26).

Table 3.15 Young's S-stress formula 1 used for Summer season		
Iteration	S-stress	Improvement
1	.46858	
2	.37171	.09688
3	.44740	-.07570 *

Stress and squared correlation (RSQ) in distances RSQ values are the proportion of variance of the scaled data (disparities) in the partition (row, matrix, or entire data) which is accounted for by their corresponding distances. Stress values are Kruskal's stress formula 1.

	Table 3.16 Stress and RSQ values for Summer season							
Matrix	Stress	RSQ	Matrix	Stress	RSQ	Matrix	Stress	RSQ
1	0.089	0.927	2	0.084	0.935	3	0.24	0.92

Average (rms) over matrices

Stress = 0.41090 RSQ = 0.78245

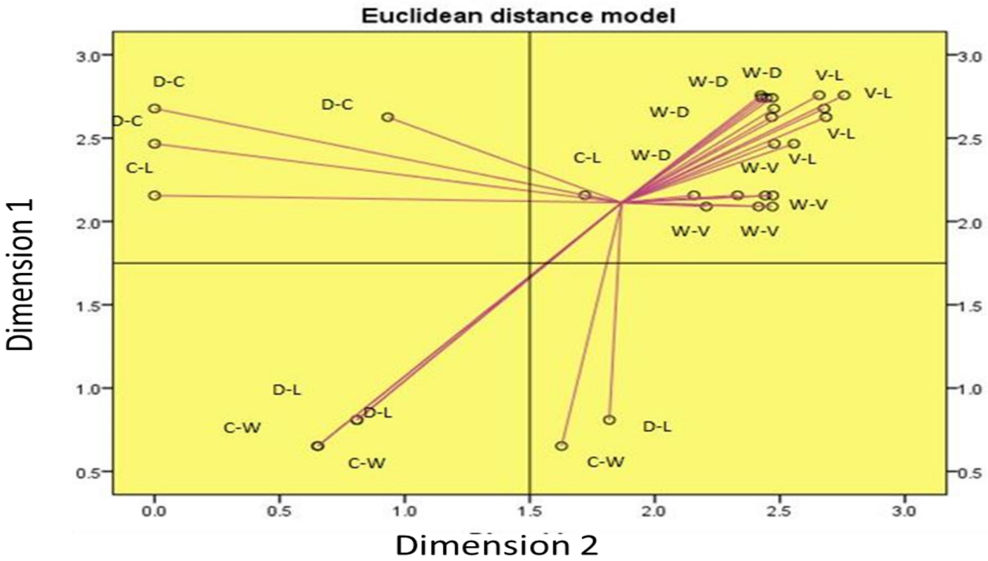

Figure 3.26 Multi-dimensional scaling (MDS) analysis between burrow parameters and crab parameters in the summer season. Labels in the above diagram represent W-D: Weight and diameter of the burrow, D-C: Opening diameter of burrow and carapace width of crab, V-L: Volume and length of the burrow, W-V: Weight and volume of the burrow, C-W: Weight and carapace width of crab C-L: Carapace width of crab and length of the burrow, D-L: Opening diameter and length of the burrow, C-W: Carapace width of crab and weight of burrow

Monsoon measurement

Table 3.17 Monsoon burrow morphology data						
Burrow number	M/F	Shape	CW/CL	Length	Volume	Weight
			mm	cm	cm3	gm
LOW TIDAL ZONE						
O-28	F	L	0.5	4.4	3.45	4.9
O-50	M	J	0.6	5	2.51	2.87
O-37	M	J	0.6	5.5	4.31	3.79
O-43	M	J	0.5	3.1	0.6	0.98
O-45	M	J	0.5	2.4	0.92	0.73
O-46	M	J	0.5	3.5	1.34	0.91
O-47	M	L	0.5	2.9	0.81	1.23
O-51	M	J	0.6	7.9	5.02	4.39
O-58	F	J	0.6	6.7	4.26	4.78
O-59	M	-	0.62	6	3.01	2.69
O-57	M	J	0.63	7.2	2.76	4.8
S-02	M	SPIRAL	0.62	8	5.08	6.36
S-04	F	J	0.5	6.5	1.83	4.53
S-05	M	J	0.8	11.3	4.34	11.3
S-06	M	J	0.7	10.5	2.06	4.89
S-07	M	J	0.8	12	4.61	10.16
S-10		J	0.82	11.8	4.53	5.98
MIDDLE ZONE						
S-08	M	J	0.5	6.5	4.13	5.25
S-09	M	J	0.8	12.4	3.5	13.8
S-13	M	L	0.82	9.9	6.29	5.77

S-14	M	J	0.8	13	8.2	8.6
S-21	F	J	0.7	10.9	4.19	5.3
S-26	M	L	0.7	10.1	1.98	9.1
S-28		J		18.1	3.55	6.77
S-38		J		12	9.42	12.84
S-58	F	J	0.6	8.3	2.34	4.53
S-34	M	J	0.7	8.1	3.11	8.66
UPPER ZONE						
D-63	M	J+C	0.7	19.2	21.7	27.8
S-17	M	MIXED		30	23.55	25.92
D-19		J		26.7	10.27	18.89
L1	F	J	0.6	10.1	5.07	11.9
D-41	M	J	0.7	20.1	15.77	17.1
L2	F	J	0.7	21.9	15	20
L3	M	L	0.7	19.5	14.2	27.75
*Blank cell in the table is because crabs were not captured in some case or were solidified along with the resin. So its measurement was not possible.						

- **Pearson correlation analysis for monsoon season**

Monsoon season demonstrated low Pearson correlation (0.05 level of significance) in upper tidal zones (UTZ), middle tidal zone (MTZ) and lower tidal zone (LTZ) as juvenile crabs accommodated in that area. They built a very weak burrow without any resting chamber. Its length and width was also not properly developed. Juvenile need sea water on regular intervals as their gills are not large. Thus they have a smaller burrow (Chakrabarti 1981).

Table 3.18 Indicates Pearson correlation between various burrow parameters for monsoon season in lower tidal zone (LTZ)					
	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	.133	1			
VOLUME	.760**	.458	1		
CW	.816**	.090	.858**	1	
LENGTH	.865**	-.060	.777**	.935**	1
**. Correlation is significant at the 0.01 level (2-tailed).					

Table 3.19 Indicates Pearson correlation between various burrow parameters for monsoon season in middle tidal zone (MTZ)					
	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	.066	1			
VOLUME	.320	.843**	1		
CW	.459	-.106	.373	1	
LENGTH	.288	-.282	.221	.740*	1
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					

Table 3.20 Indicates Pearson correlation between various burrow parameters for monsoon season in upper tidal zone (UTZ)					
	WEIGHT	DIAMETER	VOLUME	CW	LENGTH
WEIGHT	1				
DIAMETER	-.078	1			
VOLUME	-.008	.809*	1		
CW	-.109	.661	.797*	1	
LENGTH	.455	-.094	.455	.219	1
*. Correlation is significant at the 0.05 level (2-tailed).					

Regression analysis was performed to confirm correlation between three seasons and various burrow parameters

	Table 3.21 Regression analysis of burrow parameters in respective season					
Parameters	Winter		Summer		Monsoon	
	Regression equation	R2	Regression equation	R2	Regression equation	R2
	Length		Length		Length	
Volume	y= 1.2199x-16.464	0.6633	y = 1.6755x - 10.674	0.7576	y = 0.708x - 2.051	0.6725
	Carapace width		Carapace width		Carapace width	
Weight	y = 72.679x - 35.986	0.6632	y = 11.625x + 0.4618	0.1608	y = 37.766x - 21.834	0.3906
	Volume		Volume		Volume	
Diameter	y= 0.0153x + 0.5354	0.6476	y = 0.0375x + 1.5159	0.0178	y = 0.0231x + 0.6204	0.5702
	Length		Length		Length	
Weight	y= 1.5745x - 17.872	0.7357	y = 0.7586x + 0.2627	0.6713	y = 0.9719x - 1.6414	0.7588
	Diameter		Diameter		Diameter	
Carapace width	y = 1.0738x - 0.1225	0.9243	y = 1.3305x - 0.1706	0.8584	y = 0.2825x + 0.5519	0.0384

- **Regression analysis for monsoon season**

In monsoon, very weak correlation was obtained between volume and diameter of the burrow (R^2=0.57) Figure 3.27; length versus volume of burrow and weight also showed positive correlation (R^2=0.672) Figure 3.28 and (R^2=0.758) Figure 3.29 respectively; carapace width of crab and burrow diameter and weight (R^2=0.038) Figure 3.30; (R^2=0.390) Figure 3.31 respectively determining negligible correlation.

Regression graphs for monsoon season

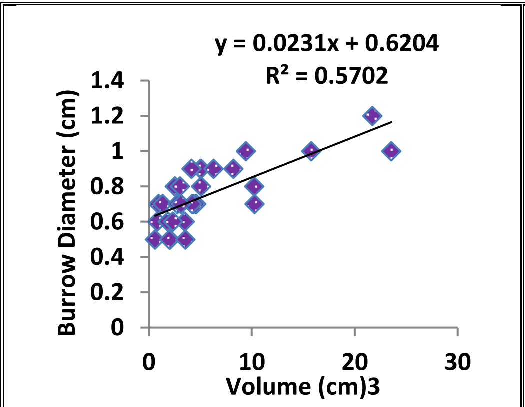

Figure 3.27 Volume and Burrow diameter

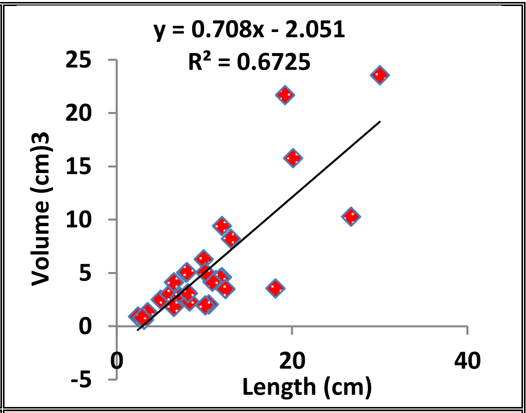

Figure 3.28 Length and Volume (cm)^3

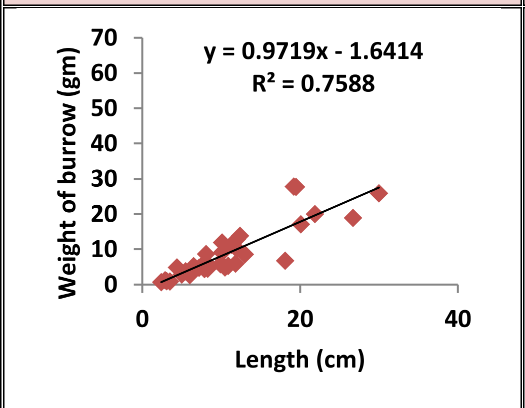

Figure 3.29 Length and Weight of burrow

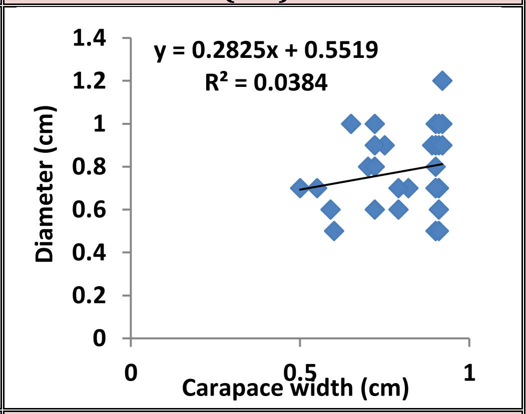

Figure 3.30 Carapace width and Diameter

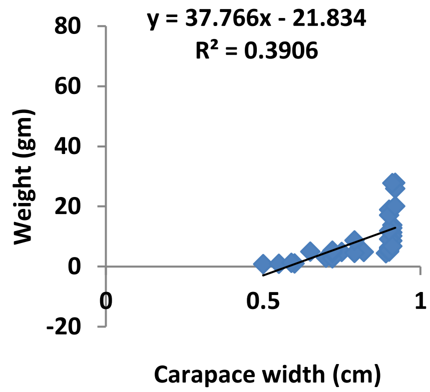

Figure 3.31 Carapace width and weight of burrow

Statistical analysis (C)

SPSS software has an attribute named 'Factor Analysis' which consist of two major types 1. Principle Component Analysis (PCA) and 2. Common Factor analysis. Most accurate and default procedure in SPSS is PCA so we have analysed our data using the same. PCA analyses the correlation or relationships between variables and basically it tries to determine a smaller number of variables that can explain these correlations. Fitting of large data base is a running problem for much analysis as huge data creates confusion for interpretation. PCA is a significant tool for reducing the problem of data over fitting. It simplifies the data and produces it as a very significant data for further interpretation.

Principle component analysis (PCA) of burrow morphology for monsoon season.

In monsson season number of variables in LTZ (L1 to L17) are seventeen, in MTZ (M1 to M10) and in UTZ (U1 to U8), which means ten in MTZ and eight in UTZ as shown in table 3.29.

Scree plot shown in figure 3.32 shows data has two major components as shown in table 3.29. Per cent variance for component 1 is 61.660%, 2 is 26.633%. Cumulative percentage for component 1 is 61.66, component 2 is 88.292%.

Figure 3.33 indicates all burrows of LTZ, MTZ and UTZ are spread widely and perfect cluster formation is not taking place for any for any of the zones. As burrows are not highly correlated with each other, 3D view in figure 3.34 shows all plots sparely plotted.

Table 3.22 Component Matrix[a] for monsoon season		
	Component	
	1	2
L1	.875	-.454
L2	.973	.050
L3	.892	-.291
L4	.859	.462
L5	.777	.461
L6	.800	.377
L7	.901	.395
L8	.924	-.110
L9	.966	-.188
L10	.922	.101
L11	.999	.053
L12	.967	-.242
L13	.987	.118
L14	.945	-.133
L15	.959	.274
L16	.983	-.070
L17	.975	.111
M1	.349	.915
M2	.698	.258
M3	-.095	.966
M4	.545	.804
M5	.166	.983

M6	**.276**	**.762**
M7	**.039**	**.999**
M8	**.544**	**.295**
M9	**.073**	**.990**
M10	**.249**	**.632**
U1	**.691**	**-.709**
U2	**.512**	**-.417**
U3	**.898**	**-.422**
U4	**.999**	**-.024**
U5	**.892**	**-.275**
U6	**.900**	**-.413**
U7	**.970**	**-.177**
.U8	**.728**	**-.661**

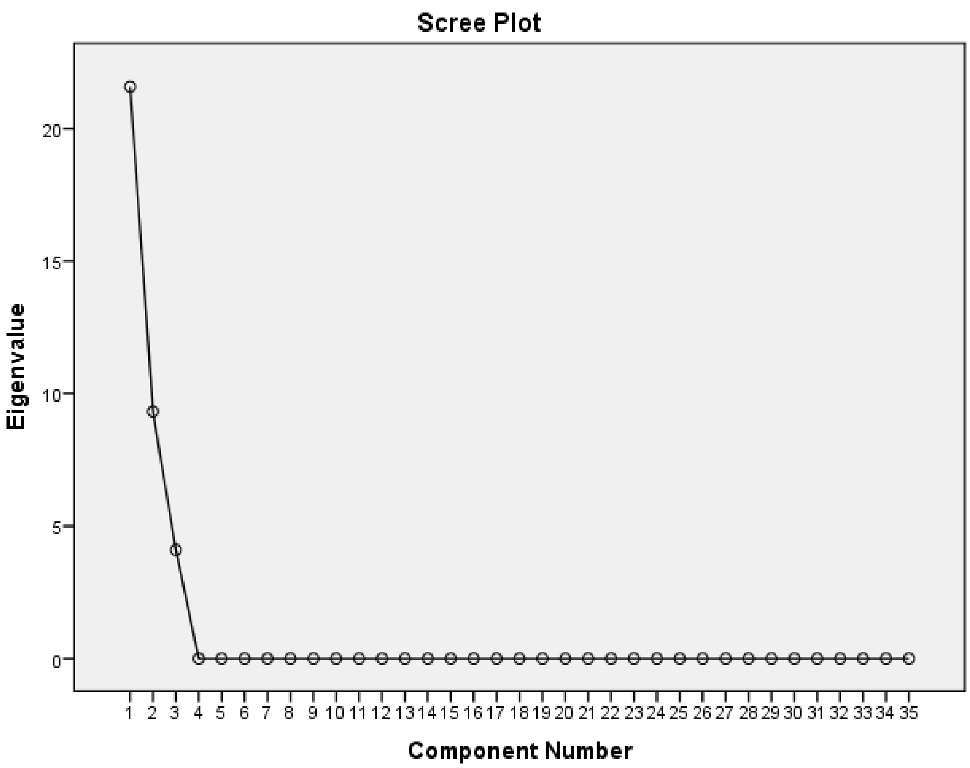

Figure 3.32 Scree plot indicating major 2 plots for monsoon season

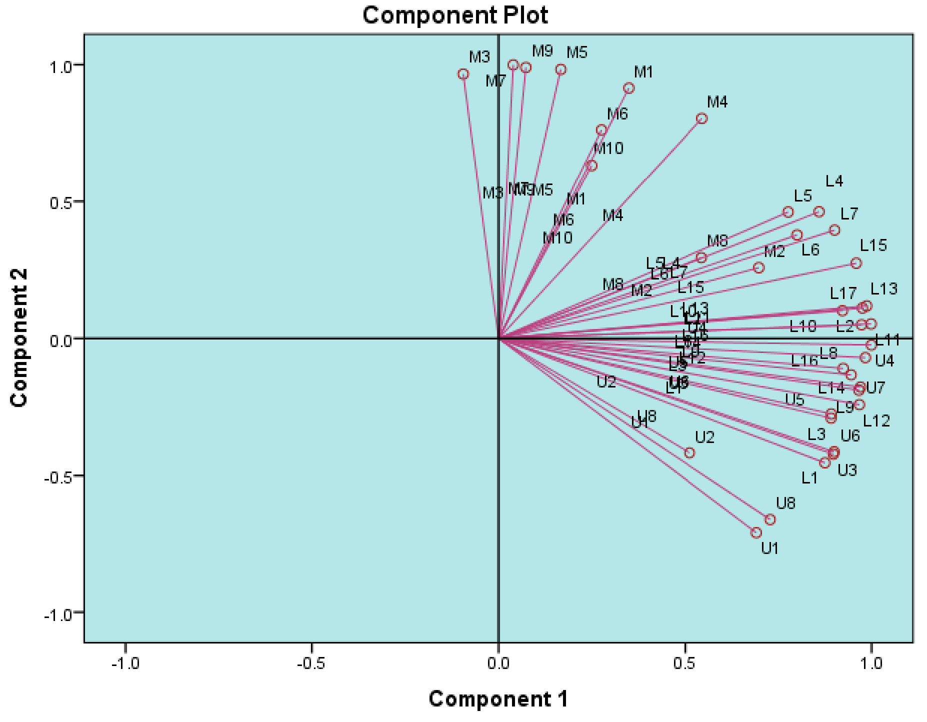

Figure 3.33 Score plots of PCA for monsoon season. L1-L17: Burrows at LTZ, M1-M10: Burrows at MTZ, U1-U8: Burrows at UTZ

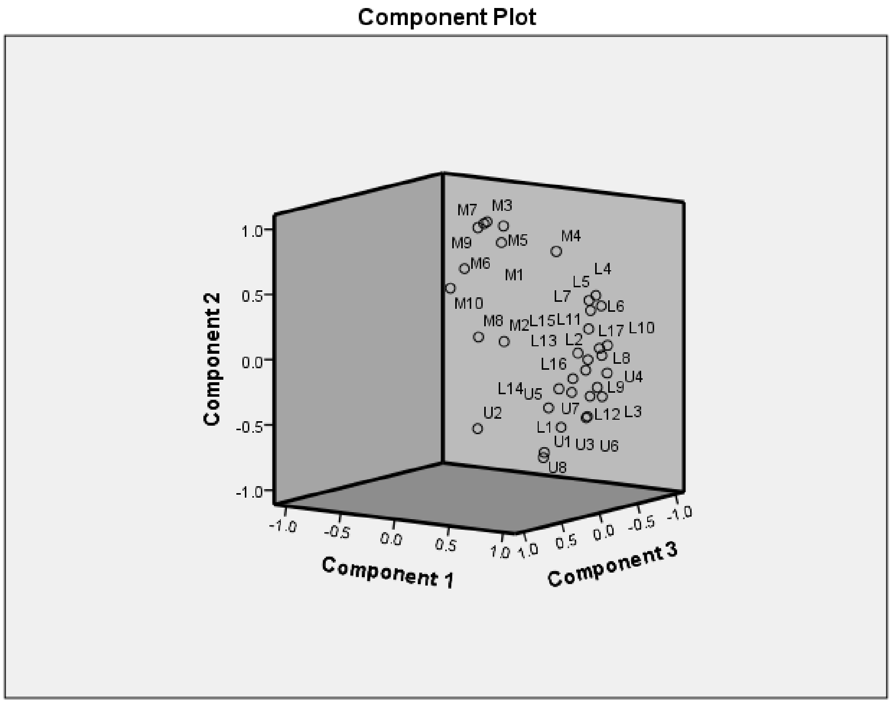

Figure 3.34 3Dimensional Score plots of PCA for monsoon season. L1-L17: Burrows at LTZ, M1-M10: Burrows at MTZ, U1-U8: Burrows at UTZ

Multidimensional analysis (MDS) for monsoon season

Multi-dimensional scaling (MDS) analysis with Euclidean distance model was used to highlight similarity among different burrow and crab parameters concerning seasonal variations. In monsoon, least parameters were clustered with each other. Some amount of grouping was seen between W-L (weight and length of burrow): V-L (volume and length of burrow) and D-V (opening diameter and volume of burrow): V-C (volume of burrow and carapace width of crab) as shown in figure 3.35.

Table 3.23 Young's S-stress formula 1 used for Monsoon season

Iteration	S-stress	Improvement
1	.39885	
2	.36453	.03432
3	.35263	.01190
4	.34389	.00873
5	.33596	.00793
6	.32834	.00762
7	.32091	.00743
8	.31370	.00721
9	.30682	.00688
10	.30043	.00639
11	.29472	.00571
12	.28982	.00489
13	.28583	.00399
14	.28276	.00308
15	.28052	.00224
16	.40262	-.12210 *

Stress and squared correlation (RSQ) in distances RSQ values are the proportion of variance of the scaled data (disparities) in the partition (row, matrix, or entire data) which is accounted for by their corresponding distances. Stress values are Kruskal's stress formula 1.

	Table 3.24 Stress and RSQ values for Monsoon season							
Matrix	Stress	RSQ	Matrix	Stress	RSQ	Matrix	Stress	RSQ
1	0.471	0.74	2	0.256	0.466	3	0.24	0.995

Average (rms) over matrices

Stress = 0.30969 RSQ = 0.51185

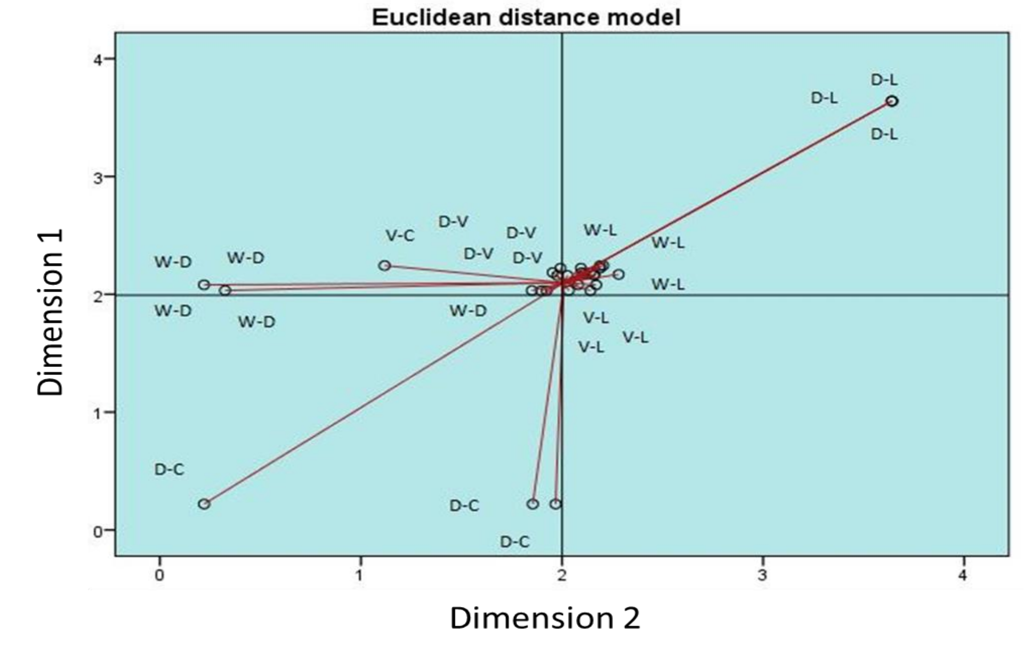

Figure 3.35 Multi-dimensional scaling (MDS) analysis between burrow parameters and crab parameters in the monsoon season. Labels in the above diagram represent W-D: Weight and diameter of the burrow, D-C: Opening diameter of burrow and carapace width of crab, V-C: Volume of burrow and carapace width of crab, D-V: Opening diameter and volume of the burrow, W-L: Weight and length of the burrow, D-L: Opening diameter and length of the burrow

3.4 Discussion

In the present study, fewer burrow casts from female crabs were collected compared to males. Studies on the population ecology of *Ilyoplax sayajiraoi* by Vaidya and Vachhrajani 2021 noted sex ratio as 10:13, indicating the male population three times higher than females. Large crabs possess a considerably larger gill surface area (Chakrabarti 1981) to permit a long-time exposer to the air. These crabs entirely stay in their burrows during daytime; as a result, their burrows are deeper and complex compared to juveniles. Juveniles need seawater frequently as their gill surface area is smaller than larger crabs. Thus more giant crabs have burrowed in UTZ and juvenile burrows in LTZ closet to the seashore. Analysis showed that burrow diameter is significantly smaller at foreshore compared to that of backshore, suggesting that larger individuals reside along the backshore where they excavate deeper and larger diameter burrows to minimize chances of desiccation. A similar type of study was carried out by Chan *et al* in 2005 on crab *Ocypode ceratophthalma* in sandy shore of Hong Kong obtaining equivalent results for the present study. Trivedi and Vachhrajani in March-April 2014 performed similar analysis on Ghost crabs at two sandy shorelines of Gujarat, Sutrapada and Kodinar.

The endings of J and single tube structured burrows did not reach the groundwater table, but the burrows' sediment was highly moist. In peak summer highest sediment temperature reaches 45^{o}C and above lethal to shore organisms. In the present burrow analysis, sediment temperature reduces rapidly with an increase in depth reaching up to 24^{o}C, thus providing shelter to *Ilyoplax sayajiraoi* in distressful conditions. Single tube burrows constructed by *Uca pugilator* (Bosc), *Sesarma* *longipes* (Krauss), *Cardisomacarnifex* (Herbst),and *Macrophalmus parvimanus* (Guerin) are temporary burrows to escape high tides (Braithwaite & Talbot, 1972; Christy, 1982).

The present study enlightens few behavioural aspects of species that add-ons to work carried out on newly discovered species *Ilyoplax sayajiraoi.* According to season and size, species *Ilyoplax sayajiraoi* living on muddy coast creates burrows with different shapes and sizes. Burrows serve multiple functions in the entire life of an individual.

In monsoon season, juveniles are high, and adults (male and female) are lesser in number (Vaidya and Vachhrajani 2021). Their burrows are not complete and properly developed (Chakrabarti 1981). This gives rise to less cluster formation in MDS analysis showing the most minor similarity. In winter and summer seasons, MDS analysis demonstrated better cluster formation as all burrow parameters correlate. For crabs, this season is 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 with the least disturbance. As shown in figure RSQ value for summer and winter are above 0.5 and below 0.2 for stress value. This shows value is approaching towards absolute fit and giving a good cluster formation. Monsoon season shows a low RSQ value which indicates data is not showing a perfect fir and thus dispersed clusters are formed in this season.