CHAPTER 2

POPULATION ECOLOGY OF *ILYOPLAX SAYAJIRAOI* AT THE MUDFLATS OF KAMBOI

- 2.1 Characteristic features and species of genus *Ilyoplax*
- 2.2 *Ilyoplax sayajiraoi* : Discovery and Morphology
- 2.3 Concept of population ecology
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2.1 Characteristic features and species of genus *Ilyoplax*

2.1.1 Genus *Ilyoplax*, Stimpson 1858

Crabs of this genus are also known as depositor crabs, identified by square-shaped carapace and length of right and left cheliped. Each adult in a male has one of his claws (left or right) larger than the other. The crab wields its cheliped if he observes any female crab to attract her or observe any potential threat. When threatened, it links its claws with another in either a strenuous fight or ceremonial encounter. Till now, 28 species of genus *Ilyoplax* have been discovered. They are as follows,

Table-2.1 Species of genus *Ilyoplax*

Sr.no	Species name
1.	*Ilyoplax pusilla* (De Haan, 1835 [in De Haan, 1833-1850])
2.	*Ilyoplax tenella* Stimpson, 1858
3.	*Ilyoplax orientalis* (de Man, 1888 [in de Man, 1887-1888])
4.	*Ilyoplax stapletoni* (de Man, 1908)
5.	*Ilyoplax lingulata* (Rathbun, 1909)
6.	*Ilyoplax deschampsi* (Rathbun, 1913)
7.	*Ilyoplax philippinensis* (Rathbun, 1914)
8.	*Ilyoplax integra* (Tesch, 1918)
9.	*Ilyoplax stevensi* (Kemp, 1919)
10.	*Ilyoplax frater* (Kemp, 1919)
11.	*Ilyoplax gangetica* (Kemp, 1919)
12.	*Ilyoplax formosensis* Rathbun, 1921
13.	*Ilyoplax delsmani* de Man, 1926
14.	*Ilyoplax yuhana* Rathbun, 1931
15.	*Ilyoplax serrata* Shen, 1931
16.	*Ilyoplax pingi* Shen, 1932
17.	*Ilyoplax dentimerosa* Shen, 1932
18.	*Ilyoplax dentata* Ward, 1933

19.	*Ilyoplax punctata* Tweedie, 1935
20.	*Ilyoplax obliqua* Tweedie, 1935
21.	*Ilyoplax longicarpa* Tweedie, 1937
22.	*Ilyoplax tansuiensis* T. Sakai, 1939
23.	*Ilyoplax ningpoensis* Shen, 1940
24.	*Ilyoplax spinimera* Tweedie, 1950
25.	*Ilyoplax strigicarpus* Davie, 1990
26.	*Ilyoplax pacifica* Kitaura & Wada, 2006
27.	*Ilyoplax danielae* Davie & Naruse, 2010
28.	*Ilyoplax sayajiraoi* Trivedi, Soni, Trivedi & Vachhrajani, 2015

Characteristic feature of genus- *Ilyoplax*

2.1.2 Foraging

Ilyoplax built their burrows in areas above (25meter) the lowest low tide mark and below (25 meters) the highest low tide mark. This makes the habitat scattered in a predefined zone, which becomes their foraging area.

Thus their habitat is flooded twice in 24 hours, leading to the removal of debris and renewal of organic content in the uppermost sediment layer. Most importantly main intake elements are bacteria, algae, and detritus material. *Ilyoplax* feed on wet sediment and curved cheliped play a crucial role in removing the debris out for feeding. Once fed, the debris is sifted through the spoon-tipped setae. The second maxillipeds are of prime importance for this. Miller, in 1961 confirmed that water gets added to the buccal cavity along with the organic debris (sediments). Further, the heavy inorganic particles sank to the base of the buccal cavity. The remaining is less dense that remains suspended. After the intake of most organic matter, the unusable inorganic matter is rejected in the form of a small pellet at the upper part of the third maxillipeds. Obtaining the size of 3 mm, it gets detached by the claw of one of the cheliped and passes under the walking legs of crabs (Vogel, 1984). Studies showing foraging behavior describe that crabs rarely fed in the same region twice. The crabs only removed 3 mm of sediment as they foraged, so the biomass concentrations between 0-3mm depths vary from other depths deeper than 3mm. Feeding crabs move sideways along a radius from the burrow, creating a row of pellets in a tangent to the burrow entrance. Crabs retreat back to their burrows if they find any vibrational disturbances passing through. Once it had passed, the crabs re-emerged and continued to feed along the same trench.

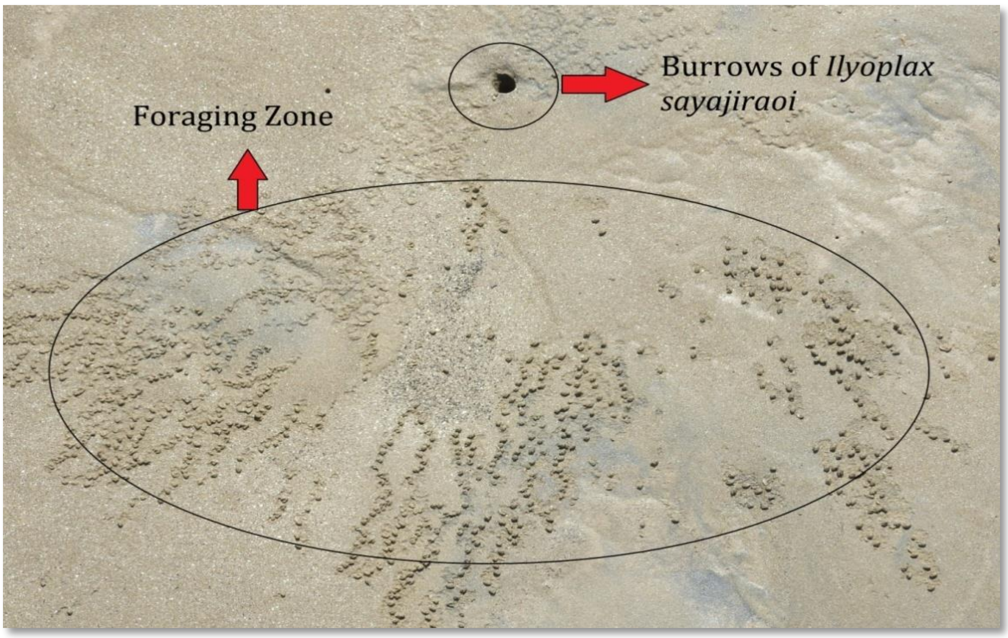


Figure 2.1 Foraging area of crab *Ilyoplax sayajiraoi*

2.1.3 Burrowing activity

Crabs have the potential to change the physical properties of habitat as they directly influence the sediment and other communities by abiotic (burrowing) and biotic (feeding) activities and thus also known as bioengineers or ecosystem engineers (Katz, 1980; Montague, 1980; Bertness and Miller, 1984; Bertness, 1985; Genoni, 1991) and burrow of fiddler crabs facilitate the general aeration of the sediments. A burrow functions as a refuge from desiccation and predators and the site for mating (Christy, 1982).

The burrows act as oxygen inlet tubes (figure 2.1) and increase the sediment oxygen levels in the deep surface (Katz, 1980; Bertness, 1985). The burrows are speculated to act as outlet tubes for toxins such as sulfides, reducing the accumulation of metabolic products in the sediments.

It increases soil drainage efficiency, sediment redox potential, below-ground decomposition and associated with the growth of cordgrass, *Spartinaalterniflora* (Katz, 1980; Bertness and Miller, 1984). Land crab activity is regulated by a combination of air and soil surface temperature, relative humidity, the intensity of insolation (solar radiation), and the availability of protective cover, be it leaf litter, suitable cavities, or soil for burrowing, which is further influenced by the soil compaction (Bliss et al., 1978; Green, 1997; Brook, et al., 2009). The optimum temperature for land crab activity appears to be about 30^{o}C, with virtually no activity below 18^{o} C (Bliss et al., 1978). Hence, to mitigate the desiccating effects of the high temperatures that crabs require to be active, their activity is primarily restricted to periods and locations with high humidity.

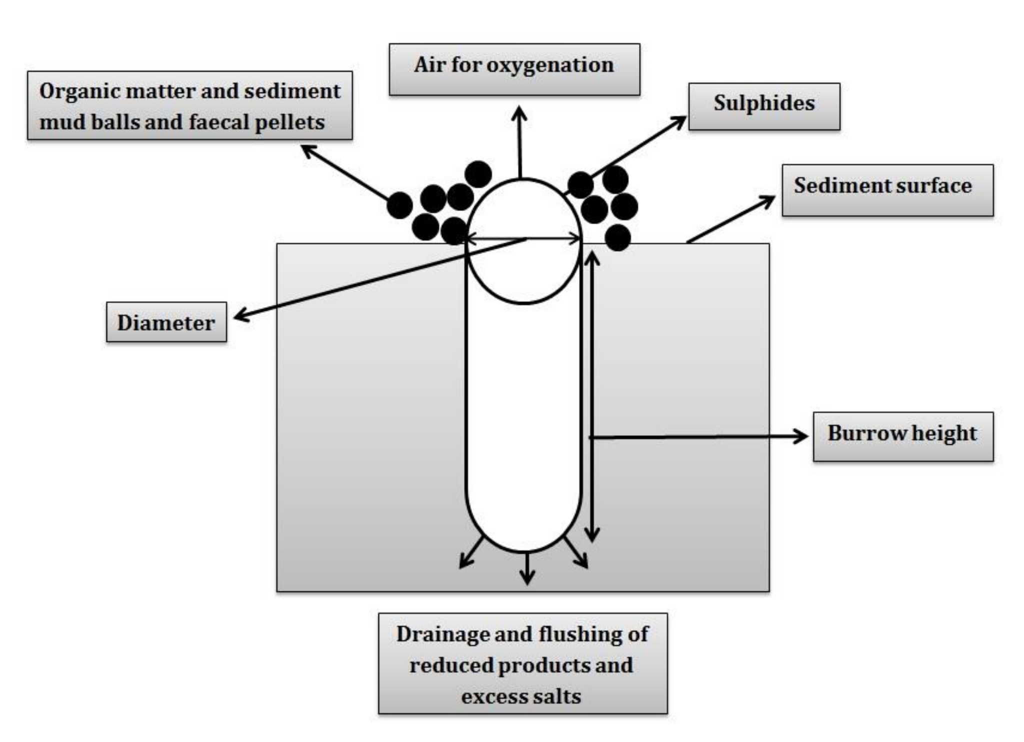


Figure 2.2 Conceptual diagram of function attributed to the burrow of semaphore crab.

Island species are highly vulnerable to anthropogenic impacts, of which invasive alien species (IAS) introductions are often the most severe (Russell et al., 2017) that causes 86% of island endemic species extinction (Bellard et al., 2016). IAS interrupt ecosystem functioning through predation and competition with other biotic components (Athens et al., 2002; Towns et al., 2006; Hilton and Cuthbert, 2010). As keystone consumers (Paine, 1966), the removal of or reduction in crab abundance through the introduction of IAS can trigger a tropic cascade of effects, leading to a reduction in island ecosystems in the worst cases (O'Dowd et al., 2003; Pitman et al., 2005; Nigro et al., 2017).

Various species of semi-terrestrial groups selectively burrow into the intertidal substrate, from coarse beach sand to fine clay-rich marshy mud (Teal, 1958). It appears that changes in elevation, vegetation, and sediment composition determine which species dominate in a given setting.

2.1.4 Drove formation

The formation of dense aggregations of crabs is known as droves (Crane, 1975), is a behavior that has been observed in several species of *Ilyoplax.* Most ocypodid excavate their burrows into intertidal substrates and forage on the surface in the vicinity of the burrow openings. Droving was first time reported in *Ilyoplax deschampsi* by Rathbun in 1913. In several ocypodidae species, drove formation has been attributed to having a reproductive function by increasing the opportunity for crabs to encounter potential mates. Secondly, drove formation is due to dry sediment conditions in burrow areas, forcing crabs to aggregate in an area where the sediment is more to facilitate feeding and other vital activities (Ono, 1965; Wada, 1981). Droving within a drove area provides numerous potential advantages to an individual crab. Wandering offers passive defense against predation by the effects of dilution and confusion (Russo et al., 1998). It also increases the likelihood of encountering richer substrates (Gherardi et al., 2002).

There are certain disadvantages associated with this behavior, like conspecies sharing resources and competing with each other. The wandering/lost crabs can only construct igloos as it is less time-consuming than vertical burrow construction. This should be completed before tide inundates the complete area. Sediments are also waterlogged to a certain extend to form a new excavated vertical burrow (Gherardi et al., 2002). If a lost crab is large enough, it possesses a good option to forcibly enter in smaller crab's residence and remove that crab out, making it his/her refuge place.

2.2 *Ilyoplax sayajiraoi* - Discovery and morphology

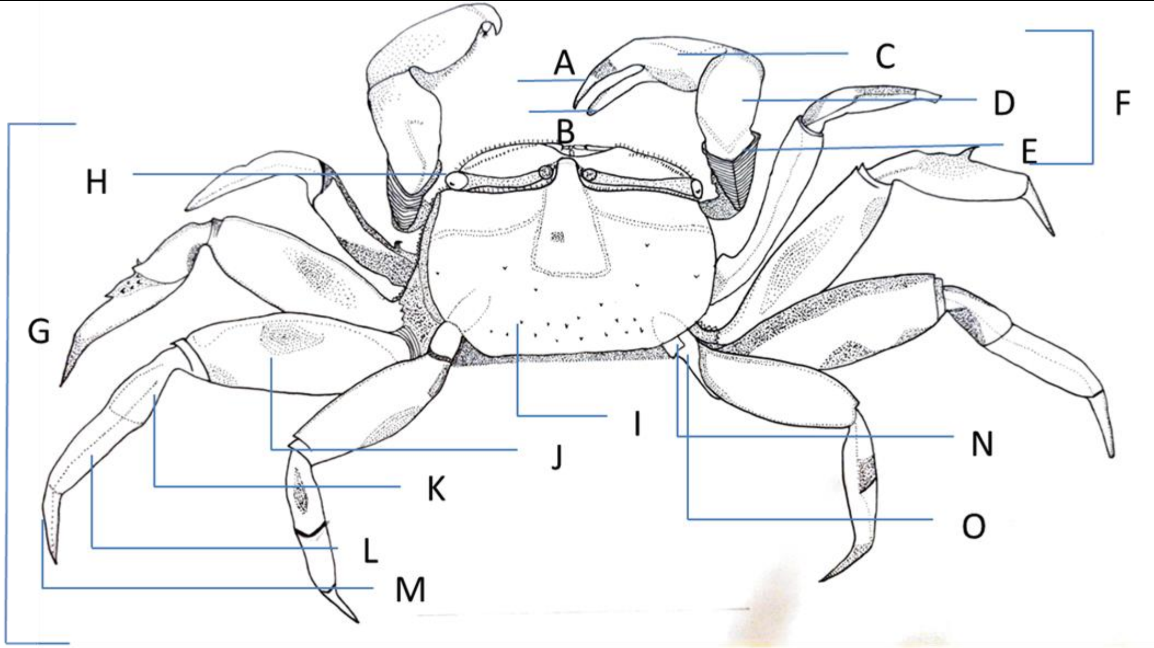
2.2.1 Discovery

Trivedi et al. in 2014 discovered a new species, *Ilyoplax sayajiraoi*, as a part of the research oriented project "Documentation of crustacean biodiversity of Gujarat," which was sponsored by Gujarat State Biodiversity Board, Government of India, Gujarat undertaken by Marine Biodiversity and Ecology Laboratory, Department of Zoology, Faculty of Science, The M. S. University of Baroda, Gujarat, India. The specimen was collected from coastal areas of Kamboi located on the extreme interior of the Gulf of Khambhat near to the lower estuarine region of the Mahi Sagar River on the western side of Bharuch District of Gujarat. This species resembles *Ilyoplax stevensi* and *Ilyoplax frater* with several morphological variations described further. Both species were described by Kemp in 1919. The diversity and taxonomy of brachyuran crabs belonging to the family Dotillidae found in coastal areas of India have been studied (Alcock, 1900; Kemp, 1919). Eleven species and four genera belonging to the family Dotillidae have been reported from India (Alcock, 1900; Kemp, 1919). *Ilyoplax gangetica* (Kemp, 1919) and *Ilyoplax Stapletoni* (de Man, 1908) are two of eleven species belonging to the genus *Ilyoplax* are found from India (Alcock, 1900; Kemp, 1919). Genus *Ilyoplax* has specimens much smaller in size than usual ones and plays a vital role at both sandy and muddy beaches.

2.2.2 Morphology

The upper hard surface of crustaceans is the carapace. In *Ilyoplax sayajiraoi*, it is transversely oblong and olive green in fresh specimens. Its breadth is one and half of the length. It is convex on both ends. Patterned ridges present on the convex structure of the carapace are an identification key for *Ilyoplax sayajiraoi*. The anterolateral border is convex, and the breadth in the middle is larger than the breadth between orbital angles.

At branchial regions, small tubercles having setae are arranged in four rows. A sharp transverse and straight ridge are present above the posterior carapace margin. The buccal cavity is entirely closed by third maxillipeds. It possesses one pair of antennae at the anterior-most end of the carapace. It possesses five pairs of walking legs, of which the first pair is modified into cheliped used for waving actions. The male chelipeds are slender, strong, and highly developed. The color of cheliped is pinkish purple in proximal end and white at distal end color. Female chelipeds are less substantial and smaller than male ones. The third pair of the leg is the longest and two and a half time the length of the carapace. All segments of the male abdomen are distinct. The second segment of the abdomen is slightly narrower than the first, the third and the fourth segment is rounded at the ends. The fourth segment is slightly narrower than the third, the breath of the fifth segment is less than the breath of the fourth segment. The sixth segment is less than twice as broad as long, and the seventh segment is triangular. The female abdomen is much broader than that of a male but narrow at the base (Trivedi et al., 2014).



A- Dactylus (movable finger), B- Fixed finger, C- Propodus, D- Carpus, E- Merus, F- Cheliped (1st pereiopod), G- Walking legs (2nd to 5th pereiopods), H- Eyes, I- Carapace, J- Merus, K- Carpus, L- Propodus, M- Dactyl, N- Basis, O- Ischium

Figure 2.3 Schematic diagram of *Ilyoplax sayajiraoi*

2.3 Concept of population ecology

A group of organisms belonging to a particular area and interbreed is termed a **population**. Different populations are separated from each other by barriers that prevent organisms from breeding. The species that forms a community are linked through competition, prey-predator relationships, and symbiosis. Population of several species that occupy on habitat simultaneously form a **biological community**. **Population ecology** is the study of ecological parameters that affect the population of specific species. Study plays a significant role in understanding conservation biology, involving major subjects like mathematics, statistics, and population dynamics. It explains many questions like which factors affect the rate of individual growth in the present and future scenarios. From forest trees to the species in successional series to laboratory fruit flies and paramecia, all populations from diseased organisms to wild-harvested fish stocks have been the subject of basic and applied population biology. The study of population ecology incorporates understanding, explaining, and predicting species distributions. Population ecology has its deepest historical roots and its most affluent development in the study of population growth, regulation, and dynamics or demography. It also includes significant events relating to growth, development, reproduction, and survival. It again may differ tremendously from one species to the other. Population ecology analyses how populations of plants, animals, and other organisms differ over a particular period and how it
interacts with their respective environment. A population is a group of organisms of the same species living in the same area at that time. They are described by:

1. Population size: The number of specimens in the population.

2. Population growth: The way size of the population changes over time.
3. Population density: Number of individuals in a particular area.

2.3.1 Population density is the number of individuals per unit area or volume. In many populations, individuals are not distributed evenly, and the dispersion (pattern of spacing among individuals) can tell a lot about the spacing of resources and interactions between individuals. A clumped dispersion pattern may reflect variations in the physical environment or a clumped food source; a uniform distribution (equal spacing between individuals) is often the result of strong intraspecific competition; random dispersion typically reflects weak interactions among individuals.

2.3.2 Population size

A Biologist cannot count every individual in a population, but it can be accomplished by sampling with a particular methodology. One way to calculate the entire population is by dividing the area and counting each individual residing in that area and finding out the actual range where their number falls. This method works effectively if the samples are representative of the entire population. It won't work well for individuals who are not uniformly present. Another methodology that researchers follow for population estimation of mobile animals is a mark-recapture method. In this process, a certain number of individuals are captured, tagged, and rereleased in the habitat.

2.3.3 Changes in population size

Populations changes in size our time. They get a distinct number of the specimen by immigration and births and specimen with emigration and mortality. Species can have varying reproductive results, life span period, and generation times, which the overall population growth. A life-history trait includes traits that impact births, death, and reproduction. On each extreme of a continuum of life-history strategies are r-selected species (they possess have short generation times, high reproductive potential) and K-selected species (those that have much longer generation time and are long-lived but have low reproductive outputs and low population growth potential as shown in table 2.2.

Table 2.2 Characteristics of r- and K-Selected Species		
Characteristics of r- and K-Selected Species		
Life history feature	r-selected species	K-selected species
Development	Rapid	Slow
Reproductive rate	High	Low
Reproductive age	Early	Late
Body size	Small	Large
Length of life	Short	Long
Competitive ability	Weak	Strong
Survivorship	High mortality of young	Low mortality of young
Population size	Variable	Fairly constant
Dispersal ability	Good	Poor
Habitat type	Disturbed	Not disturbed
Parental care	Low	High

2.3.4 Population growth

A population can increase in multiple ways like, in size, including reproduction and immigration. When a population has sufficient food or nutrients and is not greatly affected by predation, it can grow rapidly in an exponential curve. However, no population can maintain this growth forever; at some point, resources become limiting and slow down population growth (either through lower birth rate or increased birth rate). That population growth model is called logistic growth. The population levels off at the size which the environment can sustain, known as the carrying capacity of the environment. The carrying capacity is a dynamic point that fluctuates with changes in resources availability and predator behavior. Predator abundance often mirrors prey abundance with somewhat of a lag in time.

2.3.5 Limitation of population growth

Population grows at geometric or exponential rates in the presence of unlimited resources. Geometric populations grow through pulsed reproduction. All populations begin exponential growth in favourable habitats. So exponential growth may apply to populations establishing new environments during transient favorable conditions and populations with low initial population density. Geometric populations grow through pulsed reproduction. As resources are depleted, the population growth rate decreases and eventually stops. This is known as logistic growth. The population size at which growth concludes is generally called the carrying capacity (K).

2.3.6 Density Dependent Limitation

Limitations to population growth are density-dependent. Factors influencing growth include disease, competition, and predation. Factors can show either a positive or a negative correlation with regard to population size. With a positive relationship, limiting factors increase with the size of the population and stop the growth rate as population size increases. In a negative relationship, population growth is limited at fewer densities and becomes less stringent as it increases. Density-dependant issues may influence the size of the population by changes in reproduction or survival.

2.3.7 Density Independent Limitation

Issues that lower population growth can be defined as environmental stress, including limitations in food, predation, and other density-dependent factors (Sibley and Hone 2002). Environmental stress affects population growth without considering the density of the population. Density-independent factors like environmental stressors and catastrophe are not influenced by population density change. While the previously mentioned density-dependent issues are often biological, density-independent issues are often abiotic. These density-independent factors include food, pollutants, and climate extremes, which include seasonal cycles such as monsoons. Catastrophic issues impact population growth like fires and cyclones.

The nutrient quality in an environment system affects the performance of an organism to survive, develop and reproduce. Lesser the quality of the nutrients, higher the environmental stress. As for example the freshwater Laurentian Great Lakes, particularly in Lake Erie, the factor limiting algal growth was found to be phosphorus.

2.3.8 Quadrat analysis

A quadrat is a particular area of the community to be evaluated. Quadrats may be of any appropriate size but specifically square, rectangular, or circular. A single quadrat doesn't fulfil the requirements of the researcher, so triplet samples are usually taken.

The sampled community is branched into sub-areas depending upon the topographical aspect and specific physical factors. This type of approach gives a representative sample of the distinguished physical and floristic features of the community, known as stratified random sampling. The collected sample data from various quadrants are summed together and considered to constitute an appropriate sample of the community. Quadrats sampling defines various measures of abundance that can be calculated to find the influence of each species in that particular quadrat. Four major measure of abundance is A. Counts – means a simple number of individuals of a species. B. Cover – the percentage (%) area of the quadrat occupied by any species. C. Density – quantifying the number of specimens of a species per unit area. D. Frequency – the area of quadrats sampled in which the specific species is shown. Density and frequency analysis is then analyzed for every species from the complete data set by adding all of the quadrats. To evaluate the representation of each species relative to the entire community, their relative area cover and relative density and frequency are considered. Relative area cover is the cover of an individual species as a percentage of the total area covered; hence expressed as a percentage. "Importance value" defines the measure of the complete influence of any species in the community. An Importance Value is the combination of the relative cover, relative density, and relative frequency of each species.

2.4 Population ecology of *Ilyoplax sayajiraoi*

2.4.1 Methodology

1. As shown in figure: 2.4, entire area of *Ilyoplax syajiraoi* is divided into 5 segments each at a distance of 200 meter, thus covering 1000 meter of the area horizontally and vertically at a distance of 10 meter. Per segment 1 quadrat is placed.

2. Random sampling was carried out with the help of quadrat sampling technique at predetermined time period every month for one year.

3. Specimens were collected and stored in 10% formalin and brought back to laboratory to carry out various morphological analysis like, sex determination (male/female/ovigerous female/

juvenile), size determination (by measuring carapace width and length) and chela length.

4. Statistical analysis were carried out to get various relationship curves between parameters and seasonal changes in population.

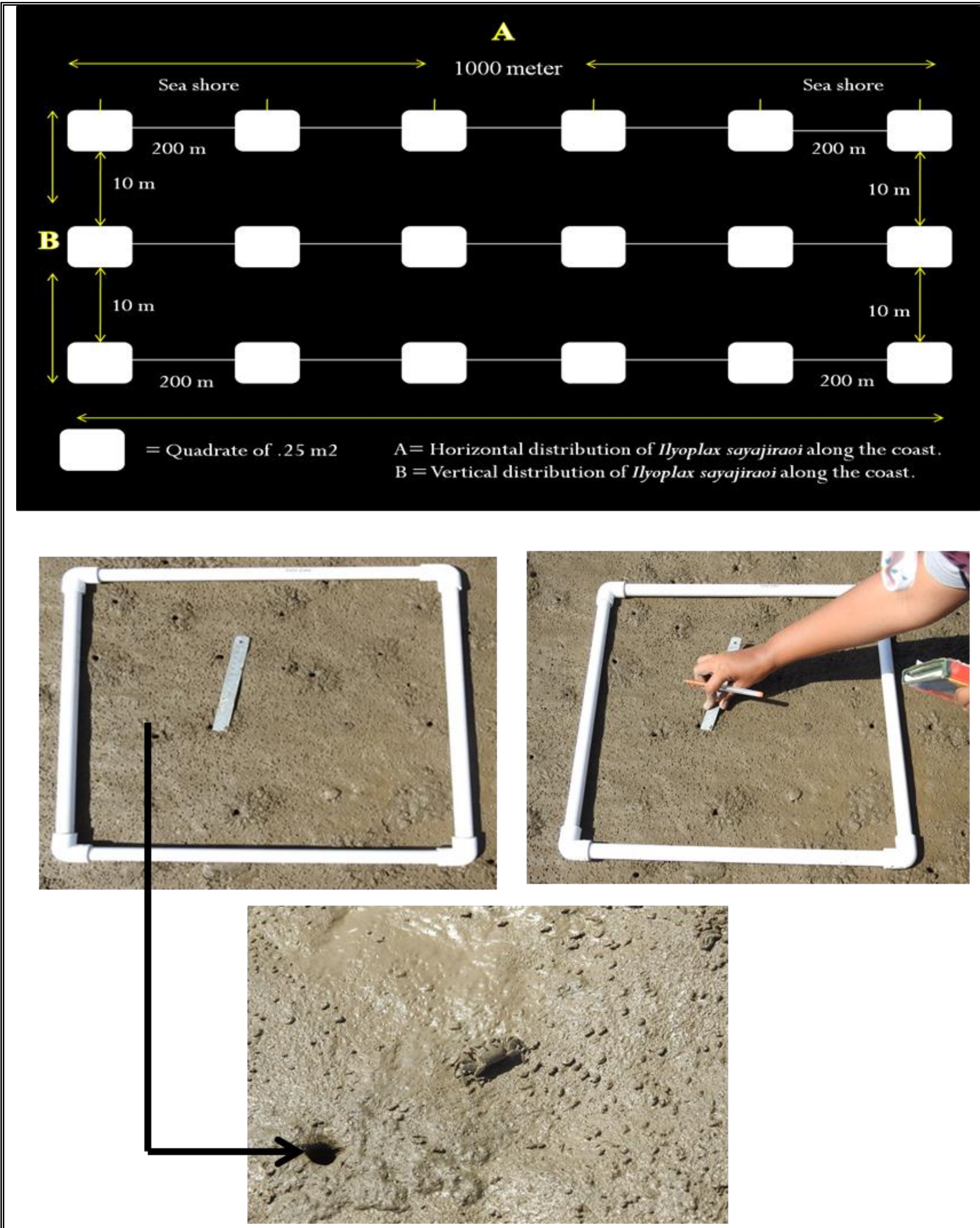


Figure 2.4 Methodology for population ecology

2.4.2 Observations and Results

a Population size and distribution of *Ilyoplax sayajiraoi* (male, female, ovigerous female and juvenile) and sex ratio

Monthly surveys took place from August 2016 to July 2017. Three transects were kept from the lower tidal zone to the higher tidal zone. On each transect, 0.25 m^2 quadrates were kept at a distance of 200 m for 1 km to get crab density. Specimens were collected during low tide by collecting individuals on the surface or gently inserting a garden trowel under the burrow and lifting up until the crab came on the surface. All captured organisms were labeled and stored in formalin for further analysis. Measurements were taken using vernier caliper (± 0.01 mm accuracy) and weigh balance (± 1 mg). The population size structure was analyzed by identification of male/ female/ ovigerous/ juvenile, body weight, carapace width (CW), carapace length (CL), length of males' major cheliped (propodus), and breeding period (Macia et al. 2001; Litulo 2004a). The population structure was studied as a function of the size-frequency distribution of the individuals. Specimens were grouped in 1mm size class intervals, from 4to 12mm CW. For different sets like CW vs. burrow diameter, for which Pearson's coefficient was calculated to establish the relationship between two variables. In ovigerous females, the class interval was 0.5mm from 7 to 11mm. Specimens were grouped in 1mm size class intervals, from 4 to 12mm CW. Males sho0wed an elevated population mark in December and January with a significant decrease in September. Females marked the highest population in August and June, giving the least number in December. Ovigerous females showed the highest significant difference in October, April (with the highest number), and February, September (with the lowest number), as shown in Figure 2.5.

A total of 1139 specimen of *Ilyoplax sayajiraoi* were collected, of which 576 were male, 421 female, and 142 juvenile, as shown in table 2.3.

Table 2.3: Month wise population density of Male-Female crabs (*Ilyoplax sayajiraoi*)

Month	Male	Percentage	Female	Percentage	Sex ratio (Male: Female)	Total
Aug*	36	36.61	62	63.39	0.58	98
Sep*	22	66.67	11	33.33	2.00	33
Oct	52	55.67	42	44.33	1.26	94
Nov	22	44.08	28	55.92	0.79	51
Dec*	28	73.45	10	26.55	2.77	38
Jan	91	65.38	48	34.62	1.89	139
Feb*	56	74.23	19	25.77	2.88	75
Mar*	61	70.00	26	30.00	2.33	87
Apr	44	52.82	39	47.18	1.12	83
May	39	48.34	41	51.66	0.94	80
Jun	71	53.63	62	46.37	1.16	133
Jul*	55	62.84	32	37.16	1.69	87
Total	576	57.76	421	42.24	1.37	997

***Significant deviation from the expected 1:1 proportion.**

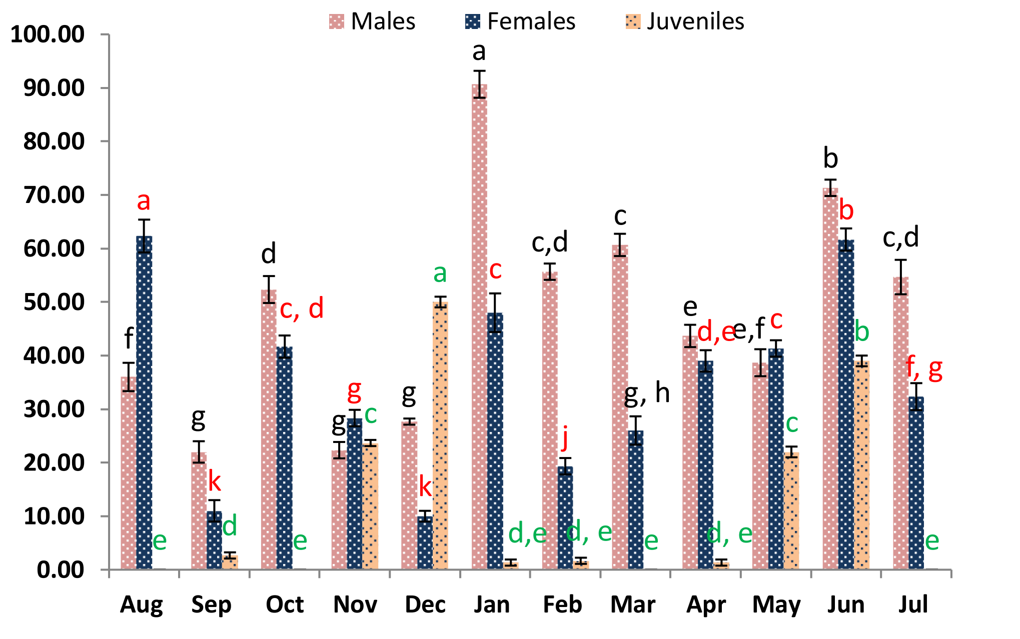


Figure 2.5 ***Ilyoplax sayajiraoi*, yearly size frequency distribution of all individuals sampled at Kamboi, GOKh, from August 2016 to July 2017. Error bars in graph represent standard deviation (n=3). Letters a, b, c…k represent significant difference at p<0.05 between the same sample with respect to months. (Black color letter on bar denotes male whereas red and green color represent female and juvenile respectively).**

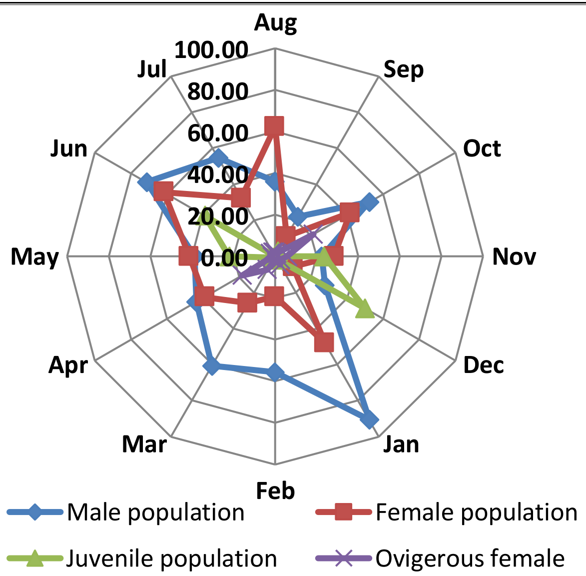


Figure 2.6 Radar diagram for population of male, female, juvenile and ovigerous female in accordance to month

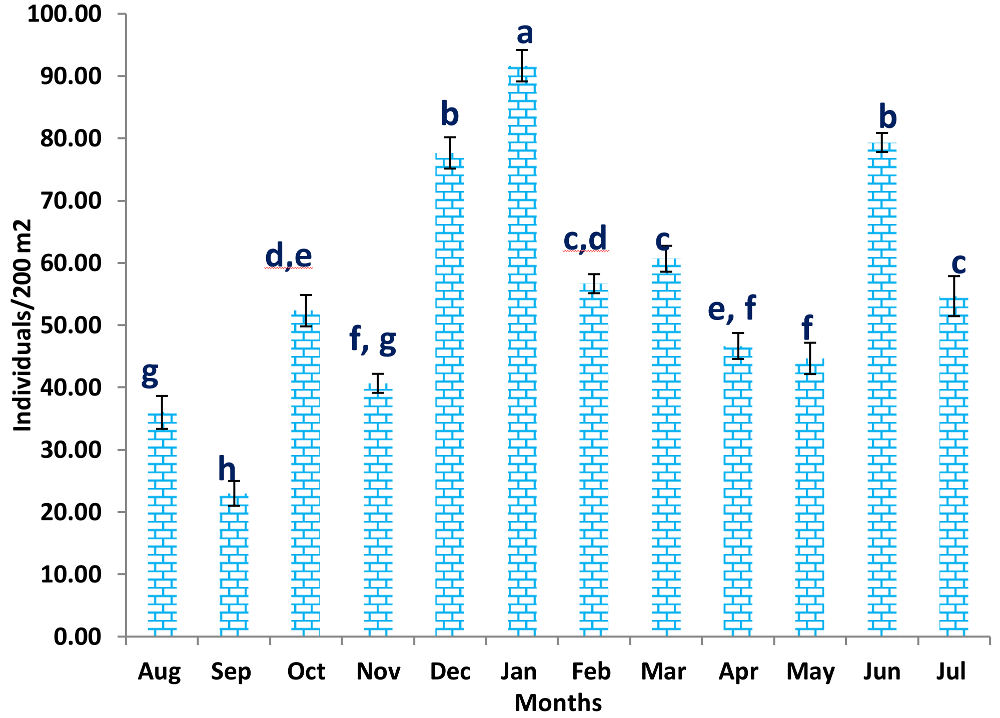


Figure 2.7 *Ilyoplax sayajiraoi,* yearly size frequency distribution of male sampled at Kamboi, GOKh, from August 2016 to July 2017. Error bars in graph represent standard deviation (n=3). Letters a, b, c…h represent significant difference at $p<0.05$ between the same sample with respect to months.

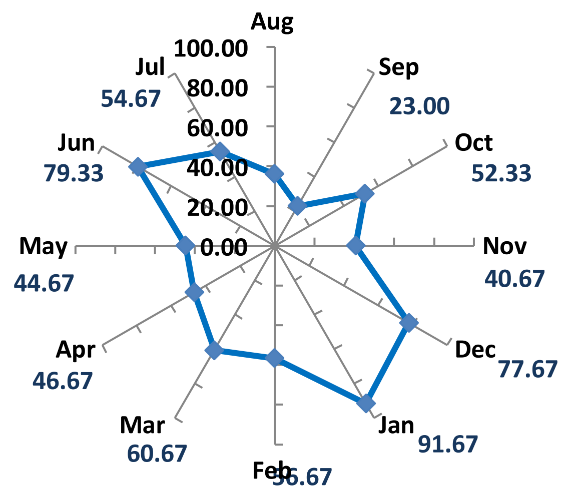


Figure 2.8 Radar diagram for population of male in accordance to month

Table 2.4 Correlation analysis showing monthwise population of males												
	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**
Aug	1											
Sep	-.756*	1										
Oct	-.300	-.397	1									
Nov	0.000	-.655	.954**	1								
Dec	.676	.993**	.500	.737*	1							
Jan	.901**	-.397	-.684	-.434	.289	1						
Feb	.866**	-.327	-.737*	-.500	.217	.997**	1					
Mar	.999**	-.721	-.350	-.052	.636	.923**	.891**	1				
April	.908**	.961**	.127	.419	.923**	.636	.577	.885**	1			
May	.901**	-.397	-.684	-.434	.289	1.000**	.997**	.923**	.636	1		
June	.866**	.982**	.217	.500	.954**	.564	.500	.839**	.996**	.564	1	
July	.764*	-.156	.845**	-.645	.041	.968**	.984**	.797*	.423	.968**	.339	1

**** Correlation is significant at the 0.01 level (2 –tailed). * Correlation is significant at the 0.05 level (2-tailed).**

Male population in all seasons was in proper proportion, total population of male comprised of 576 specimens. They dominated the whole population distribution amongst females, Juveniles and ovigerous females. Thus sex ratio gave a biased ratio towards male population. Highest population was seen in the month of January having 90 males per 200 m^2 area followed by June having 80 individuals per 200 m^2 area. Lowest population was observed in the month of September having approximately 22 individuals per 200 m^2 area followed by November having 40 approximate individuals per 200 m^2 area. There was no particular modal peak observed in male population distribution.

Male population was 0.3 times greater than female population. Most correlated months were December and June, February and March, April and May, August and November. The month of January and September were least correlated with other months.

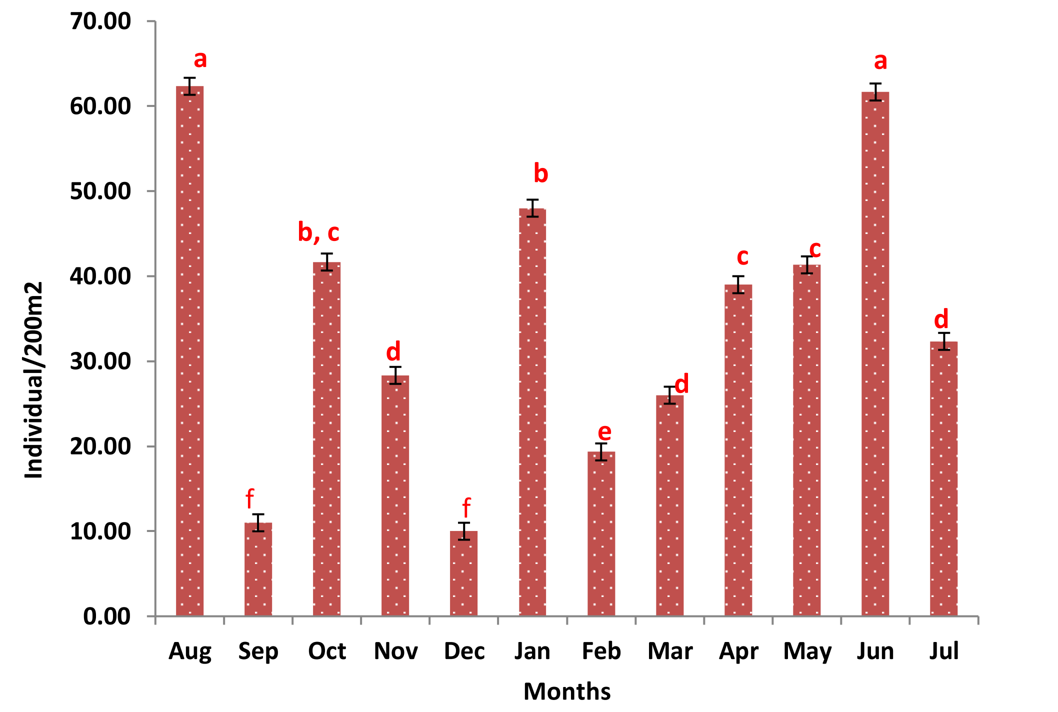


Figure 2.9 *Ilyoplax sayajiraoi,* yearly size frequency distribution of females sampled at Kamboi, GOKh, from August 2016 to July 2017. Error bars in graph represent standard deviation (n=3). Letters a, b, c...f represent significant difference at p<0.05 between the same sample with respect to months.

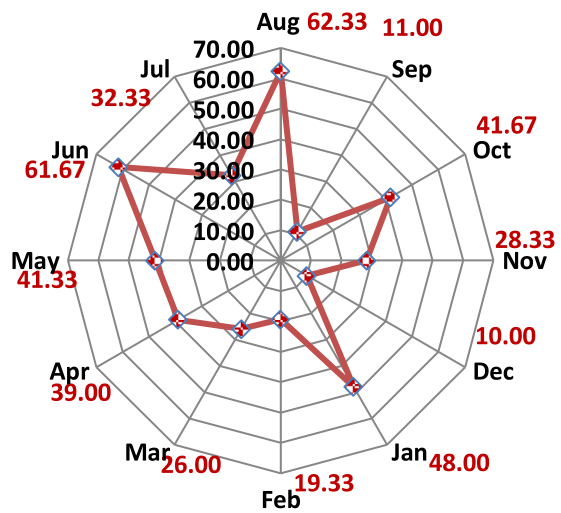


Figure 2.10 Radar diagram for female population distribution in accordance to the month

Table 2.5 Correlation analysis showing monthwise population of females

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July
Aug	1											
Sep	.327	1										
Oct	.577	.961**	1									
Nov	.500	.982**	.996**	1								
Dec	-.327	-1.000**	-.961**	-.982**	1							
Jan	.545	.971**	.999**	.999**	-.971**	1						
Feb	.500	.982**	.996**	1.000**	-.982**	.999**	1					
Mar	.990**	.189	.454	.371	-.189	.419	.371	1				
April	.982**	.500	.721	.655	-.500	.693	.655	.945**	1			
May	.500	.982**	.996**	1.000**	-.982**	.999**	1.000**	.371	.655	1		
June	.577	.961**	1.000**	.996**	-.961**	.999**	.996**	.454	.721*	.996**	1	
July	.954**	.596	.795*	.737*	-.596	.771	.737	.901**	.993**	.737*	.795*	1

**** Correlation is significant at the 0.01 level (2 –tailed). * Correlation is significant at the 0.05 level (2-tailed).**

Female population in all seasons was less in proportion compared to males. Thus sex ratio gave a biased ratio towards male population. Highest population was seen in the month of August having 65 males per 200 m^2 area followed by June having 62 individuals per 200 m^2 area. Lowest population was observed in the month of December having approximately 9 individuals per 200 m^2 area followed by September having 11 approximate individuals per 200 m^2 area. There was no particular modal peak observed in female population distribution.

Female population was 0.3 times lesser than male population. Most correlated months were August and June, October and January, April and May, July and November, September and December. The month of February was least correlated with other months.

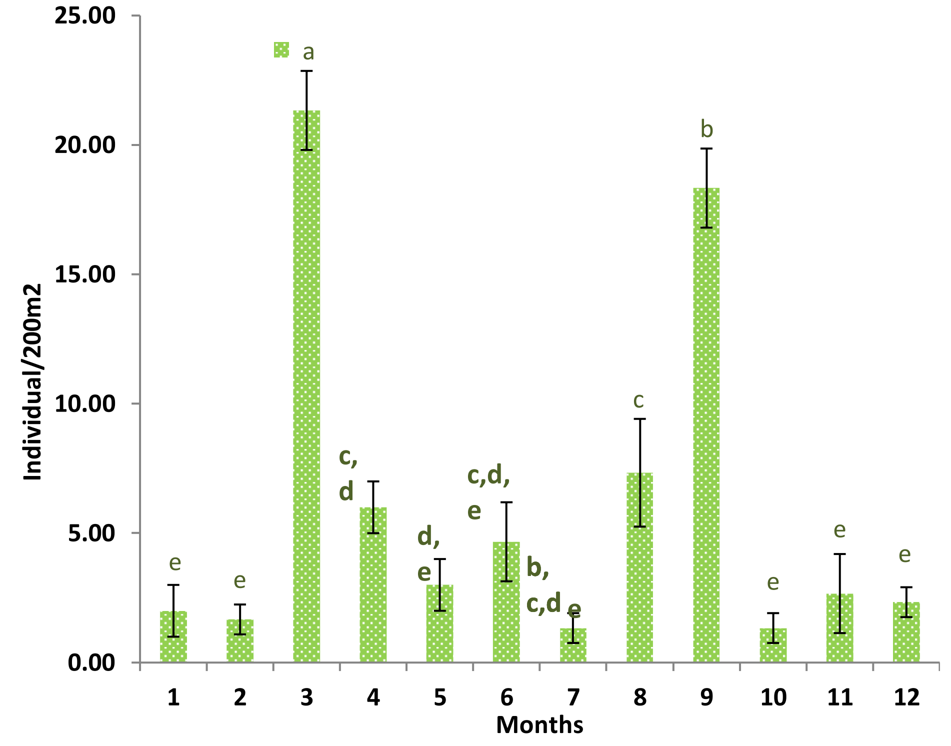


Figure 2.11 *Ilyoplax sayajiraoi,* yearly size frequency distribution of ovigerous females sampled at Kamboi, GOKh, from August 2016 to July 2017. Error bars in graph represent standard deviation (n=3). Letters a, b, c...f represent significant difference at p<0.05 between the same sample with respect to months.

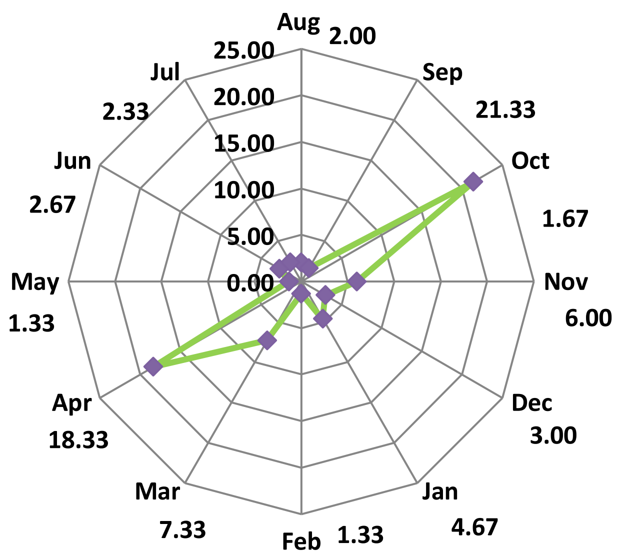


Figure 2.12 Radar diagram for ovigerous population distribution

Table 2.6 Correlation analysis showing monthwise population of Ovigerous female

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July
Aug	1											
Sep	0.000	1										
Oct	-.655*	.756*	1									
Nov	.500	.866**	.327	1								
Dec	1.000**	0.000	-.655*	.500	1							
Jan	-.655*	-.756*	-.143	-.982**	-.655*	1						
Feb	-.866**	.500	.945**	0.000	-.866**	.189	1					
Mar	.961**	-.277	-.839**	.240	.961**	-.419	-.971**	1				
April	-.982**	.189	.786*	-.327	-.982**	.500	.945**	-.996**	1			
May	0.000	-1.000**	-.756*	-.866**	0.000	.756*	-.500	.277	-.189	1		
June	.982**	-.189	-.786*	.327	.982**	-.500	-.945**	.996**	-1.000**	.189	1	
July	0.000	-1.000**	-.756*	-.866**	0.000	.756*	-.500	.277	-.189	1.000**	.189	1

** Correlation is significant at the 0.01 level (2 –tailed). * Correlation is significant at the 0.05 level (2-tailed).

Ovigerous female population in all seasons was in very less proportion. It gave a bimodal population growth that gave rise to overall population throughout the year. Highest population was seen in the month of January having 90 males per 200 m^2 area followed by June having 80 individuals per 200 m^2 area. Lowest population was observed in the month of September having approximately 22 individuals per 200 m^2 area followed by November having 40 approximate individuals per 200 m^2 area. There was no particular modal peak observed in male population distribution.

Male population was 0.3 times greater than female population. Most correlated months were December and June, February and March, April and May, August and November. The month of January and September were least correlated with other months

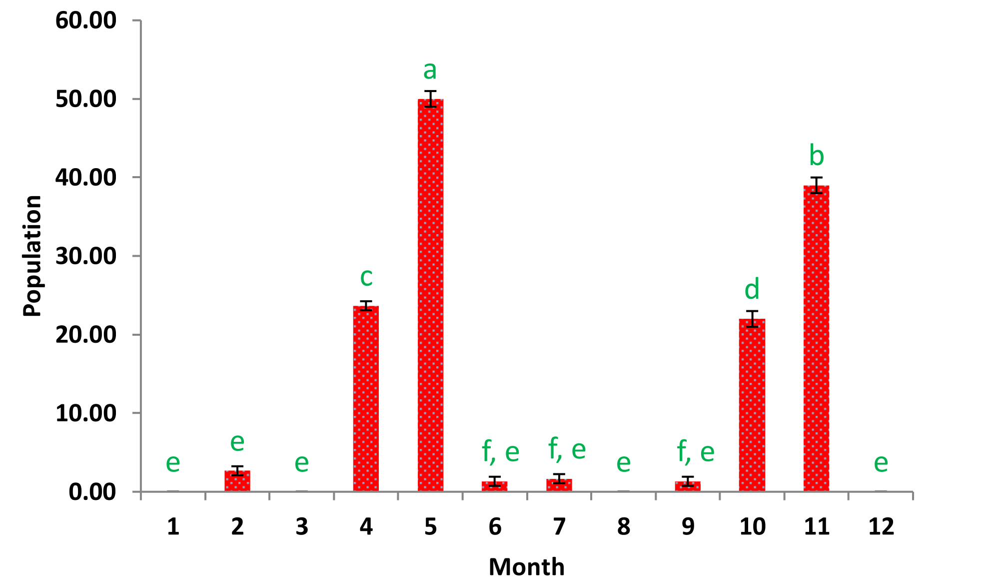


Figure 2.13 *Ilyoplax sayajiraoi*, yearly size frequency distribution of juveniles sampled at Kamboi, GOKh, from August 2016 to July 2017. Error bars in graph represent standard deviation (n=3). Letters a, b, c…f represent significant difference at p<0.05 between the same sample with respect to months.

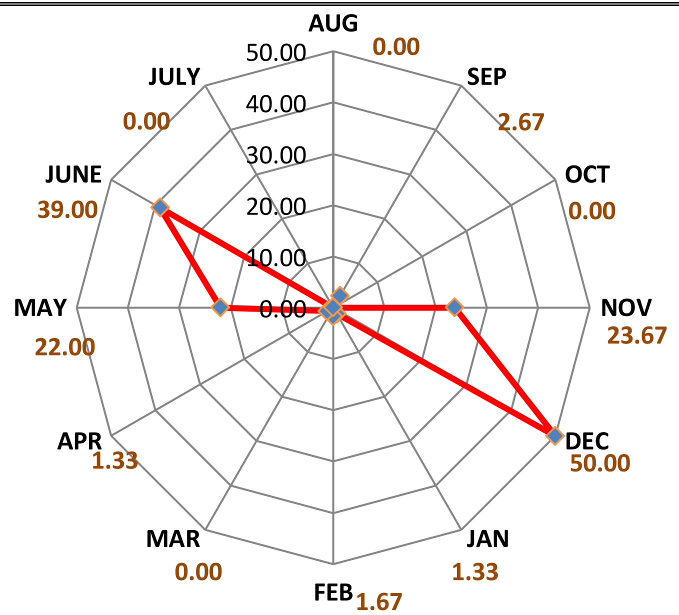


Figure 2.14 Radar diagram for juveniles population distribution

Sex ratio

Male: female ratio was 10:13, giving variability in the expected ratio of 1:1. There is a significant difference between male-female populations as the Pearson correlation is 0.189 and notably biased towards males. December is significantly different from all other months showing negligible correlation. All months except September, December, August, and February show a significant correlation, α =0.05 (Figure 2.15)

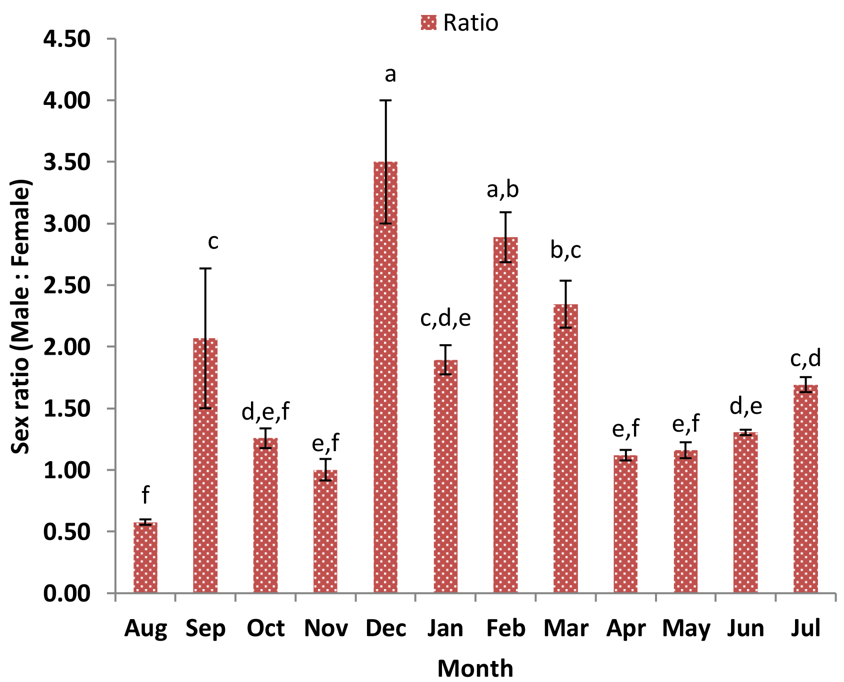


Figure 2.15 Month wise population ratios of male & female. Error bars represent standard deviation (n=3). Letters a, b, c…f represent significant difference at p<0.05 between the sample with respect to months.

b. Size and carapace width

Size range within-population statistics was 4.00-11.37 mm CW (mean ± SD: 7.68±2.0) for males, 4.00-10.78 mm (mean ± SD: 7.39±2.0) for non-ovigerous females and 7.0-10.78 mm (mean ± SD: 8.94±0.80) for ovigerous females. The average size of *Ilyoplax sayajiraoi* males was significantly different from females. Specimens showing carapace width 3.9 mm and below were counted under juveniles. Monthly size-frequency distribution gave a uni-modal structure where highest males concentrated in carapace width range, 7.0-7.9, and females in 8.0-8.9 (Figure 2.16). Maximum ovigerous female were present in class 8-8.9 mm (Figure 2.16). Ovigerous female and juvenile recruitment showed a bimodal distribution pattern for maintaining the overall size of the population, as shown in Figure 2.11 and Figure 2.13.

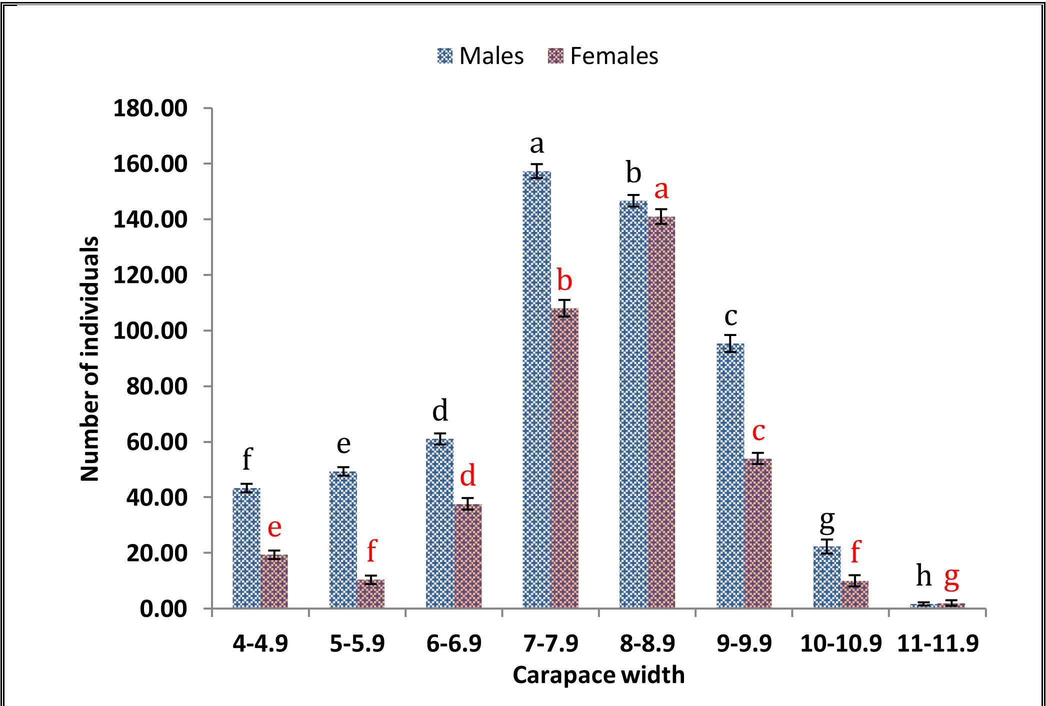


Figure 2.16 *Ilyoplax sayajiraoi,* number of males and females falling in different range of carapace width. Error bars in graph denote standard deviation (n=3). Letters a, b, c...h represent significant difference at p<0.05 between the sample with respect to carapace width. Letters on bar with black color indicate male whereas red indicate female.

c. Distribution of *Ilyoplax sayajiraoi* on mudflats of Kamboi based on physical characteristic of sediment

1. Temperature

In LTZ sediment temperature does not go beyond 31°C. In this zone highest population of *Dotilla* species is seen followed by *Ilyoplax* species and at last *Uca* species (Figure 2.17). In MTZ temperatures are slightly higher than LTZ; *Ilyoplax* requires optimum temperatures to flourish in a particular area. Thus highest population of *Ilyoplax* is seen here followed by *Uca* and then *Dotilla* (Figure 2.18). In UTZ temperatures are highest of all the three zones *Uca* species numbers are highest here followed by *Ilyoplax* and a last *Dotilla* (Figure 2.19).

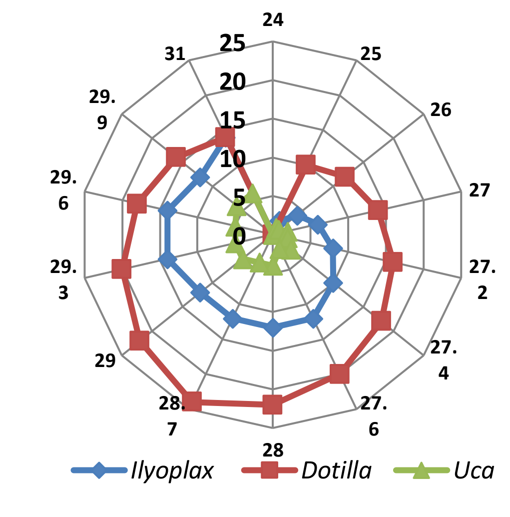


Figure 2.17 Radar diagram of species vs. temperature (LTZ)

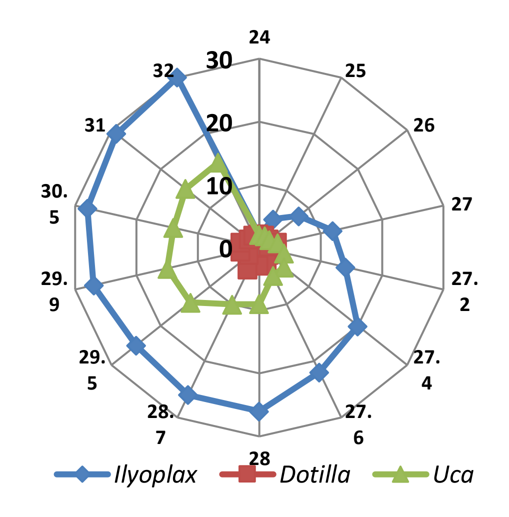


Figure 2.18 Radar diagram of species vs. temperature (MTZ)

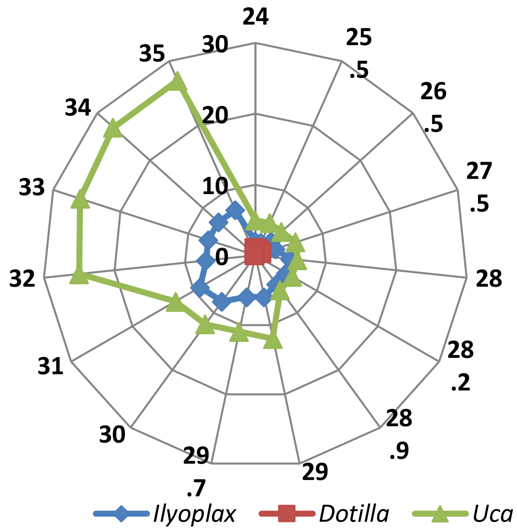


Figure 2.19 Radar diagram of species vs. temperature (UTZ)

2. pH

In LTZ pH of sediment does not go beyond 6.7. In this zone highest population of *Dotilla* species is seen with lowest pH range followed by *Ilyoplax* species and at last *Uca* species (Figure 2.20). In MTZ pH is slightly towards neutral that is optimum for *Ilyoplax* to flourish. Thus highest population of *Ilyoplax* is seen here followed by *Uca* and then *Dotilla* (Figure 2.21). In UTZ pH goes slightly towards alkalinity with highest population of *Uca* followed by *Ilyoplax* and a last *Dotilla* (Figure 2.22).

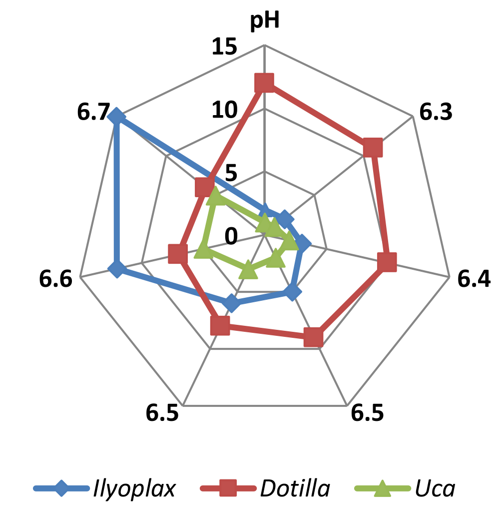


Figure 2.20 Radar diagram of species vs. pH (LTZ)

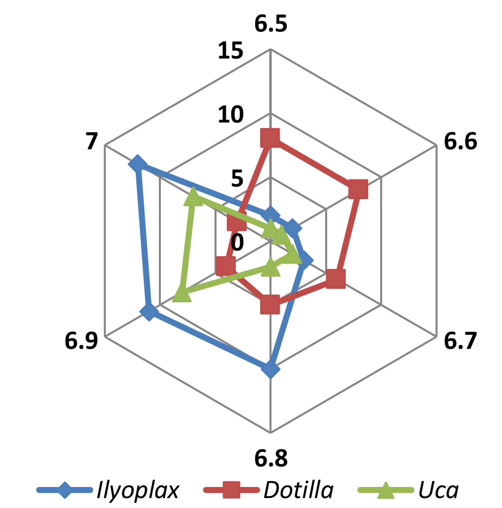


Figure 2.21 Radar diagram of species vs. pH (MTZ)

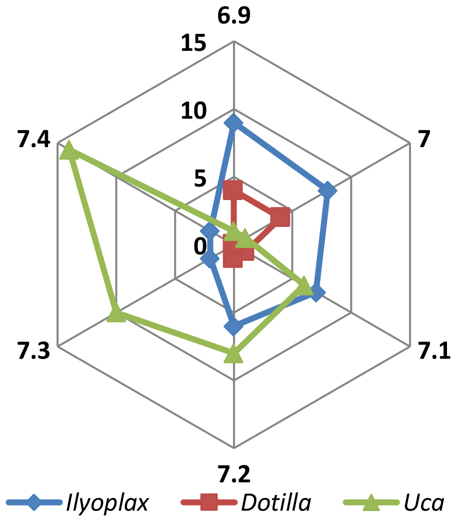


Figure 2.22 Radar diagram of species vs. pH (UTZ)

3. Per cent Moisture content (%)

In LTZ highest moisture content (60%) is observed that favours *Dotilla* species followed by *Ilyoplax* and *Uca* (Figure 2.23). In MTZ maximum moisture content is 30% that favours growth of *Ilyoplax* followed by *Uca* and *Dotilla* (Figure 2.24). In UTZ sediment has lowest moisture content, *Uca* cheliped are strongest to build burrow in such conditions so they are highest in number followed by *Ilyoplax* and *Dotilla* (Figure 2.25).

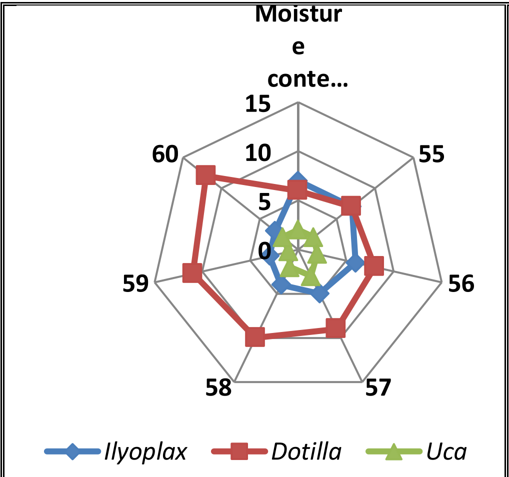


Figure 2.23 Radar diagram of species vs. moisture content (%) (LTZ)

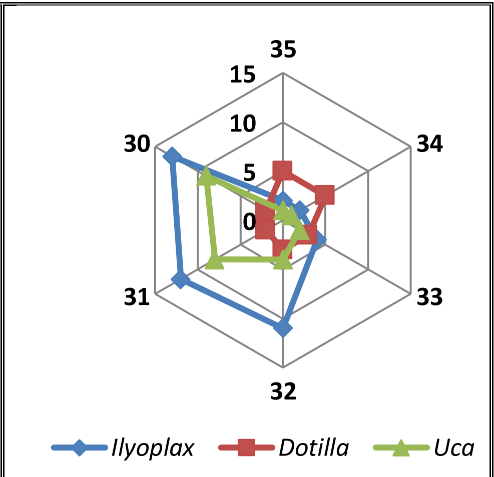


Figure 2.24 Radar diagram of species vs. moisture content (%) (MTZ)

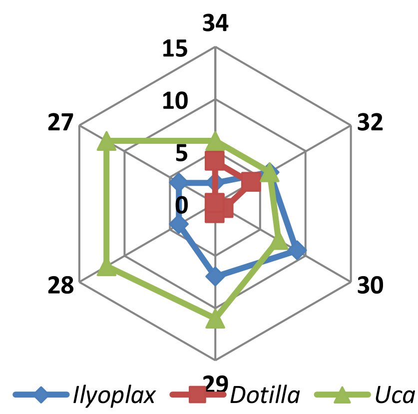


Figure 2.25 Radar diagram of species vs. moisture content (UTZ)

4. Sediment composition

Dotilla species is seen highest with sediment of highest silt content followed by *Ilyoplax* and *Uca* (Figure 2.26). *Ilyoplax* is seen large numbers with sediments having highest percentage of sand followed by *Uca* and *Dotilla* (Figure 2.27). *Uca* is seen maximum with sediment having highest gravel content followed by *Ilyoplax* and *Dotilla* (Figure 2.28).

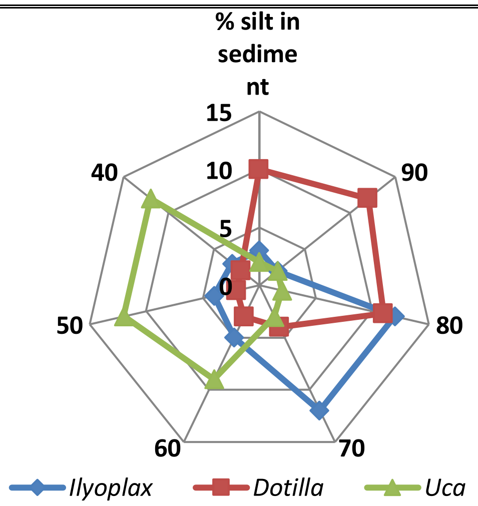


Figure 2.26. Radar diagram for % silt composition in sediment and species distribution (LTZ)

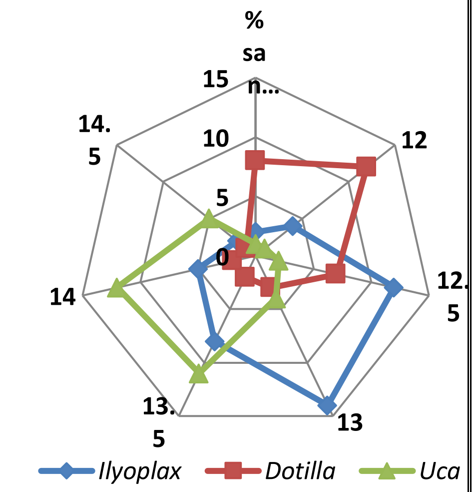


Figure 2.27 Radar diagram for % sand composition in sediment and species distribution (MTZ)

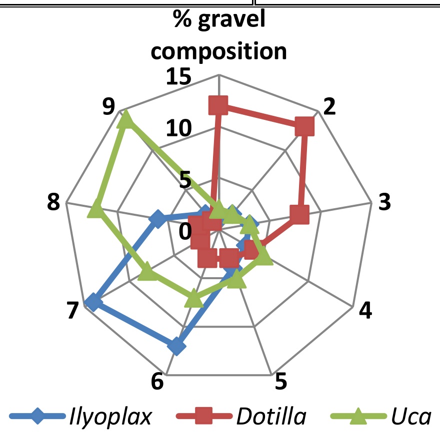


Figure 2.28 Radar diagram for % gravel composition in sediment and species distribution (UTZ)

Table 2.7 Relation between physical characteristics of sediments and species						
	LTZ		MTZ		UTZ	
	Regression equation	R2	Regression equation	R2	Regression equation	R2
Sediment temperature						
Ilyoplax sayajiraoi	y = 2.2447x - 53.054	0.9	y = 3.8783x - 89.518	0.87	y = 0.5748x -11.483	0.6803
Dotilla blanfordi	y = 2.1071x - 42.511	0.4	y = 0.0375x + 1.5159	0.02	y = -0.1067x + 3.4142	0.5257
Uca annuplies	y = 0.9781x - 23.941	0.9	y = 2.2256x - 54.387	0.88	y = 2.6073x - 64.079	0.8376
Sediment pH						
Ilyoplax sayajiraoi	y = 2.2143x - 2.4286	0.9	y= 0.0444x + 6.5278	0.81	y = -x + 13	1
Dotilla blanfordi	y = -13x + 93.5	0.6	y = -x + 13	1	y = -0.2x + 7.75	0.9143
Uca annuplies	y = 10x - 62.286	0.6	y= 0.75x - 0.2857	0.9	y = 0.1147x + 6.8824	0.8521
Salinity						
Ilyoplax sayajiraoi	y = -0.25x + 11.083	0.2	y = 0.1136x + 38.451	0.17	y = 0.7143x + 2.3333	0.169
Dotilla blanfordi	y = -0.6667x + 40	0.2	y = 0.3529x + 38.588	0.09	y = 0.2857x + 39.143	0.0714
Uca annuplies	y = 0.3529x + 38.353	0.1	y = 0.1491x + 38.677	0.15	y = 0.2051x + 38.282	0.2051
Moisture content						
Ilyoplax sayajiraoi	y = 3.9423x + 48.904	0.9	y = 0.2096x + 1.8357	0.91	y = 3x + 18	0.6857
Dotilla blanfordi	y = 0.1854x - 2.3227	0.9	y = 3.5385x - 4.7507	0.92	y = 0.2286x - 4.7143	0.9143
Uca annuplies	y = 0.2346x - 7.2231	0.9	y = 0.3371x - 4.7507	0.96	y = 2.5x - 35	1

2.4.3 Discussion

A. Population size and distribution of *Ilyoplax sayajiraoi* (male, female, ovigerous female and juvenile) and sex ratio

Monthly size analysis showed uni-modal and bi-modal distribution. Such patterns may have attributed to migration, differential mortality, and growth rates (Diaz and Conde 1989; Yamaguchi 2001; Colpo and Negreiros-Fransozo 2004). Ovigerous female and juvenile recruitment showed a bimodal distribution pattern for maintaining the overall size of the population. A low population was seen in April and May; a significant increase in temperature gives rise to harsh environmental conditions for crabs to survive. The maximum surface temperature observed during that period was 40°C, and burrow temperature was 34°C. Juvenile recruitment was outrageous in winter and monsoon as overall temperatures were low and prohibitive in the summer season.

The sex ratio differed significantly from the expected value of 1:1, and ratio obtained was 10:13. This shows male population is 0.3 times more than male population. The unbalanced sex-ratio in the population was reported as reflection of different foraging behaviour between males and females with males as more active grazers looking for food away from shelter whereas females tend to graze near their shelter. This could make males more exposed to sampling (Arab et al., 2015; Abele et al., 1986). This suggests that male population is more active and mobile as compared to female population which is comparatively inactive. This makes male highly viable and can easily be handpicked.

Breeding increases mortality rates in females which can also affect the sex ratio and reduces overall population of female.

Energy allocation to reproduction at the expense of growth in females gives sexual dimorphism where males reaching larger size than females (Flores and Negreiros-Fransozo 1999; Johnson 2003). In 2016 a similar study was carried out on *Callinectes sapidus* (blue crabs), showing a substantially more male-biased ratio; as females mature asynchronously, males mature at a smaller size than females; thus female maturation period is prolonged, and the male maturation period is diminutive. Consequently, during sampling at any period, male individuals will always overpower the female individuals. The calculation ratio is challenging because it is difficult to tell the difference between females that will mature on their successive moult from those that will need multiple moults to mature (Rains et al., 2016).

The species' population is restricted to a particular area and requires specific habitat to perish, making species *Ilyoplax sayajiraoi* highly habitat-specific, limiting its distribution. In the present scenario, the Gulf of Khambhat is bordered by many industries. A slight change in *I.sayajiraoi's* habitat by pollutant influx from industries will affect its population and distribution. Thus population structure of this species will act as baseline data for such researches establishing it as a bio-indicator.

B. Size and carapace width

A crab with size less than 4mm is considered juvenile as specimens have no well-developed sex organs which can differentiate them into male and female. Average size of *Ilyoplax sayajiraoi* male is (mean ± SD: 7.68±2.0). Highest number of males falls under the range 7-7.9mm and 8-8.9mm.Suggesting maximum males are in this range below which number decreases drastically, as capturing of these crabs becomes difficult for this range. Above this range number does not reduce drastically as it can be handpicked easily. Average size of

Ilyoplax sayajiraoi female is (mean ± SD: 7.39±2.0) and for ovigerous female is (mean ± SD: 8.94±0.80). Average range for carapace width of ovigerous female is greater than males and non-ovigerous females because it has to carry complete egg sac including all eggs within. This makes ovigerous females more morphologically larger than others.

C. Distribution of *Ilyoplax sayajiraoi* on mudflats of Kamboi based of physical characteristic of sediment

Distribution of species is temperature dependent as in LTZ temperature of sediment is lowest which favours increase in population of *Dotilla* species. *Ilyoplax* species requires optimum temperature and thus settles in MTZ. *Uca* species is strongest of all the three species and thus it can resist maximum temperature and flourishes at UTZ.

Dotilla cannot resist high temperature and thus in MTZ and UTZ its population decreases tremendously. *Dotilla* prefers soft sediment so that it can easily build its burrows as this species is not morphologically strong. Thus maximum numbers of *Dotilla* species are observed in LTZ. *Uca* is comparatively a strong species and thus it can dig hard surfaces. Maximum *Uca* species are seen in UTZ.

Abundance of crab is a factor of characteristic feature of sediment properties. According to the table 2.7 pH and temperature shows high correlation with values more than 0.5. Salinity does not change much in three zones (LTZ, MTZ, UTZ) so regression values are not above 0.5 showing no change with salinity content. Composition of gravel is lowest in LTZ, medium in MTZ and highest in UTZ which can be correlated with species population for example, highest population of *Dotilla* in LTZ, *Ilyoplax* in MTZ and *Uca* in UTZ. This is because *Dotilla* and *Ilyoplax* can hardly dug sediment having higher gravel content.

Thus where silt concentration is present their distribution is also higher. Whereas *Uca* can dig harder sediments so their population is higher in sediments with more gravel concentration.