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Original Article

The distribution and population ecology of semaphore crab *Ilyoplax sayajiraoi* Trivedi, Soni, Trivedi and Vachhrajani 2015, on mud flat region of Gulf of Khambhat, Gujarat, India

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Abstract
The semaphore crab *Ilyoplax sayajiraoi* is a newly discovered species distributed in the Gulf of Khambhat, Gujarat, India. Consequently, almost no information is available regarding its population structure. The distribution of species is limited to upper most reaches of the gulf and thus any alteration in the habitat will eventually affect its population. Studies on the population structure of *I. sayajiraoi* will provide baseline data for future studies and probably, it has potential to serve as a bioindicator species. Morphometric measurements of the carapace (width and length), cheliped and body weight were measured for specimens, collected monthly. The growth was not isometric, demonstrating a significant difference in carapace of males and females, giving sexual dimorphism. Relationship established between carapace width and weight indicate that species is allometric in nature. Sex ratio was 1.3 : 1 (M : F). Ovigerous female and juvenile recruitment showed a bimodal distribution pattern for maintaining the overall size of population.

Keywords: Dotillidae; Gulf of Khambhat; *Ilyoplax sayajiraoi*; population ecology; semaphore crab

1 | INTRODUCTION

In terms of abundance, biomass, and species richness, macro-invertebrates are the most important wetland-dependent fauna in freshwater and marine ecosystems (Bedford *et al.* 2001). Crustaceans are one of the macro-invertebrates that form majority among all other species (Levin 2013). They exhibit a fundamental role in transferring energy to marine and terrestrial habitats, as organisms of higher tropic levels consume them (Lee 1998; Hartnoll *et al.* 2002). Crab *Ilyoplax sayajiraoi* of the family Dotillidae is a newly discovered crustacean distributed on intertidal mudflat habitat (Trivedi *et al.* 2015). Distribution pattern and population structure studies are generally carried out as a part of ecological studies (Fielder 1970; Yamaguchi and Tanaka 1974; Wada 1981; Clayton and Al-Kindi 1998). Similar studies have been carried out on genus *Scopimera* (e.g. Silas and Sankarankutty 1967; Fielder 1971; Wada 1976, 1983a, 1983b). Population structure has been evaluated by several methods that include size-frequency distributions, sex ratio, juvenile recruitment and reproductive season (Thurman 1985; Diaz and Conde 1989; de Arruda Leme and Negreiros-Fransozo 1998; Yamaguchi 2001).

In the present study, we investigated the population structure and the relationships between various morphometric characters (carapace width / length and body weight) of *I. sayajiraoi* at the Gulf of Khambhat. The study outcomes are expected to help in the sustainable management of the crab species.

2 | METHODOLOGY

The Gulf of Khambhat, situated between Saurashtra peninsula and the mainland Gujarat, is known for its extreme tides and variation in average heights (Figure 1). It is 70 km wide at its mouth and about 18 km wide at the extreme end near lower estuarine region of Mahisagar River. The mudflats of Kamboi, located on the upper reaches of the Gulf, were selected as sampling area. The climate of this area is tropical and the annual water temperature varies from 25 to 39°C.

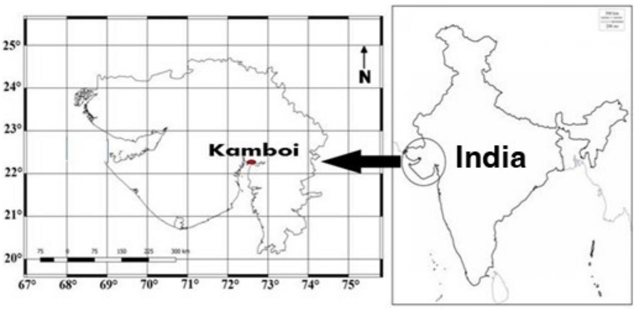

FIGURE 1 Map of the study area, Kamboi, Gujarat.

Monthly surveys were carried out from August 2016 to July 2017. Three transects were laid from the lower tidal zone to the higher tidal zone at a distance of 1 km each. On each transect, 0.25 m^2 quadrates were fixed at a distance of 50 m each. Specimen were collected during low tide by collecting individuals on the surface or gently inserting a garden trowel under the burrow and lifting the sediments upwards until the crab came out on the surface. All captured organisms were labelled and stored in formalin for further analysis. Measurements were taken using Vernier calliper (± 0.01 mm accuracy) and weigh balance (± 1 mg). The population size structure was analysed by identification of male / female / juvenile, body weight, carapace width (CW), carapace length (CL), length of males' major cheliped (propodus) following standard literature (Macia *et al.* 2001; Litulo 2004).

The population structure was studied as a function of size frequency distribution of the individuals. Specimens were grouped in 1 mm size class intervals; from 4 to 12mm CW.

Statistical analysis was performed using SPSS software (version 20). One-way ANOVA followed by Tukey's test was incorporated to detect the significance of difference ($p < 0.05$) between various parameters. Pearson correlation was used to assess the relationship between population growth of male, female and juvenile.

3 | RESULTS

3.1 Population distribution

A total of 1139 specimen of *I. sayajiraoi* were collected comprising of 576 male, 421 female and 142 juvenile (sex unidentified; Table 1). Males showed 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) (Figure 2).

TABLE 1 Month-wise population density of *Ilyoplax sayajiraoi*.

Month	Male		Female		Sex ratio (M:F)	Total
	n	%	*n*	%		
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, (Pearson coefficient was 0.189).

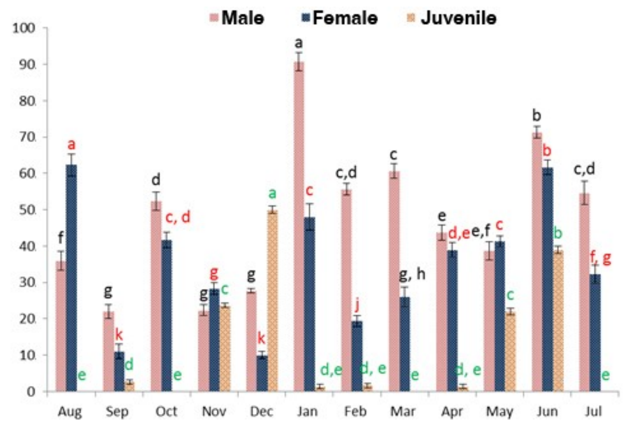

FIGURE 2 Size frequency distribution of *Ilyoplax sayajiraoi* individuals sampled at Kamboi, from August 2016 to July 2017. Error bars in graph represent standard deviation ($n = 3$). Columns with different letters on the top were significantly different ($p < 0.05$) between the same sample (male, female and juvenile) with respect to months.

3.2 Sex ratio

Sex ratio was recorded as 1.3 : 1 (M : F), 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 ($p < 0.05$; Figure 3).

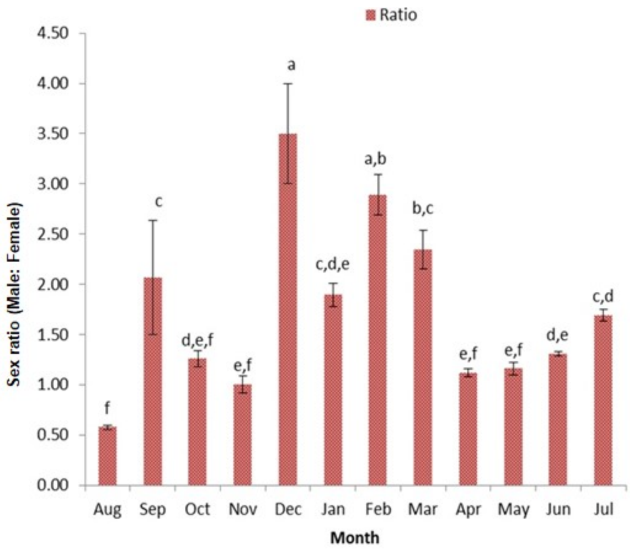

FIGURE 3 Month wise population ratios of male and female. Error bars in graph represent standard deviation (n = 3). Columns with different letters on the top were significantly different ($p < 0.05$) among months.

3.3 Size and carapace width (CW)

Size range within-population statistics was 4.00 – 11.37 mm CW (mean ± SD: 7.68 ± 2.0 mm) for males, 4.00 – 10.78 mm (7.39 ± 2.0 mm) for non-ovigerous females and 7.0 – 10.78 mm (8.94 ± 0.80 mm) for ovigerous females. The average size of males was significantly different from females. Specimens with CW of 3.9 mm and below were counted as juveniles. Monthly size-frequency distribution gave a unimodal structure where the highest males concentrated in CW range, 7.0 – 7.9 mm, and females in 8.0 – 8.9 mm (Figure 4). Maximum ovigerous female were present in class 8-8.5 mm (Figure 5). Ovigerous female and juvenile recruitment showed a bimodal distribution pattern for maintaining the overall size of the population (Figures 2 and 6).

4 | DISCUSSION

The sex ratio obtained (1.3 : 1) differed significantly from the expected value of 1 : 1. 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.

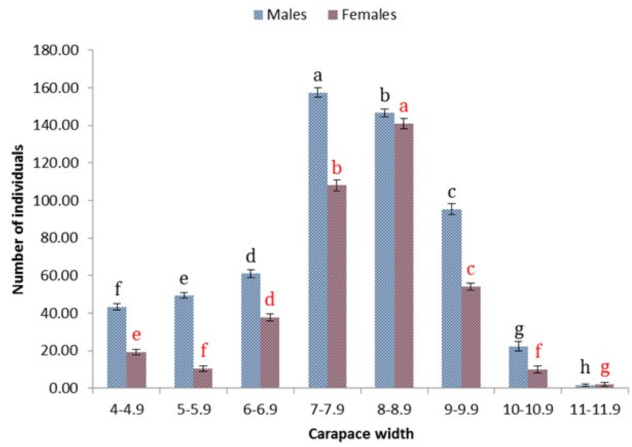

FIGURE 4 *Ilyoplax sayajiraoi*, number of males and females in different range of carapace width. Error bars denote standard deviation (n = 3). Columns with different letters on the top were significantly different ($p < 0.05$) between the sample with respect to carapace width.

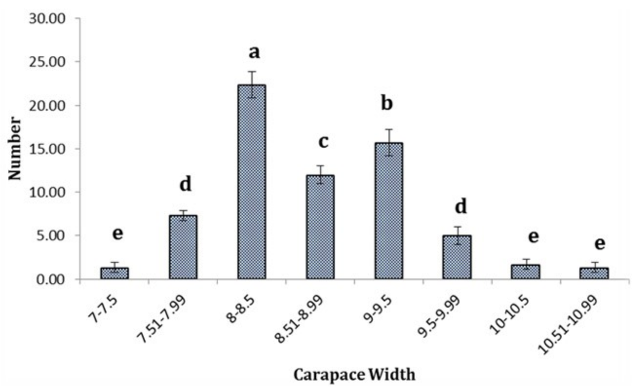

FIGURE 5 Number of ovigerous females belonging to carapace width categories. Error bars denote standard deviation (n = 3). Columns with different letters on the top were significantly different ($p < 0.05$) between the ovigerous female with respect to carapace width.

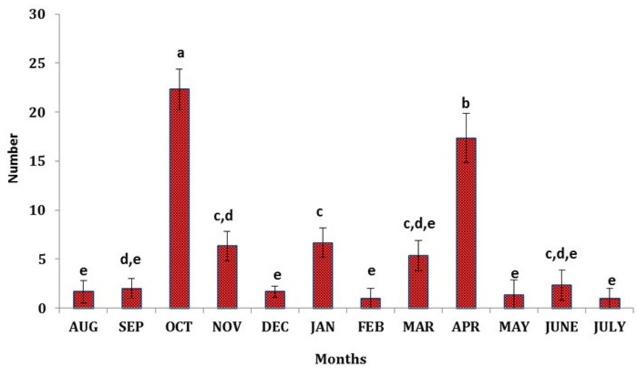

FIGURE 6 Bimodal distribution of ovigerous females forming the highest peak in the month of October and April. Error bars denote standard deviation (n = 3). Columns with different letters on the top were significantly different ($p < 0.05$) between the ovigerous female with respect to months.

This could make males more exposed to sampling (Abele *et al.* 1986; Arab *et al.* 2015). After breeding increase in mortality rates in females can also affect the overall sex ratio. 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 by Rains *et al.* (2016) 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).

Monthly size analysis showed unimodal and bimodal 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 species' population is restricted to a particular area and requires specific habitat to perish, making species *I. sayajiraoi* highly habitat-specific, limiting its distribution. In the present scenario, the Gulf of Khambhat is bordered by many industries. A slight change in the habitat of this species by pollutant influx from industries will affect its population and distribution. Thus population structure of this species, obtained in this study, may act as baseline data for future studies especially for establishing this species as a bioindicator.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION
GV collected the samples, carried out laboratory work and prepared the manuscript; **KDV** prepared, reviewed and finalized the manuscript. Both authors have read and approved the manuscript for publication.

DATA AVAILABILITY STATEMENT
The data supporting the findings of this study are available within the article and with authors which may be obtained from the corresponding authors on reasonable request.

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