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Population dynamics of *Maydelliathelphusa masoniana* Henderson 1893 from freshwater bodies of Jammu region (Jammu and Kashmir, India)

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ABSTRACT

Maydelliathelphusa masoniana Henderson 1893 is a Gecarcinucid crab found in various water bodies of Jammu region, wherein the population structure, growth parameters and effect of rainfall on the recruitment of juveniles have been studied. A total of 437 crabs were sampled randomly on monthly basis between October 2017 and September 2019, of which 118 were males, 174 females and 145 immature individuals. Population analysis of the species shows that asymptotic carapace width ($CW\infty$) was 58.80 mm with growth coefficient (K) 0.750 $year^{-1}$ and growth performance index (ϕ) of 3.414. The von Bertalanffy model indicated a relatively slow growth in the crab species, with a maximum life span of 4.743 years and natural mortality estimated as 1.10 $year^{-1}$. The results indicated that spawning in this species can be considered seasonal while the simultaneous emergence of juveniles with high rainfall levels can probably be due to higher food availability and potential sites for protection from various predators in the natural habitat. The distorted sex ratio (1:0.64) (♀:♂) may be attributed to parameters such as growth rate, mortality, behavioral difference, differential habitat, food restriction, and abiotic influence on the sexes. The results showed that proper management is very critical for survival and development of *M. masoniana* crab in freshwater bodies of Jammu region.

***Key words :** Gecarcinucidae, Jammu, Recruitment, Sex ratio, Von Bertalanffy model*

Introduction

Crabs are decapod crustaceans known to be reported in almost all the freshwater bodies from fast flowing streams to sluggish lowland rivers, crop fields, pools, tree holes, leaf axils and nearly every possible habitat on earth. Crabs can tolerate a wide range of environmental variations (Wolcott, 1988). The term freshwater crab refers particularly to those crabs which are adapted either to freshwater, semiterrestrial or terrestrial mode of life and are characterized by having a life cycle that is completely independent of marine water system. Freshwater crabs are crustaceans, belonging to group that also includes prawns, lobsters, crayfish, and hermit crabs. The main characteristic feature shared by them is the presence of five pairs of thoracic appendages known as pereiopods. In freshwater crabs, the first pair of pereiopods is modified to form specialized structures known as chelipeds or pincers. The remaining four pairs of pereiopods are relatively unmodified and serve as unspecialized walking legs.

The freshwater crabs can be divided into the primary freshwater crab families and the secondary freshwater crab families. The former includes five families viz. Gecarcinucidae, Potamidae, Potamonautidae, Pseudothelphusidae, and Trichodactylidae, while the later are represented by

Goneplacidae, Hymenosomautidae, Ocypodidae, Sesarmidae, Portunidae, Xanthidae, and Varunidae (Yeo *et al.,* 2008; Vogt, 2014). Among five primary families, Gecarcinucidae and Potamidae are very well confirmed in Indian subcontinent whereas the secondary families Hymenosomautidae, Sesarmidae, and Varunidae are represented by only a few species in the freshwater zones. From the Indian subcontinent, a total of 96 species have been categorized under 41 genera within 6 families (Wood-Mason, 1871, Henderson 1893, Alcock 1910, Bott, 1970; Bahir and Yeo, 2007; Ng *et al.,* 2011).

The term population dynamics enfolds the long lasting and significant changes in number, size, recruitment pattern, sex ratio, growth pattern, and age composition of the set of organisms. All these changes are influenced both by the environmental factors and the biological processes that play important role in determining the population structure of any organism. Various studies on population structure and the dynamicity of hermit crab have been conducted in various parts of the world. The tropical regions (Kamalaveni, 1949); temperate regions (Asakura and Kikuchi, 1984); European and Mediterranean regions (Lancaster, 1990) have been extensively investigated and most of the work has been done in determining the population structure and sex ratio of crab population in these particular areas.

Bharathi *et al.* (2017) studied the sex ratio and the reproductive performance of the female mud crab *Scylla serrata* from Mangroves in Andhra Pradesh, India. This mud crab is a continuous breeder showing peak seasons during the months of October, November and December i.e., during the winter season. The sex ratio was found out to be 1:1.09 (M: F) showing highest abundance in the month of December (1:1.8) and lowest in the month of May (1:0.84).

Indian union territory of Jammu and Kashmir has been well bestowed with a variety of mountain ranges and large number of lentic and lotic water bodies which serve as suitable habitat for a diverse range of organisms including decapod crustaceans and various other taxonomic groups. In local water bodies of Jammu, the predominant freshwater crab species reported so far is *Maydelliathelphusa masoniana* Henderson 1893. Many significant studies on various aspects of *M. masoniana* have been reported such as its eco-biology (Meenakshi, 2015), nutritional status (Manhas, 2017), reproductive biology and life cycle (Gupta, 2017), parasitic load (Anjum, 2011), morphometric characterization (Kour *et al.,* 2019).

However, to the best of our knowledge, not much importance has been given to the dynamicity that exist in the population structure of these freshwater crabs. To this end, here we aim to study the population dynamics of freshwater crab *M. masoniana* by examining the juvenile recruitment period, sex ratio and natural mortality. This species of Gecarcinucid crabs has been chosen to get a better understanding of population biology for Gecarcinucidae freshwater crab of the area as these aspects of population biology have not been evaluated so far from the region.

The reproductive traits of a population can be considered as important factors contributing to the development of various management plans that aim to help in the conservation of a particular species within the environment. Furthermore, the knowledge of juvenile recruitment has also known to play much important role for understanding the ideal seasonal dates for fishing purposes (Costa and Fransozo, 1999; Costa *et al.,* 2008). These additional set of information can be used to study the ecology of the organism especially reproductive biology, development, mortality, fertility, and migration (Hutchinson, 1981).

Materials and Methods

Study site and collection of data

Regular collection on monthly basis was done for a period of two years (October, 2017 to September, 2019) to study various aspects of population biology of freshwater crab *Maydelliathelphusa masoniana* from local streams of Jammu region (Fig. 1). The collection area was distributed over two districts viz. Jammu and Kathua with 6 different collection sites. The local streams of Jammu district are fed by rivulets of river Chenab whereas the streams of Kathua district are fed by rivulets of river Ravi. Crabs can be found under algal mats, stones, and in burrows along the side of the streams. Samples were collected by hiring the service of local fishermen, placed in ice buckets and transported to University of Jammu. The crabs were identified and sexed using morphometric characterizations with special emphasis on pleon and carapace morphology. Carapace width (CW) was measured in mm using digital vernier caliper. Collected specimens were kept frozen and subsequently thawed before examination in the laboratory.

Following stages of *M. masoniana* were deter-

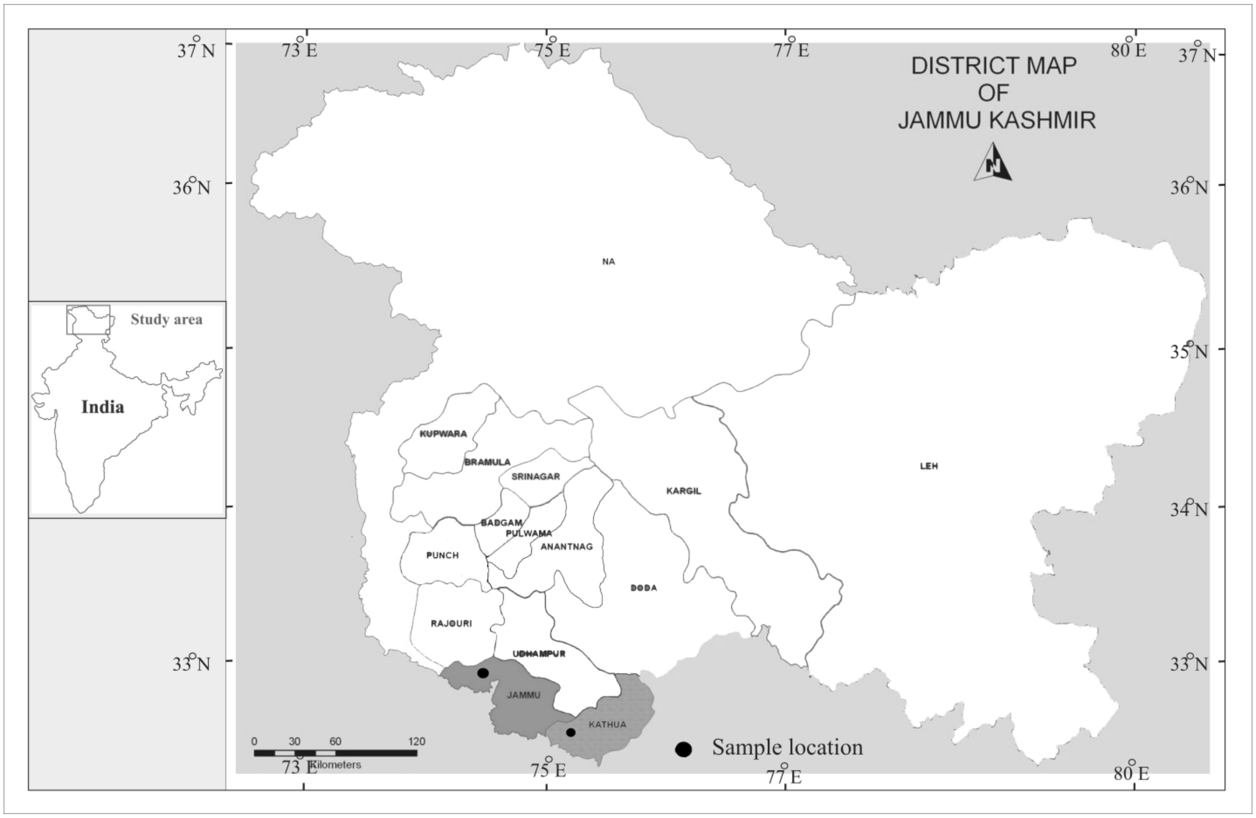

Fig. 1. Sampling location of *Maydelliathelphusa masoniana* from two districts (Jammu and Kathua) of Jammu Region, Jammu and Kashmir.

mined on the basis of gonopodal development microscopically: immature (IM) characterized by an absence of visible gonopod in males and pleopods in females; maturing (Mt) characterized by visible gonopodal (males) and pleopodal (females) folding but haven't attained the size of sexual maturity; mature males (MM) characterized by T shaped abdomen and two pair gonopods; mature females (MF) characterized by U shaped abdomen and four pair pleopods and ovigerous females (OF) characterized by females carrying eggs in the abdominal cavity. According to Manhas *et al.,* (2018) males of *M. masoniana* attain sexual maturity at 40 mm while females attain their sexual maturity at 30mm.

Estimation of growth, recruitment, mortality, sex ratio, and abiotic parameters

i. **Growth parameters:** For the characterization of growth parameters, a total of 437 individuals of *M. masoniana* were taken in mm unit and further categorized into 10 groups of 5mm length interval and further analysiswas done using FISAT II (FAO-ICLARM Stock Assessment Tools 2006, Rome, Italy) (Gayanilo *et al.,* 1995). Growth parameters i.e., asymptotic length ($L\infty$) or asymptotic carapace width ($CW\infty$) and growth coefficient (K) were analyzed using von Bertalanffy growth function (VBGF) in ELEFAN-1 (Pauly & David, 1981). The computed value of $CW\infty$ and K were then used to estimate the growth performance index (ϕ) (Pauly and Munro, 1984) by using the equation:

$$\phi = 2 \log CW_{\infty} + \log K$$

Estimation for the age at birth or hypothetical age at which growth is zero (t_o) was intended to obtain information for complementing the peak of spawning. The value of t_o can be obtained by equating the values of K and $CW\infty$ (or$L\infty$) values in the Pauly's equation (Pauly, 1980):

$$\log(-t_o) = -0.3922 - 0.2752 \log(CW_{\infty}) - 1.038 \log K$$

where K is growth coefficient, CW_{∞} is asymptotic carapace width and t_o (initial condition parameter) is the age at which carapace width can be considered equal to zero.

VBGF has been used to describe age curve in terms of carapace width by using nonlinear estimation (Pauly *et al.*, 1992) with the help of following equation:

$$CW_t = CW_\infty (1- e^{-K (t-to)})$$

where CW_t is length at time t, CW_∞ is asymptotic carapace width, K growth coefficient, t is age at time zero and t_o is hypothetical age at which growth is zero. Maximum age can be estimated using the equation $T_{max} = 3/K$ (Pauly, 1980).

Natural longevity can be described as the life span for a species and is achieved by a species in cohorts of 99% until all the members of the cohorts die a natural death (Sparre and Venema, 1998). According to Moses 1990, for short lived organisms the maximum carapace width (CW_{max}) = 0.95 (CW_∞) thus, the modified equation to estimate t_{max} can be calculated as:

$$t_{max} = 2.9957/K + t_o$$

ii. **Mortality parameters:** Estimation of total mortality (Z) was computed through linear relationship that exists between natural logarithm occurring from the change in number of crabs per unit time of growth to i class with age, which is known as length-converted catch curve (Pauly, 1984) expressed with the formula:

$$\ln (N_i/\Delta t) = a + bt_i$$

where N is the number of crabs in length class i, Δt is the time needed for crab species to grow in length class to i, t is the age (or more precisely relative age, calculated with the help of $t_o = 0$) related to median value of i class and b is the slope.

Natural death (M) can be estimated using the empirical Pauly's equation:

$$\log M = -0.0066 - 0.279 \log CW_\infty + 0.6543 \log K + 0.4634 \log T$$

where M is natural death, CW_∞ is asymptotic carapace width, K is annual growth coefficient of VBGF and T is average annual temperature of the habitat (in °C). Values of N and M were further taken under consideration for the estimation of death of caught crabs (F) by using the relationship: F = Z-M, where Z is total mortality and M is natural mortality (Gayanilo *et al.*, 1995).

iii. **Recruitment pattern:** Determination of recruitment pattern by addition of first individuals into the crab population was supported by an approach method facilitated by FISAT (Sparre and Venema, 1998). The normal distribution of recruitment pattern can be determined by using NORMSEP (Pauly and Caddy, 1985) in FISAT. This program helps in reconstruction of recruitment pulses from a set of length frequency data with subsequent adjustments by way of VBGF

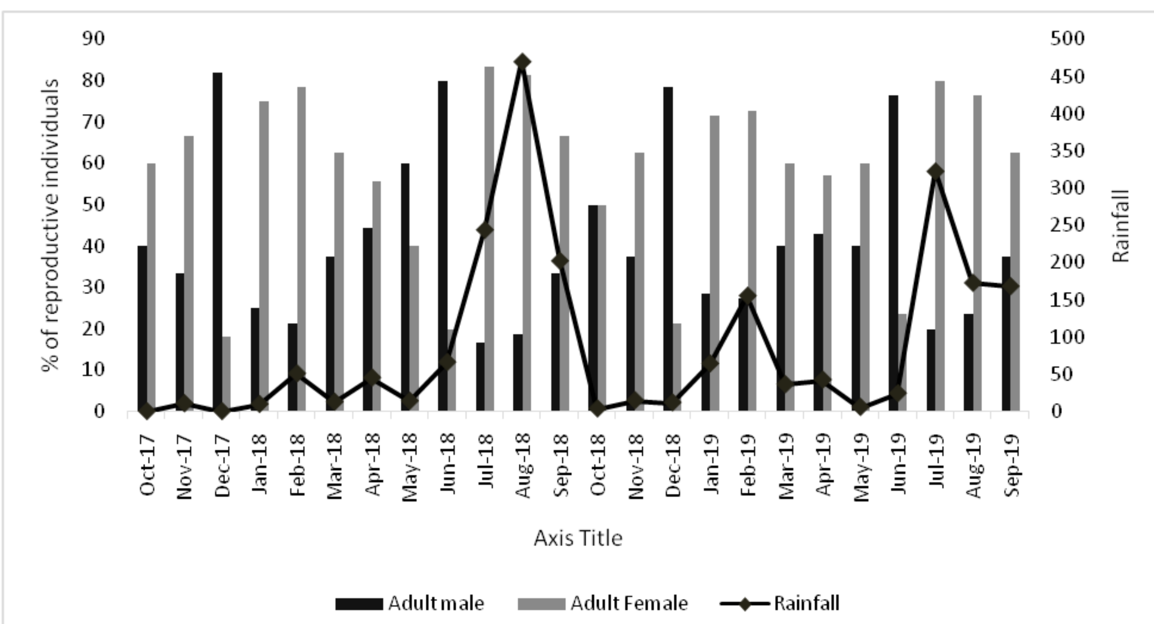

Fig. 2. Relationship between monthly rainfall and relative percentage of males and females individuals (M + Mt) of *Maydelliathelphusa masoniana* from October 2017 to September 2019.

curve to determine the number of pulses per year and the relative strength of these pulses. The final value estimates of CW∞, K, and t_o were used in the calculation of recruitment curve.

iv. Sex ratio: Chi square test (χ^2) at 5% significance level (Sokal and Rohlf, 1995) has been adapted to determine whether the sexes followed 1:1 ratio or varied over the study months.

v. Abiotic factors: Monthly data of rainfall was provided by SKUAST (Sher-e-Kashmir University of Agricultural Sciences and Technology) Jammu. Spearman correlation was used to test the possible relationship between variations in above mentioned abiotic factors with reproductive and juvenile recruitment activity.

Results

The average rainfall recorded in the first study year was ± 95.44 mm and the highest level of it was found in the month of August 2018 (470.4 mm). In the second year, the average rainfall was ± 98.63 mm and the highest level of it was found in the month of July 2019 (322.8 mm). In contrast a complete absence of rainfall was recorded in the months of October 2017 and December 2017 (Fig. 2).

A total of 437 crabs were collected during the study period (October, 2017 to September, 2019) of which 118 were males (both MM + Mt), 174 females (MF, Mt, and OF) and 145 immature individuals. The ovigerous females were recorded in the months of January 2018 (n=3), June 2018 (n=2), January 2019 (n=2), June 2019 (n=1), and July 2019 (n=1)as depicted in Fig. 3. Immature individuals were recorded highest in the months of March 2018, September 2018, March 2019, and April 2019 (Fig. 4).

There was negative correlation between rainfall and number of males (r = -0.201) though not significant p value (p = 0.344), while the females showed positive correlation (r = 0.545) and significant p value (p = 0.005). Though, immature individuals showed non-significant correlation (p = 0.384) with rainfall, yet higher number of juveniles were recorded in the months with highest rainfall or months just after the months with highest rainfall.

The age group which existed within the population showed the structure of the population. Based on the length frequency data obtained over 24 months by using FISAT sub program ELEFAN, it was calculated that *M. masoniana* asymptotic carapace width (CW∞) was 58.80 mm with growth coefficient (K) 0.750 year^{-1} and growth performance index (ϕ) of 3.414. The analysis of individual distribution during the study period have been the basis for

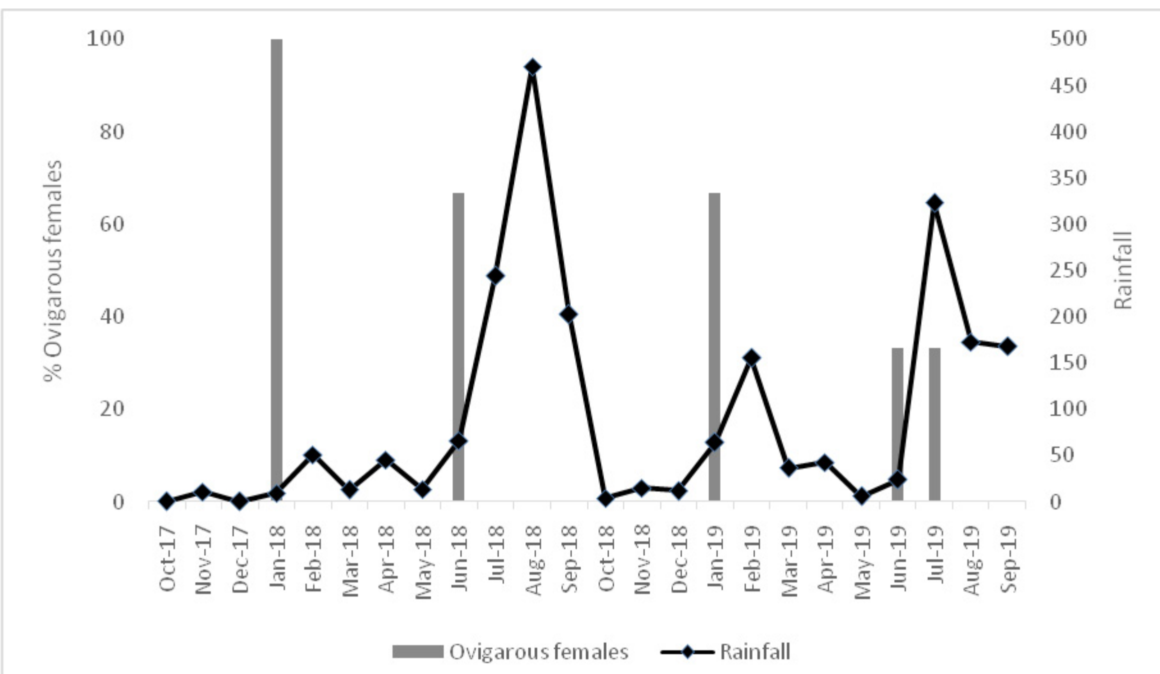

Fig. 3. Relationship between monthly rainfall and relative percentage of ovigerous females (OF) of *Maydelliathelphusa masoniana* from October 2017 to September 2019.

various growth parameters and thus were used to plot the von Bertalanffy growth curve (Fig. 5).

From the values of CW∞ and K, t_o was calculated to be -0.749 years. The value of t_o has also been used as initial condition parameter which helped in determining the point in time when the carapace width of the population was zero. Based on the above known values the von Bertalanffy equation can be modified as:

$$CW_t = 58.80\ (1 - e^{-0.750(t+0.749)})$$

By using the above data, a relationship can be established between the carapace width and age for the growth curve. Moreover, maximum age was estimated to be 4.743 year^{-1}. Not much study regarding such growth parameters has been conducted so far for *M. masoniana* and as such the values obtained in this study can be used as initial information that can be used as basis for further comparisons.

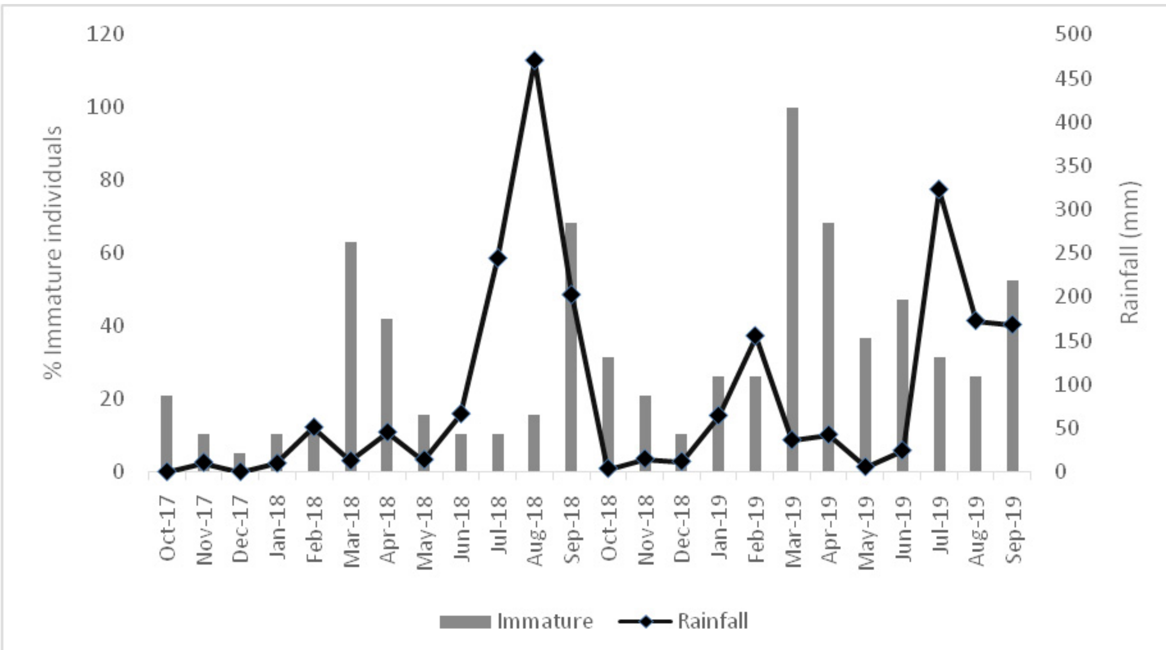

Fig. 4. Relationship between monthly rainfall and relative percentage of immature individuals of *Maydelliathelphusa masoniana* from October 2017 to September 2019.

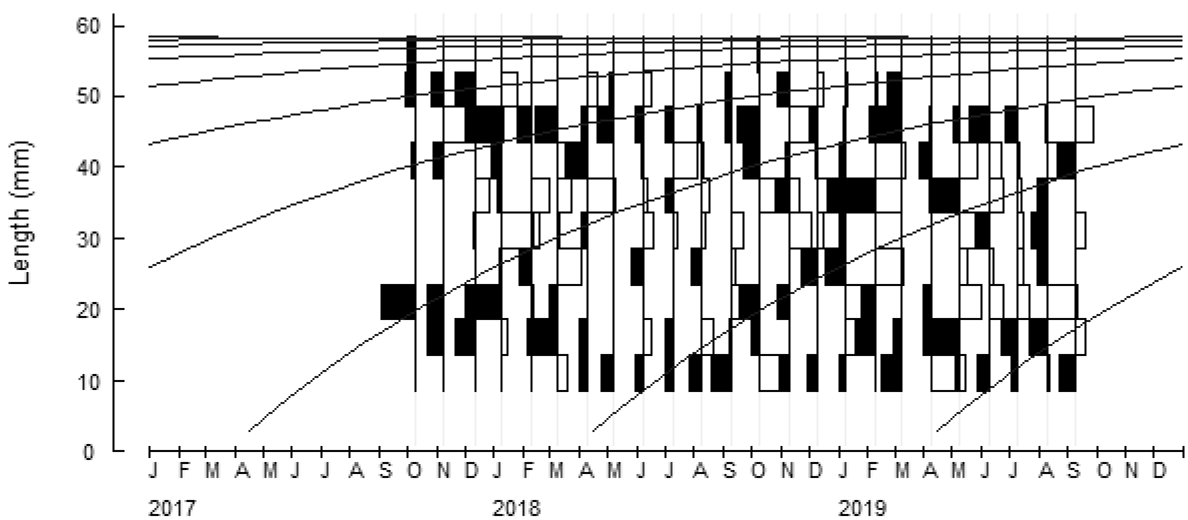

Fig. 5. Carapace width frequency distribution with growth curves of *Maydelliathelphusa masoniana* in Jammu region.

Mortality parameters have been evaluated from the length converted catch curve (LCCC) by plotting relative age of the sample (dt) against the natural logarithm of number of individuals per class ($N_t/\Delta t$), resulting in linear equation of LCCC (Fig. 6). Total mortality (Z) for the species was found out to be 1.98 year^{-1}, natural mortality (M) was calculated to be 1.10 year^{-1} and mortality due to catch (F) was 0.88 year^{-1}. From the mortality parameters, it is evident that mortality due to natural causes is higher than catchment. This indicates that probability of death from natural causes such as predation, poor environmental condition, disease etc. is much higher than anthropogenic causes.

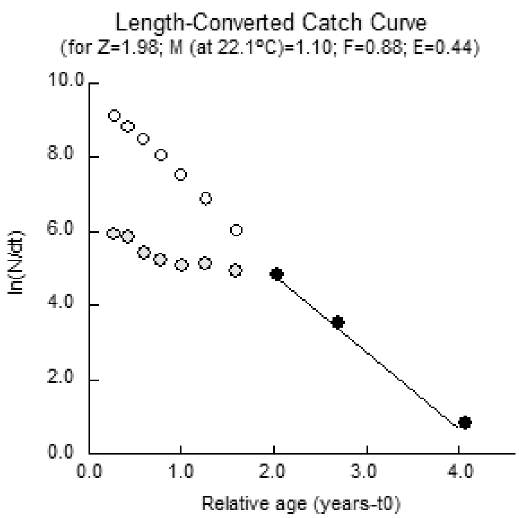

Fig. 6. Length-converted catch curve (LCCC) of *Maydelliathelphusa masoniana*

Analysis of recruitment pattern of *M. masoniana* from FISAT showed that addition of new individuals has known to occur each month with variable numbers, though higher percentage of new recruitment can be seen one in the month of February and other by the end of June and starting of July. Recruitment pattern has marked influence on population dynamics in nature, as adding new individuals is a positive cycle that stabilizes the population itself (Fig. 7).

The sex ratio was 1:0.68 (♀ : ♂) with a comparatively larger number of females than males. The overall sex ratio showed a significant deviation from 1:1 ratio only in specific months whereas in other months, the ratio remained nearly constant. The sex ratio varied monthly, with significant male deviated population in the months of June and December over the study period while significant female deviated population was seen in the months of January, February, July and August (Table 1).

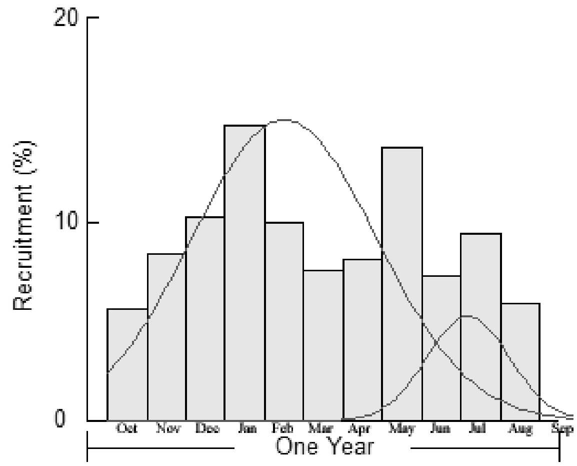

Fig. 7. Recruitment pattern of *Maydelliathelphusa masoniana* from Jammu region.

Discussion

The size frequency distribution pattern of a particular population is a dynamic characteristic that is result of change throughout the year as a result of reproductive pattern and rapid juvenile recruitment (Thurman 1985; Tao *et al.*, 1994). In *Maydelliathelphusa masoniana*, it was seen that bimodality in the pattern of distribution was seen with two clear peaks, one in the month of February and other in the end of June and starting of July, indicating a precise period for the recruitment of juveniles into the population. This suggests that the reproductive pattern in this species show seasonal variation with biannual breeding periods. These results coincide with the observations of Meenakshi, (2015); Gupta, (2017); and Manhas *et al.*, (2018) who suggested *M. masoniana* to be a biannual species, breeding in the months of June-July and December-January. It is generally seen that the juvenile recruitment is high when the concentration of nutrients is comparatively high in the environment (Goncalves *et al.*, 2003). A similar bimodal pattern of distribution can also be seen in the population of freshwater crab *Trichodactylus borelliansii* (Collins and Williner, 2006).

Hartnoll and Gould (1988) put forth that a well-defined reproductive period in certain species of brachyurans can be seen as a strategy to release the young offspring in an environment where they have favorable conditions for their development. Mansur and Hebling (2002) described that the reproductive months or the months in which ovigerous females or juveniles carrying females in the species *Dilocarcinus pagei* and *Sylviocarcinus australis* were found to coincide with the period of highest rainfall. These authors suggested that the rise in the water level of the river helps to facilitate the dispersal of young individuals and also increases the availability of shelter for the newly hatched offspring. The present work showed synchronization between juvenile recruitment and precise period of highest rainfall. Davanso *et al.*, 2013 also found a similar relationship existing between juvenile recruitment and rainfall. The reason behind this pattern of distribution on its higher availability of food and nutrients is higher in these periods as rain brings allochthonous nutrients from other water bodies and further removes organic matter from the sediments. This maximizes individual growth (Hartnoll and Gould, 1988).

The overall sex ratio for *M. masoniana* was found to be 1:0.68 (♀ : ♂) with more of females than males. The sex ratio was not always significantly different in all the months rather a particular pattern was observed in some months. Significantly more number of males were seen in the months of December and June while significantly more females were seen in the months of January, February, July, and August. Ovigerous females (OF) were observed in the months of January, June, and July. Sex ratio variation in particular months can be attributed to various factors such as sexual difference that occur in the spatio-temporal distribution and mortality in the population (Wada *et al.*, 2000), food restrictions, migration, differential life span, extent of utilization of particular habitat (Johnson, 2003), differential mortality between the sexes, behavioral characteristics (Devi and Smija, 2014) and the differential mode of competition for the food resource and predation (Collins and Williner, 2006). Sex ratio determination is an important tool in population assessment as a significant variation in sex ratio has been known to internally regulate the population size by affecting its reproductive potential (Lardies *et al.*, 2004). Thus, differences in spatial and temporal distribution existing between the sexes and seasonality in the re-

Table 1. Proportion of males and females individuals of *Maydelliathelphusa masoniana* from October 2017 to September 2019.

Month and year	Male	Female	P value	Test stats (X^2 chi square)	F:M (♀ : ♂)
Oct,2017	2	3	0.65472085	0.2	1.5:1
Nov,2017	2	4	0.41421618	0.666666667	2:1
Dec,2017	9	2	0.03480848	4.454545455	0.2:1
Jan,2018	4	12	0.04550026	4	3:1
Feb,2018	3	11	0.03250944	4.571428571	3.7:1
Mar,2018	3	5	0.47950012	0.5	1.7:1
Apr,2018	4	5	0.73888268	0.111111111	1.3:1
May,2018	6	4	0.52708926	0.4	0.7:1
Jun,2018	12	3	0.02013675	5.4	0.3:1
Jul,2018	2	10	0.02092134	5.333333333	5:1
Aug,2018	3	13	0.01241933	6.25	4.3:1
Sept,2018	2	4	0.41421618	0.666666667	2:1
Oct,2018	4	4	1	0	1:1
Nov,2018	3	5	0.47950012	0.5	1.7:1
Dec,2018	11	3	0.03250944	4.571428571	0.3:1
Jan,2019	8	20	0.0233422	5.142857143	2.5:1
Feb,2019	6	16	0.03300626	4.545454545	2.7:1
Mar,2019	4	6	0.52708926	0.4	1.5:1
Apr,2019	3	4	0.70545699	0.142857143	1.3:1
May,2019	4	6	0.52708926	0.4	1.5:1
Jun,2019	13	4	0.02904902	4.764705882	0.3:1
Jul,2019	3	12	0.02013675	5.4	4:1
Aug,2019	4	13	0.02904902	4.764705882	3.3:1
Sept,2019	3	5	0.47950012	0.5	1.7:1

productive behavior of *M. masoniana* may be responsible for the imbalance in the sex ratio.

Biological interpretation of CW∞ of crabs refers to mean width of very old individuals (strictly very old) and growth rate K can be considered a curvature parameter which determines at what pace the crab grows to reach its approximate asymptotic carapace width. Attributed to various studies it is clear that some species (specifically short lived), almost reach the value of asymptotic carapace width at the age of one or two years and having high growth rate (Koch *et al.*, 2005). This type of growth pattern is usually common in tropical species. Several other species on the contrary have a rather flat growth curve with comparative low growth rate and thus take more years to reach the asymptotic carapace width. This pattern of growth is common in temperate species as low temperature can be a potent factor to limit the feeding time and affect the growth and reproduction in land crabs (Wolcott, 1988).

The life expectancy seen in *M. masoniana* was approximately 4.743 years, which represents a longer life span. Accordingly, the data from growth curve suggests that *M. masoniana* have low growth rate and relatively longer life span thus suggesting that the growth of the species is rather slow. A similar pattern of growth and life expectancy can be seen in *Sodhiana iranica* (Sharifian *et al.*, 2017).

The age at zero carapace width (t_o) has been estimated to be -0.749 years for *M. masoniana*. A negative value of t_o has been observed in most of the species and only a few species are known to have positive t_o values. A negative t_o value has been evaluated which indicates that the growth in juveniles is more rapid than the adults and converse case observed with lower growth rate of juvenile than adults in positive t_o value (King, 1995). Considering that *M. masoniana* is a freshwater crab and juveniles are known to hatch from the eggs, it can be justified that the growth rate in juveniles is higher than adults.

The estimated natural mortality calculated for *M. masoniana* is 1.10 year^{-1}. Natural mortality of a population has been known to depend on various environmental factors and is also affected by the relative abundance of its predators in the habitat (Safaie *et al.*, 2013). An important relationship exists between growth rate and natural mortality, as it has been seen that species with a low growth rate have low natural mortality too (Sparre and Venema, 1998). Natural mortality also shows a good degree of relationship with reproduction. As such, species known to have higher mortality rates may compensate for their loss by producing more eggs (Gunderson and Dygert, 1988). Depending on the environment and the species, the value of natural mortality to growth rate shows a ratio in the range 1.5 to 2.5. While taking into consideration the comparative low growth of *M. masoniana*, the ratio of natural mortality to growth rate makes it is evident that the natural mortality for this species is comparatively low.

Conclusion

From this study it can be concluded that various parameters of population dynamics help in understanding the life-history processes of a species. The study constitutes a prior attempt to impute population ecology of *M. masoniana*. Due to the relative slow growth of *M. masoniana* and the susceptibility of this species to various environmental pollution factors, proper management is critical for its preservation in its natural habitat. The results here provide the valuable information regarding the growth and recruitment pattern which would be helpful for any conservation or management program of this species.

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Author's Contribution

H.K and S.L designed the study. H.K and N.S collected the data. H.K, S.L and N.S were involved in data analysis and data interpretation. All the authors are involved in writing and reviewing of the manuscript.

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