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ORIGINAL ARTICLE

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Correlation between body size and fecundity in fish louse *Argulus bengalensis* Ramakrishna, 1951 (Crustacea: Branchiura)

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Abstract The life history traits like fecundity and body size are useful predictors of life history strategies of organisms. The information on these aspects provided necessary input for control measures for ectoparasites. In view of this, the variations in the life history traits of the fish louse *Argulus bengalensis* Ramakrishna (1951) were assessed using age as an explanatory factor. The analyses revealed that the body weight (BW) is related to age in males as: y (BW) = 0.03 × (Age)–2.58: and in females as: y (BW) = 0.89 + 0.13x (Age). The body length and age relationship in males is observed as: y (BL) = 2.94 + 0.01x (Age) and in females as: y (BL) = 2.89 + 0.06x (Age). The degree of sexual dimorphism (DD) for BL is positively correlated ($r = -0.358$; df = 43; $P < 0.001$) with age while DD for BW is negatively correlated ($r = -0.525$; df = 43; $P < 0.001$) with age. The eggs/clutch remained between 02 and 43 for the 21st and 38th day old females. The fecundity as a function of age could be represented as: y (Eggs) = 1.62x (Age)–27.92. The increase in BW with age in female *A. bengalensis* favoured greater resource allocation for egg production, while in males it likely favours dispersal ability. Since body size and fecundity varied with age, the relative abundance and extent of infestation in fish host would vary with age composition of the population and recruitment of juveniles. The impacts of host specific variations on these features need to be tested further.

Keywords *Argulus bengalensis* · Fecundity · Morphometric parameters · Life history traits

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Introduction

The parasitic interaction of *Argulus* (Crustacea: Branchiura) affects fish health at large and is a recognized problem in commercial aquaculture worldwide (Poly 2008). It depends on the freshwater and marine fish species as hosts for most part of their life cycle (Kearn 2004). *Argulus bengalensis* is common to abundant in the fish farms of West Bengal, India. Their ability to propagate and affect different fish species has been illustrated (Campbell 1971; Natarajan 1982; Mikheev et al. 2001; Bandilla et al. 2004; Hakalahti et al. 2004; Schram et al. 2005). Thus an appraisal of the morphometric and reproductive features of adults can help to predict the possible stability in growth pattern and abundance in nature. Fecundity can also be used as an indicator to evaluate the possible consequences at the population level and can provide information for management strategies (Harrison et al. 2006). Fecundity-body size relation has been used in evaluation of the species specific population dynamics of the ectoparasites like mosquitoes (Mayer et al. 1992). The life history traits like body weight, body length and fecundity in the continuum of age provide vital information about the life history adaptations enabling precision in projecting the heterogeneity of the population (Morand et al. 1999; Poulin and Mouillot 2003; González and Poulin 2005). In the present study we tested these propositions for the fish louse *Argulus bengalensis* that is common to abundant in the fish farms of West Bengal, India. The results would supplement data for comparison and analysis of species specific adaptations of fish louse in general and different species of *Argulus* sp. described (Ramakrishna 1951; Thomas and Devaraj 1975; Natarajan 1982) from India. The information on the life history traits of *A. bengalensis* would facilitate assessment and predictions of the population dynamics and can supplement appropriate management strategies for maintenance of fish health.

Materials and methods

Collection and rearing of fish louse

The fish were captured from different *Argulus* infested commercial fish farms from, Guskara (23°30N 87°45E/23.50°N 87.75°E), Churulia (23°47N 87°05E/23.78°N 87.08°E) and Kalna (23°13N 88°22E/23.22°N 88.37°E) of West Bengal, India with the help of traditionally used fishing nets and anesthetized with MS—222 (Sigma, India). The attached fish louse were then removed with the help of a scalpel and transferred into a container containing water. To avoid a homogenic population and maintain a heterogenic stable population of parasites, specimens were captured from different locations. In this study the fish farms were infested with only single argulid species *Argulus bengalensis* (Ramakrishna 1951). Identification of the parasite was performed following Ramakrishna (1951). The collected lice (P-generation) were kept in 15 nos. glass aquaria (58 cm × 26 cm × 38 cm) separately with proper aeration and *Cirrhinus mrigala* Hamilton (19.6 ± 1.22 cm), an Indian major carp as host for their maintenance and propagation (F2 generation). The egg clutches (by P-generation adults) laid on the wall of the glass aquaria were observed every 24 h and transferred to a beaker of 50 ml size containing pond water. The juveniles hatching on the same day were grouped together to constitute a cohort of F1 generation. The culture (F1 generation) was propagated in a similar way to obtain the adults of the F2 generation considered for the study. Owing to the maintenance of the culture as cohorts, age of an individual *A. bengalensis* could be followed. Data on the body weight (to the nearest 0.1 mg) and body length (to the nearest 0.1 mm) of individuals of a particular age were taken and recorded for both sexes. To note the fecundity (nos. of eggs/clutch), a female of known age was isolated and placed in glass beaker of 50 mL for a period of 24 h. If the beaker was found positive with an egg clutch, the number of eggs was counted and recorded along with the data of the body weight and body length of the female. The age of the female on that day was also recorded (i.e. +1 day from the day isolated from culture). In case the glass beaker was found empty the female was not considered any further for the study. (About fifteen females did not lay egg within 24 h post isolation.) Females of *Argulus* sp. are iteroparous and lay eggs repeatedly in their life time. To avoid disruption of the cohort and assure that data on fecundity of a particular age class is obtained, a female was used once for the fecundity data. For analyses, 143 adult laboratory cultured F2 generation *A. bengalensis* (65 male and 78 female) of different ages (in days) were considered.

Measurement of fish louse

In laboratory, the cultured lice from the same age group were cleared in lactic acid (Schram et al. 2005) and anesthetized with MS—222. Measurements of the parasites were performed using an ocular micrometer and a stage micrometer under a laboratory microscope (Olympus, India) and recorded from posterior of caudal rami to anterior edge of carapace (Hakalahti et al. 2004). The weight of the individuals was recorded using a pan balance (SHIMADZU) and the measurements were restricted to body weight (BW) and body length (BL). Moreover, BL/BW ratio was considered as a derived variable to represent shape of the individuals. To comment on the differences in the body weight and body length between the sexes, a quotient of degree of sexual dimorphism was deduced

Table 1 Pearson correlation matrix among different variables in (A) male ($n = 65$) and (B) female ($n = 78$) of *A. bengalensis* and (C) corresponding degree of sexual dimorphism (DD) for 47 pairs

Variables	BW	BL	Age
A. Male *A. bengalensis*			
BL	0.685*		
Age	0.897*	0.520*	
AS	−0.974*	−0.521*	−0.919*

Variables	BW	BL	Age	Eggs
B. Female *A. bengalensis*				
BL	0.731*			
Age	0.841*	0.670*		
Eggs	0.822*	0.701*	0.861*	
AS	−0.825*	−0.232*	−0.642*	−0.570*

Variables	Age	DD-BW	DD-BL
C. Degree of sexual dimorphism between male and female *A. bengalensis*			
DD-BW	−0.525*		
DD-BL	0.358*	0.196*	
DD-AS	0.828*	−0.468*	0.391*

BW body weight, mg; *BL* body length, mm; Age (days); *AS* aspect ratio, BL/BW; Eggs nos./clutch

* $P < 0.05$

based on the following equation (Sharmila Bharathi et al. 2003, 2004) after arranging the data on body weight and length in ascending order of age:

For a particular trait and a pair of male and female *A. bengalensis*,

$$DD_i = [(\text{female}_i - \text{male}_i)/(\text{female}_i + \text{male}_i)/2]$$

Here DD_i is the degree of sexual dimorphism for the *i*th pair of *A. benglensis* belonging to a particular age. A regression equation of DD-BL and DD-BW was constructed as a function of age to comment on the variation in the DD with age. For obtaining the degree of sexual dimorphism, 47 pairs of females and males of different ages could be considered.

Statistical analysis

The data obtained on the morphometric features namely body length (BL), body weight (BW) of both male and female individuals and data on fecundity (eggs laid) of females were subjected to correlation analysis. Regression equations (Zar 1999) were constructed using BL, BW, and BL/BW ratio and fecundity as dependent variable and age as independent variable. In case of BL and BW relation, BW was considered as independent variable. The degree of sexual dimorphism (DD) based on the age was deduced to represent the variation in the sexes. Regression analysis was made with respect to the degree of sexual dimorphism for a particular morphometric feature against age. All the

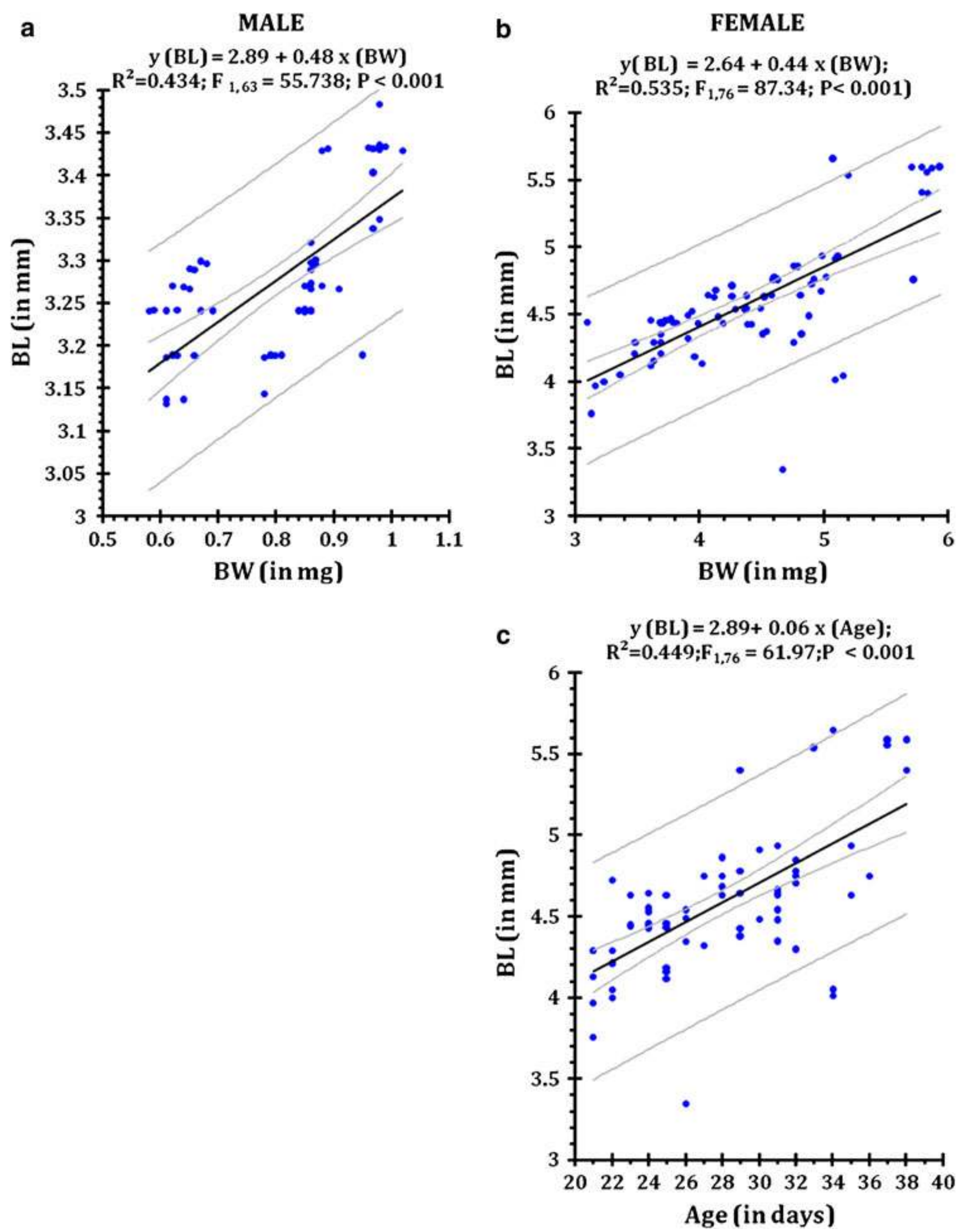
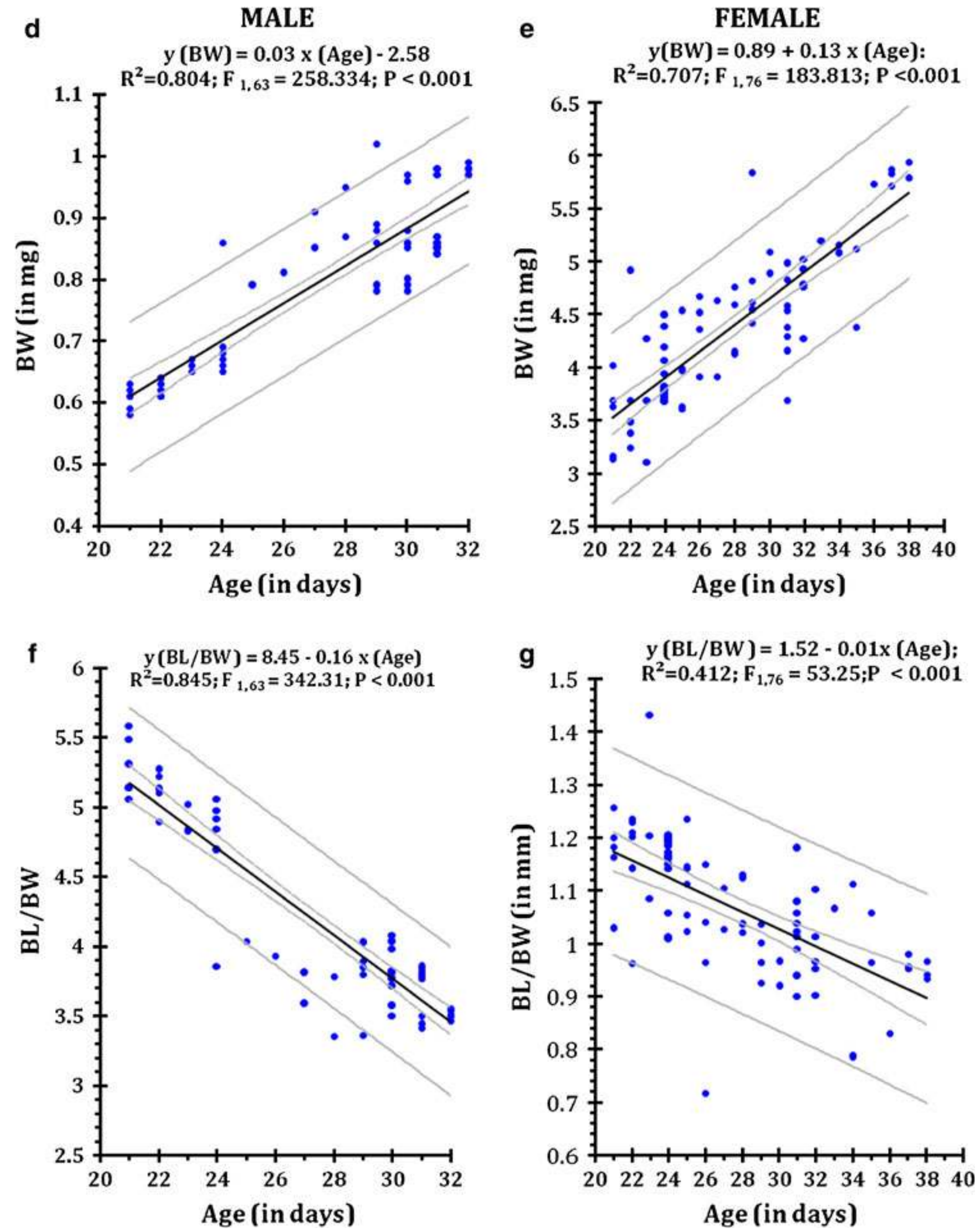


Fig. 1 Linear regression equations between length and weight of (**a**) male, (**b**) female and length and age of (**c**) female; weight and age of (**d**) male, (**e**) female; aspect ratio visà-vis age of (**f**) male and (**g**) female *A. bengalensis*

Fig. 1 continued



statistical analyses were performed using *XL*-STAT for windows (Addinsoft 2009).

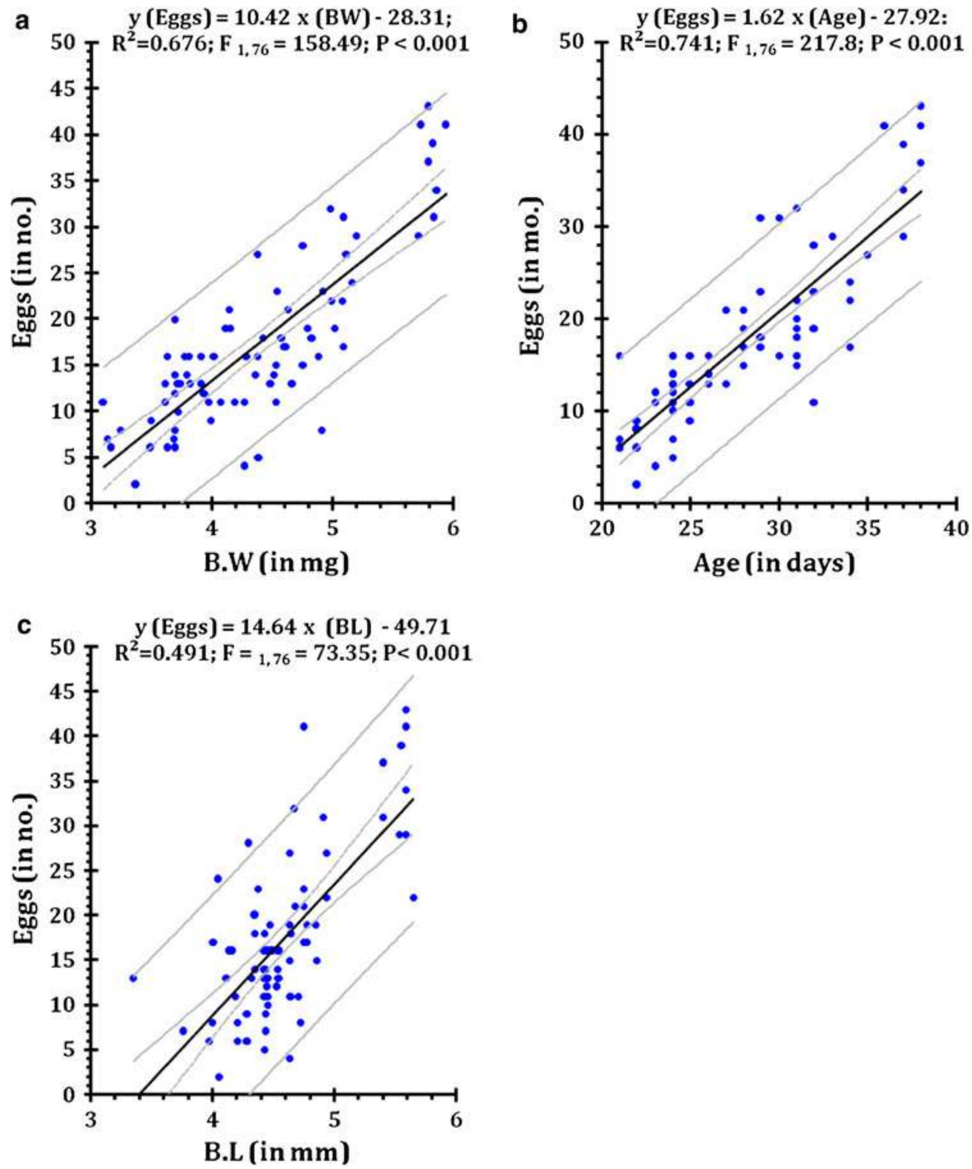
Results

The age of the male *A. bengalensis* ($n = 65$) considered in this study was between 21 and 32 days (mean 27.6 days ± 0.49 SE) while the age of the females were between 21 and 38 days (mean 27.85 days ± 0.55 SE). The body weight (BW) of the male *A. bengalensis* ($n = 65$) ranged between 0.58 and 1.02 mg (mean 0.81 mg ± 0.02 SE) and the body length ranged between 3.13 and 3.48 (mean 3.28 mm ± 0.01 SE) with an BL/BW ratio being 4.15 mm/mg ± 0.08 SE (range 3.36–5.88 mm/mg).

The body weight (BW) of the female *A. bengalensis* ($n = 78$) ranged between 3.1 and 5.94 mg (mean 4.9 mg ± 0.082 SE) and the body length ranged between 3.35 and 5.65 (mean 4.57 mm ± 0.05 SE) with an BL/BW ratio being 1.06 mm/mg ± 0.02 SE (range 0.72–1.43 mm/mg). The body weight (in mg; BW), body length (in mm; BL) and BL/BW aspect ratio (in mm/mg; AS) varied with the age of *A. bengalensis* for both the sexes. These features exhibited a positive correlation with age and among themselves (Table 1A, B).

The data obtained on these life history traits were applied for regression analyses. The analyses revealed that

Fig. 2 Correlation between eggs/clutch (no.) and **a** weight; **b** age; and **c** length of female *A. bengalensis*



in males the body length (x) is related to body weight (y) as: $y = 2.89x + 0.48$ ($r^2 = 0.434$; $F_{1,63} = 55.738$; $P < 0.001$). The relation between body length (y) and age (x) was: $y = 2.94x + 0.01$ ($r^2 = 0.271$; $F_{1,63} = 23.404$; $P < 0.001$), while the relation between body weight (y) and age (x) was: $y = 0.03x - 2.58$ ($r^2 = 0.804$; $F_{1,63} = 258.334$; $P < 0.001$). In case of females the relationship between the body length (x) is related to body weight (y) as: $y = 2.64x + 0.44$ ($r^2 = 0.535$; $F_{1,76} = 87.34$; $P < 0.001$). The relation between body length (y) and age (x) was: $y = 2.89x + 0.06$ ($r^2 = 0.449$; $F_{1,76} = 61.97$; $P < 0.001$), while the relation between body weight (y) and age (x) was: $y = 0.89x + 0.13$ ($r^2 = 0.707$; $F_{1,76} = 183.813$; $P < 0.001$) (Figs. 1, 2).

The number of eggs present per clutch was between 02 and 43 (mean 17.32 ± 1.05 SE). The number of eggs laid (y) by a female *A. bengalensis* was used as an indicator of fecundity. The eggs/clutch (y) was related with age (x) as : y (eggs) $= 1.62x - 27.92$ ($r^2 = 0.741$; $F_{1,76} = 217.8$; $P < 0.001$); with body length (x): y (eggs) $= 14.64x - 49.71$ ($r^2 = 0.491$; $F_{1,76} = 73.35$; $P < 0.001$); with body weight (x): y (eggs) $= 10.42x - 28.31$; ($r^2 = 0.676$; $F_{1,76} = 158.49$; $P < 0.001$) (Fig. 2).

A significant degree of sexual dimorphism was noted with respect to the body weight and body length of *A. bengalensis*. The mean values of degree of sexual dimorphism varied for BW and BL and BL/BW ratio (Fig. 3). The correlation coefficients (r) among the variables are shown in Table 1C. It was noted that the females were of higher age and length than males but the males had a higher BL/BW ratio, indicating that in males the length per unit weight was higher.

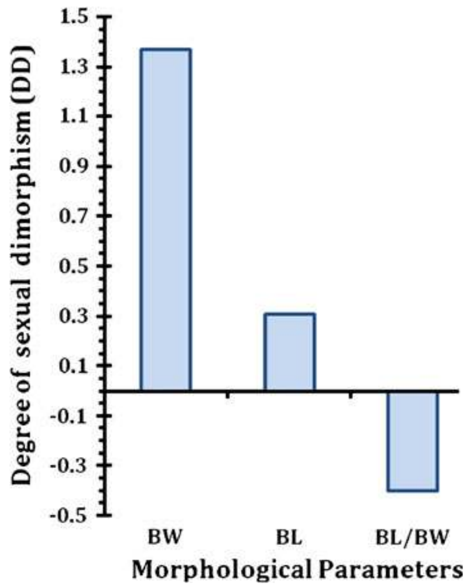


Fig. 3 The mean degree of sexual dimorphism (DD) between male and female *A. bengalensis* ($n = 47$ pairs of *A. bengalensis*) (SE omitted due to values less than 0.03). *BW* weight, mg; *BL* length, mm; aspect ratio; BL/BW

Discussion

The life history theory encompasses the strategies to secure reproductive fitness in the context of environmental conditions to which the organisms are adapted. Fecundity as a life history trait allows quantification of reproductive fitness of organisms. Other life history traits like the body weight and body length of organisms reflect the resource available for allocation towards safe and sound reproductive effort (Taylor et al. 2009). Reproductive effort can be viewed as investment towards making new viable individuals to perpetuate and increase the number of existing genes of the organism in context. A key element of the life history strategy is to maximize reproduction to attain maximum fitness (Llodra et al. 2000). Evolution favours such life history strategy that maximizes propagule numbers in the context of existing environmental conditions. Thus a correlation between the body size (body weight, body length) with the fecundity is expected as evident in the life history features of insects and crustaceans, adapted to free living or ectoparasitic mode of life (Poulin and Hamilton 1997; Pasternak et al. 2004).

The relation between body size and fecundity in ectoparasites like insects and crustaceans bear relevance in understanding population attributes. Predictions can be made on the population growth and fitness at the individual and population level. The intensity and prevalence of *Argulus* sp. depend on host specificity and host body weight (Shafir and Oldewage 1992; Walker et al. 2008) and switching between hosts species (Mikheev et al. 2004; Bandilla et al. 2008). Relative density and population growth of *Argulus* sp. is dependent on the intrinsic rate of increase and the characteristic life history traits of the individuals constituting the population. This would enable adoption of appropriate management strategy with higher precision.

From the morphometric data and their interrelation it appears that in *A. bengalensis* the body weight and body length features are dimorphic. This can be attributed to the fact that the females carry the eggs and thus are evolutionary selected for larger in size. Smaller size in males facilitates dispersal in space. The fecundity was found to be a positive function of age, and the age was positively related to body size and body length. Thus with increase in age, body length (BL), body weight (BW) and fecundity (F) increases. In comparatively older female fecundity is higher and is expected to lay more eggs and contribute more to the increment of the population contrast to the relatively younger female in the population (Fig. 2). In crustaceans, free-living or parasitic fecundity is a positive function of body mass and length. In parasitic Ascothoracida and Rhizocephala, the body size is correlated with fecundity (Poulin and Hamilton 1997). It has been demonstrated in caridean shrimps *Mirocaris fortunata* (Decapoda: Caridea), fecundity and biomass are positively correlated to cephaolothoracic length (Llodra et al. 2000). In brachyuran crab *Portunus spinimanus* fecundity is positively related to the body size (Santos and Fransozo 1997).

Further studies incorporating other life history parameters and their trade-offs should be carried out to infer about the relative importance of body size and fecundity as life history traits in *A. bengalensis.* Nonetheless this is the first report on the relation between the morphometric correlates and fecundity of *A. bengalensis* that can help to deduce the population growth based on the body size and fecundity.

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