

Size at maturity, reproduction and recruitment in an amphidromous shrimp *Caridina serratirostris* De Man, 1892 in Reunion Island (Decapoda: Atyidae)

PIERRE HOARAU¹

1 : pierre.hoarau@oce.ae

ABSTRACT: Fisheries of small freshwater shrimps are relatively important in certain countries. In Reunion Island, South-West Indian Ocean, a traditional recreational fishery particularly targets *Atyoida serrata* (Spence Bate, 1888), which is endemic of the south-west Indian Ocean. However, a species with an Indo-Pacific distribution *Caridina serratirostris* (De Man, 1892), which is a threatened species at the island scale, can occur as a by-catch. Knowledge of the biology and particularly the reproduction is essential to preserve this species. A population of *C. serratirostris* was sampled by electrofishing on five occasions from August 2015 until May 2016 on the Marsouins River. The size at maturity of females was estimated at 13.5 mm but the reproductive population comprised less than 6% of the total catch. Reproduction occurred throughout the survey but an increase was observed during the hot and wet season. The main factor that influenced the onset of the reproduction was the temperature. The reproductive season was followed by a recruitment peak. Firstly, this study suggested to acquire knowledge of the stock distribution in order to conserve them. Secondly, it recommended a global crustacean fishing closure during the reproductive season.

RÉSUMÉ : La pêcherie de petites crevettes est une activité relativement importante dans certains pays. A l'île de La Réunion, dans le Sud-Ouest de l'océan Indien, une pêche traditionnelle cible *Atyoida serrata* (Spence Bate, 1888) endémique du Sud-Ouest de l'Océan Indien. *Caridina serratirostris* (De Man, 1892), une espèce à répartition Indo-Pacifique, est localement menacée. Elle peut être capturée comme prise accessoire. La connaissance de la biologie et plus précisément la reproduction est indispensable pour la préservation de cette espèce. Une population de *C. serratirostris* a été échantillonnée par pêche électrique à cinq reprises entre août 2015 et mai 2016 sur la Rivière des Marsouins. La taille à maturité des femelles a été estimée à 13,5 mm. La population d'individus matures représentait moins de 6% de l'ensemble des captures. Même si la reproduction a été observée tout au long du suivi, elle a considérablement augmenté au cours de la saison chaude et humide. Le principal facteur qui a influencé le déclenchement de la saison de reproduction était la température. Après cette saison de reproduction, un pic de l'effectif de jeunes individus a été enregistré. Cette étude recommande l'acquisition de données sur la répartition des populations afin de les conserver. Elle conseille également une fermeture de la pêche durant la période de reproduction.

KEYWORDS: By-catch, shrimp, size structure, maturity, reproduction, recruit.

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INTRODUCTION

The biodiversity of freshwater ecosystems has a high value in terms of aspects of economy, cultural, esthetic, recreational activity and scientific interest (DUDGEON *et al.*, 2006). For example, Atyidae Randall, 1840 and Palaemonidae Rafinesque, 1815 shrimps represent an important fishery resource (ALMEIDA *et al.*, 2010; BOGUHE *et al.*, 2011) and are generally targeted for personal consumption, as well as for being sold fresh, salted or dried (BLANCO, 1935; KIENER, 1963; POWELL, 1983). In Reunion Island, a traditional recreational fishery of small amphidromous shrimps targets *Atyoida serrata* Spence Bate, 1888. This species is endemic of the south-west Indian Ocean. It is also the most abundant of the island's crustaceans (HOARAU & VALADE, 2015). *Caridina Serratiostris* De Man, 1892 is a lowland species with an Indo-Pacific distribution (MARQUET *et al.*, 2002; SAITO *et al.*, 2012; YATSUYA *et al.*, 2012). It can occur as by-catch in the *A. serrata* fishery. This species is locally considered as a vulnerable species (IUCN France *et al.*, 2013). In the context of biodiversity conservation, knowledge of the reproductive biology of *C. serratiostris* is particularly needed to aid sustainable management of stocks.

The most important aspects of the reproductive biology are the characterization of the reproductive population and the seasonality of the reproduction. Firstly, in the genus *Caridina* H. Milne-Edwards, 1837, females mature at small sizes (<15 mm total length, SOOMRO *et al.*, 2011). Secondly, the reproduction increases or takes place during the hot or the rainy season in Atyidae (IDRISI & SALMAN, 2005; DHAOUADI-HASSEN *et al.*, 2006; HOFFMANN & NEGREIROS-FRANSOZO, 2010; ZARE *et al.*, 2011). Finally, the reproductive season is generally followed by a recruitment period in *Caridea* (ETIM & SANKARE, 1998; MATELATTO & BARBOSA, 2005; LIMA *et al.*, 2014; NOVAK *et al.*, 2015; KADJO *et al.*, 2017) linked with a decrease in stream flow (BAUER & DELAHOUSSE, 2008).

This study focused on the reproductive biology and the recruitment in *C. serratiostris*. In amphidromous shrimps, management actions can more easily take place in the freshwater environment. This study aimed to 1) estimate the size at maturity; 2) characterize the reproductive population; and 3) determine the phenology of reproduction and recruitment in relation to environmental variations. This paper suggested actions and strategies to aid management of the island's *C. serratiostris* stocks.

MATERIAL AND METHODS

LOCATION AND SAMPLING

Reunion Island belongs to the Mascarene Archipelago located in the South-West of the Indian Ocean (*Fig. 1*). The Marsouins River is situated in the North-East of the island. The sampled site was positioned near the mouth of the stream (altitude: 2m, sea distance: 0.01km). Samplings occurred on five occasions from August 2015 until May 2016. Shrimps were caught by electrofishing (Hans Grassl® IG200-2B) using the point abundance sampling (PAS) method, which is particularly useful in the study of the size structure of crustacean (FIEVET *et al.*, 1996). A total of between 90-101 PAS per occasion was systematically placed ("zigzag") along the sampled site taking care to avoid disturbing the fauna between each PAS. Each PAS lasted 30 seconds with shrimps collected in two downstream-placed nets (2 mm mesh, net width of 0.45m).

SIZE STRUCTURE AND MATURITY

Shrimps were measured (Total Length (TL) - tip of the rostrum to the end of the telson) and ovigerous females identified. The global size structure of the all shrimps caught during the study was determined using 2 mm size classes over the range 2 – 22 mm. Data of the samplings that occurred in February 2016 and May 2016 (number of shrimps involved, $n=514$), which were the months with the highest number of ovigerous females, were used for estimating size at maturity. A general linear model (GLM family binomial, NELDER & WEDDERBURN, 1972) was used to examine the changes in the proportion of ovigerous females with increasing size (TL). Ovigerous females were categorized as 1, whereas other individuals were categorized as 0. The significance of explanatory variables was then assessed using a sequential analysis of deviance (Chi square test). Based on the model outputs, the length at which 50% of females were ovigerous was considered as the size at maturity (ZARE *et al.*, 2011). This method considers all the population size structure instead of some individuals.

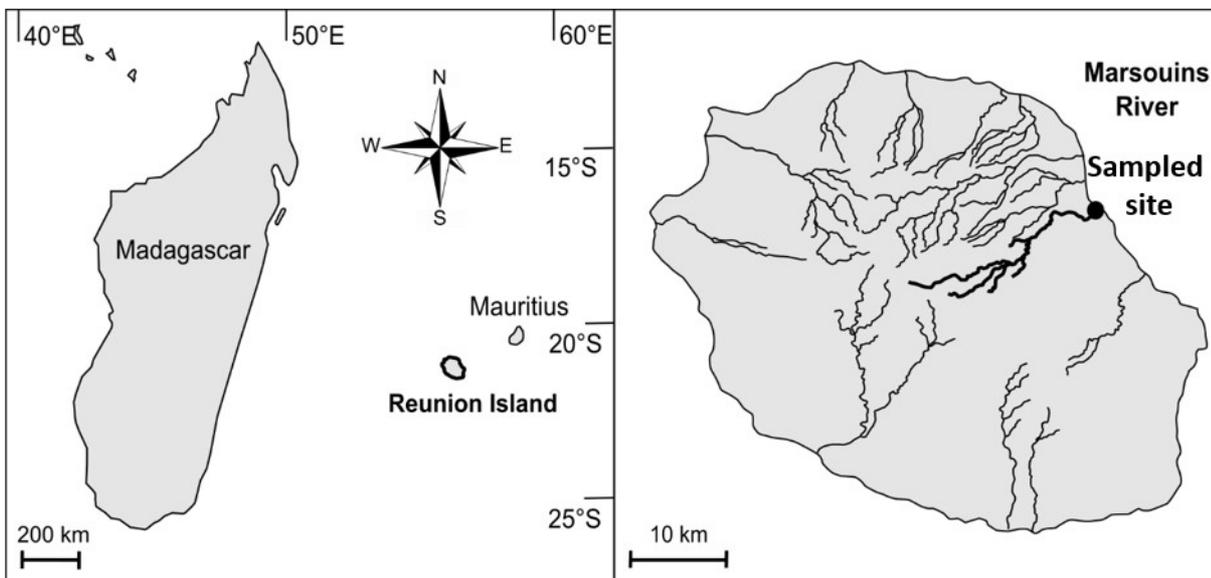


Figure 1. – Location of the sampled site on the Marsouins River, Reunion Island, South-West Indian Ocean.

REPRODUCTION, RECRUITMENT AND ENVIRONMENTAL FACTORS

Information concerning daily discharge over the entire period of study was accessed on-line (Office de l'Eau: www.eaureunion.fr; Office's station code: 27054, 5.2km upstream). Information concerning air temperature (AT) was similarly available for the entire period of study (www.meteofrance.re, Météo France's station Saint-Benoit, the nearest to the stream mouth), whereas stream water temperature (WT) for station 27054 was available for the period May 2016 to July 2016 only. However, monthly water and monthly minimum air temperatures over the period November 2010 to December 2016 were highly correlated (p -value F-test regression: $<2.2 \cdot 10^{-16}$, $n = 53$ $R^2=0.94$: $WT = 7.1928 \cdot 10^{-1} AT + 4.7785$) thus permitting estimation of water temperature over the period of study.

Shrimps were classified in three stages according to their size and stage of development. These groups were: recruits (individuals less than 7 mm TL (ARDA 2012)); ovigerous females; and non-ovigerous individuals greater than 7 mm. Catch data for each maturity stage was expressed as

catch per unit of effort (CPUE - number of shrimps / number of PAS). Recruitment was here defined as the arrival in river of young shrimps. The abundance of ovigerous females was the indicator used to study the reproduction. The same GLM procedure employed for maturity analyses was also used to assess the effect of the water temperature and discharge on the onset of the reproductive period. The proportion of ovigerous females in shrimps with a size equal or over 11 mm TL (size of the smallest ovigerous female, n=127) was examined according to the monthly mean of both parameters for the month of sampling as well as the preceding one (ovigerous females:1; others: 0).

RESULTS

SIZE STRUCTURE AND SIZE AT MATURITY

The size structure of the 1,570 shrimps caught during the study was strongly skewed towards small shrimps with individuals less than 5 mm TL comprising 57.5% of the sample (*Fig. 2*). Individuals greater than 12 mm TL comprised only 5.5% of the total number of shrimps collected. A total of 64 ovigerous females was collected. The average TL of ovigerous females was 15.6 ± 3.0 mm (mean \pm standard error) and ranged from 11 to 22 mm TL. The probability for a shrimp to be an ovigerous female during the favorable season varied significantly with the TL (p-value: <0.001, Explain Deviance: 67.3%). It was equal to 0 for shrimps below 8 mm, whereas it was equal to 1 for individuals above 20 mm. The proportion of ovigerous females observed fitted very well with the model outputs apart from the 16 mm size class (*Fig. 3*). It could be due to female which had released their eggs before samplings. Based on the model the size at which 50% of individuals were ovigerous females was estimated at 13.5 mm TL. This value was considered in this study as the size at maturity of female in *C. serratiostris*.

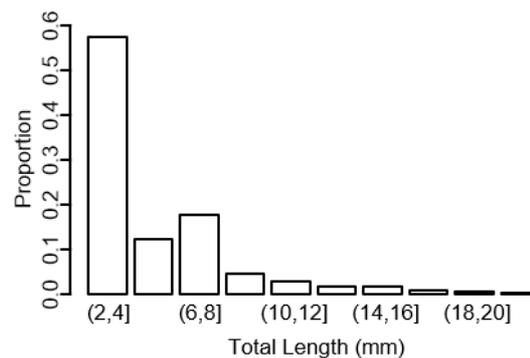


Figure 2. – Size structure of *Caridina serratiostris* caught between August 2015 and May 2016 on the Marsouins River, Reunion Island, South-West Indian Ocean (n=1570).

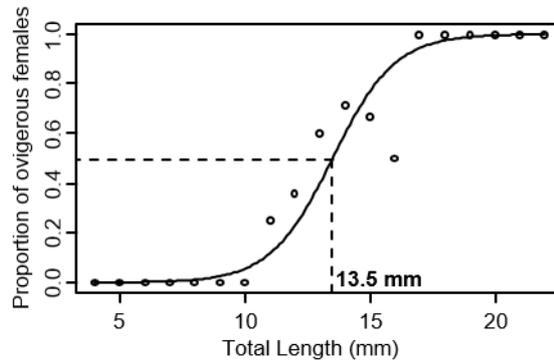


Figure 3. – Proportion of ovigerous females in *Caridina serratiostris* according to the Total Length (TL) in February and May 2016 on the Marsouins River, Reunion Island, South-West Indian Ocean (n=514). The solid line illustrates the model outputs (binomial).

REPRODUCTION AND RECRUITMENT SEASON

Both water temperature and discharge varied in magnitude over the period of study (Fig. 4). Changes in water temperature were seasonal with a gradual increase from 16-18°C during the dry season (June- August) to between 20.2°C and 21.5°C in the wet season. Stream flow varied from between 5.0m³/s and 8.8m³/s from March to November, increasing to more than 11m³/s in December/January and peaking at a maximum of 22.7m³/s in February 2016.

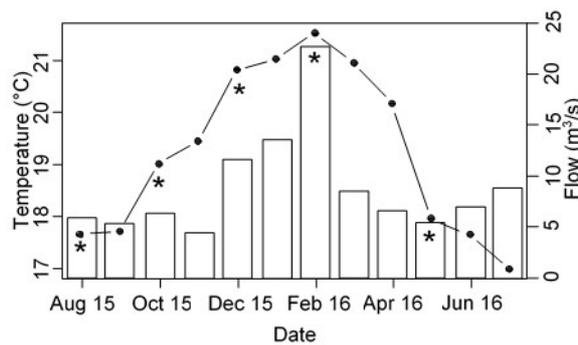


Figure 4. – Monthly means of temperature (line) and flow (barplot) in August 2015 to July 2016 on the Marsouins River, Reunion Island, South-West Indian Ocean. « * » indicates the samplings.

CPUE for each maturity stage remained relatively low from August 2015 to December 2015 but increased at the two last samplings (Fig. 5). Any ovigerous females were caught in August 2015, abundances stayed low in October 2015 and December 2015, increased in February 2016 (0.2 CPUE) and slightly decreased in May 2016 (0.1 CPUE). Reproduction (TL>11 mm) was only linked with the temperature of the month preceding the sampling (p-value: 0.006575). Abundances

of recruits were very low during the three first samplings (<0.1 CPUE). It slightly went up in February 2016 (0.2 CPUE) and boomed in May 2016 (5.1 CPUE). Abundances of other individuals remained relatively low from August 2015 to December 2015 (<0.2 CPUE). Then it gradually increased and reached a maximum at 1.1 CPUE in May 2016.

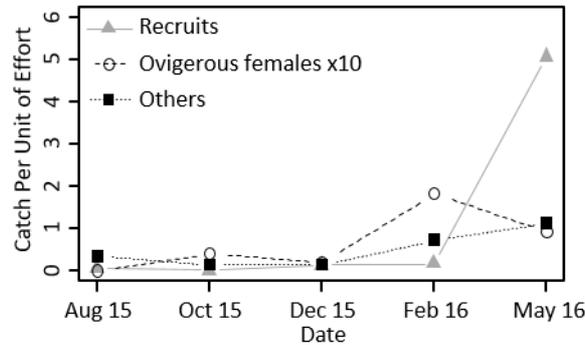


Figure 5. – Catch Per Unit of Effort of *Caridina serratiostris* according to the stage in August 2015 to May 2016 on the Marsouins River, Reunion Island, South-West Indian Ocean.

DISCUSSION

REPRODUCTIVE POPULATION

Caridina is characterized by a small size (<50 mm) (KEITH *et al.*, 2006) and shrimps are less numerous in larger size classes (HART, 1981); however, they mature at very small size (SOOMRO *et al.*, 2011). *C. serratiostris* is the smallest crustacean which inhabits rivers of Reunion Island and has maximum size of 20 mm TL (KEITH *et al.*, 2006). Small mature females are common in *Caridina*, despite the fact that some species reach a higher maximum size. For example, in *Caridina typus* H. Milne Edwards, 1837 and *Caridina sakishimensis* Fujino & Shokita, 1975, which grow respectively to 34.8 mm TL (KEITH *et al.*, *loc.cit.*) and 29.1 mm, the smallest ovigerous females observed are 11.7 mm and 16.9 mm (SOOMRO *et al.*, 2011). Nonetheless, larger shrimps are less numerous. For instance, the relative abundance declines with an increasing size in *Caridina nilotica* (HART, 1981).

The biggest shrimp captured in this study was 22 mm TL, the smallest ovigerous female 11 mm and the size where 50% of individuals (females and undetermined) were ovigerous females was estimated at 13.5 mm. However, model outputs did not fit with the observation for one size class that should otherwise have showed a high proportion. ZARE *et al.* (2011) suggest that the term “apparent maturity” is preferred as maturity status is qualified only on the presence of the attached eggs neglecting the case where some mature females may have released their eggs prior to being collected. Although the differentiation between sexes was not possible in this study, it was unlikely that a size dimorphism, otherwise well-known in Atyidae (CHACE, 1983; KEITH *et al.*, 2006; THOMAS & JAY, 2007; ZARE *et al.*, 2011), could have influenced determination of size at maturity. Finally, based on the size at maturity and the size structure, the reproductive population showed a relatively low abundance since it was inferior to 5.5% of total catch.

REPRODUCTION AND RECRUITMENT

Shrimp reproduction is controlled by environmental factors (BAUER, 1992) and atyid reproduction typically occurs over the hot or the rainy season. For example, *Atyephyra desmaresti* (Millet, 1831) and *Potimirim brasiliensis* Villalobos, 1960 reproduction begins in the spring and continues through the summer (DHAOUADI *et al.*, 2006; DA ROCHA *et al.*, 2013). Most authors (e.g. IDRISI & SALMAN, 2005; YAM & DUDGEON, 2005) suggest or demonstrate that reproduction is cued by environmental temperature although HOFFMANN & NEGREIROS-FRANSOZO (2010) demonstrate that the percentage of ovigerous females of *Potimirim glabra* (Kingsley, 1878) is positively correlated to temperature as well as stream flow. Coincidence of elevated discharge and temperature during the tropical wet season makes it difficult to disentangle the relative importance of either temperature or stream flow.

Ovigerous females of *C. serratiostris* were caught on four of the five dates of sampling on the Marsouins River but the greatest number of ovigerous females was recorded in February and May 2016, a period of high temperature and contrasted discharge. Water temperature is an important factor cuing the onset of the reproductive period in atyid species. In this study the temperature in the preceding month was more important than at the time of sampling. For example, whilst water temperatures in December 2015 were high, the number of ovigerous females was low. Water temperatures in the month preceding this occasion were low. In contrast, while May 2016 was characterized by low temperature, this sampling occasion was distinguished by a high proportion of ovigerous females. However, water temperatures preceding this occasion were high. Temporal variations in stream flow was unlikely to cue reproduction in *C. serratiostris* in the Marsouins River, as stream flow was markedly different in those months in which ovigerous females were plentiful.

The reproductive season is generally followed by a recruitment period in *Caridea* Dana, 1852. It happens a little time after the reproductive season in the genus *Macrobrachium* Bate, 1868 (MANTELATTO & BARBOSA, 2005). A considerable increase in recruit arrivals is observed 1 to 4 months after the reproductive period (ETIM & SANKARE, 1998; LIMA *et al.*, 2014; NOVAK *et al.*, 2015) was linked with a decrease in flow (BAUER & DELAHOUSSAYE, 2008). In *Atya scabra* (Leach, 1816) it occurs throughout the year but peaks are observed during the dry season (KADJO *et al.*, 2017). The recruitment in *C. serratiostris* occurred throughout the survey but increased considerably one month after the increase of reproduction in May 2016 which is characterized by a low discharge.

Species or size selection seems unfeasible in small shrimp fishery. However, the establishment of sanctuaries and seasonal closures appear to be the key of the preservation of *C. serratiostris*. Firstly, the differentiation between genus *Atyoida* de Haan, 1849 and *Caridina* is complex in a fishery context due to their very low size (< 50 mm), (KEITH *et al.*, 2006). Secondly, *C. serratiostris* is not directly targeted. The main management action in order to protect this species, would be to restrict small shrimp fishing in parts of rivers where significant populations are present and particularly the downstream (MARQUET *et al.*, 2002; SAITO *et al.*, 2012; YATSUYA *et al.*, 2012). Finally, a global crustacean fishing closure during the reproductive period in the hottest months from December to April would be beneficial for *C. serratiostris* as well as for the *Macrobrachium* and *Atyoida* genera (HOARAU, unpublished data). To conclude, an evolution of regulations based on the biology is the key for a sustainable management of targeted species as well as by-catch.

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