Nauplius
The Journal of The Brazilian Crustacean Society
e-ISSN 2358-2936
www.scielo.br/nau
www.crustacea.org.br

Gonadosomatic index and weight/length relationship in females of three penaeoidean shrimps impacted by fisheries on the southeastern Brazilian coast

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SUBMITTED 20 July 2020
ACCEPTED 21 August 2020
PUBLISHED 04 December 2020

DOI 10.1590/2358-2936e2020045

Abstract

The aim of this study was to evaluate the gonadosomatic index (GSI) and the weight/length ratio in important shrimp populations (*Xiphopenaeus kroyeri* (Heller, 1862), *Litopenaeus schmitti* (Burkenroad, 1936), *Rimapenaeus constrictus* (Stimpson, 1874)) from the northern littoral of São Paulo State. The samples were collected between 2015 and 2016, with 212 females that were identified, classified according to their gonadal development stage, and measured (CL). The gonads were macroscopically classified into immature, spent and developed, and were then removed. Both body (BodW) and gonad (GonW) dry weights were obtained in order to calculate the gonadosomatic index. Weight/length relationship and weight gain rate were assessed. The weight gain presented negative allometry, indicating that the animals grow faster than they gain weight. The weight/length relationship showed a pattern of continuous reproduction, as previously determined for tropical species. From the GSI values, it was possible to separate the three predetermined gonadal stages, proving that macroscopic evaluation is reliable for evaluating the reproductive period of these shrimps. These results can be used as a guide for fishery stocks management and monitoring.

Keywords

Allometry, gonads, reproduction, São Paulo State, Ubatuba

Recently, the world's shrimp fishery has reached a catch of ~3.4 million tons per year. These animals represent about 16% of the world's exportation, of which 60% comes from fisheries and only 40% coming from shrimp farms, making shrimps one of the most important fishery resources, mainly in tropical countries (Food and Agriculture Organization of the United Nations, 2015). In Brazil, São Paulo State is one of the regions that keeps track of its fishery, with data showing that the biggest catch volume belongs to the cities of Santos/Guarujá, followed by Cananéia and Ubatuba (Ávila-da-Silva *et al.*, 2019). Although the main fish species captured is Brazilian sardine (*Sardinella brasiliensis* (Steindachner, 1879)), the second most captured animal is seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862), with an average catch of ~1,734 tons per year from 2013 to 2017, becoming in 2018 the most exploited fishery resource in the São Paulo State (2,246 tons) (Ávila-da-Silva *et al.*, 2019). In the shallow regions exploited by artisanal shrimp fishery, the species in the family Penaeidae stand out, especially the seabob shrimp *X. kroyeri* and the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936). In addition to catching the targeted species, roughneck shrimp *Rimapenaeus constrictus* (Stimpson, 1874) and many other species are caught as bycatch by the non-selective trawl equipment used in fishery, and often have no commercial value due to their small sizes (Castilho *et al.*, 2008; Lopes *et al.*, 2017).

These penaeoidean shrimps do not incubate their eggs on pleopods during embryonic development (Dall *et al.*, 1990). Therefore, to evaluate the reproductive output of these animals, the gonadosomatic index is used. The gonadosomatic index (GSI) is the ratio between the gonad weight and the total weight of the individual (Anderson *et al.*, 1985; Ohtomi and Yamamoto, 1997). Besides reproductive features, the weight/size relationship can reveal important information about weight gain and population biomass of determined species (Froese, 2006; Taddei *et al.*, 2017).

The ecological cycles and distinct reproductive strategies of penaeoid shrimps vary. The juvenile and subadult shrimps of *L. schmitti* are commonly found in inshore regions, such as bays, until they reach gonadal maturity, when they migrate to offshore regions during the breeding and spawning periods (Dall *et al.*, 1990). *Xiphopenaeus kroyeri* exhibits a life cycle with inshore to offshore movements with increasing age, but with juveniles not utilizing estuaries to grow to the subadult stage before later migrating offshore (Castilho *et al.*, 2015). Lastly, in *R. constrictus* the entire juvenile to spawning adult portion of the life cycle may occur in inshore waters (Costa and Fransozo, 2004). But, these three species do support the paradigm of latitudinal trends in life-history traits for crustaceans, with a generally more continuous reproduction throughout the year, shorter lifespan, and faster growth in tropical and subtropical seas compared to higher latitudes. (Bauer, 1992; 2004; Castilho *et al.,* 2007; 2015). Due to intensive fisheries and the ecological importance of these three species (seabob shrimp, white shrimp, and roughneck shrimp), the objective of this study was to characterize reproductive traits (GSI and gonadal maturity) and to evaluate the weight/length ratio; both indicators used in biological fishery studies of commercial species.

The samples were collected seasonally between January 2015 and December 2016 in Ubatuba, (23°26′S 45°02′W), northern coast of São Paulo State, Brazil. The samples were collected using an artisanal fishery boat equipped with 'double-rig' nets. The sampling stations presented depths ranging from 5 to 20 m. During the trawls, the boat was kept at 1.6 knots for 30 minutes, sampling approximately 0.5 miles (1.5 km) in each sampling station.

The shrimps were identified with specialized literature (Pérez Farfante, 1988; Pérez Farfante and Kensley, 1997; Costa *et al*., 2003), and a total of 212 females had their carapaces measured from the post-orbital margin to the posterior margin of the carapace (CL) using a digital caliper (Castilho *et al*., 2007). The females were sorted based on the presence of the thelycum (Boschi and Scelzo, 1977; Dall *et al.,* 1990). The female's reproductive status was assessed through macroscopic evaluation of their gonads (color and volume). Females were classified into three stages: immature, presenting thin and transparent gonads; developed, presenting greenish gonads, larger and thicker than the previous stages; and spent, if they were white and much larger and thicker than those of immature females (Costa and Fransozo, 2004; Campos *et al*., 2009; Machado *et al*., 2009; Castilho *et al.,* 2015). This macroscopic classification is a reliable method that has been corroborated by histological studies (Dumont and D'Incao, 2004; Campos *et al*., 2009). These females had their gonads dissected and were then conditioned in separated aluminum trays (with known weight), along with their gonads. The material was dried at 60 °C for 48 h. Afterwards, the animals and their gonads were weighed on an analytical balance (0.0001 g), where body weight (BodW) and gonad weight (GonW) were obtained. The gonadosomatic index (GSI) was calculated through the equation: GSI = (GonW/BodW) x 100. Scatter plot graphs were used to explore the relationship between female sizes (sorted by gonad development stage) and GSI, in an attempt to evaluate the energy invested during the reproduction process. The data was log-transformed and linear regressions were made to test the relationship between carapace length and GSI.

The relationship between BodW and CL was tested using the Standard Major Axis routine (known as "Type II Linear Regression") through SMATR package (Warton *et al*., 2012) in R (R Development Core Team), this analysis decreases the effect of residuals providing a better line of fit for allometric relationships (for more information please see Warton *et al*., (2006)). Prior to the analysis, the data was log-transformed, the slopes (b) of each relationship were tested. In this relationship, b value is the allometric weight gain rate, with $b < 3$ signifying negative weight gain, $b = 3$ isometric weight gain and $b > 3$ positive weight gain (Froese, 2006).

A significant relationship was found between carapace length and GSI for the species studied (*X. kroyeri* $r^2 = 0.33$, $p < 0.05$, $F = 51.63$; *L. schmitti* $r^2 = 0.49$, $p < 0.05$, $F = 27.8$; *R. constrictus* $r^2 = 0.14$; $p < 0.05$ $F = 12.36$). The shrimps presented negative allometry ($b < 3$) for weight/carapace relationship, indicating that these animals tend to grow more quickly than they gain weight (Tab. 1). Despite the positive relationship between GSI and CL, the low determination coefficient values (r^2) could be a result of females being caught after extruding their embryos, since the animal starts a new reproductive cycle when the gonad weight decreases, returning to a spent developmental stage. However, the carapace length remains constant, which explains the larger females with low gonad weights (Branco *et al*., 1992; Costa and Fransozo, 2004; Castilho *et al*., 2007). Moreover, the animal's CL does not represent the whole-body design, because females grow in width and volume when they reach sexual maturity (Froese, 2006; Santos-Filho *et al*., 2016). *Xiphopenaeus kroyeri*, *L. schmitti* and *R. constrictus* had a mean size of 18.47 ± 4.7 mm CL, 40.68 ± 4.57 mm CL, and 10.13 ± 2.5 mm CL, respectively. The mean gonadosomatic index for *X. kroyeri* was 4.14 ± 4.24% (mean ± SD), ranging from 0.05 % to 16.38 %. For *L. schmitti,* the mean GSI was 4.98 ± 3.61% (mean ± SD), ranging from 0.07 % to 11.09 %. For *R. constrictus* females, the mean GSI value was 2.02 ± 2.9% (mean ± SD), ranging from 0.06 % to 14.36 % (Tab. 2). The macroscopic evaluation of the gonads *in situ* separated the specimens into different gonadal development stages. The mean GSI for the different stages was 0.6 % immature, 0.88 % spent and 7.65 % developed for *X. kroyeri* shrimps, 1.93 % spent and 6.75 % developed for *L. schmitti* shrimps; 1.47 % immature, 1.11 % spent and 7.67 % developed for *R. constrictus* shrimps (Fig. 1).

Table 1. Weight x length relationship of three Penaeidae species [seabob shrimp (*Xiphopenaeus kroyeri*), white shrimp (*Litopenaeus schmitti*), roughneck shrimp (*Rimapenaeus constrictus*)], sampled in Ubatuba, São Paulo, Brazil. Values with * were statistically significant from isometry (b = 3) ($p < 0.05$).

Species	Linearized Equation lny = lna + b.lnx	r^2	Slope (b)(H_0: b=3)	Allometry
Xiphopenaeus kroyeri	log Weight = -3.53 + 2.61log CL	0.91	2.61*	—
Litopenaeus schmitti	log Weight = -0.36 + 0.83 log CL	0.89	0.83*	—
Rimapenaeus constrictus	log Weight = -3.25 + 2.35log CL	0.93	2.35*	—

Table 2. Carapace length variation (mm) and mean values of weight, carapace length and gonadosomatic index for seabob shrimp (*Xiphopenaeus kroyeri*), white shrimp (*Litopenaeus schmitti*), and roughneck shrimp (*Rimapenaeus constrictus*) females from Ubatuba region, São Paulo, Brazil. ("n" = number of specimens analyzed)

	Xiphopenaeus kroyeri (n = 106)	*Litopenaeus schmitti* (n = 30)	*Rimapenaeus constrictus* (n = 76)
Mean weight (g) ± SD	0.69±0.45	9.61±2.33	0.14±0.08
CL variation (mm)	7.16 to 29.61	31.61 to 50.98	4.32 to 15.27
Mean CL (mm) ± SD	18.47±4.7	40.68±4.57	10.13±2.5
Mean GSI (%) ± SD	4.14±4.24	4.98±3.61	2.02±2.9

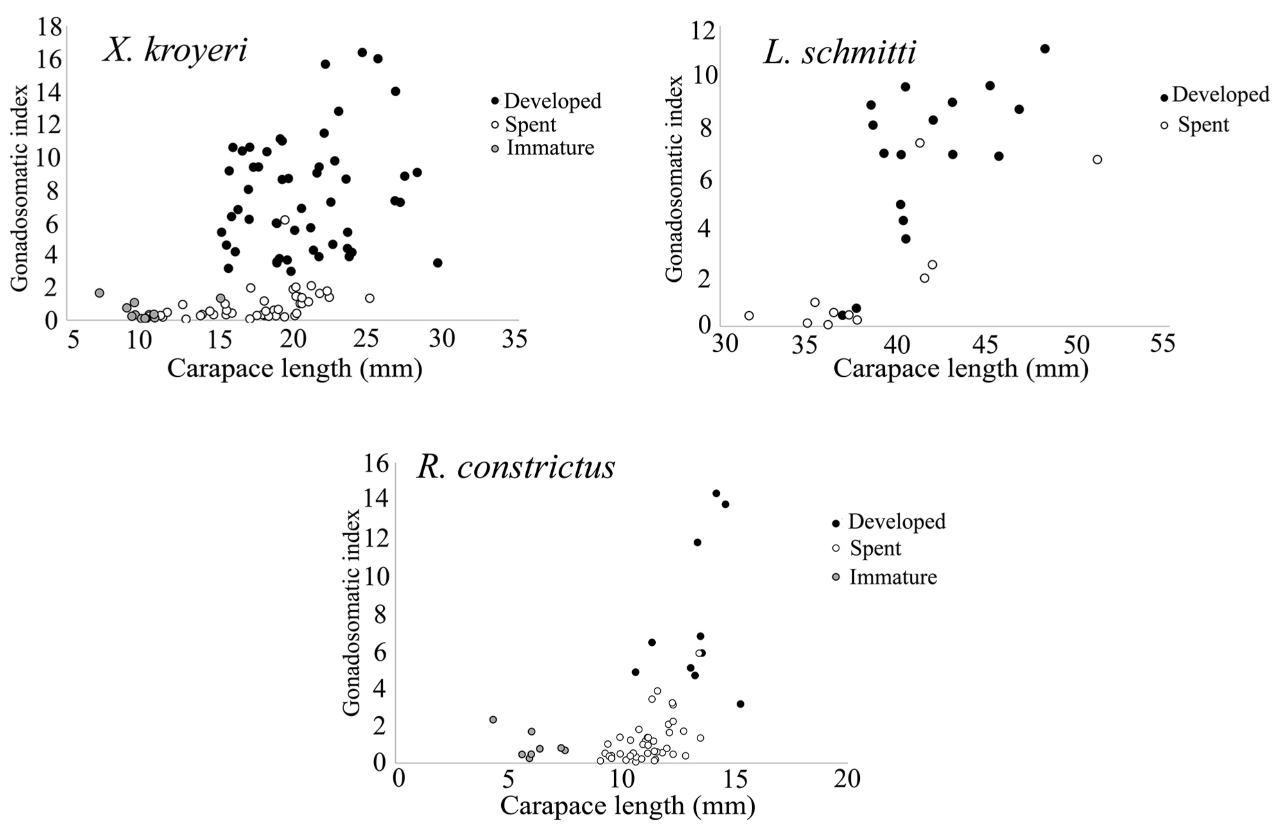

Figure 1. Dispersion graphs of the gonadosomatic index separated by gonad development stage and size of the individual for each species studied: seabob shrimp (*Xiphopenaeus kroyeri*), white shrimp (*Litopenaeus schmitti*) and roughneck shrimp (*Rimapenaeus constrictus*).

The smaller specimens classified as spent herein presented sizes close to those estimated for sexual maturity, such as: 14.50 mm for *X. kroyeri* and 7.8 mm for *R. constrictus* (Costa and Fransozo, 2004; Castilho *et al.*, 2015). Since *L. schmitti* has type II development as proposed by Dall *et al.* (1990) in which the species use the estuary during development and the immature stage is found transitioning from estuary to the coast. Hence, in the present study we could not actually evaluate the changes in GSI between immature and spent stages, however, we suggest that the GSI changes could be close to its sexual maturity as seen for the other species. After the spent stage, the reproductive specimens (in development and with developed gonads) of all species start with approximately 4 % gonadosomatic index. This 4 % could be the beginning of gonad development for reproduction. Some authors found a transition to mature stage around GSI 6.9%, which is close to the value reported in the present study. Several authors proposed that somatic growth is restrained and energy is allocated to gonad development during reproduction (Christiansen and Selzo, 1971; O'Connor, 1979; Hartnoll, 1982; 1985; Minagawa *et al*., 2000). The gonad weight of crustaceans changes drastically during the reproductive period, consequently, changing the growth rate in relationship to the weight gain rate (Branco *et al*., 1992).

White shrimp, seabob shrimp and roughneck shrimp are species with continuous reproduction (Heckler *et al*., 2013; Castilho *et al*., 2015; Garcia *et al*., 2016; Simões *et al*., 2017), therefore, they tend to invest energy into reproduction all year-round. In this scenario, where energy is constantly being directed to reproduction (gonad development), the allometry of the weight/length relationship is expected to be negative, because they reproduce more than once a year. This leads to high-energy expenditure, and consequently, the animal will lose weight by the end of the reproductive cycle, and then start a new reproductive cycle. The animals will have to gain weight again in the same year due to the energetic demand for reproduction. The white shrimp also presented negative allometry for weight/length relationship, which could also be related to the reproductive cycle. Although, when in captivity this species can improve the weight/length relationship up to $b = 2.82$, which would still be negative allometry (Henriques *et al*., 2014), this difference could be related to the rearing system which eliminates the environmental stress.

Ubatuba is important for artisanal fishery, as it harbors the profitable species seabob shrimp and white shrimp, as well as the bycatch of roughneck shrimp. Therefore, constant assessment of fishery stocks through population studies is needed, considering the reproduction patterns and singularities of each species.

Acknowledgements

The authors thank many colleagues from the NEBECC group who helped with sampling and laboratory analyses. This study was carried out in compliance with current Brazilian state and federal regulations for wild animal sampling (MMA-SISBIO license [#44945-1]). This research was financed by the São Paulo Research Foundation—FAPESP under Grant [#2010/50188-8, #2015/13639-5, #2015/01959-5]; Brazilian National Council for Scientific and Technological Development – CNPq under Grant [#311034/2018-7]; and Coordination for the Improvement of Higher Education Personnel – CAPES CIMAR under Grant [#23038.004310/2014-85].

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