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Reproductive biology of ridgeback shrimp *Solenocera choprai* (Decapoda, Penaeoidea, Solenoceridae) off Mangalore coast, south India

AAYATHAN P DINESHBABU[1]* AND JOSEPH K MANISSERY[2]

[1]*Mangalore Research Center of Central Marine Fisheries Research Institute, Mangalore 575 001, Karnataka, and* [2]*Department of Aquaculture, College of Fisheries, Mangalore 575 002, Karnataka, India*

ABSTRACT: The ridgeback shrimp *Solenocera choprai* has emerged as one of the important commercial species in 60–100 m depth zone off Karnataka coast, India, since 1993. Studies were conducted on *S. choprai* to understand its reproductive biology which can help in formulating policies for management of the species. The diagnostic features of reproductive morphology of the species were studied and illustrated in detail. Based on the coloration and size of the ovary and ova diameter variations, five stages of maturity in female *S. choprai* were identified. The mature ova are fully yolked with diameters between 0.24 and 0.35 mm. Size at maturity (50%) has been estimated at 54.5 and 66.5 mm total length (TL) in males and females, respectively. The gonadosomatic index (GSI) showed an increasing trend according to the advancement of maturity of the ovary, and monthly mean GSI showed a positive correlation with monthly percentage of spawners. *Solenocera choprai* was found to be a continuous breeder with two peaks: a major peak in November and another extended peak during January–February. The estimated numbers of ova in the mature ovary were 38 532 and 133 689 in shrimps measuring 80 and 110 mm TL, respectively. A sigmoidal increase in the female-to-male sex ratio with increase in size was noticed in the species. A χ^2-test showed that the annual distribution of females and males is not significantly different from a 1:1 ratio at the 1% level.

KEY WORDS: **fecundity, Mangalore, maturity, reproductive biology, reproductive morphology, sex ratio, shrimp, *Solenocera choprai*.**

INTRODUCTION

Solenocera choprai, a penaeid shrimp belonging to Solenoceridae family, is widely distributed in the Indo-Pacific and reported from eastern coast of Africa, Madagascar, the Gulfs of Suez and Arabia, Pakistan, India, Malaysia, the Philippines, Indonesia, Taiwan, Thailand and north-east and north-west Australia.[1] Although 10 species belonging to the genus *Solenocera* were reported from the Indian coast, only *Solenocera crassicornis* formed a regular commercial fishery. Along the Mangalore coast (south India), *S. choprai* emerged as a fishery resource at a depth of 60–100 m from 1993 onwards. During 2002, the landing of this species was approximately 3186 t, which formed more than 50% of the total shrimp landing from this coast. During 2002 and 2003 the species contributed approximately $US1.2m (Indian Rs. 60m) to the fishery, the economy of the coast and reduction of the landing of the species was found to affect the economic feasibility of fishing operations. Increased commercial importance of the species has led to increased fishing pressure and an immediate study on its reproductive biology is essential to regulate exploitation and for proper management and conservation. The present study is expected to help in understanding and predicting the biological changes in the population of *S. choprai*. Until the early 1990s, the shrimp fishery of the coast was constituted entirely by species belonging to the Penaeidae family and the biology of these species was studied extensively. Since *S. choprai* is a comparatively new entry to the shrimp fisheries of the coast, detailed studies on the reproductive

*Corresponding author: Tel: 91-082-4242-4152.
Fax: 91-082-4242-4061. Email: dineshbabuap@yahoo.co.in
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morphology were conducted before studying its reproductive biology.

A preliminary study[2] conducted for Bombay waters, India is the only report available on the reproductive biology of this species. However, the reproductive biology of other species belonging to the Solenoceridae family has been studied extensively. Some of these studies include Kunju[3] and Sukumaran[4] on *S. crassicornis* from Bombay waters, Chalayondeja and Tanoue[5] on *S. prominestis* in Kagoshima Bay, Southern Japan, Gueguen[6] on *S. acuminata* in French Guiana and Ohtomi *et al.*[7] on *S. melantho* in Kagoshima Bay, Southern Japan. Baelde[8] conducted detailed studies on the reproductive biology of *Haliporoides sibogae* from south-east Australia.

MATERIALS AND METHODS

Samples of *S. choprai* were collected from the trawl landings of Mangalore and Malpe fisheries harbor (Fig. 1) twice a week during 2003 and 2004. In total 3275 shrimp were used for reproductive biology studies of the species. Trawling operations from these harbors were carried out from January to June and from August to December during these years. The data during July could not be collected because of the monsoon ban on trawling imposed by the Karnataka State Government, India. The petasma and thelycum were examined using a microscope (Olympus, Tokyo, Japan) with a camera attachment to understand the reproductive morphology. The length and weight of the samples were recorded and ovaries from females were dissected out. The color and size of the ovaries were recorded before preserving them in 5% formalin. The maturity stages were defined for fresh specimens based on the color and thickness of ovary.[9] However, the different maturity stages were confirmed by microscopic examination of ova diameters. For ova diameter studies, small portions of ovary (~10 mg) taken from the anterior, middle and posterior parts of the ovary were teased out on a glass slide and 300 ova from each portion were examined under the microscope. As the diameter of ova collected from different regions of the ovary did not indicate any variation, further studies on fecundity and ova diameters were carried out using a portion of the ovary on the right side of first abdominal segment. The diameters of ova were measured using an ocular micrometer, where one division equals 0.0150 mm. The ova were irregular in shape and measurement of each ovum was taken in the same parallel plane using the mechanical stage of the microscope in order to avoid errors due to distortion and subjective bias.

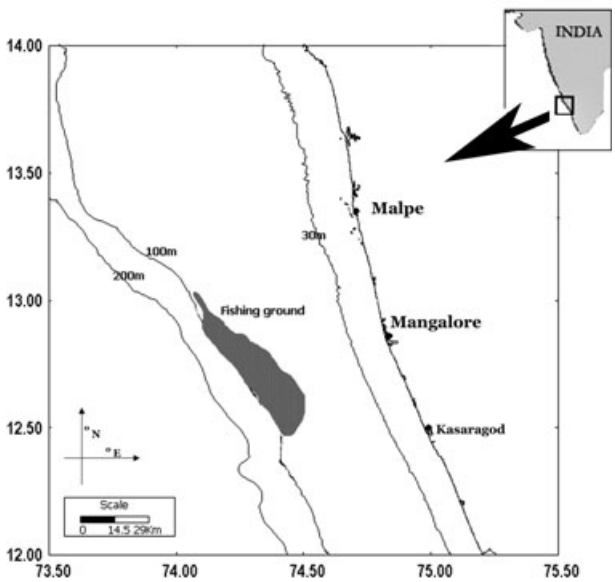

Fig. 1 Map showing fishing grounds for *Solenocera choprai* off Mangalore, India.

The size at first maturity (50%) was found by fitting a logistic curve[10] to a proportion of mature females at total length. Shrimp with well-formed petasma and with the presence of spermatophores in the terminal ampoule were taken as mature males.[8] To determine the size at first maturity, 133 males of size ranging 51–58 mm and 829 females measuring 61–77 mm were examined.

Preserved ovaries were washed, dried using blotting paper and weighed, and a subsample was taken and weighed to the nearest 0.001 g using an electronic balance. Mature ova present in the subsample were counted using a counting slide. From the number of ova in the weighed subsample, fecundity was calculated using the formula:

$$\text{Fecundity} = \frac{\text{total weight of the ovary}}{\text{weight of the sample}} \times \text{number of ova in the sample}$$

The relationships of fecundity on total length, total weight and ovary weight were found by fitting regression lines on natural logarithms of observed values by a least-squares method.[11] For fecundity studies, females with mature ovaries in the range 79–110 mm were examined.

For gonadosomatic index (GSI) estimation the method described by Ohtomi[7] *et al.* was followed. By this method GSI was calculated by the formula:

$$GSI = 100 \times GW/BW$$

where GW is wet gonad weight and BW is the body weight of the shrimp before removal of gonads. The

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sex ratio of *S. choprai* was studied based on the monthly estimated numbers during 2003 and 2004 in order to obtain a true representation of males and females in the population. Homogeneity of the sex ratio (based on observed numbers) over months in two years was tested for a 1:1 sex ratio using a χ^2-test.[11]

RESULTS

Fishing method

Solenocera choprai were caught in trawl nets operated from mechanized vessels. Multi-day fleet trawlers of 9.75–15 m overall length fitted with engines of 53–102 hp made trips lasting 7–8 days and had fish-holds of varying capacity to store the catch in ice. The cod end mesh size of the shrimp net was 18–20 mm. Since the catch of the species is poor during the day compared to night, trawling for *S. choprai* is conducted at night.

Reproductive morphology

The petasma is formed by the fusion of endopods of the first pair of pleopods, and is an elongated structure with an expanded middle portion (Fig. 2). The two halves of the petasma are united anteriorly, each terminating at its distal end in three lobes which are armed along their free distal margins with minute spines. Dorso-lateral lobules of the petasma bear 20–30 terminal spinules each. The dorso-median lobule also has the same number of spinules but the disto-lateral lobule has 12–18 spinules (Fig. 2).

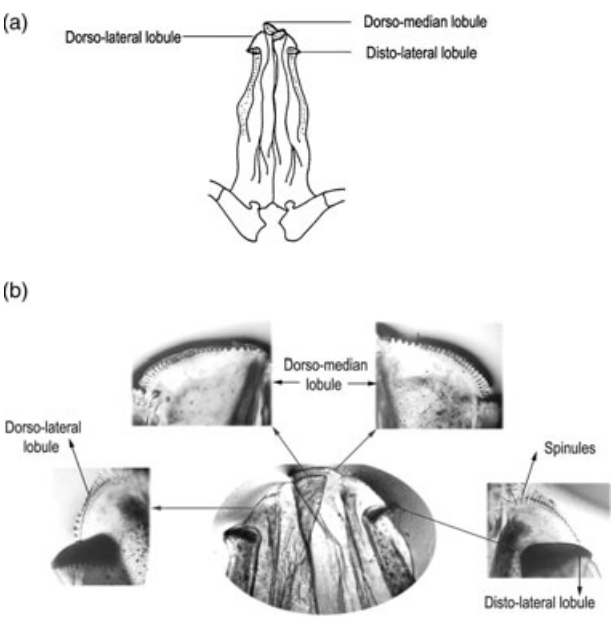

Fig. 2 Diagnostic features of the external reproductive structures of male of *Solenocera choprai* (a) structure of petasma and (b) petasma showing diagnostic features.

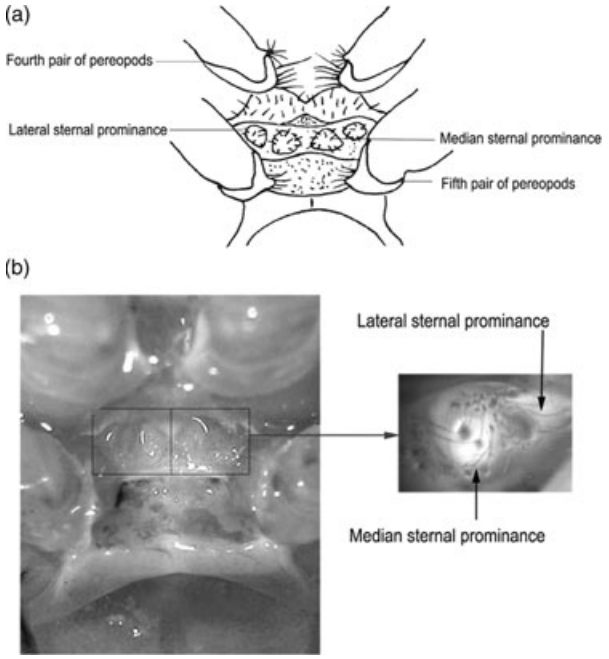

Fig. 3 Diagnostic features of the external reproductive structures of female *Solenocera choprai* (a) structure of thelycum and (b) thelycum showing diagnostic features.

The thelycum is more or less rounded (Fig. 3). The sternum between the third pair of pereopods is raised into a pair of vertical plate-like structures, the inner margins of which are in close contact with one another. There is a rounded median sternal prominence between the third and the fourth pair of pereopods. Between the coxa of the fourth pair of legs is a pair of inwardly directed narrow vertical plates, the distal margins of which are closely arranged. Below these plates, the sternum is hollowed out in to a pit. In front of this pit is a pair of small sternal prominences. The median pair is larger than the lateral pair. The sternum between the bases of the fifth pair of pereopods is a broad vertical trapezoid plate.

Reproductive organs

The male reproductive system in *S. choprai* consists of a pair of testes, vas deferens, terminal ampoules and a petasma. The testes consist of four lobes located in the cardiac region dorsal to the hepatopancreas. The narrow tube which follows

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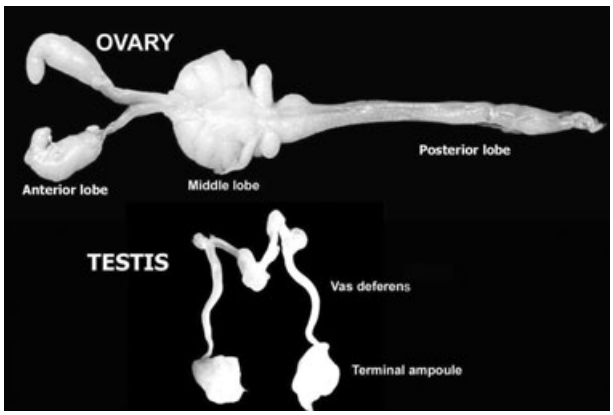

Fig. 4 Reproductive systems of male and female of *Solenocera choprai*.

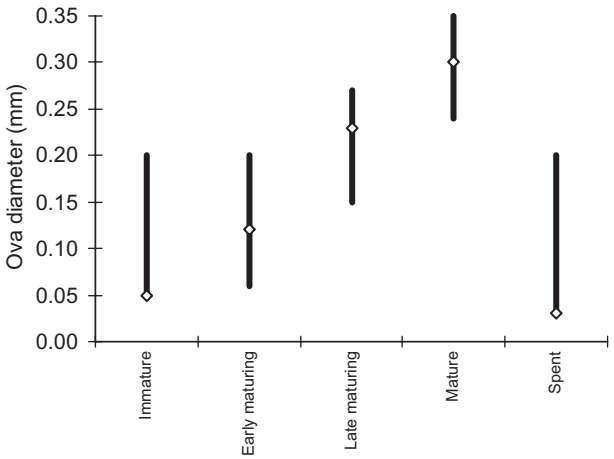

Fig. 5 Size range (bars) and modal values (◇) of ova diameters in immature, early maturing, late maturing, mature and spent-recovering ovaries of *Solenocera choprai*.

this portion is the vas deferens that traverses through muscle of the cephalothorax and opens at the base of fifth pereopod through the terminal ampoule.

The female reproductive system in *S. choprai* consists of ovaries, oviducts and a single thelycum. The mature ovaries are paired organs, situated dorsally extending from the base of the rostrum to the last abdominal segment. They are bilaterally symmetrical and partly fused. Each half of the ovary consists of three lobes, of which the slender anterior lobe occupies the cephalic region and lies in close proximity to the esophagus and cardiac region of the stomach. The middle lobe has six finger-like lateral lobules. The lateral lobules are located dorsally to the large mass of the hepatopancreas and ventrally to the pericardial chamber. The posterior lobes of the ovary extend the entire length of the abdomen. The two halves of the ovary are united, one at the base of the anterior lobe and other at the tip of the posterior lobe in the sixth abdominal segment. The thin oviducts start from the tip of the penultimate lobules of the middle lobe on both sides and run downwards to the external gonopore on the third pereopod (Fig. 4).

Maturity stages in females

Based on the color and size of the ovary and ova diameter variations, five stages of maturity in female of *S. choprai* were identified: immature, early maturing, late maturing, mature and spent-recovering. The ova diameter frequency distribution of maturing ova in different stages of maturity is shown in Figure 5.

Immature stage

The ovary is thin, translucent, unpigmented and confined to the posterior part of the cephalothorax and abdomen. Microscopic examination of the immature ovary revealed that the ovary contains tiny ova with clear cytoplasm and conspicuous nuclei. Diameters of the ova varied from 0.015 to 0.09 mm, but the mode was between 0.03 and 0.05 mm.

Early maturing stage

The size of the ovary increased, anterior lobes are further developed and extended forward in the cephalothorax, and the middle lobes and rudiments of their lobule are developed. The posterior lobe increased in girth. The general color of the ovary is yellowish. The ovary in this stage contains two groups of ova: immature and developing. The developing ova were translucent because of accumulation of yolk in the cytoplasm and ova diameters measured between 0.06 and 0.2 mm with a mode between 0.11 and 0.14 mm.

Late maturing stage

The ovary is developed further, and the anterior, middle and posterior lobes filled the cephalothorax completely. The color of the ovary is generally orange, sometimes with branched brownish chromatophores distributed over the surface. The ovary is visible clearly through the exoskeleton. The developing ovum is opaque, with the nucleus completely invisible (Fig. 6), and measures 0.15–0.27 mm with a mode between 0.23 and 0.24 mm.

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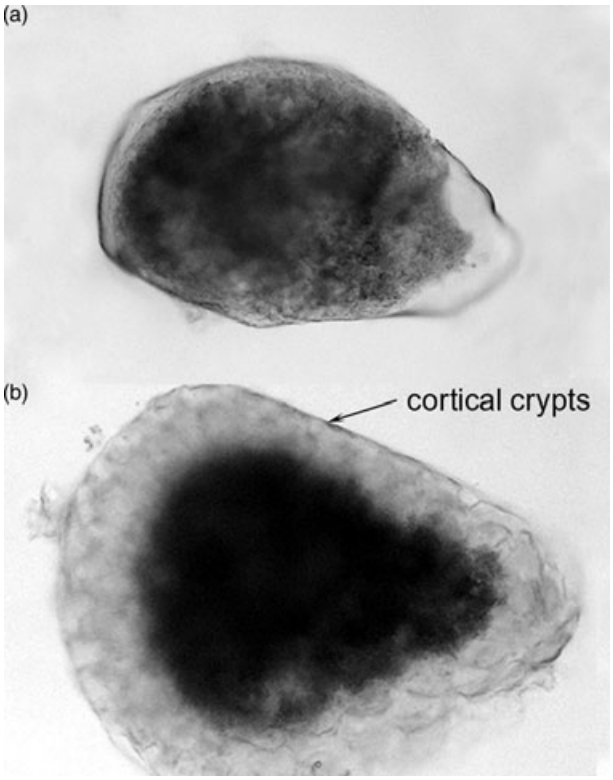

Fig. 6 (a) Maturing and (b) matured ovum of *Solenocera choprai* showing the presence of cortical crypts while maturing.

Mature stage

The ovary is very clearly visible through the exoskeleton with anterior and middle lobes are well developed. The color of the ovary is brownish-orange. Due to the fullness of the ovary, the lateral lobules of the middle lobe are folded and occupy the entire space available in the cephalothorax. The mature ova are opaque and fully yolked. Cortical crypts were found in the periphery of the ova (Fig. 6). The ova diameter ranged 0.24–0.35 mm with mode between 0.29 and 0.32 mm.

Spent-recovering stage

After extrusion of ova, the gonad reverted almost immediately to the immature condition. The ovarian lobes are flaccid and appear whitish. The ovary contains ova that are similar to those in the immature stage. In the spent-recovering stage, the eggs are found to have a size of 0.02–0.09 mm, similar to the immature stage.

Gonadosomatic index (GSI)

The gonadosomatic index of *S. choprai* in various stages of ovary development is presented in Figure 7. In the present study GSI was observed to increase with the advancement of maturity of the ovary and there is no significant correlation ($r^2 = 0.055437$) between GSI and total length of the shrimp, which indicated that GSI is independent of size of the females.

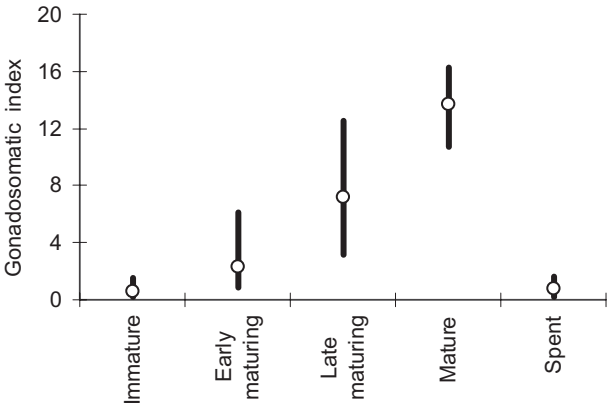

Fig. 7 Standard deviation (bars) and mean (○) of the gonadosomatic index of *Solenocera choprai* at various stages of ovarian maturation.

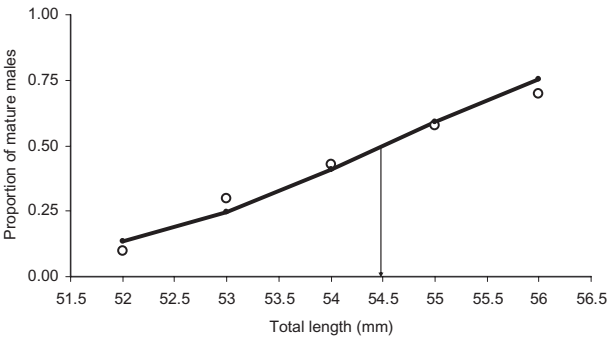

Fig. 8 Determination of size at first maturity curve for male *Solenocera choprai*. Line, logistic curve; observed values (○); $n = 133$. Vertical line near 54.5 mm shows size at first maturity.

Size at first maturity

Male

In the present study the smallest male in the mature condition with well developed petasma and having spermatophores in the terminal ampoule measured 52 mm. It was noticed that 50% of the observed males attain maturity at 55 mm (Fig. 8). Hence, the size at first maturity (50%) in males of *S. choprai* was estimated as 54.5 mm. All the males above 58 mm were mature.

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Female

The smallest female having mature ovaries was found to have a total length of 62 mm. The proportion of mature females indicated that the minimum size at first maturity (50%) was 66.5 mm (Fig. 9).

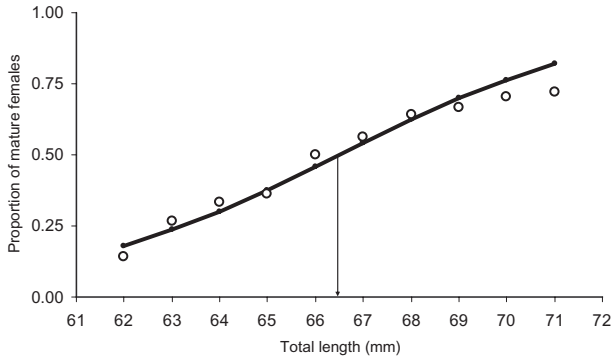

Fig. 9 Determination of size at first maturity curve of female *Solenocera choprai*. Line, logistic curve; observed values (○); $n = 829$. Vertical line near 66.5 mm shows size at first maturity.

Spawning season

During 2003, the percentage of mature females recorded was the highest during November (23.96%) with the peak extending until December. During January and March 2003 the percentages of mature females were also comparatively high (Fig. 10). In 2004, the highest percentage of mature females was seen in November (26.67%) with another peak in January and February. A high percentage of matured females was also observed in August 2004. From these observations, it can be inferred that *S. choprai* is a continuous breeder with two peak breeding periods. To understand the relationship between mean monthly GSI values and spawning season, the monthly mean GSI values and the percentage of mature females were compared. Mean GSI values also showed a similar trend to that observed in the case of mature females both the years (maturity data for July could not be collected because of the monsoon ban on trawl fishery). During 2003, females of *S. choprai* in the size range 91–110 mm formed the major spawning population of the fishery, whereas in 2004 the smaller size range of 81–90 mm formed the major spawning population.

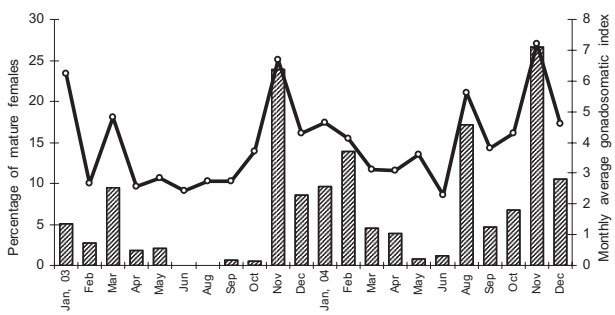

Fig. 10 Percentage of mature females (bars) and monthly average gonadosomatic index (GSI) (○) of *Solenocera choprai* during 2003–2004. $n = 3108$.

Fecundity

The estimated number of ova in the mature ovary of *S. choprai* females measuring 80 and 110 mm total length (TL) was 38 532 and 133 689, respectively. Fecundity increased generally with increase in size. In order to identify the factor which could be used as a best predictor of fecundity, regression analysis was carried out between fecundity and total length, total weight and ovary weight. It was observed that there were no significant differences in the coefficient of variation (r^2) using these three variables ($\log_e$ fecundity with $\log_e$ total length of 0.8818, $\log_e$ fecundity with $\log_e$ total weight of 0.8626 and $\log_e$ fecundity with ovary weight of 0.9037). It was inferred that ovary weight could be used as a single best predictor for fecundity of *S. choprai* and is more reliable than total length and body weight. The relationship is given as:

$$\log_e \text{ fecundity} = 10.99881 + 0.867432 \times \log_e \text{ ovary weight}$$

$$\text{fecundity} = 59802.64 \times \text{Ovary weight}^{0.867342}$$

Sex ratio

During 2003 and 2004, of 3275 shrimp analyzed, 1657 were females and 1618 were males (ratio 51:49). A χ^2-test showed that the annual distribution of females and males is not significantly different from a 1:1 ratio at a 1% level. The size-wise analysis (5-mm intervals) showed that as the length range increased the percentage of females also increased (Fig. 11).

DISCUSSION

The photographic illustration of the reproductive morphology of the species given in the present report is probably the first of its kind and the reproductive morphology agrees with the descriptions

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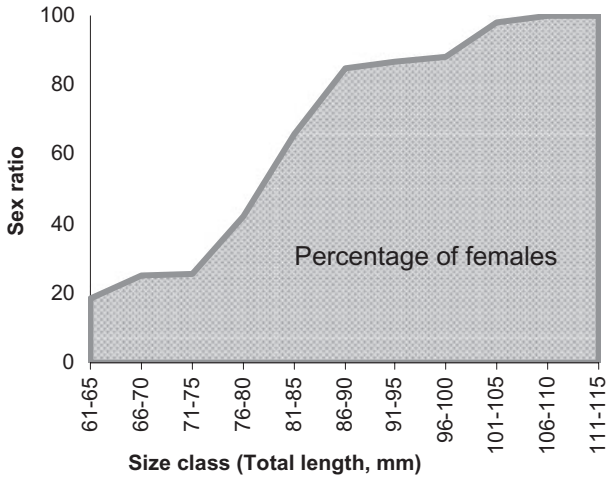

Fig. 11 Sex ratio of *Solenocera choprai* in different size classes.

of *S. choprai* given by Nataraj.[12] The study of the reproductive system revealed that it is typical of penaeid shrimps described by Dall *et al*.[9] The five stages of maturity in females of *S. choprai* were recognized in the present work, which agrees with the observations in *S. melantho* [7] and in *Haliporoides sibogae*.[8]

The mature ova are fully yolked with diameters ranging 0.24–0.35 mm, which is in agreement with the findings for *S. choprai* from Bombay waters[2] (0.20–0.30 mm). The reported mean oocyte diameter of penaeid shrimps[13,14] ranged 0.25–0.35 mm. Microscopic examination of mature ova during the present study showed the formation of cortical crypts at the periphery of the ova. Similar cortical crypts formation was reported in *Sicyonia ingentis* [15] and in *S. melantho.* [7] Ohtomi *et al*.[7] described the appearance of cortical crypts as a sign of commencement of spawning in *S. melantho*.

Burukovskij,[16] working on deepwater shrimp *Plesiopenaeus edwardsianus*, used joining of endopods of the first pair of pleopods to form petasma as an indicator of sexual maturity. However, Baelde,[8] working on another deep sea species *H. sibogae*, stated that the formation of petasma occurred well before the spermatophores were fully developed and suggested that swelling of terminal ampoules was a better criterion for male sexual development in this species. During the present study the method described by the latter was followed for determining male maturity. It was found that the size at first maturity (50%) was 67 mm [16 mm carapace length (CL)] and 55 mm (12 mm CL) in females and males, respectively. No reports on size at first maturity of *S. choprai* are available in the literature for comparison with the present results. In Japanese waters female *S. melantho* was found to mature at a size of 25.3 mm CL. Based on the results of growth studies on the species,[17] it is estimated that male and female *S. choprai* attain lengths of 68 and 85 mm, respectively, at the end of the first year. Since the size at maturity has been estimated at 55 and 66 mm in males and females, respectively, the shrimp is able to mature and spawn before they complete one year of life (8–9 months).[17] A similar finding was reported in *S. acuminata* from French Guiana.[6]

The simultaneous occurrence of females at all stages of maturity and the presence of ripe oocytes throughout the season indicate that *S. choprai* is a continuous breeder. Similar activity was recorded in *S. melantho* [7] and in *H. sibogae*.[8] Aravindakshan and Karbari[2] found the maximum number of matured females in the fishery in September. During the present study, gravid females were found throughout the season, but during October–December the percentages of spawners were the highest.

It is reported that in penaeoid shrimps fecundity ranges from 250 000 to 950 000 oocytes.[18] Fecundity in *S. choprai* ranged between 38 532 and 133 689 oocytes during the present study. The maximum number of ova (133 689) was found in a female of 110 mm TL, which is in agreement with the findings of is Aravindakshan and Karbari,[2] who estimated the fecundity of *S. choprai* as 130 850 oocytes for a female of 107 mm TL from Bombay waters.

During the present study, the sex ratio of *S. choprai* was not substantially different from 1:1. However, in landings dominated by smaller shrimp, the sex ratio was found to show a domination of males and in landings dominated by bigger shrimp, the sex ratio was dominated by females. The size-wise sex ratio showed a sigmoidal increase in female-to-male sex ratio. Baelde[8] reported that sex ratio for total population of royal shrimp *Haliporoides sibogae* was close to 50%, but it varied markedly with the size of shrimp. The sigmoidal increase in female-to-male sex ratio with size increase has been observed in many species of marine crustaceans.[18,19] The possible factors attributed by these reports[18,19] to this phenomenon were difference in growth and migration behavior between males and females, changes in mortality and catchability, particularly after breeding, and sex reversal patterns. Differential growth in males and females of *S. choprai* was established by Dineshbabu and Manissery[17] and the largest male observed is 94 mm TL while females measuring 110–114 mm TL were observed in significant numbers. They also stated that the time taken to reach 94 mm by males and 114 mm by females is

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almost the same (30 months). However, as suggested by Baelde,[8] who also reported sigmoidal increase in female-to-male sex ratio in *H. sibogae*, further examination of changes in female and male reproductive organs and analysis of individual cohorts over time are required to assess correctly the reason for this phenomenon.

The results of reproductive studies will help to understand the capability of stock to replenish itself with increasing exploitation levels. The information on the period of spawning, fecundity and size at maturity will in turn help in evolving management policies such as fishing closure seasons, minimum size of capture and restriction of fishing effort.

ACKNOWLEDGMENTS

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