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Reproductive Biology of the White-spotted Rabbitfish, *Siganus canaliculatus* (Park, 1797) in the Arabian Sea coast of Oman

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Abstract—The reproductive biology of the white-spotted rabbitfish, *Siganus canaliculatus*, was studied on the Arabian Sea coast of Oman between April 2005 and March 2007. The males matured (L_{50}) at 22.6 cm and females attained maturity at 23.9 cm TL when both were close to one year of age. The population of *S. canaliculatus* spawned twice a year, with major activity during November-February and minor activity during June and July. A higher monthly GSI during November-January and a drop in monthly relative condition (Kn) from a peak during November to February coincided with the peak spawning months. Individual fish spawned more than once a year. Fecundity ranged from 242 x 10^3 to 608 x 10^3 eggs. The sex-ratio indicated a dominance of males during 2005-06 and females during 2006-07.

INTRODUCTION

Rabbitfishes (Siganidae) are moderate-sized, commercially important fishes in the Indo-West Pacific region (Randall, 1995) and several species of *Siganus* are considered excellent candidates for mariculture due to their fast growth, herbivorous feeding habits and tasty flesh (Lam, 1974). On the northern Arabian Sea coast of Oman, siganid resources are harvested by gill nets, traps, beach seines and trawl nets. A drastic increase in the annual average catch from 126 t during 1994-2000 to 866 t in 2001-2006 showed that siganids have become highly targeted in recent years by fishers in Oman (GoSO, 2003, 2007).

Of the six species of siganids, the white-spotted rabbitfish, *Siganus canaliculatus* (Park, 1797), is dominant in landings on the Arabian Sea coast of Oman where catches were 571 t and 443 t during 2005-06 and 2006-07 respectively (GoSO, 2003, 2007; MSFC, unpub. data). In spite of its commercial and cultural importance, no information is available on the biology of *S. canaliculatus* in the northern Arabian Sea and Gulf of Oman. The present study was undertaken on the reproductive biology of *S. canaliculatus* along the Arabian Sea coast of Oman to assess the status of the fishery for the development of suitable management measures for sustainable harvest of the resource.

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MATERIAL AND METHODS

A total of 1014 specimens of *S. canaliculatus* consisting of 525 males and 489 females were randomly collected on a monthly basis between April 2005 and March 2007 from fishers using different artisanal gear (gill nets of various mesh size, traps and beach seines) in the coastal waters of the Arabian Sea between Lakbi and Salalah (Fig. 1).

The fish were brought to the laboratory and, after washing, their total length (TL) was measured to the nearest 1 mm using a fish measuring board and the total wet weight (TW) was recorded to the nearest 1 g using an electronic balance. Each fish was then cut open and the sex and maturity stage were recorded. The gonads and liver were removed and weighed to the nearest 0.001 g using an electronic balance.

The male maturity stages were assessed according to the macroscopic development of testes in the body cavity and female maturity by macroscopic examination of ovaries in the body cavity and microscopic examination of the eggs (Jayabalan, 1986; Jayasankar, 1990). Six stages of maturity (I-Immature; II-Maturing 1; III-Maturing 2; IV-Mature; V-Ripe/Running and VI-Spent) could be recognized in both males and females (Table 1).

Figure 1. Map showing the Omani coasts of the Arabian Sea and Sea of Oman.

Table 1. Classification of gonadal maturity stages in *Siganus canaliculatus* in the Arabian Sea coast of Oman.

Stage of maturity	Male	Female	
	Nature and extent of testis in body cavity	Nature and extent of ovary in body cavity	Appearance of ova under microscope
I Immature	Small, transparent, pale, occupying a very small portion up to 1/3 of body cavity	Small, transparent, pale, occupying a very small portion up to 1/3 of body cavity, ova not visible to naked eye	Irregular, small, yolkless/ yolk deposit just started, transparent with partially visible/clearly visible nucleus
II Maturing 1	Whitish, translucent, occupying about 1/2 of body cavity	Pale yellow, granular ova visible to naked eye, occupying about 1/2 of body cavity	Medium-sized, assuming a round shape, opaque, with fair amount of yolk
III Maturing 2	Creamy white, occupying about 3/4 of body cavity	Pale yellowish, blood vessels visible on dorsal side, ova clearly visible, occupying about 3/4 of body cavity	Medium-sized, opaque, fully yolked
IV Mature	Creamy white, soft, occupying full length of body cavity	Pinkish-yellow, blood vessels prominent, large ova prominently visible, occupying full length of body cavity	Large, mature, transparent at periphery
V Ripe/Running	Not encountered	Not encountered	-
VI Spent	Flabby, reddish, occupying about 1/2 of body cavity.	Flaccid, reddish, occupying about 1/2 of body cavity	Medium-sized ova present with disintegrating ripe ova

The development of immature to mature ova was studied by measuring the diameter of the eggs and also the extent of yolk deposition at the different maturity stages (except stage V) in 35 ovaries preserved in 5% neutral formalin. The diameter of about 200 ova was measured in each ovary using an ocular micrometer fitted to the eyepiece of the microscope (Jayabalan, 1986; Zacharia and Jayabalan, 2007). The ova diameters in ovaries of the same stage were pooled and grouped into 40 µ class intervals for percentage frequency curves. Ova <80 µ in diameter were not measured from stage II onwards as they were numerous in all active ovaries.

The spawning season of *S. canaliculatus* was determined by monitoring the shift from mature to spent gonads during various months and the monthly gonado-somatic index (GSI). The latter was calculated for males and females using the formula GSI = GW/TW x 100 (Busacker *et al.*, 1990), where GW was the gonad weight (g) and TW the body weight (g). The monthly relative condition factor (Kn) was estimated to establish the condition of the fish as $Kn = TW/aL^b$ (Le Cren, 1951), where TW was the observed weight and aL^b the calculated weight obtained from the length-weight relationship (Al-Marzouqi *et al.*, 2009a). Spawning frequency was determined in individual fish from the modal size classes of ova at advanced stages of maturity.

Length at first maturity (L_{50}) was determined by grouping the fish sex-wise into 1 cm size classes; from stage III onwards they were considered to be mature. A logistic curve was fitted to the cumulative percentage of mature fish against the length intervals separately for each sex using Excel.

Fecundity was estimated gravimetrically for 15 stage IV ovaries preserved in 5% neutral formalin. A subsample was removed and weighed to the nearest 1 mg in an electronic balance and stored in 'modified Gilson's fluid' (Simpson, 1951; Bagenal & Brawn, 1971) for two days. All the mature eggs were counted using a counting chamber under a binocular microscope. Fecundity was calculated for the total weight of the ovary from the number of mature ova in the subsample. Relationships between fish fecundity and total length, and total weight and ovary weight were transformed into logarithmic form using the equation, Log F = Log a + b log X, where log F was the fecundity, a and b were constants and log X the variable (fish length, fish weight or ovary weight). Deviation from a 1:1 sex ratio was tested for annual data using the chi-squared (X^2) test.

RESULTS

Maturity stages, gonado-somatic index and relative condition factor

Five of the six gonad maturity stages (I-Immature; II-Maturing 1; III-Maturing 2; IV-Mature; V-Ripe/Running and VI-Spent) could be established in male and female fish based on macroscopic and microscopic observations (Table 1); no male or female fish with stage V gonads were collected. Ova ranged in size from ≤80 μ in stage I ovaries to a maximum diameter of 686-714 μ in mature stage IV ovaries (Fig. 2). In stage VI ovaries, the ripe ova had been shed and the residual ova were 325-350 μ in diameter along with few larger ova.

Pooled monthly GSI values of males and females (Fig. 3) revealed that females always had a higher GSI than males. The highest values in males (1.65) and females (3.47) were recorded during November. A drop in GSI values from November to February was indicative of the peak spawning season. Minor spawning activity also appeared to occur during June-July.

Overall, monthly Kn values were slightly higher in males than in females (Fig. 4), with a minor peak during August and a major peak during November.

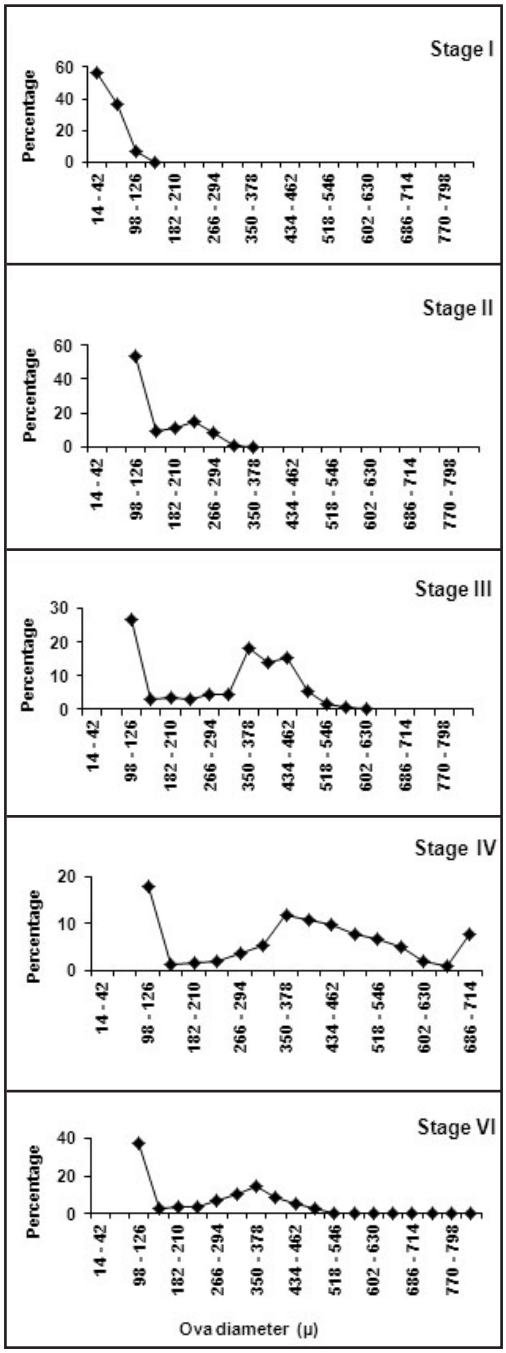

Figure 2. Development of ova to maturity in *Siganus canaliculatus* in the Arabian Sea coast of Oman.

Table 2. Fecundity in *Siganus canaliculatus* in the Arabian Sea coast of Oman.

TL (cm)	Total wt (g)	Ovary wt (g)	Fecundity
26.5	294	13.2	242 042
27.9	350	13.41	272 807
29.1	388	14.66	322 159
29.5	388	15.50	384 965
30.0	360	15.60	348 086
30.7	416	18.24	414 276
32.6	497	15.66	412 950
33.8	695	16.72	407 562
34.8	796	17.80	434 397
35.4	612	21.20	484 809
36.0	929	24.43	495 489
36.2	1 002	21.39	470 803
37.2	903	18.33	476 792
37.3	1 113	26.14	589 955
37.5	1 025	35.28	607 615

Length at first maturity

Siganus canaliculatus up to 19 cm in TL were all immature and the length at which 50% were mature was estimated to be 22.6 cm for males and 23.9 cm for females (Fig. 5). The smallest spent male and female fish were 21 and 23 cm in TL, respectively. All males ≥29 cm and all females ≥30 cm in TL were mature. Age estimates (Al-Marzouqi *et al.*, 2009a) indicated that both male and female fish matured close to one year in age.

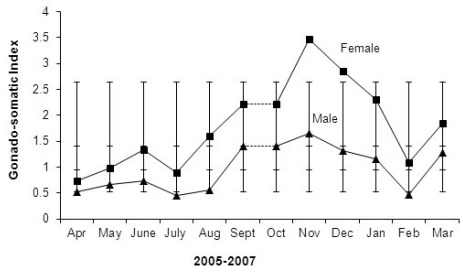

Figure 3. Gonado-somatic indices in *Siganus canaliculatus* during 2005-2007 in the Arabian Sea coast of Oman.

Fecundity, spawning season and frequency

The egg count in *S. canaliculatus* ranged from 242 x 10^3 to 608 x 10^3 eggs (Table 2). Its fecundity increased with increase in length and weight. The logarithmic relationship between fecundity (F) and length of fish (L) was linear (Fig. 7a):

$$Log\ F = 0.4896 + 2.0484\ log\ L (R^2 = 0.8441)$$

The relationship between fecundity (F) and body weight (W) was also linear (Fig. 7b):

$$Log\ F = 4.2454 + 0.4939\ log\ w (R^2 = 0.7881)$$

The relationship between fecundity (F) and ovary weight (OW) was expressed by the equation (Fig. 7c):

$$Log\ F = 4.5337 + 0.8537\ log\ OW (R^2 = 0.8045)$$

Higher percentages of mature testes and ovaries occurred during November-January and spent males and females were encountered from November to February (Fig. 6). This indicated that spawning in *S. canaliculatus* occurred during November to February in Oman. Monthly progressions in gonad maturity indicated that a minor spawning event also occurred during June and July. Double spawning was corroborated by the incidence of bimodal egg sizes in mature ovaries (Fig. 2).

Table 3. Spawning season of *Siganus canaliculatus* in different regions.

Region	Spawning period	Reference
Singapore	Jan.-April	Soh (1976)
Palau	March-May	Hasse *et al.*, (1977)
Asian estuaries	Jan.-April	Jayaseelan (1998)
Hong Kong	March-June	Sadovy (1998)
Japan	April-June	Hoque *et al.*, (1998)
Japan	March-August	Kanashiro *et al.*, (1999)
Arabian Gulf UAE	April-July, Nov.	Grandcourt *et al.*, 2007
Arabian Sea	Nov.-Feb., June-July	Present study

Table 4. Comparison of fecundity in *Siganus canaliculatus* in the Arabian Sea coast of Oman with previous studies.

Region	Fecundity	Reference
Palau	295 750	Hasse *et al*., (1977)
Gulf of Mannar, India	33 711-284 516	Jayasankar, (1990)
Ras Al Khaimah, Arabian Gulf	1 000 000	Al-Ghais, (1993)
Japan	520 000-2 500 000	Hoque *et al.,* (1999)
Arabian Sea	242 042-607 615	Present study

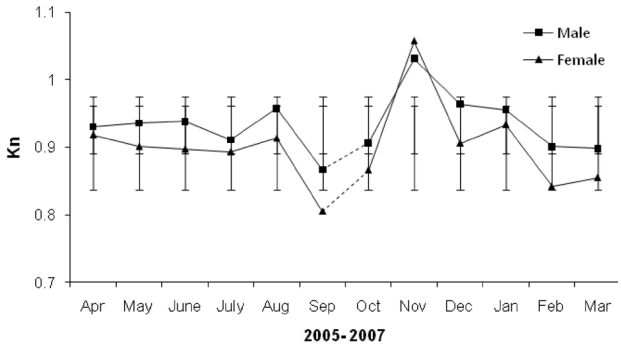

Figure 4. Monthly relative condition factors (Kn) of *Siganus canaliculatus* during 2005-2007 in the Arabian Sea coast of Oman.

Sex-ratio

The annual male to female ratio of 1:0.81 during 2005-2006 indicated a dominance of males and, during 2006-2007, the ratio was 1:1.15 showing a dominance of females. While the sex-ratio for 2005-2006 was significant at the 5% level (chi-squared value = 8.3448) indicating heterogeneity in the distribution of sexes, it was not significant during 2006-07 (chi-squared value= 1.8292).

DISCUSSION

The size range of *S. canaliculatus* recorded in artisanal catches in this study was 15-38 cm in TL. Its size frequency distribution in artisanal catches during 2005-2007 revealed that fish measuring >24 cm of TL contributed about 75.8% to the total catch and fish ≥28 cm comprised about 51.4% of the total catch (Al-Marzouqi *et al.*, 2009b).

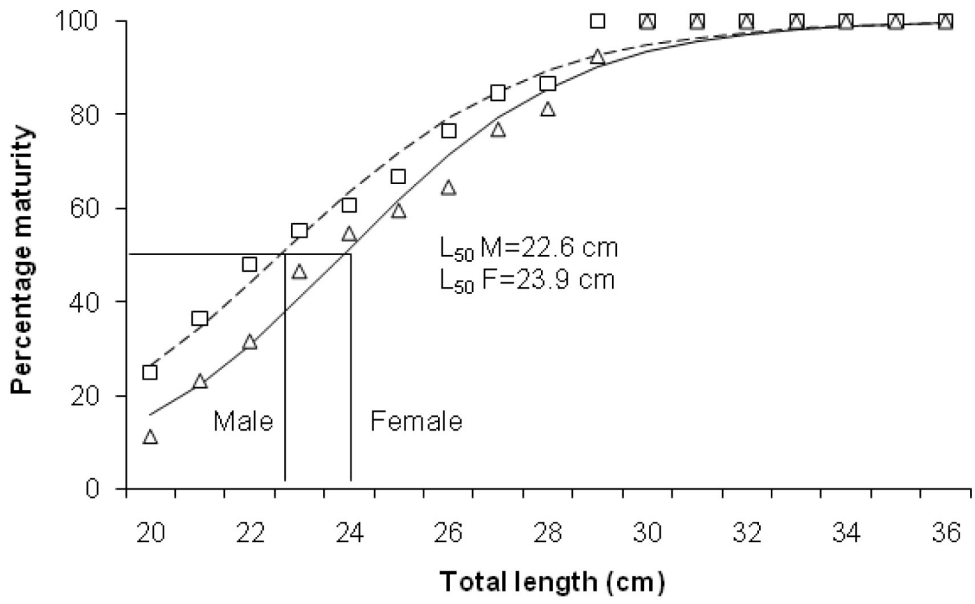

Figure 5. Size at first maturity of *Siganus canaliculatus* in the Arabian Sea coast of Oman.

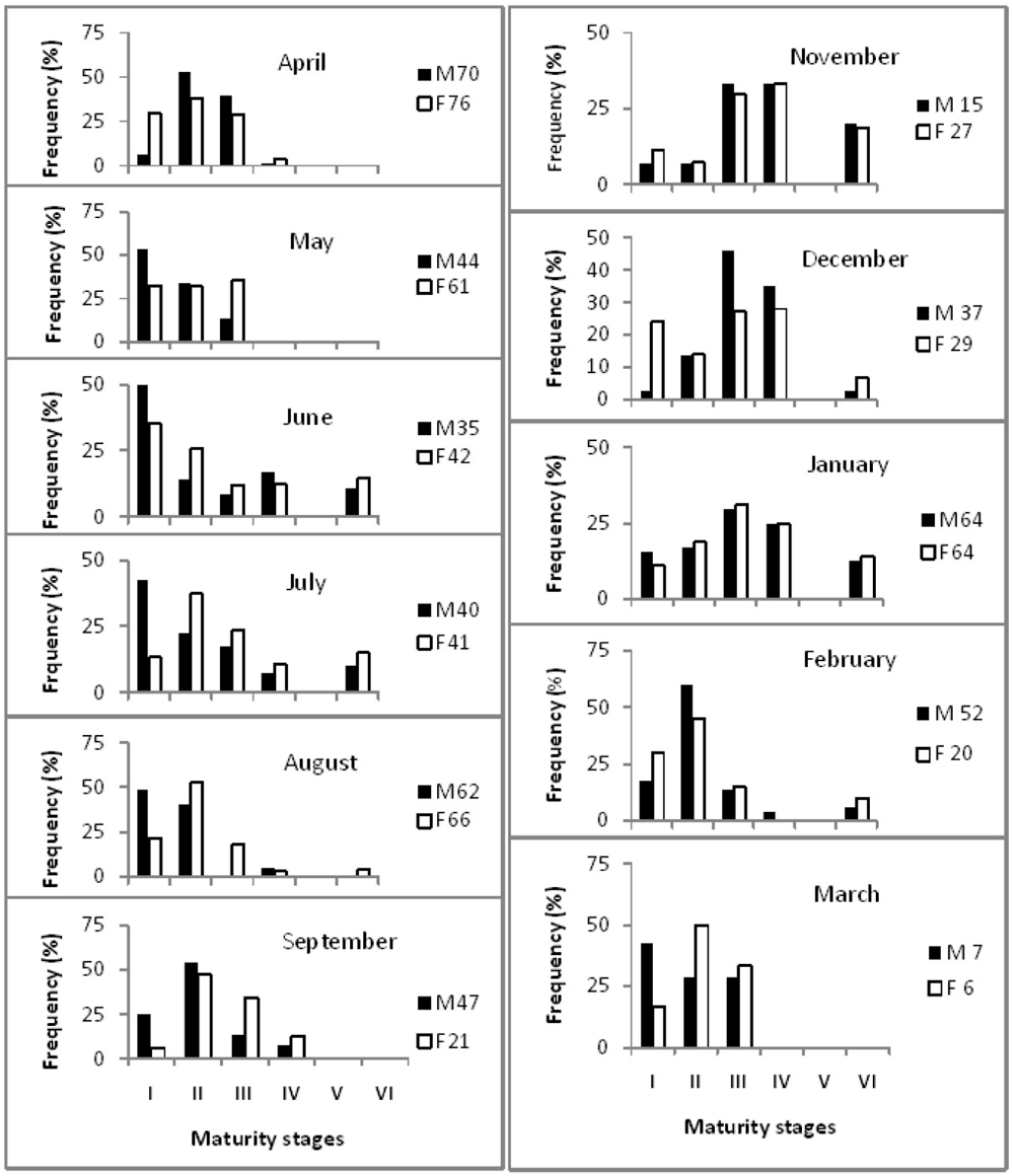

Figure 6. Distribution of monthly maturity stages of *Siganus canaliculatus* gonads during 2005-2007 in the Arabian Sea coast of Oman (pooled data).

The calculated lengths at first maturity for male and female fish of 22.6 cm and 23.9 cm respectively are below these values, suggesting that the majority of fish would get an opportunity to spawn before they are caught. Hence, the present harvest pattern is considered sustainable and no management strategy is needed for this resource at present.

Spawning of *S. canaliculatus* in the Arabian Sea was found to occur between November and February with a second, minor peak during June and July (Fig. 6). During the spawning months, the majority of mature fish were caught with empty or quarter-full stomachs (Al-Marzouqi *et al.*, 2009a); this may be due to cessation of, or little feeding, during spawning as reported in several fisheries (Baheeruddin and Nayar, 1961).

Males mature at a smaller size than females along the Arabian Sea coast of Oman, a finding similar to that encountered in the Arabian Gulf in the UAE (Grandcourt, *et al.*, 2007). However, females attain maturity sooner than males in the Arabian Gulf along the coast of Qatar (El-Sayed and Bary, 1994).

The length at maturity of *S. canaliculatus* differs geographically. Females attain maturity at 18 cm SL in Singapore (Soh, 1976, cited by Grandcourt *et al.*, 2007), 17.7 cm TL in Indian Ocean waters (Jayasankar, 1990), 17.2 cm in Qatar (El-Sayed and Bary, 1994), and 25.7 cm FL in the UAE (Grandcourt, *et al.*, 2007). The length at maturity of males obtained in the present study (22.6 cm TL) was comparable with the study undertaken in the UAE (Grandcourt, *et al.*, 2007). In the Arabian Sea, maturity in *S. canaliculatus* appears to be attained close to one year of age (Al-Marzouqi *et al.*, 2009a) as in the Caroline Islands, Palau (Hasse *et al.*, 1977).

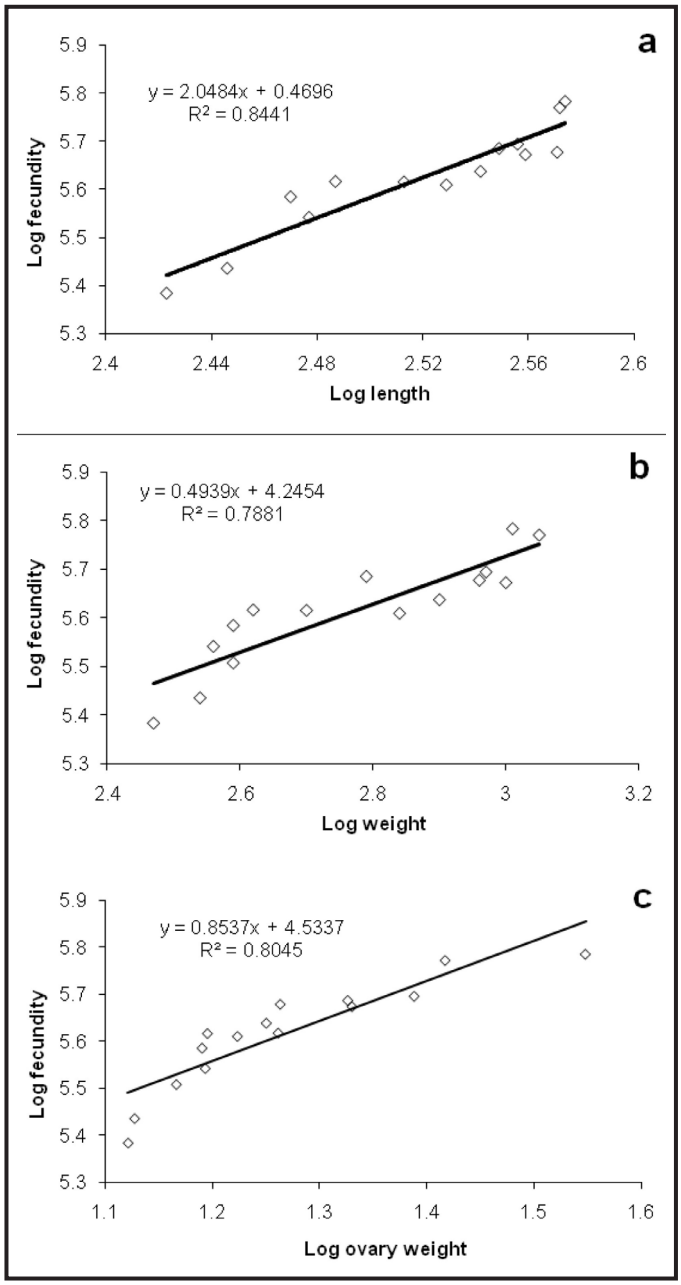

Figure 7. Fecundity of *Siganus canaliculatus* relative to a) total length b) body weight and c) ovary weight in the Arabian Sea coast of Oman.

The maximum diameter of mature eggs (686-714 μ) in the present study is similar to that of mature eggs (530-700 μ) recorded in India (Jayasankar, 1990). In the Indian Ocean, several species of fishes are continuous breeders with prolonged spawning, lasting 7-9 months in a year (Qasim, 1973). In the present study, *S. canaliculatus* appeared to spawn for at least six months during November-February, with another minor spawning event in June and July (Fig. 6). The latter fact was corroborated by bimodal size classes of ova in mature ovaries, with the smaller mode remaining after spawning in class VI ovaries (Fig. 2). Spawning twice in *S. canaliculatus* within a year as in Omani waters was similarly recorded at Palau (Hasse *et al.*, 1977) and Japan (Hogue *et al.*, 1998, 1999). However, the spawning season and duration of

spawning in *S. canaliculatus* appears to differ regionally (Table 3). Similarly, its fecundity also varies considerably in populations inhabiting various seas (Table 4). While its fecundity in the present study was lower than in the Arabian Gulf (Al-Ghais, 1993) and Japanese waters (Hoque *et al.*, 1999), it was much higher than at Palau (Hasse *et al.*, 1977) and in the Indian Ocean (Jayasankar, 1990).

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