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Patterns of reproduction and spawning of the kingfish (*Scomberomorus commerson*, Lacépède) in the coastal waters of the Sultanate of Oman

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Abstract

Patterns of reproduction and spawning were determined for the kingfish (*Scomberomorus commerson*, Lacépède) in two oceanographic regions of the Sultanate of Oman. During 2 years of sampling, 1264 fish were purchased from fishermen at landing sites along the Arabian Sea and the Gulf of Oman. Sizes of males and females were similar in both regions but more females were caught along the Gulf of Oman than along the Arabian Sea coast. Females matured at a significantly smaller length and about 2 months earlier than males in both regions. For both sexes, the fish collected along the Arabian Sea matured approximately 10 cm smaller and 6 months earlier that those of the Gulf of Oman. Analysis of the reproductive stages and gonosomatic index revealed a single yearly reproductive cycle beginning in February and ending with a single spawning period in May–June, just prior to the onset of the summer oceanographic regime. Reproductive stages and growth also indicated that 40% of the landings along the Arabian Sea is composed of fish before their first reproduction (Stage I) whereas along the Gulf of Oman, only 25% of the fish were caught before entering active reproduction. Several indicators suggest that kingfish stocks are under intense pressure and that management of this species should be implemented rapidly if they are to remain sustainable.

Keywords: *Scomberomorus commerson*; Sultanate of Oman; Reproduction; Size at first maturity; Spawning

1. Introduction

The kingfish, *Scomberomorus commerson*, Lacépède is an epipelagic species found throughout the coastal tropical waters of the Indo-Pacific (McPherson, 1992). In Oman, the distribution of *S. commerson* extends along the entire 1720 km of the coastline where it occurs at depths less than 100 m (Randall, 1995). The kingfish is considered the most important commercial pelagic species, and consequently, commands a high market price both in Oman and other Gulf Co-operative Council (GCC) countries (Al-Hosni and Siddeek, 1999). After an initial increase from 1980 to 1988, fisheries statistics

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have shown a progressive 10-fold decline in the numbers and biomass of *S. commerson* landed in Oman, from a high of 27,834 tonnes in 1988 to a low of 2088 tonnes in 2002 (Anonymous, 2002). During the same period, the numbers of fishermen and size of the fishing fleet has increased dramatically as a direct result of government subsidies.

The kingfish fishery is based on traditional practices along most of the coastline: family operated 5–10 m fiberglass boats powered by outboard petrol engines with trawling lines, hand lines, set nets and drift gill nets (Al-Oufi et al., 2000). In the Arabian Sea, along Masirah Island (Fig. 1), however, a semi-industrial fishery has developed with kilometre-long gill nets set from large wooden dhows with a crew of 5–10 fishermen (Omezzine et al., 1996).

Evaluating the breeding activity of a commercially exploited species is an essential component of fisheries research to provide management options for the protection of spawning stocks (Begg, 1998; Mackie and Lewis, 2001). In the northern Indian Ocean and Western Pacific, the reproductive biology of *S. commerson* is relatively well understood. In northeast Australia, two distinct stocks of *S. commerson* have been identified. For the eastern stock, peaks in spawning occur in late spring (November and October) where fish attain length at first maturity at 79 cm (McPherson, 1993). The more equatorial northern Australian stock experi-

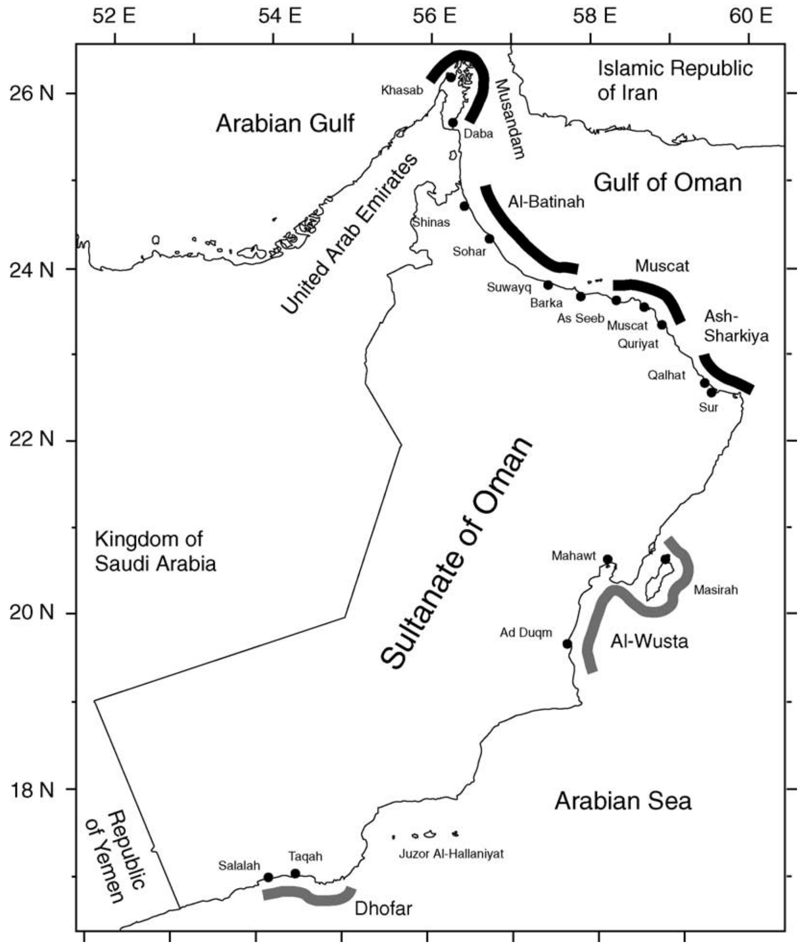

Fig. 1. Sampling areas for the *Scomberomorus commerson* populations used in this study. The Gulf of Oman samples included fish collected in Musandam, Al-Batinah, Muscat and Ash-Sharqiya regions whereas the Arabian Sea samples included fish collected in Masirah, Al-Wusta and Dhofar regions.

ences a more protracted spawning season of approximately 6 months (August to December) and a slightly longer length at first maturity of 82 cm (McPherson, 1993). In the northern Indian Ocean bordering India, size at first maturity were reported to be slightly smaller (75 cm) with a spawning season spanning 9 months from January to September (Devaraj, 1983).

Although a few studies have applied stock assessment techniques to *S. commerson* length–frequency data from Oman, none have quantified the frequency or timing of spawning (Dudley et al., 1992; Bertignac and Yesaki, 1993; Siddeek and Al-Hosni, 1998; Al-Hosni and Siddeek, 1999). The principal aim of this study is to describe the reproductive output and spawning patterns of the kingfish. Specifically, we set out to examine the sex ratios and sex-specific size distributions along the entire Oman coast; determine the length and age at first maturity for fish from the Gulf of Oman and Arabian Sea coasts; describe the maturity stages of female *S. commerson* over a 24-month-period and identify peaks in spawning using maturity stages and gonosomatic indices (GSI).

2. Materials and methods

In total, 1264 fish were collected from January 2000 to December 2001 from the Gulf of Oman and the Arabian Sea coast of Oman. Fish were purchased regularly directly from artisanal fishermen at several landing sites in each of six regions of Oman: Musandam, Al-Batinah, Muscat, Ash-Sharqiya, Al-Wusta and Dhofar (Fig. 1). Because in each of the six regions, samples were bimonthly, fish from the north coast, west of Ras-Al-Hadd including Musandam, Al-Batinah, Muscat and Ash-Sharqyia were assigned to one group and those collected along the east coast, south of Ras-al-Hadd including Masirah, Al-Wusta and Dohfar were assigned to another group, resulting in nearly monthly samples in both regions. The subdivision of the landing sites into two regions is not only convenient but corresponds also to large differences in oceanographic and climatic regimes. The eastern shores of Oman face the Arabian Sea and are under the direct influence of strong monsoonal wind, generating strong, annual upwelling events (Smith, 2001). Along the Gulf of Oman, the seasonal alternation of the marine climate appears less marked although local, wind-driven upwelling events of limited duration are also present (Claereboudt et al., 2002).

Fork length to the nearest centimetre and weight to the nearest 0.01 kg, were measured for all fish. The abdominal cavity was dissected and ovaries or testes were weighed to the nearest gram. Reproductive maturity stages were assessed macroscopically using a six-element scheme based on gonad size and appearance (Tables 1 and 2).

A subset of 236 ovaries were fixed and preserved in 10% formalin. Central sections were embedded in wax, sectioned at 3 μm and stained with Hematoxylin–Eosin stains. For this subset, gonad maturation was categorized histologically using a simplified six-stage description scheme based on Mackie and Lewis (2001) and compared with the macroscopic assessments for validation.

A gonosomatic index (GSI) was calculated for each fish using the following formula

$$\mathrm{GSI} = \frac{\text{mass of gonad (g)}}{\text{gutted fish mass (kg)}},$$

where mass of gonad is the mass of the fresh gonad, blotted on absorbing paper.

Mean GSI's were calculated for each calendar month for the Gulf of Oman and Arabian Sea populations. The size at first maturity, considered as the size at which 50% of the fish reach reproductive maturity (L_{50}), was calculated by plotting cumulative maturity probability versus fork lengths. Only fish larger than the smallest mature fish and smaller than the largest immature fish were considered. Although this procedure reduces considerably the number of fish in the analysis, in many long-lived species, a large proportion of the fish are caught outside of the small size window during which maturity takes place.

Since the size at maturity is defined as the median (L_{50}) of the size distribution of maturing fish, median tests (Zar, 1984) were used to compare length at first maturity between samples. Size distributions between regions and sexes were compared using χ^2 tests (Zar, 1984). Deviation from expected sex ratios of 1 were analyzed by one-dimensional Pearson's χ^2 tests with Yates correction for continuity (Zar, 1984).

Growth curves in both regions were calculated from a subset of the fish collected for which otolith aging was available (McIlwain et al., 2005). von Bertalanffy growth function (VBGF) curves

Table 1
Macroscopic and histological criteria for assessing stages of reproductive development in female *Scomberomorus commerson*

Reproductive stage		Macroscopic characteristics	Histological characteristics
I	Immature	Ovary glassy, small with compact wall, eggs invisible	Small oocytes imbedded in ovigerous tissue Tunica thin tightly encases ovarian lamellae Cytoplasm stongly basophilic with no vacuoles
II	Maturing	Eggs distinguishable Ovary opaque, small but rich in blood vessel	Oocytes expand Nucleus and cytoplasm increasingly eosinophyllic. Chorion visible in some oocytes
III	Mature	Ovary orange compact and breakable but no sexual products released when pressed	Oocytes at maximum development Cortical alveoli abundant, coalescing towards the center. Yolk globules abundant and progressively replacing cytoplasm Zona radiata thick
IV	Spawning	Ovary translucid Eggs are large, nearly transparent Walls are elastic	Rapid increase in size of oocytes (hydration) Zona radiata thin Oocytes free in the ovarian lumen
V	Spent	Ovary looks like water filled sacs Genital aperture inflamed Some ooctes may be found	Residual oocytes in various stages of atresia. Tunica stretched and follicles mostly empty
V–II	Resting–maturing	Ovary opaque, pink similar to II	Small oocytes imbedded in ovigerous tissue Tunica thick Atretic bodies common Cytoplasm more lightly colored

Table 2
Macroscopic criteria for assessing stages of reproductive development in male *Scomberomorus commerson*

Reproductive stage		Macroscopic characteristic
I	Immature	Testes small, glass like, transparent
II	Maturing	Testes opaque, reddish to white, small and compact
III	Mature	Testes opaque, white and releasing small amount of sperm when pressed
IV	Spawning	Testes opaque, wall loose and sperm released when pressed
V	Spent	Testes short, dark reddish, no sperm released Wall flaccid and rich in blood vessels
V–II	Resting–maturing	Testes opaque, creamy and compact

$L_t = L_{-}(1 - e^{-K(t-t_0)})$ were fitted to length at age data for each region and individual sexes using the Maximum Loglikelihood function in Poptools, an add-in software to Microsoft Excel® (CSIRO, Canberra, Australia). The VBG functions for different regions and sexes were compared using the analysis of residual sums of squares (ARSS) (Chen et al., 1992).

3. Results

3.1. Size composition and sex ratio

Length frequencies of *S. commerson* samples from the north and east coasts were significantly different (χ^2 test, d.f. = 9, $\chi^2 = 41.27$, $p < 0.0001$). There were a higher proportion of smaller fish (60–90 cm) along the Arabian Sea coast and a larger proportion of larger fish (100–120 cm) caught along the Gulf of Oman (Fig. 2). The size of fish included in the analysis ranged from 40 to 170 cm with a mode around 100 cm in the Gulf of Oman and 90 cm for the Arabian Sea population. The smallest fish, 38.5 in length (fork length) was caught in Al-Batinah whereas the largest specimen analyzed was 165 cm and caught in the Capital area (Quriyat).

In total, 495 males and 596 females were included in the analysis. The sex ratio in the Gulf of Oman samples (331 males and 447 females; M/F = 0.74) was significantly different from 1 (χ^2 test with Yates correction,

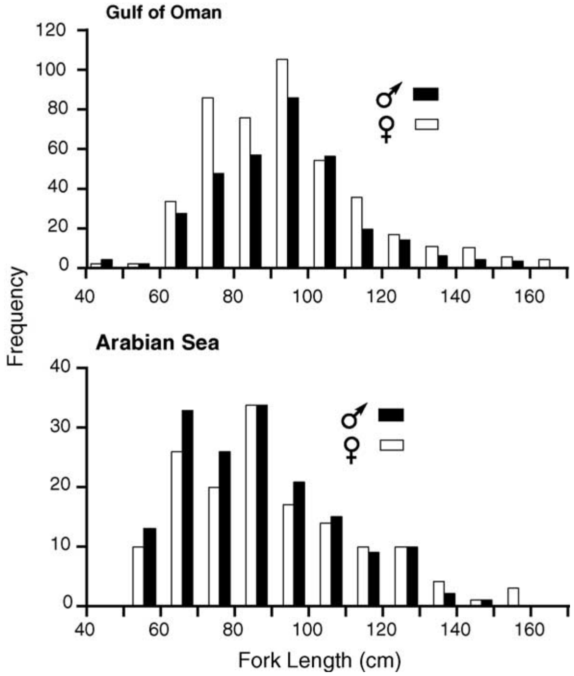

Fig. 2. Length frequency distribution of male and female *Scomberomorus commerson* in the sample collected in the Gulf of Oman and the Arabian Sea.

d.f. = 1, $\chi^2 = 16.99$, $p < 0.0001$) but did not differ significantly in the Arabian Sea samples (164 males and 149 females; M/F = 1.10) (χ^2test with Yates correction, d.f. = 1, $\chi^2 = 0.62$, $p = 0.42$). The distribution of sizes among both males and females showed a double mode (Fig. 2; 60 and 100 mm) in both sampling areas and were not significantly different (χ^2 test, d.f. = 8, $\chi^2 = 11.08$, $p = 0.19$ and d.f. = 8, $\chi^2 = 3.18$, $p = 0.92$ in the Gulf of Oman and Arabian Sea samples, respectively).

3.2. Size and age at first maturity

A plot of the relative cumulative proportion of mature fish versus fork length indicated differences both between sexes and between areas (Fig. 3). In both regions, female kingfish matured at a significantly smaller length than males (Table 3; Median test, $\chi^2 = 18.8$, $p < 0.0001$ and $\chi^2 = 5.30$, $p < 0.021$ for the Gulf of Oman and Arabian Sea samples, respectively). For both sexes, the fish collected along the Arabian Sea matured approximately 10 cm smaller that that

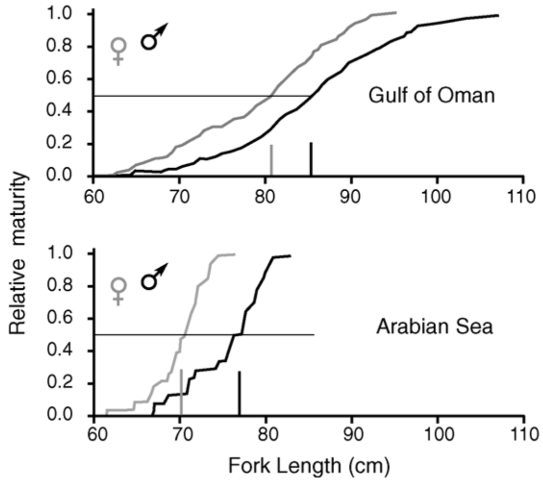

Fig. 3. Cumulative relative frequency of the length at first maturity for male and female *Scomberomorus commerson* in the Gulf of Oman and the Arabian Sea. The 50% maturity is marked by a thin horizontal line.

of the Gulf of Oman (Table 3; Median test, $\chi^2 = 22.3$, $p < 0.0001$ and $\chi^2 = 33.175$, $p < 0.021$ for males and females, respectively). The comparison of the von Bertalanffy growth curves indicated significant effect of origin (Gulf of Oman versus Arabian Sea) and sex on the growth function (ARSS, $p < 0.02$ for all three comparisons) with fish along the Arabian Sea growing faster than that of the Gulf of Oman and in each region, females growing slightly faster than males. A transformation of size at first maturity into age at

Table 3
Length at first maturity of *Scomberomorus commerson* measured for both sexes in two areas of the coast of Oman. Only fish larger than the smallest mature fish and smaller than the largest immature fish were considered. Although the number of fish collected from the Arabian Sea was relatively large ($n = 177$), most of these fish were either small immature or large fish and did not fall in the size range used in the analysis

	Gulf of Oman	Arabian Sea
Smallest mature male	58.4	65.8
Largest immature male	106.8	79.7
50% maturity length	84.6	76.1
n	244	20
Smallest mature female	57.1	61.6
Largest immature female	92.6	74.7
50% maturity length	80.7	70.7
n	301	23

Table 4
Parameters of the von Bertalanffy growth function, size and age at first maturity of *Scomberomorus commerson* calculated for both sexes in two areas of the coast of Oman

Region	L_χ (cm)	K	T_0	Maturity (cm)	Age (year)
Arabian sea-males	118.82	0.652	−0.623	76.1	0.94
Arabian sea-females	133.37	0.412	−1.119	70.7	0.71
Gulf Oman-males	131.32	0.325	−1.736	84.6	1.44
Gulf Oman-females	154.32	0.173	−2.981	80.7	1.29

first maturity using the empirical growth equations indicates that male fish matured slightly later than females (2 months approximately) but that generally, kingfish from the Gulf of Oman matured much later (6 months) than the Arabian Sea population (Table 4).

3.3. Stages and reproductive season

Stages of gonad development were identified macroscopically in both sexes and histologically in a subset of females (Tables 1 and 2). A comparison of histological and macroscopic staging indicates a sex identification error <3%, most of the errors occurring with immature fish at Stage I (Table 5). Overall, 47% of the fish were staged properly using the macroscopic method (Table 5), however, inevitable errors were introduced in the staging using the macroscopic method. Most of these errors occurred between successive stages (I–II, II–III or III–IV) (Table 5) or between closely related stages (II and V–II). Overall, 86% of the fish were identified within one stage of the actual histologically determined stage. The largest error occurred in mature female (III) where most of the individuals were identified as maturing (II) morphologically.

The following results are based on macroscopically determined stages of both males and females. Abundance of immature fish (Stage I) shows a yearly cycle with an almost complete absence during the summer months along both coasts (May–August in the Gulf of Oman and May–October in the Arabian Sea; Fig. 4). For the remainder of the year (September–April), up to 25% of the catch along the Gulf of Oman was made of immature individuals (Stage I). This percentage reached 40% along the coast of the Arabian Sea during the same period.

The gametogenetic cycle began in February in both areas with fish successively entering the developing stages (Stages II, III) of the reproductive cycle (Fig. 4). Mature and spawning stages (Stages III, IV) were observed mostly in May and June and no mature stages were observed between August and February (Fig. 4). By July, most fishes were in post-spawning stages (Stages V, V–II) indicating the end of the spawning season. Fish in post-spawning stage (spent, Stage V) were observed as early as April and as late as June. Spawning seemed to occur synchronously in both areas although the bimonthly sampling did not allow analysis at a fine temporal scale.

Table 5
Comparison of identification of female *Scomberomorus commerson* reproductive stages by macroscopic and histological characteristics

	Macroscopic evaluation							
Histology	I	II	III	IV	V	V-II	Male	Total
I	15	5				2	5	27
II	4	25			5	8		42
III		15	2		1	3		21
IV		1	1	4	2	2	1	11
V		1	6	6	13		1	26
V-II		15	2	4	36	51		109
Total								236

The values outside of the diagonal represent numbers of misidentification in macroscopic evaluation. Shaded areas indicate numbers of convergence in macroscopic and histological stage identification

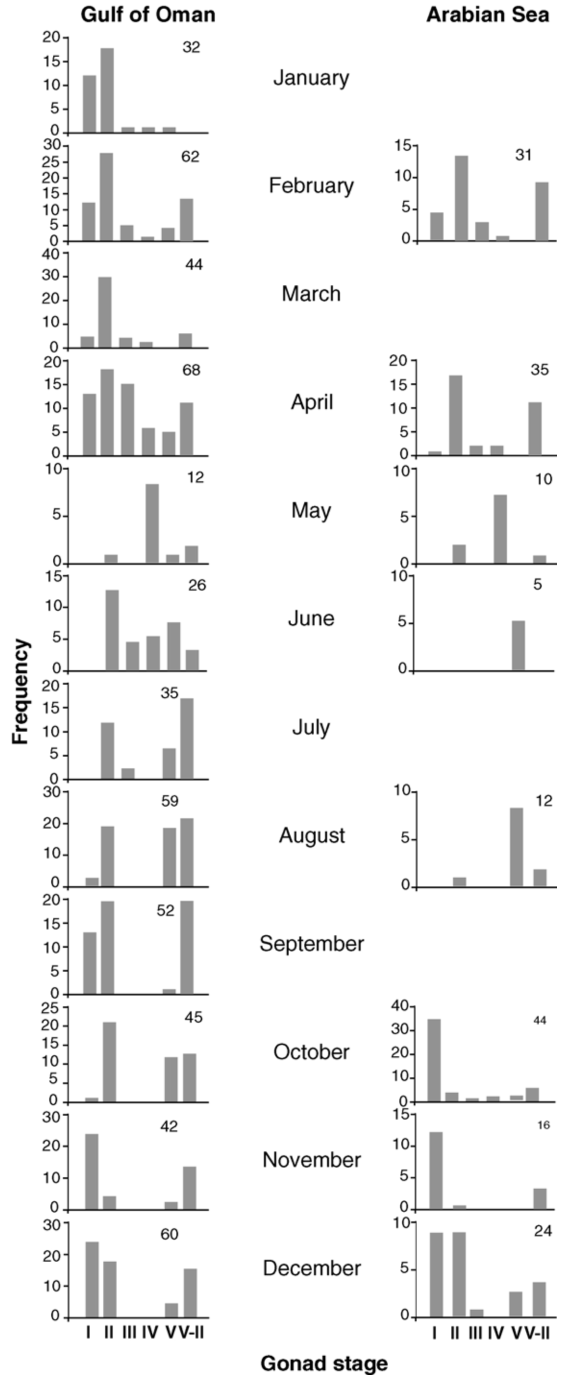

Fig. 4. Distribution of reproduction stages (male and female *Scomberomorus commerson* grouped together) in the Gulf of Oman and the Arabian Sea. Data from two successive years were grouped.

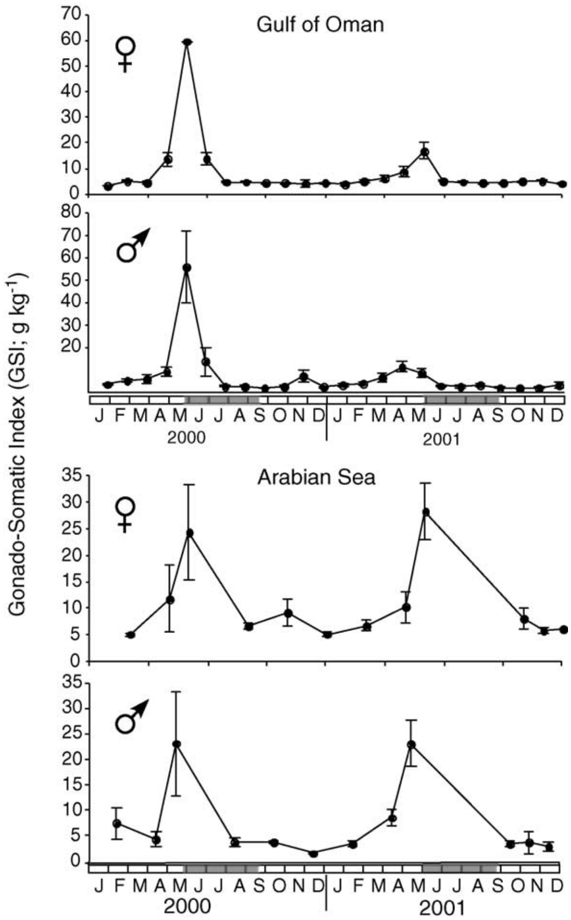

Fig. 5. Gonosomatic index (GSI) for male and female *Scomberomorus commerson* in the Gulf of Oman and the Arabian Sea during two successive years.

3.4. GSI and reproductive cycle

The monthly variation in GSI followed that of the macroscopic stages. Maximum gonad development occurred simultaneously in both sexes and in both areas in April–May, after a 3-month-growth-period of the gonads (Fig. 5). Spawning was synchronous both years and characterized by a sharp decline in GSI that occurred between May and July in both areas, just prior to the onset of the summer oceanographic regime (Fig. 5). In Oman, the oceanographic conditions along both the Gulf of Oman and the Arabian Sea are driven by the yearly arrival of the southwest Monsoon (Khareef) in June which brings major changes in the coastal water

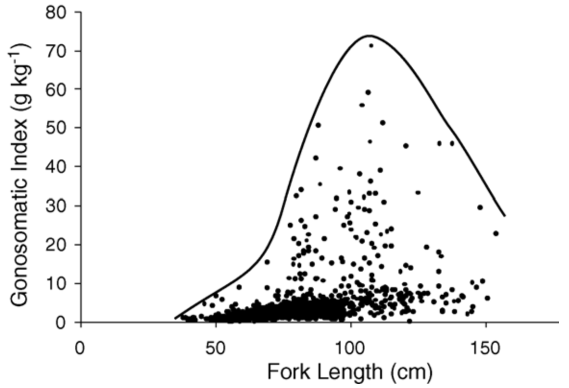

Fig. 6. Gonosomatic index (GSI) vs. fork length in all sampled *Scomberomorus commerson* (males and females grouped together). The line was eyeballed to fit the upper side of the dataset corresponding to maximum GSI.

temperature regime, nutrient richness and current directions (Claereboudt et al., 2002; Smith, 2001). The end of the monsoon in October brings a second yearly change in the marine climate.

Maximum GSI increased with fish size until a fork length of about 110 cm then decreased for larger fish (Fig. 6). Minimum GSI increased slightly with fish size (Fig. 6).

4. Discussion

We observed a significant dominance of females in the catches from the Gulf of Oman but not from the Arabian Sea. This difference in the relative abundance of females in the catches can result either from differences in the actual sex ratio in the fish stock or from a bias introduced in the samples by the fishing methods used by traditional Omani fishermen. Although no biological explanation was given, a similar bias favoring females has been reported in the line fishery of another scombrid species (*Scomberomorus cavalla*) along the south coast of the USA (Trent et al., 1987). A very similar trend was reported for the Natal (South Africa) line fishery in which females *S. commerson* in the catches were almost twice as abundant as males (Govender, unpublished). On the contrary, observations from India (Devaraj, 1983) revealed that males were almost always slightly more abundant than females in the catches. The hypothesis of a fishing bias is supported by differences in fishing gear used along the Gulf of Oman and the Arabian Sea (Claereboudt et al., 2004). Along the Gulf of Oman, a combination of hooks and lines and drift gill nets are used to capture kingfish, possibly favoring females through the line fishing. Along the Arabian Sea (especially around the island of Masirah where most of the fish in our samples were purchased), most of the landings result from large driftnets, which are unlikely sex selective. On the other hand, the dominance by females was found in the 60–90 cm size range whereas hook and line fishing targets usually larger fish but catch fish of many sizes.

The same difference in fishing gear might also explain the difference in size distribution between fish caught along the north and east coast. In Oman, there are no regulations as yet on the mesh size of nets used for kingfish fishery. The large, loosely hung, drift nets used by fishing dhows in the Arabian Sea could capture virtually fishes of all sizes including sometimes very larger numbers of small juveniles whereas in the Gulf of Oman, the hook and line fishery targets fish larger than 80 cm and thus tends to increase the proportion of larger fish in the fishery. This was confirmed during one sampling trip when 65 small juveniles (<50 cm) were collected from a single large fishing boat (Dhow). Because they appeared only once, in one landing site, these fish were not included in the present analysis.

The published values of size at first maturity for *S. commerson* coincide well with our data (Table 3). *S. commerson* size at first maturity is attained at about 70–80 cm FL in Madagascar, Fiji and north-eastern Australia (Collette and Russo, 1984; McPherson, 1993) but not before 90–105 cm in South Africa (Govender, unpublished). In India, at the same latitude as Oman, *S. commerson* appears to mature around 75 cm (Devaraj, 1983). Values as small as 55 cm have been reported for East-African populations (Williams, 1964).

The smaller size at maturity in the Arabian Sea samples could not be due to a slower growth rate. Instead growth parameters suggest a faster growth rate along the Arabian Sea than along the Gulf of Oman and that this Arabian Sea population matures, some 6 months earlier. It is possible, however, that the observed differences (earlier maturity, smaller size at maturity) arose from progressive changes in reproductive biology induced by intense fishing pressure. Although fish grow faster and mature earlier along the Arabian Sea, still 40% of the fishery is supported by fish before their first reproduction (Stage I) whereas along the Gulf of Oman, 25% of the fish were caught before entering active reproduction. This kind of fishing pressure could possibly progressively push the population towards a maturation at smaller length and increase the risk of recruitment failures. The slightly smaller size at first maturity in females observed in both populations is possibly the result of a larger energetic investment in females, even prior to entering the first reproductive period.

Both the variations in GIS and the succession of gonad stages suggest the existence of a single synchronous spawning period occurring in May–June. Although post-spawning stage fish were observed as late as December, no spawning fish was observed after June and this suggests that if protracted spawning takes place, it is unlikely in the areas surveyed in this study. A similar spring spawning occurs in *S. commerson* in the Great Barrier Reef (McPherson, 1993) as well as in other species of the same genus. *S. queenslandicus* and *S. muroi* both have a spring spawning in Eastern Australia (Begg, 1998) and so does *S. cavalla* in southern USA (Collette and Russo, 1984). In contrast, Devaraj (1983) reported three distinct peaks of *S. commerson* spawning around the Indian Peninsula. In South Africa (Govender, unpublished) as well as in Zanzibar (Williams, 1964), *S. commerson* appears to have a protracted spawning season extending over most of the summer (October–November to April–May).

The strong seasonality in the fishery (most fishes are caught during the winter months) combined with a drop in the catch in both sampled region during April–May supports the idea of a migration (at least partial) out of Omani water during the reproductive season. The traditional fishing communities believe that *S. commerson* participates in a lengthy migration, moving northwards during the summer months to spawn in the Arabian Gulf (Ministry of Agriculture and Fisheries, Muscat, unpublished data). Although the strong decrease in catches observed during the spawning season, and the decrease in GSI in large individuals support the hypothesis of a reproductive migration, part of the populations from both areas were locally engaged in spawning activity. Fully mature (Stage III), spawning (Stage IV) and spent (Stage V) individuals have been found along both coasts in April–June supporting the existence of local spawning grounds along both the Gulf of Oman and the Arabian Sea. Kingfish (*S. commerson*) in eastern Australia are known to migrate and aggregate in larger numbers around several reefs just prior to spawning in the spring (Welsh et al., 2002). Along the coast of South Africa, *S. commerson* seem to migrate north to Mozambique to spawn then back south again for feeding (Govender, unpublished). Similar large-scale migrations have also been reported for *S. cavalla* in the Atlantic (Sutter et al., 1990) and *Scomberomorus plurilineatus* in South Africa (Chale-Matsau et al., 1999).

Our data indicate that GSI decreases in fish larger than 1.1–1.2 m. This resulted either from an actual decrease in the GSI or possibly to the absence of large, fully mature fish in the sample. This would be the case if the largest reproductors underwent reproductive migration outside the sampled areas and would not be caught in fishing gear within the Sultanate of Oman.

In light of the continuous decline in kingfish landings (Al-Abdessalaam et al., 1995) and three stock-assessment studies (Al-Hosni and Siddeek, 1999; Dudley et al., 1992; De Rodellec et al., 2001), the present set of biological data confirms that the populations of kingfish in the Sultanate of Oman undergo intense fishing pressure, particularly along the Arabian Sea coast. Our data indicate that most fish are allowed to reproduce at most once before capture and aging data on the same fishes (McIlwain et al., 2005) suggest that few fish reach their third year (about 110 cm in fork length) or second reproductive period. In order to reduce the risk of overfishing and the sustainability of the resource, it would be beneficial to allow a larger proportion of the fish to reach full maturity at about 100 cm in length. In addition, the decrease in catches during most of the reproductive season and the low numbers of spawning-stage fish in the samples suggests some form of reproductive migration outside the territory investigated in this study.

The current data set, only spans 2 consecutive years, and thus, limits considerably our understanding of the dynamics of the kingfish population in Oman. Future studies and management should address the issue of migration, particularly during the reproduction season but also focus on gear characterization and juvenile catches if more accurate stock assessments are to be made.

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