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A per-recruit assessment of the kingfish (*Scomberomorus commerson*) resource of Oman with an evaluation of the effectiveness of some management regulations

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Abstract

The status of the kingfish resource of Oman has been assessed using a per-recruit model noting that there are differences in growth and mortality between the sexes (amongst other parameters). It is estimated that at the current fishing mortality rate the spawning biomass per-recruit for females is 16% and that of males is 27%, indicating that the fishery is overfished, with a high chance of recruitment failure in the future. A number of management scenarios, based on minimum size limits and closed seasons were evaluated for this fishery in order to determine which of the scenarios would increase spawning biomass per-recruit without compromising yield per-recruit harvest rates to levels which may lead to socio-economic hardship amongst fishers. It has been shown that closed seasons and minimum size limits may be the most effective current means of achieving these objectives and it is proposed that a closed season, coupled with a minimum size of 45 cm (FL) for both sexes, be implemented each year from the 1 March to 30 April. This would increase spawning biomass per recruit to 29% for females and 40% for males, when compared to an unfished state and over the long-term.
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Keywords: Scombridae; *Scomberomorus commerson*; Kingfish; Yield per-recruit analysis; Narrow barred Spanish mackerel; Oman

1. Introduction

The kingfish, *Scomberomorus commerson*, is the most valued of all coastal fishes in the Sultanate of Oman. The high demand for kingfish has resulted in tremendous fishing pressure on this resource in recent decades resulting in significant declines. The highest recorded catch peaked at 27,834 t in 1988 but has declined to 2559 t in 2001 (Anon, 2001). Because of its high status in the Omani fishery, kingfish has received a large amount of scientific interest and research in recent years (Dudley et al., 1992; Bertignac and Yesaki, 1993; Abdessalaam et al., 1995; Siddeek and Al-Hosni, 1998; Al-Hosni and Siddeek, 1999; De Rodellec et al., 2001; Al-Oufi et al., 2002; Claereboudt et al., 2004, 2005; McIlwain et al., 2005).

Along Oman's 3240 km long coast, traditional fishing communities target this species using a variety of fishing gear e.g. handlines with either live or dead bait, drift and set gill nets, trolling lines and more rarely beach seines. The preferred fishing methods are drift, known locally as *Hayal* and set nets known locally as *Mansab*. A drift gill net known locally as *Tasgeed* where the net is set close to the sea floor to capture larger kingfish during the winter months is also employed but is discouraged because of the damage it can cause to coral reefs and other passive fishing gear such as traps. Of the deployed gear, 39% constitute drift nets followed by 30% of set net usage, with remaining gear types contributing 31% (Claereboudt et al., 2004). Fishing generally occurs off boats (an insignificant amount is taken by trawlers) that vary in length from small fibreglass boats (4–10 m) fitted with outboard motors ranging in horsepower from 40 to 115

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to large wooden dhows (∼25 m) powered by inboard diesel engines. Usually, the latter boats set longer nets than the former ones and hence, experience higher catch rates of kingfish. The total catches of the fibreglass boats are very much larger than those of dhows because of their relative abundance in the fishing fleet.

Currently the kingfish fishery in Oman is unregulated. It is an open-access fishery with neither input nor output controls. This is despite recent research pointing out the high fishing pressure on this species. For example, Siddeek and Al-Hosni (1998) estimated various biological reference points for this fishery based on length–frequency data for the period 1987–1995 and concluded that there was a need to reduce fishing mortality by 17–40%. De Rodellec et al. (2001) using a multi-species surplus production model described the dynamics of the large pelagic fishery (kingfish, longfin and yellowfin tunas) and found that fishing effort needed to be reduced by 60% from its current level and that the kingfish fishery displayed all the "symptoms" of an overfished stock.

In this paper we investigate a number of management scenarios on minimum legal size and seasonal closure for the kingfish stock of Oman using an age-structured per-recruit model. We also identify scenarios that will lead to sustainable fishing of this stock for management consideration.

2. Materials and methods

Between January 2000 and December 2001 biological data were collected on a bi-monthly basis from six Omani regions (Musandam, Al Batinah, Muscat, Ash Sharqiyah, Al Wusta and Dhofar) (see Claereboudt et al. (2005) and McIlwain et al. (2005) for a more detailed description of the sampling programme). These sampling areas cover the entire Omani coastline. Random samples, 1244 fish in total, were derived from the traditional coastal fishery and were purchased from fish sellers in local markets. Length measurements, such as total (TL), fork (FL) and standard lengths (SL) were measured to the nearest cm and total mass (W) to the nearest 100 g. Sex was determined macroscopically and later confirmed histologically (Claereboudt et al., 2005). Sagittae otoliths were collected from each fish. A detailed description for the preparation of the otoliths for age determination and validation is outlined in McIlwain et al. (2005). Biological data, in particular the age and length data, used in this study were first reported in McIlwain et al. (2005).

2.1. Growth

McIlwain et al. (2005) describe both the relative and absolute growth of kingfish in Oman, but on a spatial scale, because they concluded that there were growth differences in the various fishing areas. At this stage it is unclear if kingfish captured in these various regions are of separate stocks or not, though there is some evidence, from a genetic study, that kingfish in Oman's waters represent a single unit stock (van Herwerden, unpubished data). In this study (and mainly to simplify the modelling), we assume that the kingfish of Oman is a single stock and ignore the spatial differences in growth. As a result, a spatially combined growth curve needed to be fitted. Utilising the data reported in McIlwain et al. (2005) the following analyses on relative and absolute growth were undertaken.

The parameters (a, b) of the fork length at mass relationship,

$$\log W = b \log \mathrm{FL} + \log a + \varepsilon \quad (1)$$

were estimated using a nonlinear routine that minimised the negative of the log-likelihood assuming that the residuals (ε) were independent random variables that followed a normal distribution with mean = 0 and variance σ^2 (Hilborn and Walters, 1992). The length at mass data were fitted separately to the sexes because there are differences in growth (see below).

The Von Bertalanffy growth function,

$$L_t = L_\infty(1 - \exp(-k(t - t_0))) + \varepsilon \quad (2)$$

where L_t is the mean length (FL) at age t and L_∞, k and t_0 are constants that represent the asymptotic mean length, the growth rate parameter and the mean theoretical age of the fish at zero length, respectively. The parameters of the model when data for both sexes were combined as well as separated were estimated using a maximum likelihood technique (described above) assuming normality in the residuals and equal variance, at each age. Left and right 95% confidence intervals of the parameters were calculated using the likelihood profile technique (Lebreton et al., 1992). To statistically test whether a combined sex growth model or sex-separated models better described the length-at-age data an analysis of residual sum of squares (ARSS) method was applied (Chen et al., 1992).

2.2. Mortality

Instantaneous total mortality (Z), for each sex, was estimated from catch curves by fitting a linear regression to the descending limb of the curve with numbers-at-age transformed into ln (numbers)-at-age (Ricker, 1975). The slope of the regression provided an estimate of Z. Pauly's (1980) empirical equation was used to estimate the instantaneous natural mortality rate (M) for each sex assuming that the mean annual environmental temperature along Oman is 26 °C (personal observations, M.R.G. Claereboudt). The current instantaneous fishing mortality rate (F_{curr}) was calculated as Z–M, for each sex. The estimates of M and F were assumed to be constant and independent of age.

2.3. Age-at-capture and age-at-maturity

Age-at-first capture and age-at-50% maturity for each sex was estimated by converting the lengths at which they become apparent into ages using the appropriate Von Bertalanffy growth functions. The sizes-at-first capture and the sizes-at-50% maturity were obtained from Claereboudt et al. (2005).

2.4. Per-recruit analysis

2.4.1. Model description

The status of the Omani kingfish stock was assessed using a per-recruit analysis (Beverton and Holt, 1957). Two variables, the spawner biomass per-recruit (SBR) and yield per-recruit (YPR), were calculated for various fishing mortalities ranging from zero to large values ($\sim$1 year^{-1}). The traditional per-recruit model (Beverton and Holt, 1957) was modified to evaluate the effects of closed seasons on SBR and YPR. This was achieved by assuming a time step of 1 month in the per-recruit model. SBR and YPR models were developed separately for each sex. We assume a maximum lifespan of 10 years for male kingfish and 20 years for females and these correspond to the oldest individuals observed in the catch (McIlwain et al., 2005).

The SBR (expressed in mass g) for each sex s was calculated using the following equation:

$$\mathrm{SBR_s} = \frac{\mathrm{SB_s}}{R_\mathrm{s}} = \sum_{t=0}^{t_{\max}} \exp(-((F_{\mathrm{s},} S_{\mathrm{s},t} A_{\mathrm{s},t}) - M_\mathrm{s})t) a_\mathrm{s} (L_{\mathrm{s},t})^{b_\mathrm{s}} G_{\mathrm{s},t} \quad (3)$$

where $\mathrm{SB_s}$ is the total spawner biomass (in g) for sex s, R_s the number of recruits and was set to 1, F_s and M_s the fishing and natural mortality rates for sex s, respectively, a_s and b_s the length–mass constants for each sex s, $L_{\mathrm{s},t}$ the predicted Von Bertalanffy mean length-at-age t for sex s, and $t_{\max}$ is the maximum observed age in the fishery, for sex s and the unit is in months and $G_{\mathrm{s},t}$ is the fraction of mature fish at age t and sex s and was assumed to be knife-edged i.e.

$$G_{\mathrm{s},t} = \begin{cases} 0, & \text{if } t < t_m \\ 1, & \text{if } t \geq t_m \end{cases} \quad (4)$$

where t_m is the age-at-50% maturity. $S_{\mathrm{s},t}$ is the gear selectivity at age t and sex s and is also assumed to be knife-edged i.e.

$$S_{\mathrm{s},t} = \begin{cases} 0, & \text{if } t < t_\mathrm{c} \\ 1, & \text{if } t \geq t_\mathrm{c} \end{cases} \quad (5)$$

where t_c is the age-at-first capture. $A_{\mathrm{s},t}$ indicates whether a particular month corresponding to age t and sex s is open to fishing or not. If it is open to fishing it takes on a value of 1 and if not 0. The month when $t = 0$ was set to May i.e. when recruitment is assumed to occur and was chosen because the gonadosomatic index was the highest in this month (Claereboudt et al., 2005).

YPR, in numbers, for sex s was calculated as:

$$\mathrm{YPR_s} = \frac{\mathrm{YP_s}}{R_\mathrm{s}} = \sum_{t=0}^{t_{\max}} \frac{F_\mathrm{s} S_{\mathrm{s},t} A_{\mathrm{s},t}}{F_\mathrm{s} S_{\mathrm{s},t} A_{\mathrm{s},t} + M_\mathrm{s}} \exp((-(F_\mathrm{s} S_{\mathrm{s},t} A_{\mathrm{s},t}) - M_\mathrm{s})t) \times (1 - \exp(-(F_\mathrm{s} S_{\mathrm{s},t} A_{\mathrm{s},t}) - M_\mathrm{s}) \quad (6)$$

where $\mathrm{YP_s}$ is the total yield in numbers for a cohort throughout its lifespan.

The YPR, in mass g, which is termed $\mathrm{YPR_{s\,(mass)}}$ was calculated from the following formula:

$$\mathrm{YPR_{s\,(mass)}} = \sum_{t=0}^{t_{\max}} \mathrm{YPR}_{\mathrm{s},t} a_\mathrm{s} (L_{\mathrm{s},t})^{b_\mathrm{s}} \quad (7)$$

where $\mathrm{YPR}_{\mathrm{s},t}$ is the yield per recruit in numbers for age class t and sex s.

2.5. Management scenarios

We evaluated four different harvesting strategies that were different from the current state of an unregulated fishery, the base case in this study. These four different harvesting strategies were compared to the base case to evaluate the best compromise between the conservation of SBR and maximising YPR. These harvesting strategies were termed Scenarios 1–4.

In Scenario 1, the FL-at-first capture was set equal to the FL-at-50% maturity i.e. 80.4 cm for males and 84.7 cm for females and a closed fishing season was set extending from September to October of each year for the entire lifespan of the cohorts modelled.

For Scenario 2, we retained the same closed season as in Scenario 1 but set the FL-at-first capture to a FL currently observed in the fishery i.e. 45 cm for both sexes.

In Scenario 3, the FL-at first capture was set equal to the FL-at-50% maturity but the closed season now extended from March to April.

For Scenario 4, the same closed season as in Scenario 3 was modelled with a FL-at-first capture equal to 45 cm for both male and female kingfish.

2.6. Biological reference points

A number of biological reference points were estimated in order to determine the current status of the kingfish resource as well as to evaluate the effectiveness of new regulations. $F_{20\%}$ and $F_{40\%}$ are defined as fishing mortality rates that reduce spawner biomass per recruit to 20 and 40%, respectively, when compared to an unfished state where SBR is assumed to be at a level of 100%. Another biological reference point, $F_{\max}$ defined as the fishing mortality that produces maximum yield per recruit was also estimated.

Table 1
The values of parameters used in the per-recruit analysis

Parameter	Value	Source
a_{males}	0.00353	This study
b_{males}	3.173	This study
$a_{females}$	0.005030	This study
$b_{females}$	3.093	This study
L_∞ (males) (cm)	134.7	This study
k (males) (month^{-1})	0.023	This study
t_0 (males) (months)	−27	This study
L_∞ (females) (cm)	151.3	This study
k (females) (month^{-1})	0.016	This study
t_0 (females) (months)	−33.744	This study
M (males) (month^{-1})	0.041	This study
M (females) (month^{-1})	0.031	This study
F_{curr} (males) (month^{-1})	0.034	This study
F_{curr} (females) (month^{-1})	0.045	This study
t_{max} (males) (months)	120	McIlwain et al. (2005)
t_{max} (females) (months)	240	McIlwain et al. (2005)
FL-at-50% maturity (males) (cm)	84.7	Claereboudt et al. (2004)
FL-at-50% maturity (females) (cm)	80.4	Claereboudt et al. (2004)
FL-at-first capture (males and females) (cm)	45	McIlwain et al. (2005)

Note: Certain lengths were converted to ages using the appropriate Von Bertalanffy parameters.

3. Results

3.1. Growth

Generally, both sexes have similar growth rates when they are small in size, but at larger lengths, males are much heavier (Table 1 and Fig. 1).

Using marginal zone analysis, McIlwain et al. (2005) have shown that the assumption of annual banding in the otoliths of kingfish is a valid one. Based on their age determination the maximum age attained by male kingfish is 10 years while females attained a much greater maximum age (20 years) (Fig. 2). The small 95% confidence ranges for the Von Bertalanffy parameters indicate that they are estimated reasonably well (Table 2 and Fig. 2). The ARSS analysis indicated that there was a significant difference between growth in males and females ($F_{3955} = 1.6$). On average, females live longer and attain larger sizes than males; however, male growth rate is higher than that of females.

3.2. Mortality

The catch curve estimates of Z for male and female kingfish are 0.892 and 0.901 year^{-1} and are fairly similar for both sexes (Fig. 3). The estimates of M are 0.490 and 0.376 year^{-1} for males and females, respectively. Thus, the estimates of F_{curr} for each sex are 0.402 year^{-1} for males and 0.534 year^{-1} for females. It is apparent that females are fished at a higher rate than males.

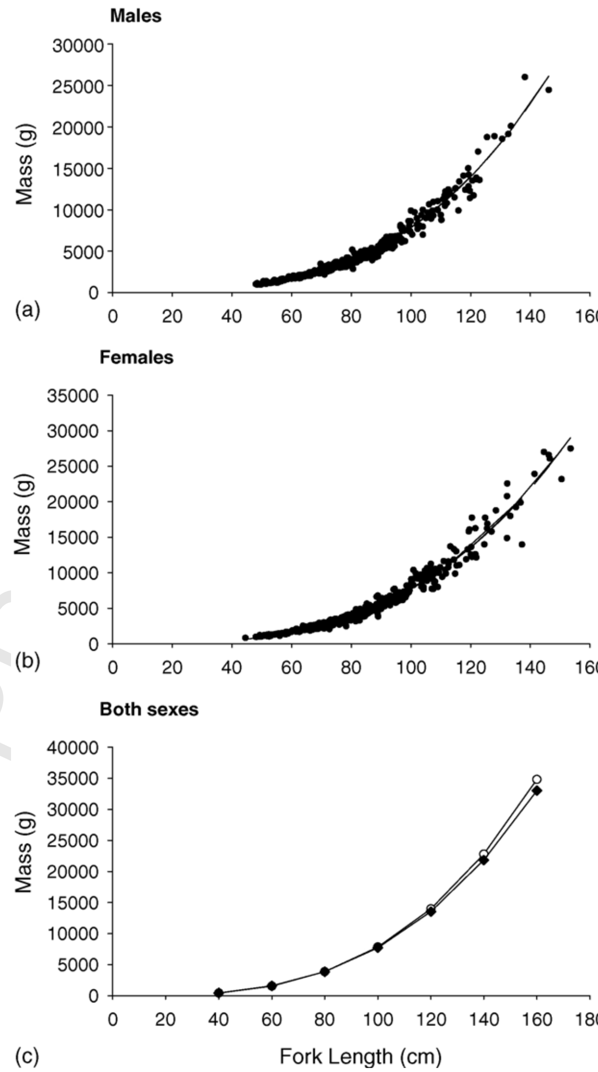

Fig. 1. The fork length vs. mass relationships for: (a) male and (b) female kingfish. In the case of males, the a and b parameters have the values 0.00353 and 3.173 (n = 414) while for females it is 0.00503 and 3.093 (n = 537), respectively. The last panel (c) compares the growth of males and females.

Table 2
The Von Bertalanffy growth parameters estimates and their 95% confidence intervals

Parameter	Value	Left 95% CI	Right 95% CI
L_∞ (both sexes) (cm)	146.4	140.0	153.5
k (both sexes) (year^{-1})	0.216	0.189	0.246
t_0 (both sexes) (years)	−2.618	−2.381	−2.883
L_∞ (males) (cm)	134.7	125.9	145.7
k (males) (year^{-1})	0.278	0.222	0.342
t_0 (males) (years)	−2.250	−1.940	−2.622
L_∞ (females) (cm)	151.3	143.3	160.6
k (females) (year^{-1})	0.195	0.164	0.230
t_0 (females) (years)	−2.812	−2.490	−3.193

The value of the negative log-likelihood when fitted to both sexes was 6426.03 and when fitted to the male and female data was 2586.73 and 3500.91, respectively.

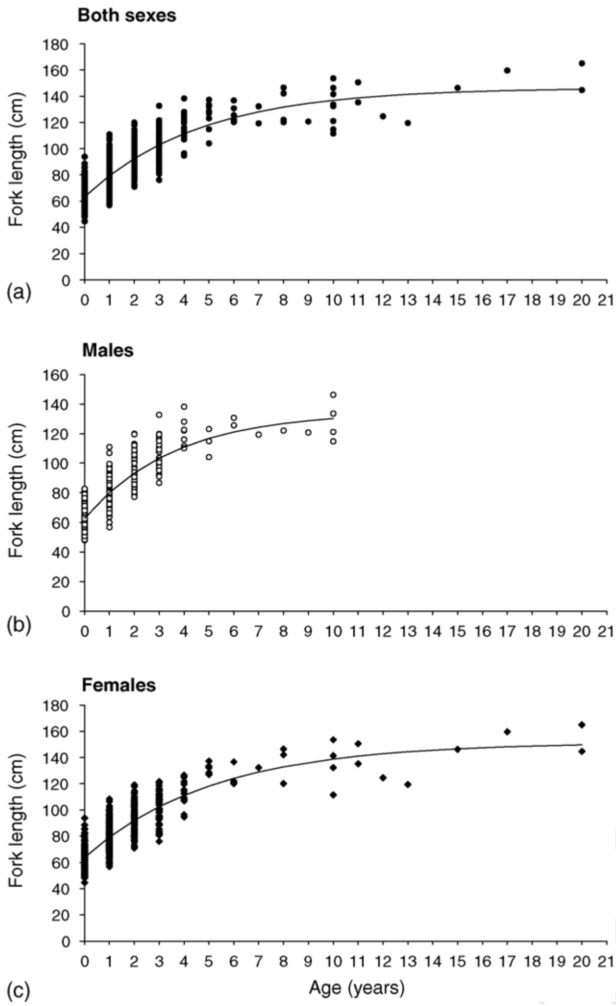

Fig. 2. Von Bertalanffy growth fits to the age-length data for: (a) both sexes ($n = 961$); (b) for male ($n = 415$); (c) female kingfish ($n = 545$).

3.3. Per-recruit analysis

The values of the parameters used in the per-recruit analysis are given in Table 1. At the current fishing mortality rates (F_{curr}) the SBR for males is at 27% while that for females is at about 16%, when compared to a state of no exploitation (Fig. 4a). For the base case, the YPR curves, in numbers, increases monotonically suggesting that YPR can increase indefinitely, however, the YPR, in mass suggests that a maximum yield can be attained at an F value equal to 0.96 year^{-1} for male kingfish and at a value equal to 0.72 year^{-1} for female fish (Table 3 and Fig. 4b).

It is also apparent that an introduction of a closed season helps to conserve SBR (Table 3 and Figs. 5a–8a). For example, in all scenarios and immaterial of whether the FL-at-first capture is set at the FL-at-50% maturity or to an age corresponding to the FL-at-first capture, the SBR is only reduced to 20%, in both sexes, at very high fishing mortality rates (Table 3). Moreover, for all scenarios and for both sexes the $F_{40\%}$ are similar regardless of when the closed season is set or what the minimum size at first capture is.

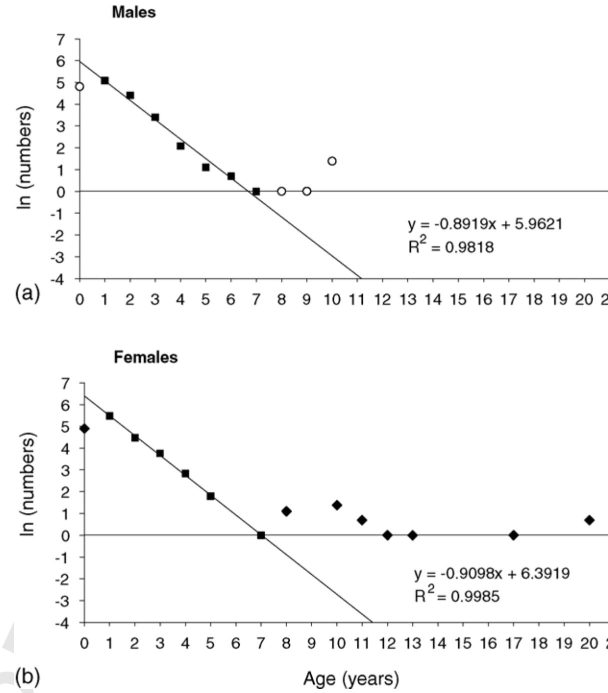

Fig. 3. Linear regressions fitted to the descending limb of: (a) male and (b) female catch curves. The slope of the regression provides an estimate of Z. Points used in the regression are shown as squares.

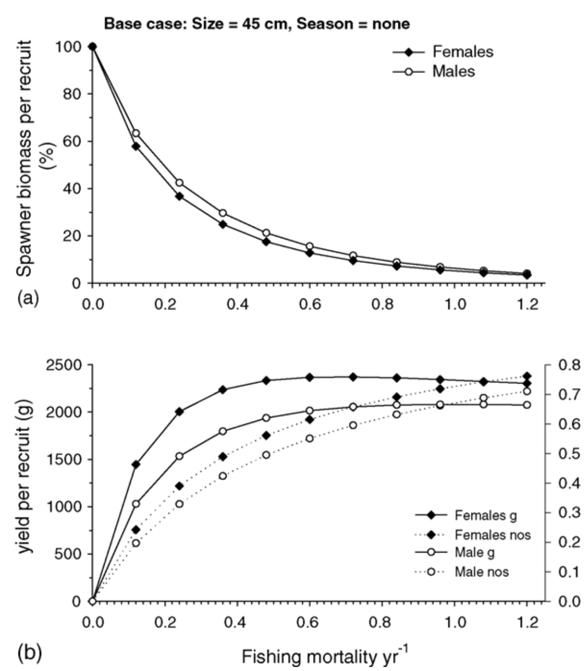

Fig. 4. Projected trajectories of: (a) spawner biomass per recruit (base case: size 45 cm; season = none) and (b) yield per recruit vs. fishing mortality rates for the Omani kingfish stock. The base case refers to the current situation. Size refers to the FL-at-first capture and season refers to the months that are closed to fishing. The spawner biomass is expressed as a percentage of the spawner biomass per recruit when the stock is in a pristine state. The spawner biomass per recruit when $F = 0$ is 115,982 and 203,007 g for males and females, respectively.

Table 3
Biological reference points for the Omani kingfish stock for various harvesting strategies

Harvesting strategy	$F_{20\%}$	$F_{40\%}$	F_{max} (no.)	F_{max} (mass)
Base case (size = 45 cm; season = none)	0.480 (0.450)	0.245 (0.225)	– (–)	0.96 (0.72)
Scenario 1 (size = 50% maturity; season = September–October)	1.3 (1.2)	0.405 (0.34)	0.36 (0.36)	0.36 (0.36)
Scenario 2 (size = 45 cm; season = September–October)	1.3 (1.2)	0.405 (0.34)	– (–)	0.96 (0.6)
Scenario 3 (size = 50% maturity; season = March–April)	1.1 (0.96)	0.39 (0.33)	0.36 (0.48)	0.36 (0.36)
Scenario 4 (size = 45 cm; season = March–April)	1.2 (1.09)	0.38 (0.33)	– (–)	– (0.84)

All units are in year^{-1}. Size refers to the FL-at first capture and is in cm while season refers to the months of the year that are closed to kingfish fishing. The base case is the current status of the fishery. Values in parenthesis refer to females while those without parenthesis refer to males. Dashes indicate that the reference point could not be estimated.

The F_{max} in numbers could not be estimated for the base case and for Scenarios 2 and 4 because the YPR curves simply increased monotonically (Table 3 and Figs. 4b, 6b and 8b). However, they could be estimated for Scenarios 1 and 3 and they are almost similar in value for both sexes with one exception; the maximum yield in Scenario 3 is achieved at a much larger F than in Scenario 1 (Table 3).

If we consider the estimates of F_{max}, when YPR is a function of mass, we find that in Scenarios 1 and 3 maximum yields are attained at low fishing mortality rates, which are slightly lower than current fishing mortality rates (Table 3). However, for the base case as well as Scenarios 3 and 4 maximum yields in mass are only realised at very high fishing mortality rates which will certainly reduce the relative SBR to levels close to 20%.

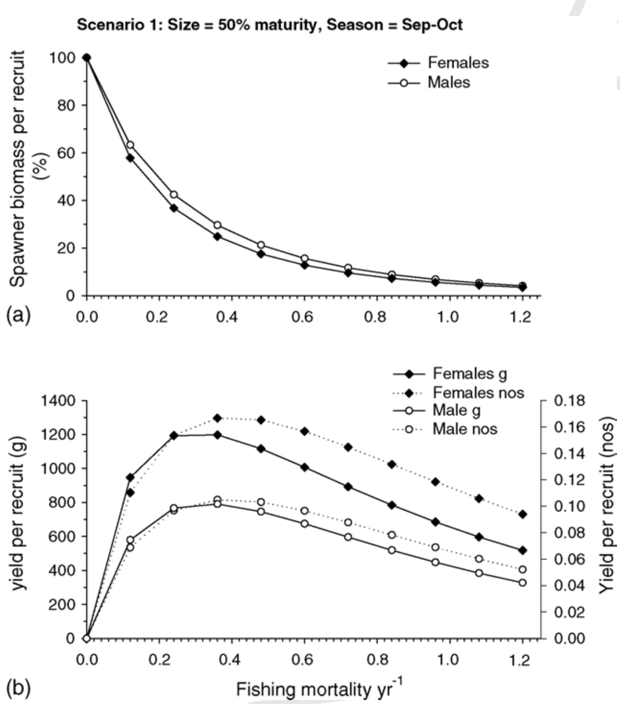

Fig. 5. Projected trajectories of: (a) spawner biomass per recruit (*Scenario 1*: size = 50% maturity; season = September–October) and (b) yield per recruit vs. fishing mortality rates for the Omani kingfish stock. Size refers to the FL-at-first capture and season refers to the months that are closed to fishing. The spawner biomass is expressed as a percentage of the spawner biomass per recruit when the stock is in a pristine state. The spawner biomass per recruit when $F = 0$ is 115,982 and 203,007 g for males and females, respectively.

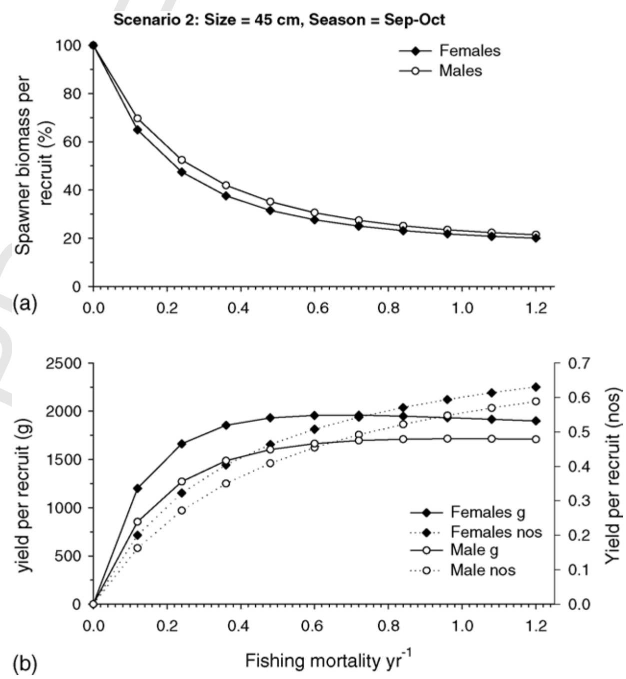

Fig. 6. Projected trajectories of: (a) spawner biomass per recruit (*Scenario 2*: size = 45 cm; season = September–October) and (b) yield per recruit vs. fishing mortality rates for the Omani kingfish stock. Size refers to the FL-at-first capture and season refers to the months that are closed to fishing. The spawner biomass is expressed as a percentage of the spawner biomass per recruit when the stock is in a pristine state. The spawner biomass per recruit when $F = 0$ is 115,982 and 203,007 g for males and females, respectively.

For Scenarios 1–4, relative SBR will increase from 27 to 40% for males and from 16 to 29% for females irrespective of the harvesting strategy chosen (Table 4). However, there is an enormous effect on the YPR. For example, Scenarios 1 and 3 will result in drastic reductions in yield; approximately 70% in numbers and about 55% in mass, irrespective of the sex. However, while Scenarios 2 and 4 achieve the same conservation of SBR as Scenarios 1 and 3, they result in far less drastic reductions in catch. In fact, Scenario 4 predicts a much smaller loss in yield than Scenario 2.

4. Discussion

There are significant differences in growth between male and female kingfish with the former growing relatively faster

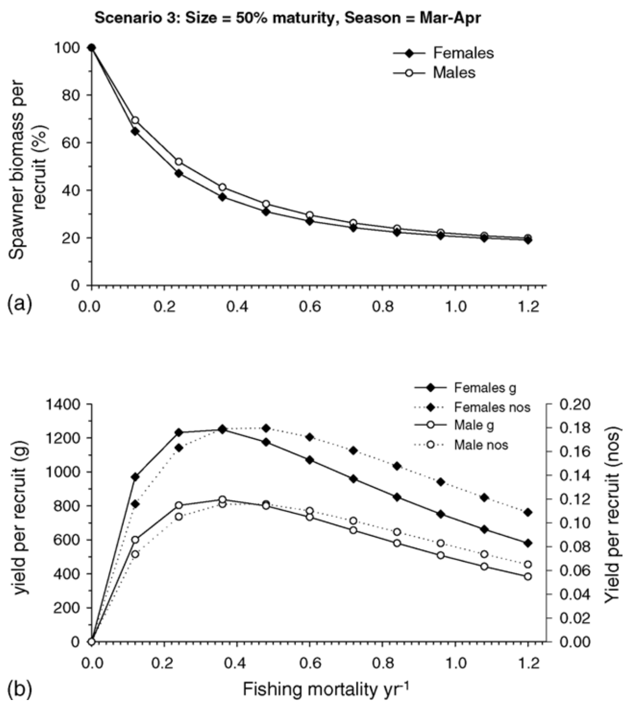

Fig. 7. Projected trajectories of: (a) spawner biomass per recruit (*Scenario 3*: size = 50% maturity; season = March–April) and (b) yield per recruit vs. fishing mortality rates for the Omani kingfish stock. Size refers to the FL-at-first capture and season refers to the months that are closed to fishing. The spawner biomass is expressed as a percentage of the spawner biomass per recruit when the stock is in a pristine state. The spawner biomass per recruit when $F = 0$ is 115,982 and 203,007 g for males and females, respectively.

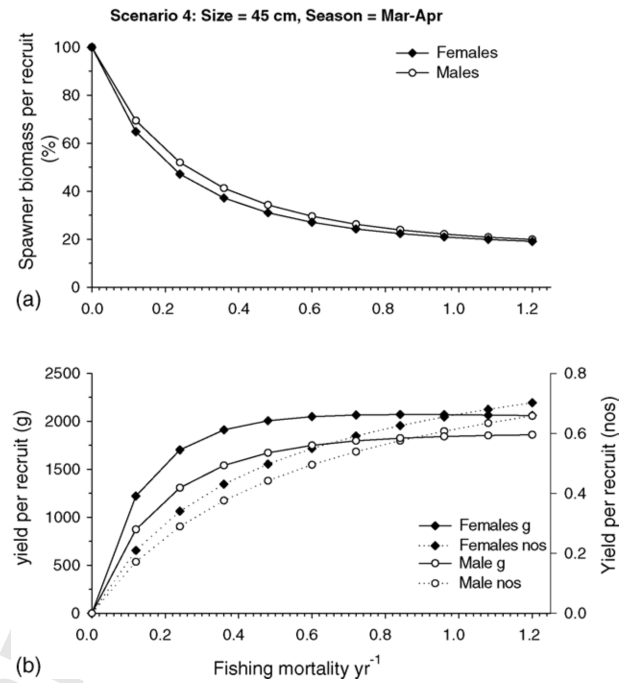

Fig. 8. Projected trajectories of: (a) spawner biomass per recruit (*Scenario 4*: size = 45 cm; season = March–April) and (b) yield per recruit vs. fishing mortality rates for the Omani kingfish stock. Size refers to the FL-at-first capture and season refers to the months that are closed to fishing. The spawner biomass is expressed as a percentage of the spawner biomass per recruit when the stock is in a pristine state. The spawner biomass per recruit when $F = 0$ is 115,982 and 203,007 g for males and females, respectively.

and reaching heavier masses, primarily, in the larger size classes. Females, however, generally live longer than their male counterparts. The longer longevity of females is unlikely to be an effect of fishing since more females are generally captured than males (Claereboudt et al., 2005) and given the higher fishing pressure on females it should be expected that there would be a reduction in the maximum observed age attained by them, but this was not so. This bias in sex ratio is probably an artefact of gear type rather than a reflection of population differences. Claereboudt et al. (2004) observed that drift and set gill nets resulted in unit sex ratios while the use of baited hooks generally was biased towards females. They surmise that because females, needing more energy for egg production, may more readily take baited hooks, particularly during dusk and dawn when they feed more actively and when trolling most commonly occurs. In the South African kingfish fishery which is predominately a recreational and commercial hook and line fishery, Govender (1995) observed that approximately twice as many females were captured than males, supporting Claereboudt et al.'s (2004) hypothesis. These observed differences in growth and fishing rates justify separate per-recruit analyses for the two sexes.

Given the lower lifespan of male kingfish it is expected that their natural mortality rate will be higher than that of females. Generally, for fishes, it has been observed that there is a correlation between lifespan and M with shorter-lived species exhibiting higher rates of natural mortality. Presumably, this would be the same for species in which one sex lives longer than the other. Pauly (1980) determined that the standard

Table 4
Different harvesting strategies and their effect on spawner biomass per recruit and yield per recruit as compared to the current harvesting strategy (base case)

Harvesting strategy	Spawner biomass per recruit	Yield per recruit (Nos)	Yield per recruit (g)
Scenario 1 (size = 50% maturity; season = September–October)	+13% [40%] (+13%) [29%]	−78% (−73%)	−58% (−56%)
Scenario 2 (size = 45 cm; season = September–October)	+13% [40%] (+13%) [29%]	−18% (−18%)	−16% (−18%)
Scenario 3 (size = 50% maturity; season = March–April)	+13% [40%] (+13%) [29%]	−73% (−70%)	−56% (−53%)
Scenario 4 (size = 45 cm; season = March–April)	+13% [40%] (+13%) [29%]	−11% (−12%)	−13% (−14%)

The (+) sign indicates an increase in the variable (when compared to the base case) while the (−) sign indicates a decrease. Values in parenthesis refer to females. Values in square brackets indicate the percentage of the variable available (as compared to an unexploited state) if the current fishing mortality rate is maintained.

deviation of log M, in his multiple regression equation to be 0.245. This provides a means of estimating 95% confidence intervals for the M estimates for males and females. The 95% confidence interval for males will, therefore, range from 0.16 to 1.48 year^{-1} and from 0.12 to 1.14 year^{-1} for females. These results are similar to values reported by Govender (1995) for the South African kingfish stock. He estimated an M value of 0.48 year^{-1}, for the combined sexes, with a 95% confidence range 0.16–1.44 year^{-1}. Based on lifehistory parameters derived from length–frequency data Al-Hosni and Siddeek (1999) estimated M values of 0.35, 0.64 and 0.77 year^{-1} (using three different empirical formulae) which are within the range estimated in this study.

At the current fishing rates the SBR for males is at 27% and that of females is 16% when compared to a pristine fishery. Values of SBR lower than 20% is a cause for concern as there is high chance of future recruitment failure (Caddy, 1998). For the Omani female kingfish stock this is the case and presuming that sperm is not limited, despite the low level of SBR for males, there is an urgent need to re-build the female kingfish stock. The results of the per-recruit analysis are not surprising given the open-access and unregulated nature of the fishery, as well as the higher proportion of the landed catch being female and immature. Claereboudt et al. (2005) report that the percentage of immature individuals in the catch can range from 35 to 89% depending on the area of landing with Al-Batinah and the Muscat regions showing the highest proportions of immature animals. Moreover, it has been recently noted that beach seines, usually used to catch other small pelagic fishes, has resulted in incidental catches of very small kingfish that are retained.

We have demonstrated that the use of closed seasons coupled with a minimum size limitation can significantly increase SBR, for both sexes, over the long-term. There is no difference between the scenarios in terms of the conservation of SBR. This is not surprising since the SBR is a function of survivors and their growth at a particular time i.e. in terms of mass, a large numbers of survivors at a small size will be equivalent to low numbers of survivors at a larger size.

We have shown that the proposed new regulations if implemented can raise SBR (when compared to an unfished state) to 40 and 29%, for males and females, respectively. However, this comes at a price. Depending on the management strategy adopted there can be a significant loss in yield, both in terms of numbers or mass harvested. On average, 27 kg of kingfish are landed per fishing trip, but this is highly variable (S.D. = 31 kg) with the selling price per kg being RO 1.34 on average (the current exchange rate is RO 1.00 = US$ 2.6) (H.S. Al-Oufi, personal communication). These can represent a significant burden to consumers, as the price would most likely to be increased by fishers to recuperate their lost earnings. On the other hand, fishers may resort to more drastic means of increasing their catch (more frequent use of bottom-set gill nets or use of smaller mesh sizes or increasing net length by joining of nets into gangs or utilising longer soak times).

We have chosen the months of March to April and September to October on which to evaluate the closed season effects. There is some justification for choosing these months. Generally, catches are very low between the months May and July, which coincides with the spawning period (Claereboudt et al., 2005) and a presumed migration to spawning grounds beyond the areas of Omani fishing. Therefore, the choice of only a 2-month closure was deemed reasonable as a longer period may place undue socio-economic hardship on fishers. Also, a study between December 1999 and December 2001 (Al-Oufi, unpublished data) found that only in 6 months did the average catch per trip exceed 27 kg: March 2000 (∼50 kg), August 2000 (∼40 kg), November 2000 (∼68 kg), January 2001 (∼45 kg) and September 2001 (∼52 kg) which represents the months of significant catches in a given year. The choice of our closed season scenarios, therefore, includes months of peak catches and presumably high fishing rates.

The choice of which scenario to adopt as a management measure will largely depend on the objectives set for this fishery by the Directorate General of Fisheries Resource of Oman. However, the adoption of a particular management strategy depends largely on the buying-in of fishers to this management strategy or plan. Given that traditional fishers account for 84% of fish landings in Oman (Al-Oufi et al., 2000) there is an urgent need to include this sector in the overall management of Omani's kingfish fishery.

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