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Biological Reference Points for Managing Kingfish, *Scomberomorus commerson*, in Oman Waters

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Abstract

The 1987-1995 length composition of quarterly catches of *Scomberomorus commerson* (Lacépède 1800) was analyzed to determine various biological reference points for management purposes. These include: fishing mortality producing maximum yield-per-recruit in weight (F_{max}), fishing mortality producing 50% relative mean mature biomass (F_{50}), and fishing mortality producing recruits that would exactly replace their parent stock (F_{rep}). F_{max} provided misleading suggestions to increase fishing mortality on the stock which is currently at a low level. On the other hand, both F_{50} and F_{rep} provided acceptable results, suggesting reduction of the current fishing mortality by 17-40%.

Introduction

The kingfish, *Scomberomorus commerson* (Lacépède 1800), is the most valued large pelagic fish caught in Omani coastal waters. The annual catch in Oman varied from a high of 27 762 t in 1988 to a low of 3 265 t in 1993; meanwhile, the total number of boats (primarily fiberglass vessels with outboard motors) in the fishery has increased from 7 442 in 1987 to 11 751 in 1996 (Al-Hosni 1996; Anon. 1997). Thus, high demand appears to have triggered overexploitation of this stock resulting in a precipitous decline in catches in recent years.

A few stock assessment studies on *S. commerson* based on short time series of length-frequency data have been reported in Oman (Dudley et al. 1992; Bertignac and Yesaki 1993). Our study considered a longer time series of data (1987-1995) to estimate growth, mortality, and a number of biological reference points.

Various biological reference points, F_{MSY} based on maximum sustainable yield criteria, F_{max} and $F_{0.1}$ based on yield-per-recruit (Y/R) criteria, F_{50} based on spawning stock biomass (SSB) criteria, and F_{rep} based on spawner-recruit relation combined with SSB criteria - have been used in the past for managing fisheries resources (Sissenwine and Shepherd 1987; Caddy and Mahon 1995). We estimated three of the above reference points, F_{max}, F_{50}, and F_{rep}, for Omani *S. commerson* stock. The F_{max} is the fishing mortality that produces the maximum Y/R in weight, F_{50} is the fishing mortality that reduces the SSB level to 50% of the unexploited level, and F_{rep} is the fishing mortality that maintains a certain SSB level such that their progenies, on the average, will exactly replace the parent stock as they grow to maturity.

Materials and Methods

Catch-at-age

The historical length and catch data of kingfish from the entire coast of Oman for 1987 to 1995 were the primary source used in this paper. We grouped the monthly sample length measurements of *S. commerson* into 4 cm intervals, raised to the month's total kingfish catch, and summed up to the quarter to obtain the catch-at-length (Al-Hosni 1996). We then decomposed the catch-at-length into catch-at-age composition using Bhattacharya's method available in the FiSAT suite of programs (Gayanilo et al. 1995). The routine estimates the mean length and catch numbers of each component (age group) distribution of the mixture. We then arranged component catch numbers according to the calendar time of sampling to identify the progression of various cohorts. Based on information on time of spawning and sampling date, we assigned ages to all catch frequencies. Thus, we produced the catch-at-age data for the virtual population analysis (VPA).

Virtual Population Analysis

VPA provides estimates of fishing mortality-at-age (F_i) and stock size-at-age (N_i) of each cohort using catch-at-age data for given input values of terminal fishing mortality (F_t) and natural mortality (M). We used the VPA program available in FiSAT (Gayanilo et al. 1995) to obtain the fishing mortality vector (an array of F_i values) for equilibrium yield-per-recruit (Y/R) and spawning stock biomass (SSB) estimation and also to determine actual spawning stock and recruitment sizes. Hosni and Siddeek (unpublished) determined the total mortality (Z) values for each biological year (September-August) from 1987-88 to 1994-95 by the catch curve method. They also estimated a plausible M of 0.64 based on life history parameters. We estimated F_t for each biological year (year-class j) by deducting this M from Z_j for tuning the VPA.

Biological Reference Points

YIELD-PER-RECRUIT IN WEIGHT (Y/R)

We used the Thompson and Bell method (Ricker 1975) to estimate Y/R. Starting from 1 000 recruits at a given age-at-first capture (t_c), we estimated the following quantities for every age (i) until the oldest age (t_{max}) to compute Y/R using the EXCEL spread sheet:

The stock size (N_{i+1}) at age i +1:

$$N_{i+1}=N_i e^{-(F_i+M)/4} \quad ...1)$$

(The Z_i (= F_i +M) was divided by 4 to make it quarterly basis).

The catch at age i (C_i):

$$C_i = [F_i/(F_i+M)](N_i - N_{i+1}) \quad ...2)$$

The yield (Y_i) at age i:

$$Y_i = C_i \bar{W}_i \quad ...3)$$

($\bar{W}_i$ being the mean weight of i-th age fish).

The yield-per-recruit in weight (Y/R):

$$(Y/R)_W = (1/R) \sum_{i=t_c}^{t_{max}} Y_i \quad ...4)$$

We employed the following weight-length relation formula to estimate mean weight-at-age from mean length-at-age:

$$W=aL^b \quad ...5)$$

where $a = 8.3X10^{-6}$, $b = 3.02$ (Al-Hosni 1996).

We calculated the current F vector by taking the weighted average of the VPA estimates of F_i for 1992-93 to 1994-95 (F_i's were weighted by N_i). We used different percentages (0-200%) of the current F vector and a range of t_c (0.5 - to 2.5 year) to calculate Y/R for determining F_{max}.

RELATIVE MEAN MATURE BIOMASS (RMMB)

The RMMB is the ratio of exploited to unexploited standing spawning stock biomass given as a percentage. If the percentage is less than 50, the stock is considered to be overexploited. We calculated the RMMB using the following formulae:

The mean exploited cohort size ($\bar{N}_i$) at i-th age group:

$$\bar{N}_i = 4(N_i - N_{i+1}) / F_i + M) \quad ...6)$$

where N_{i+1} is related to N_i by equation (1).

The exploited mean biomass (B_i) of the i-th age group:

$$(\bar{B}_i)=\bar{N}_i \bar{W}_i \quad ...7)$$

The total exploited spawning stock biomass (SSB):

$$SSB = \sum_{i=t_m}^{t_{max}} \bar{B}_i \quad ...8)$$

where t_m is the age-at-first maturity. Dudley et al. (1992) considered age-at-first maturity to be approximately 2 years and we considered t_{max} to be 4.75 years.

The virgin cohort size (N'_{i+1}) at age i+1:

$$N'_{i+1}=N'_i e^{-M/4} \quad ...9)$$

The mean virgin cohort size ($\bar{N}_i$) at i-th age group:

$$N'_i=4(N'_i-N'_{i+1})/M \quad ...10)$$

The mean virgin biomass ($\bar{B}'_i$) of i-th age group:

$$\bar{B}'_i=\bar{N}'_i W_i \quad ...11)$$

The total unexploited spawning stock biomass (SSB'):

$$SSB' = \sum_{i=t_c}^{t_{max}} \bar{B}_i \qquad ...12)$$

Therefore:

$$RMMB = (SSB/SSB') \cdot 100 \qquad ...13)$$

We used different percentages (0-200%) of the current F vector and a range of t_c (0.5 to 2.5 year) to calculate RMMB for determining F_{50} values.

REPLACEMENT FISHING MORTALITY (F_{rep})

We estimated F_{rep} using the following steps:

(i) The empirical SSB was estimated for every biological year (1987-88 to1994-95) using VPA estimates of stock size (N_i) of mature fish (2, 3, 4, and 5 year old), the corresponding total mortality (F_i + M) during the spawning period in the third quarter (March-May), and weight-at-age (W_i). Equations (6) to (8) were used to estimate SSB with N_i and (F_i + M) values determined from VPA at M=0.64.

(ii) The number of recruits were obtained from the VPA estimate of N_i for i = 0.5 year in the first quarter (September-November) for every biological year (1987-88 to 1994-95).

(iii) The $N_{0.5}$ (in millions) were plotted against SSB (in thousand t) of the previous biological year, assuming that the SSB during the third quarter in one biological year produces all recruits ($N_{0.5}$) in the first quarter of the next biological year. Then, a median line was drawn from origin through the scatter plot of $N_{0.5}$ versus SSB such that 50% of the points were on the upper side and 50% on the lower side of this line. The slope of this line was determined and its reciprocal estimated, which is equal to the optimal empirical SSB/R.

(iv) The equilibrium SSB/R was determined using equations (6) to (8) with t_m = 2 years, t_{max} = 5 years, t_c=0.5 year, M= 0.64, and different percentages (0-200%) of the current F vector. The equilibrium SSB/R were plotted against the percentage of the current F vector, and the optimal empirical SSB/R value was used to locate the percentage of the current F vector (= F_{rep}) on the X-axis.

Results

Biological Reference Points

YIELD-PER-RECRUIT IN WEIGHT (Y/R)

The current F vector given in Table 1 was used in the Y/R calculation. We changed the following two parameters in the calculation process: age-at-first capture (t_c = 0.5 to 2.5 year) and fishing mortality (0-200% of the current F vector). Fig. 1 gives the Y/R versus percentage of current F vector for different t_c. For the current t_c of 0.5 year, maximum Y/R occurred at 140% of the current F vector for M = 0.64. On the other hand, the Y/R could be increased by 7.1% of the current value, while maintaining the F vector at the status quo, if the current t_c is increased from 0.5 to 1.5 year.

RELATIVE MEAN MATURE BIOMASS (RMMB)

The RMMB estimates were obtained as by-products from the Y/R calculations, using the same F

Table 1. Fork length (FL_i), total weight (W_i), and weighted mean fishing mortality (F_i) at-age of Scomberomorus commerson *in Oman waters for determination of various biological reference points. The mean fishing mortality vector was assumed to be current.*

Age (year)	FL_i (cm)	W_i (kg)	F_i (yr^{-1})
0.50	55.2	1.5	0.247
0.75	63.2	2.3	0.366
1.00	70.7	3.2	0.840
1.25	77.7	4.2	0.176
1.50	84.2	5.4	0.158
1.75	90.2	6.6	0.000
2.00	95.9	8.0	0.057
2.25	101.1	9.3	0.068
2.50	106.1	10.8	0.438
2.75	110.6	12.3	0.726
3.00	114.9	13.7	1.019
3.25	118.9	15.2	0.812
3.50	122.6	16.7	0.821
3.75	126.0	18.2	3.804
4.00	129.3	19.6	1.718
4.25	132.3	21.0	0.058
4.50	135.1	22.4	0.409
4.75	137.7	23.7	2.477

Table 2. Virtual population analysis estimates of spawning stock biomass (SSB) and number of recruits at age 0.5 year (R) at the annual natural mortality value of 0.64 for Scomberomorus commerson*, 1987-88 to 1994-95. Data are arranged such that SSB and the corresponding R value are in the same row.*

Biological Year	SSB ($t \cdot 10^3$)	Biological year	R ($\times 10^6$)
1987-88	33.14	1988-89	3.30
1988-89	52.47	1989-90	2.72
1989-90	34.65	1990-91	3.48
1990-91	28.97	1991-92	2.55
1991-92	8.08	1992-93	1.49
1992-93	11.43	1993-94	0.31
1993-94	8.87	1994-95	0.52

vector, t_c and M values. Fig. 2 shows the RMMB versus percentage of the current F vector for different t_c. At the current t_c of 0.5 year, F_{50} = 60% of the current F. On the other hand, at the current F, the RMMB exceeded 50% at t_c>1.0 year.

REPLACEMENT FISHING MORTALITY (F_{rep})

Table 2 provides the SSB and R (= $N_{0.5}$) values for the SSB/R plot. The reciprocal of the slope of the median line in Fig. 3 (= optimal SSB/R) was 11.36. The F_{rep} for the optimal SSB/R value located on the X-axis of Fig. 4 was 82.9% of the current F.

Discussion

Y/R analysis suggests there is room to increase the current fishing mortality for every t_c value. This suggestion is inappropriate considering the sharp decline in kingfish landings. The use of maximum Y/R as a target for long-term management of pelagic fisheries has been discouraged because spawning stock biomass becomes so low at this level as to impair future recruitment (Patterson 1992; Caddy and Mahon 1995). Butterworth et al. (1989) recommend reducing the F close to the value at which the spawning stock is equivalent to 50% of its average unfished level. The F_{50} estimate for the Omani kingfish stock suggested a reduction in F ranging from 25% at t_c = 1.0 year to 40% at the current t_c of 0.5 year.

Although F_{50} is a useful biological reference point for managing a stock, it may not produce a sufficient number of recruits to maintain the size of the parent stock in the future due to environmental variation. On the other hand, because the stock-recruitment relation is difficult to ascertain for many stocks, F_{rep} based on the historical stock-recruitment scatter plot provides a reasonable biologi-

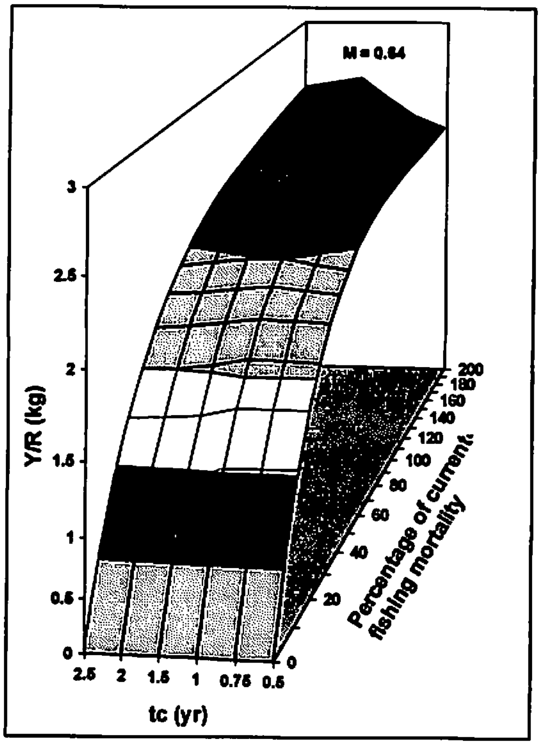

Fig. 1. Three dimensional plot of yield-per-recruit (Y/R) versus percentage of the current fishing mortality vector and age-at-first capture (tc) with M = 0.64 for Scomberomorus commerson.

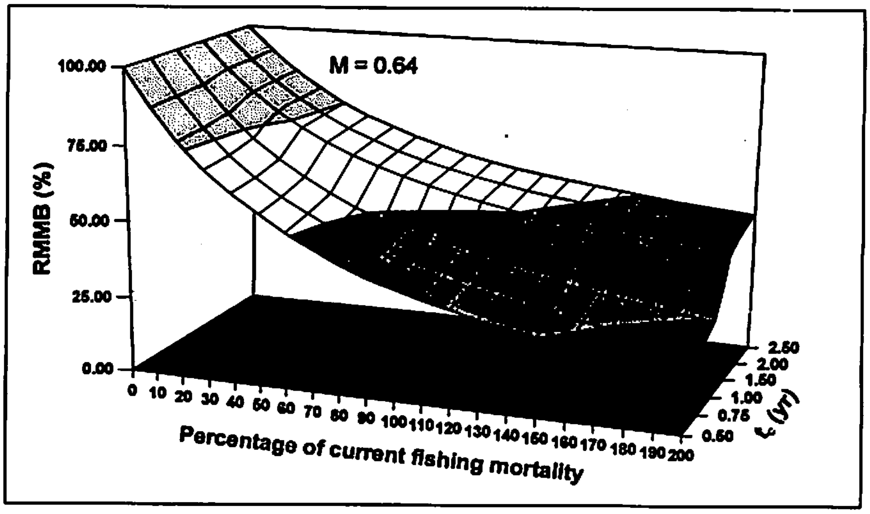

Fig. 2. Relative mean mature biomass (RMMB) versus percentage of current fishing mortality vector and age-at-first capture for Scomberomorus commerson.

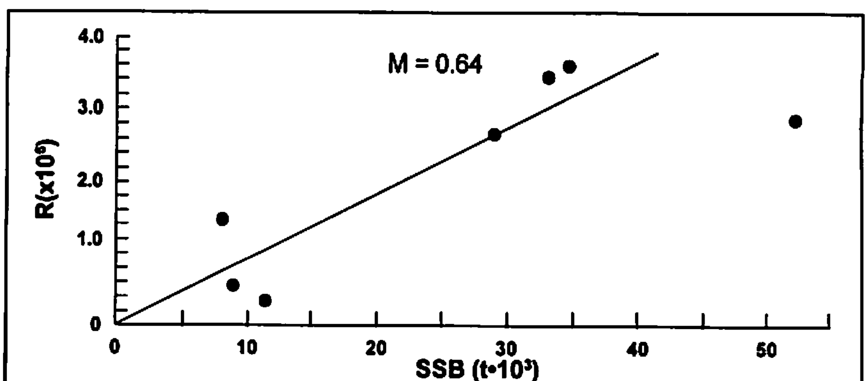

Fig. 3. Number of recruits (R) versus spawning stock biomass (SSB) scattergram showing the median line fitted by eye for Scomberomorus commerson. *R and SSB were estimated by virtual population analysis (M) = 0.64 for the 1987-88 to 1994-95 seasons.*

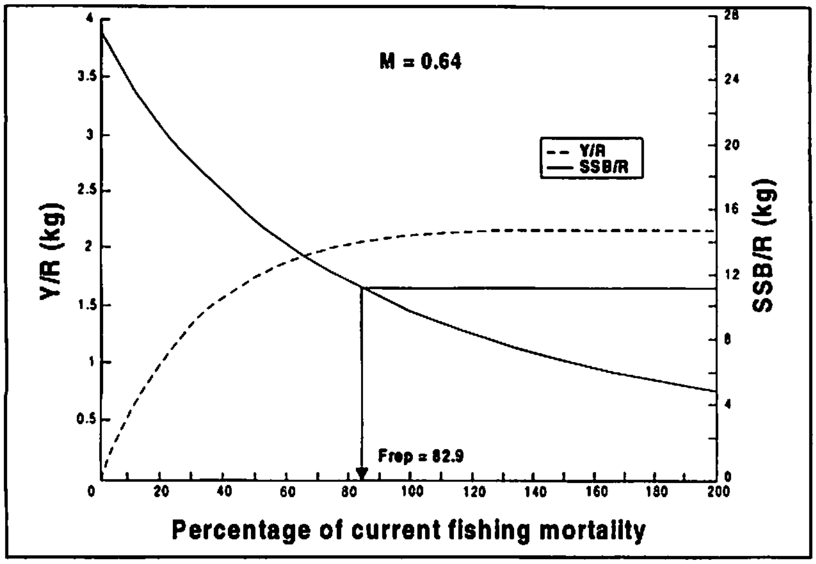

Fig. 4. Yield-per-recruit (Y/R, broken curve), spawning biomass-per-recruit (SSB/R, solid curve) and F_{rep} for Scomberomorus commerson. *See text.*

cal reference point. The estimated F_{rep} for Omani *S. commerson* stock suggested a 17% reduction in the fishing mortality at the current t_c.

A detailed report on this topic is being published. Anyone interested in receiving a copy may contact the first author.

Acknowledgments

We thank colleagues from the Marine Science and Fisheries Center, Ministry of Agriculture and Fisheries, for providing most of the raw data used in this paper. We are also grateful to the faculty of the Department of Fisheries, Sultan Qaboos University for reviewing the article and providing useful suggestions. The university has approved the publication of this manuscript. Published with the approval of the College of Agriculture, Sultan Qaboos University as Paper No. 60998.

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