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RESEARCH PAPER

An assessment of longnose trevally (*Carangoides chrysophrys*) (Cuvier, 1833) fishery in the Arabian Sea, Oman

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تقييم المصائد السمكية للصال في بحر العرب المطل على سلطنة عمان

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ABSTRACT: The present study assessed the fishery state of longnose trevally *(Carangoides chrysophrys)* in the North West Arabian Sea. Key population parameters were estimated, and yield and spawning stock biomass per recruit analyses were conducted. The equation presented by Alagaraja (1984) for estimating natural mortality resulted in M = 0.29 year^{-1} and lead to the best estimate of longevity. Hence this value was used in the yield and spawning stock biomass per recruit analyses. The total mortality (*Z*) was estimated as 0.39 year^{-1}, based on a catch curve analysis. Length-at-50% and age-at-50% captures were 38.21cm and 4 years respectively. The yield and spawning biomass per recruit analyses indicate that the current fishing mortality rate (F_{curr}) was lower than the fishing mortality corresponding to the maximum yield per recruit (F_{max}) and was also higher than the target reference point ($F_{0.1}$) , suggesting that overfishing, currently, does not occur. However, any increase in the fishing effort in the future may lead to overfishing.

KEYWORDS: Mortality, length-at-50% capture, yield per recruit, longnose trevally

المستخلص: قامت هذه الدراسة بتقييم مصائد سمكة الصال *(Carangoides chrysophrys)* في الشمال الغربي لبحر العرب. وأجريت التحاليل لموشرات مصائد الأسماك الرئيسية. وقد أسفرت المعادلة التي قدمها Alagaraja (١٩٨٤) لتقدير الوفيات الطبيعية بمعدل ٠,٢٩ في السنة وأعطت أفضل مؤشر لأقصى عمر. وبالتالي تم استخدام هذه القيمة في تقدير الكتلة الحيوية للمخزون البياض. وقدر مجموع الوفيات (*Z*) بمعدل ٠,٣٩ في السنة. استنادا إلى تحليل منحنى الصيد فقد كانت أطول ٥٠٪ من الأسماك المعرضة للصيد حوالي ٣٨,٢١سم اي في عمر ٤ سنوات. وتشير تحليلات الكتلة الحيوية للمخزون البياض إلى أن معدل وفيات الصيد الحالي (F_{curr}) أقل من وفيات الصيد المقابلة لأقصى قدر من المحصول الذي يمكن تحصيله (F_{max}). وكان أيضاً أعلى من النقطة المرجعية المستهدفة (*F0.1*)، مما يشير إلى أن هذا النوع من الأسماك لا يتعرض حاليا للصيد الجائر. ومع ذلك فإن أي زيادة في جهد الصيد في المستقبل قد تؤدي إلى الإفراط في صيد هذا النوع من الأسماك.

الكلمات المفتاحية: معدل الوفيات, الطول عند ٥٠٪ من النضج الجنسي, الانتاج لكل عنصر جديد, الصال

Introduction

The rapid increase in fishing efforts and improved fishing efficiency in the last two decades have resulted in depletion of many fisheries stocks in the world (FAO, 2007). This trend also applies to Omani fisheries. For example, kingfish (*Scomberomorus commerson*) catch in Omani waters has declined from above 20000 mt in the late 1980's to around 6000 mt in recent years, although the maximum yield was reported in 1988 at 27000 mt (GoSO, 2003). The catch of spiny rock lobster (*Panulirus homarus*) declined from above 1900 mt in 1988 to only 180 mt in 1999 (GoSO, 2000).

The Ministry of Agriculture and Fisheries Wealth plans to protect the economically important fish stocks from overfishing and longnose trevally *Carangoides chrysophrys* belong to this category. *Carangoides chrysophrys* is found in the Indian Ocean from the Red Sea and Arabian Gulf to the western of the Pacific Ocean from New South Wales to the Ryukyu Islands (Lieske and Myers, 1994). Insular localities for the species in the Indian Ocean include Madagascar, Comoros and the Seychelles (Smith-Vaniz, 1984). Longnose trevally *Carangoides chrysophrys*, abundant in Omani waters (Al-Abdessalaam, 1995), has a high economic value and supports both the commercial industrial and commercial traditional fisheries. Oman is one of the countries in the world that contributes significantly to the reported global capture production of Carangids (FAO, 2005). Though no separate catch statistics are available for *C. chrysophrys* in Oman, large jacks catch data include nine commercially important species of the family Carangidae, including longnose trevally and reported landings of 2359 mt were estimated for a value of 1.822 million Omani rials (1 OR = 2.6 USD) (GoSO, 2008). The current fishing regulations in Oman apply only to the mesh size of the demersal trawler, which operate in coastal shallow and deep water of more than 50 m depth with-

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in the continental shelf and enforce a minimum mesh size for the main net of 210 mm and 110 mm in the cod end (RRWFMCS, 1999). Minimum landing size limits in Oman fishing regulations are applied only on crustaceans (lobster) and molluscs (abalone) (RRWFMCS 1999) because they represent an unreasonable amount of additional labour for the fleet if applied to commercial fisheries where catches are large (King, 1995).

Yield per recruit models are widely used in fisheries management. In this study we developed an age-structured yield per recruit (YPR) and spawner biomass per recruit (SPR) models for the *Carangoides chrysophrys* stock in the northwestern Arabian Sea to provide scientific advice to the fisheries managers.

Methods

Sampling

Freshly landed fish were randomly selected and purchased from commercial fishermen at two landing sites on the Arabian Sea coast of the Sultanate of Oman: Al Lakbi (18^{0}11'1" N; 56^{0}32'56" E) and Raysut (16^{0}57'37" N; 53^{0}59'52" E). Sampling took place from April 2005 to September 2006. Specimens were caught with handlines, gillnets and traps. Annual strong southwest monsoon winds (between May and September) result in poor weather conditions forcing fishing activity in Al Lakbi to cease; hence, all biological sampling took place at Raysut (Al-Rasady et al., 2012; Al-Rasady et al., 2013) for a more detailed description of the sampling programme).

Population parameters

Various models were used in this study for estimating the instantaneous natural mortality rate (M) for each sex and combined sexes (Table 1).

where
K = coefficient of von Bertalanffy growth model,
Tm = maximum age or fish life span, and
$t_{m50\%}$ = the age at 50% maturity.

In order to choose the best estimate of natural mortality, the criterion proposed by Alagaraja (1984) was used as suggested by Gonçalves et al. (2003):

$(Tm)=4.605/M$

The method which gave the best estimate of longevity was applied and evaluated by a sensitivity analysis which varied M by ±10% in the per recruit analysis. Instantaneous total annual mortality rates (Z) was estimated using numbers at age data for each sex and combined with a pooled regression equation where the Z value was estimated according to Ricker (1975) from the right desending limb of a linearized age catch curve excluding age groups older than 14 yrs and those not fully recruited to the fishery (2 yrs old fish and younger for females and 3 yrs old fish and younger for males and sex combined) as suggested by Sparre and Venema (1989). The instantaneous fishing mortality (F) was estimated by subtracting the instantaenous natural mortality rate (M) from the instantaneous total mortality rate (Z).

Length at 50% capture (L_C) was estimated from the length frequency data by the method as suggested by Griffiths et al. (2006). Selectivity curves were generated by fitting a logistic function to the plot of probability of capture (Chen et al., 1992) i.e. numbers in a particular size class divided by the total number of fish sampled (expressed as percentage) against size class (L), from which the value of the parameter (L_C), the smallest size class at which 50% of the fish were fully recruited to the fishery was obtained. The logistic equation was:

$$P_L = \frac{100}{1+\exp\left(-r\left(L-L_c\right)\right)} \quad (1)$$

where P_L = percentage of capture in length class L and

r = the width of the ogive.

The von Bertalanffy (1934) equation was used to convert L_C to an age- at- 50% capture (t_c):

$$t_c = t_0 - \frac{1}{K}\ln\left(1-\frac{L_c}{L_\infty}\right) \quad (2)$$

where L_C = length-at-50% capture
L_∞ = the asymptotic length.9

Table 1. Emprical equations used to calculate natural mortality (M) for Carangoides chrysophrys in the Arabian Sea. (K) growth coefficient of the von Bertalnaffy growth model, (t_{max}) maximum age or fish life span, and ($t_{m\,50\%}$) the age at 50% maturity.

References	Equation	Assumpation
Rikhter and Efanov (1976):	$M=\left(1.52/\left(t_{m50\%}\right)^{0.72}\right)-0.155$	Close association between M and $t_{m\,50\%}$
Hoenig (1983):	$\ln\left(M\right)=1.44-0.982\ln\left(T_m\right)$	Relation between M and t_{max}
Alagaraja (1984):	$M=-\ln\left(0.01\right)/T_m$	Relation between M and t_{max}
Ralston (1987):	$M=0.0189+2.06K$	Relation between M and growth rate

Per recruit analysis

Two variables, the spawner biomass per recruit (*SBR*) and yield per recruit (*YPR*) (Beverton and Holt, 1957), were calculated for various estimates of fishing mortalities ranging from 0 to 1 yr^{-1}. The *SBR* was calculated using the following equation:

$$SBR = \frac{SB}{R} = \sum_{t=0}^{t_{max}} \exp\left(-\left(FS_t - M\right)t\right) a\left(L_t\right)^b G_t \qquad (3)$$

where

SB	=	the total spawner biomass (in g),
R	=	the number of recruits (set to 1, by definition),
F	=	instantaneous fishing mortality rate,
M	=	instantaneous natural mortality rate,
a and b	=	constants of the length–weightrelationship of combined sexes,
Lt	=	the predicted von Bertalanffy mean length-at-age t and
$tmax$ =		the maximum observed age in the fishery (year)
Gt	=	the fraction of mature fish at age t andwas assumed to be knife-edged i.e.

$$G_t = \begin{cases} 0, \text{if } t < t_m \\ 1, \text{if } t \geq t_m \end{cases} \qquad (4)$$

where t_m = the age at 50% maturity.
S_t is the gear selectivity at age t and is also assumed to be knife-edged i.e.

$$S_t = \begin{cases} 0, \text{if } t < t_c \\ 1, \text{if } t \geq t_c \end{cases} \qquad (5)$$

where t_c= the age at 50% capture.

Yield per recruit in number (YPR_S) was calculated as:

$$YPR_S = \frac{YP_S}{R_S} = \sum_{t=0}^{t_{max}} \frac{F_{S,t}}{F_{S,t} + M_S} e^{-\left(F_S S_{S,t} - M_S\right)t} \left(1 - e^{-\left(F_S S_{S,t} - M_S\right)}\right) \qquad (6)$$

where YP_s is the total yield in numbers for a cohort throughout its lifespan.

Yield per recruit (YPR) in mass was calculated from the following equation:

$$YPR_{(mass)} = \sum_{t=0}^{t_{max}} YPR_t a\left(L_t\right)^b \qquad (7)$$

where a and b are parameters of the length–weight rela-

Table 2. Natural mortality rates (*M*) estimated from different equations (Table 1) for *Carangoides chrysophrys* in the Arabian Sea. *Te*= predicted longevity in years.

Method	*M (year $^{-1}$)*			*Te* **(yr)**
	Male	*Female*	*Combined*	
Rikhter and Efanov (1976):	0.40	0.40	0.40	11.65
Hoenig (1983):	0.28	0.28	0.28	16.61
Alagaraja (1984):	0.29	0.29	0.29	16.00
Ralston (1987):	0.49	0.54	0.53	08.63

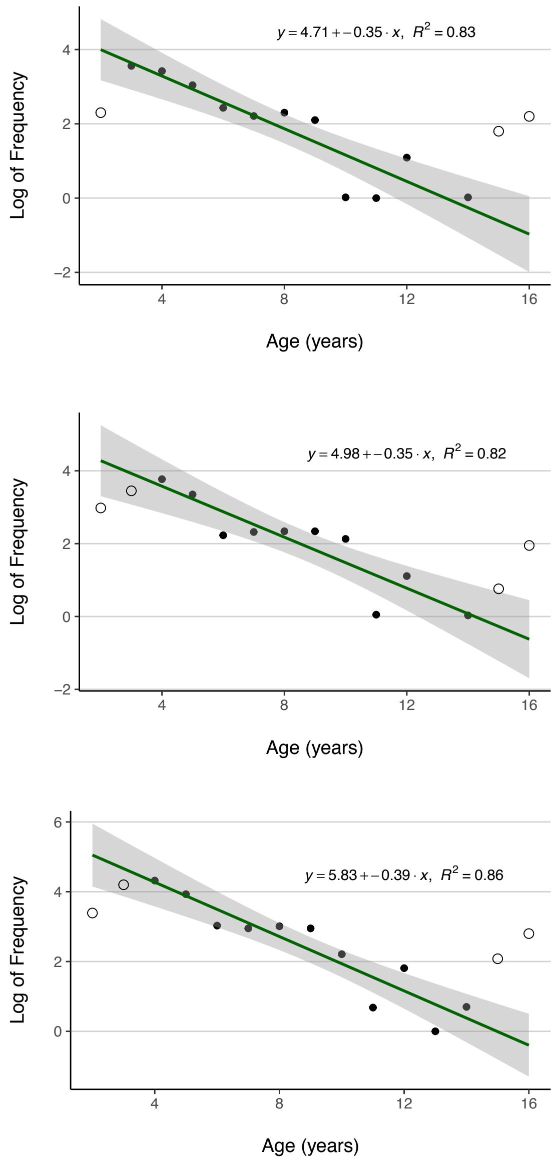

Figure 1. Age-based catch curves for males (top) , females (middle) and combined sex (bottom) for *Carangoides chrysophrys* in the Arabian Sea.

Table 3. Populations dynamic parameters of *Carangoides chrysophrys* in the Arabian Sea used in the per recruit analysis.

Parameter	Value	
a	0.0291	
b	2.7702	
L_∞	73.01	cm
K	0.25	yr^{-1}
t_0	-1.21	yr
t_{max}	16	yrs
t_c	3.85	yrs
t_m	4.83	yrs
M	0.29	yr^{-1}
-10% M	0.26	yr^{-1}
+10% M	0.32	yr^{-1}
$F_{curr\ M}$	0.0976	yr^{-1}
$F_{curr\ -10\%\ M}$	0.1264	yr^{-1}
$F_{curr\ +10\%\ M}$	0.0688	yr^{-1}

tionship of combined sexes. Biological references point (F_{max}) and ($F_{0.1}$) were estimated in order to compare them to the current fishing mortality and determine the status of the longnose trevally stock.

Results

The von Bertalanffy growth model parameters (L_∞ , K, t_o and t_{max}) were obtained from Al-Rasady (2013) and the length-weight relationships constants ($a_{sex\ combined}$, $b_{sex\ combined}$) were obtained from Al-Rasady (2012). Natural mortality and longevity, calculated for each sex and for the combined sexes, are shown in table 2.

Hoenig's and Alagaraja's equations gave the best estimates of longevity, while the rest of the methods underestimated the longevity of longnose trevally.

Total mortality rates (Z) for each sex and combined sexes are shown in figure 1. The total mortality rate for the combined sexes was higher than for each sex separately but the difference between Z for each sex was small. Fishing mortality (F) is presented in table 3. The Z for the combined sexes was only used for estimating the fishing morality. Fishing mortality had positive values when based on Hoenig's and Alagaraja's equations, but negative values based on the other models. Fishing mortality estimated by Hoenig was higher than the Alagaraja method. The total length at which 50% of longnose trevally were caught in the fishery was 38.2 cm (Fig. 2). This translates to an age of about 4 years using the von Bertalanffy growth model. Parameters used to assess the status of longnose trevally stock in the Arabian Sea using a per recruit analysis are given in table 4.

Table 4. Estimates of biological reference points for longnose trevally *Carangoides chrysophrys* captured in the Arabian Sea for varying values of natural mortality (M). Estimates of fishing mortality (F) are in the unit yr^{-1}.

	Base Case	-10% of M	+10% of M
$F_{0.1}$	0.146	0.142	*0.15*
F_{max}	0.147	0.143	*0.151*

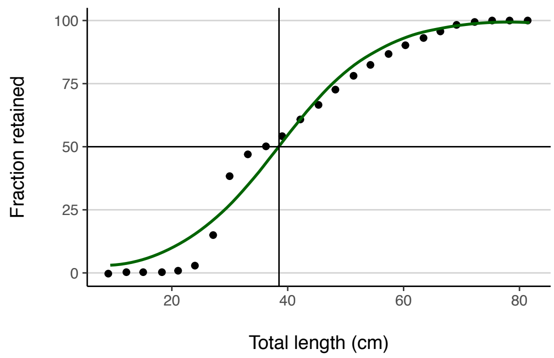

Figure 2. Selectivity curve for *Carangoides chrysophrys* in the Arabian Sea showing the mean size at 50% capture.

At the current fishing mortality rates (F_{curr}) the spawning biomass per recruit (SBR) was at 46.85% of that at the absence of fishing mortality for the base case of and 36.95% and 59.02% for the -10% M and +10% M respectively (Fig. 3). YPR curves, in mass suggests that a maximum yield can be attained at an F_{max} value equal to 0.147 $year^{-1}$, 0.143 $year^{-1}$ and 0.151 $year^{-1}$ for the base case of M and -10% M and +10% M respectively (Table 5). The estimates of $F_{0.1}$ were nearly identical to the estimates of F_{max} (Table 5).

Discussion

Equations of Hoenig (1983) and Alagaraja (1984) provide reasonable estimates of M for longnose trevally in the Arabian Sea. Griffiths et al. (2006) used various equations to estimate the natural mortality, including Hoenig's (1983) equation, for the Talang queenfish, *Scomberoides commersonnianus* (Carangidae). However, they excluded Hoenig's (1983) M estimate from the yield per

Table 5. Fishing mortality estimates for *Carangoides chrysophrys* in the Arabian Sea. Z = instantaneous total mortality rate and M is the instantaneous natural mortality rate and are given for the combined sexes. F = instantaneous fishing mortality rate. Negative value of fishing mortality are unrealistic.

Method	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})
Rikhter and Efanov (1976):	0.39	0.40	-0.01
Hoenig (1983):	0.39	0.28	0.11
Alagaraja (1984):	0.39	0.29	0.10
Ralston (1987):	0.39	0.53	-0.14

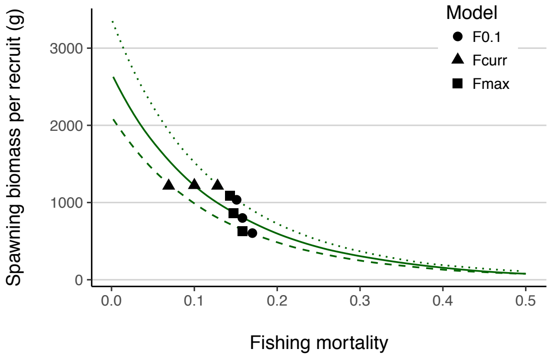

Figure 3. Spawning biomass per recruit curves for *Carangoides chrysophrys* in the Arabian Sea using different natural mortality rates. The current estimated mortality rate (M = 0.2878) is the continuous line. The dotted line corresponds to current mortality -10%, whereas the dashed line corresponds to M +10%. The black triangles are F_{curr}, the open circles are F_{max} and the black squares are the target reference point $F_{0.1}$.

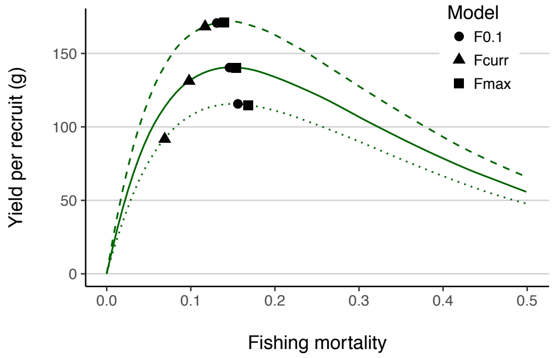

Figure 4. Yield per recruit (g) curves for Carangoides chrysophrys in the Arabian Sea using different natural mortality rates. The current estimated mortality rate (M = 0.2878) is the continuous line. The dotted line corresponds to current mortality -10%, whereas the dashed line corresponds to M +10%.The triangles are Fcurr, the circles are Fmax and the squares are the target reference point F0.1.

recruit analysis due to the large uncertainty and the fact that it tends to underestimate the maximum age (Griffiths et al., 2006). In our study Hoenig's (1983) equation overestimated the maximum age and hence we choose the estimate of *M* from the Alagaraja (1984) equation.

The estimate of natural mortality in this study was 0.29 year^{-1} which is near the higher limit of natural mortality estimated for Talang queenfish, *S. commersonnianus*, in northern Australia (0.16–0.26 yr^{-1}) (Griffiths et al., 2006) and substantially lower than that observed for the fast growing species *Carangoides bajad* and *Gnathanodon speciosus* in the Arabian Gulf (Grandcourt et al., 2004).

Total mortality rate in this study was 0.39 yr^{-1}. Values of the total mortality rate (*Z*) were 1.16 and 1.83 yr^{-1} for *C.bajad* and *G.speciosus* from the Arabian Gulf, respectively which is high, possibly due to high growth rates and/or higher fishing effort (Grandcourt et al. 2004). Natural mortality estimates other than those based on Hoenig's (1983) and Alagaraja's (1984) equations lead to negative values of *F* which are unrealistic.

The estimates of F_{max} and $F_{0.1}$ were nearly identical in value. This is not surprising as the ascending limbs of the yield per-recruit curves (Fig. 4) show little curvature (other than at the top of the curve) i.e. the ascending limbs are generally linear with a constant slope which abruptly changes at the top over a very short range of fishing mortality increase and then rapidly declines.

The current fishing mortality rate (F_{curr}), by traps and handline, is well below the maximum fishing mortality F_{max} and $F_{0.1}$ estimates. However, any future increase in fishing effort will lead to overfishing of the stock because *Carangoides chrysophrys* has a slow growth rate coupled with a high longevity. Stocks with low growth rates generally require low fishing effort to maximize the yield (King, 1995) and species with low population growth rate have a greater tendency to be overfished (Nowlis and Roberts, 1999). Maximum fishing mortality (F_{max}) is usually greater than the fishing mortality at the maximum sustainable yield (F_{msy}), and exploiting the stock at Fmax over an extended period may deplete the spawning stock and reduce future recruitment (Clarke, 1991). Harvesting at F_{max}, may in fact, lead to commercial extinction (Doubleday, 1976; Beddington and May, 1977; Beverton, 1994; Caddy and Mahon, 1995)

At the current fishing mortality rates (F_{curr}), for all the three cases of the natural mortality, the spawning biomass per recruit (SBR) is between (36.95 – 59.02) when compared to an unexploited stock. Values of SBR lower than 20% is a source for concern as there would be high possibility of future recruitment failure (Caddy, 1998).

Values of length and age at 50% capture are lower than the length and age at 50% maturity which results in immature fish being caught. The current fishing mortality rate (F_{curr}), for *Carangoides chrysophrys* from the Arabian Sea is at an optimum level and should be maintained. However, any increase in the fishing effort may lead to overfishing of this fishery.

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