Paper III

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A simple method of evaluating the state of data-poor fisheries

Exemplified by major Indian Ocean fisheries

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Abstract

A simple stock assessment method are presented, based on Richards (1959) surplus production model, FishBase parameters, and time series of catch data (from FAO statistics). Twenty-five Indian Ocean fisheries have been selected to demonstrate the method and perform stock assessments based on these very limited data sources. Two of twenty-five selected species are characterised as *healthy* through a simple stock assessment procedure, referring to the green sector of a Kobe plot. The two species represents only 2% of the total catches of the sample, while the three species characterised as *overfished, not overfishing* represent 14% of the same total (yellow sector). Thirteen species are considered being both *overfished and overfishing*, representing 40% of the total catch of the sample (red sector). The largest catches are obtained by the seven species placed in the category of *overfishing but not overfished* species, constituting 44% of the total catches of the sample (orange sector). The method is transparent and easy to implement in any fishery where reliable time series of catch data are available. In the examples provided from major Indian Ocean fisheries, the method appears to be in line with stock assessments by the Indian Ocean Tuna Commission (IOTC), when such assessments are available. However, in several cases the suggested method judge the state as more critical that the conclusions of IOTC.

Introduction

There is an increasing interest in data-poor fisheries and methods of evaluating the state of such fisheries. The introduction of *Harvest Control Rules* (HCR) makes it possible to base management principles on relevant indicators, including simple indicators of questionable quality. However, data-poor fisheries are most often found where management is not even considered and if any governmental actions are associated with such fisheries the actions are rather subsidies than restrictions.

Most fisheries in the world are in fact very data-poor fisheries, in the sense that utilised fishing effort and size and growth capacity of the exploited resources are unknown. However, catch records exist in many cases and time series of catches may serve as inputs in simple stock assessments based on commonly known surplus production models.

This paper presents a quite simple method of combining a surplus production model and individual growth parameters collected in FishBase (Froese and Pauly, 2019), in order to suggest maximum sustainable yield (MSY) from simple criteria when demanding consistency between catch times series and model predictions. The basic, and simple, assumption is that next year's fishing stock is determined by this year's stock size plus annual biological growth minus registered harvest of this year.

The method has some similarities with the one proposed by Froese et al. (2017), but makes use of a different surplus production model and does not provide any statistical analysis. In addition to assuming surplus growth to follow Richards (1959), only growth parameters obtained from FishBase (Froese et al., 2019), and FAO catch records (Anon., 2017a) have been use. The aim is to evaluate the catch time series and provide indicators reflecting the state of fisheries of limited information.

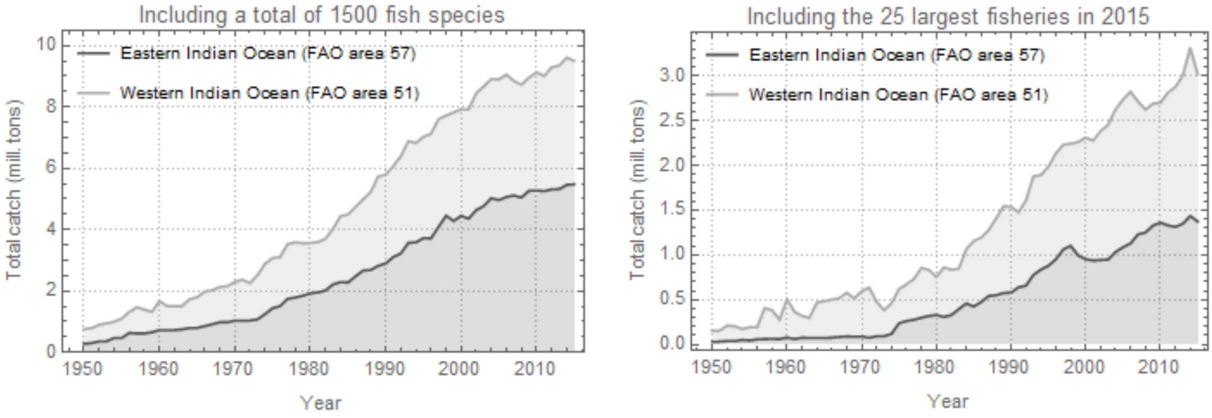

Figure 1. *Total catch of fish species in FAO areas 51 and 57, covering the western and eastern part of the Indian Ocean, respectively. The left panel shows the catch of all FAO-registered fish species during the period 1950-2015, while the right panel shows the total catch of the 25 species counting for the largest catches in 2015. Catch data have been downloaded from the online FAO database (Anon., 2017a).*

The quality and the comparability of the catch data over time may be a problem. Are the catch data representing a single stock or a sample of many fisheries on different stocks, although being the same species? These and other issues always call for concern and careful use of conclusions achieved by simple methods as suggested here. However, when few other methods are available, some crude assumption may be necessary.

The method has been applied on Indian Ocean fisheries, an area dominated by fishing activities by developing nations, but also including international actors. There has been an exponential growth in total catches in the area since the late 1950s, while there are some signs of declining growth rate in the current catch production (see figure 1).

The twenty-five largest fisheries have been selected, representing a variety of different species of varying distributions, growth patterns and economic importance. The selection of fisheries is based on catch quantities in 2015 and the availability of individual growth data in FishBase. Based on the latter, catches of frigate and bullet tunas (*Auxis thazard* and *A. rochei*, the eleventh largest catch in 2015), goatfishes (*Upeneus spp*, number thirteen) and talang queenfish (*Scomberoides commersonnianus*, number 25 in terms of 2015 catches) have been excluded from the study. The remaining 25 fish species therefore are among the 28 largest Indian Ocean fisheries, constituting almost one third of the total Indian Ocean catches in 2015.

Methodology

We employ Richards (1959) surplus production model to describe annual growth of a fish population as a function of stock biomass and harvest. The model has been adapted in order to be able to make use of catch statistics (from the FAO database over capture fisheries) and core biological parameters obtained from FishBase (Froese et al., 2019).

Pella and Tomlinson (1969) used Richards' model in their investigation of the South Pacific tuna fishery, previously studied by Schaefer (1957), who employed the Verhulst (1838) model. The Richards model may be written on the form

$$f(X_t) = r\,X_t\left(1-\left(\frac{X_t}{K}\right)^{m-1}\right) \tag{1}$$

where *r* is an intrinsic growth/mortality parameter, *m* a shape parameter, *K* the environmental capacity of the stock biomass and X_t the stock biomass at time *t*. The shape parameter gives a Verhulst (1838) model when $m = 2$, and approaches the Gompertz (1825) model as *m* approaches 1.

The harvest of year t, Y_t, is assumed to be described as the product of the fishing mortality rate, F_t, and the stock biomass, X_t, at time t:

$$Y(F_t, X_t) = F_t \cdot X_t \tag{2}$$

Equilibrium catch is obtained when equation (1) equals equation (2). Solving the equality with respect of *x* gives

$$X(F) = K \cdot \left(1 - \frac{F}{r}\right)^{\frac{1}{m-1}} \tag{3}$$

Inserting equation (3) in equation (2) gives the equilibrium yield as a function of the fishing mortality rate *F*

$$Y(F) = K \cdot F \cdot \left(1 - \frac{F}{r}\right)^{\frac{1}{m-1}} \tag{4}$$

Maximum sustainable yield (MSY) can be expressed by biological parameters from equations (1) and (2)

$$MSY = f\left(X = K \cdot m^{\frac{1}{1-m}}\right) = r \cdot K \cdot \left(m^{\frac{1}{1-m}} - m^{\frac{m}{1-m}}\right) \tag{5}$$

For some species MSY estimates are available (the Indian Ocean Tuna Commission, IOTC, has for example suggested some estimates for some tuna species). However, there are catches registered for most species during the period 1950–2015.

As shown by Eide (1989) the biological parameters *m* and *r* may be expressed by individual growth parameters (von Bertalanffy, 1938) when assuming a Beverton-Holt (1957) model and constant recruitment. According to von Bertalanffy individual weight at age, *t* is described by

$$w(t) = w_\infty \cdot \left(1 - e^{-k\cdot(t-t_0)}\right)^b \tag{6}$$

when assuming a length-weight relationship expressed by b, a theoretical age of zero weight (t_0) and the individual growth parameter k. We assume a constant annual recruitment (R), constant natural mortality (M) and Baranov mortality (Baranov, 1918). The stable stock size equilibrium of the unexploited population then is

$$K = R \cdot w_\infty \cdot \int_{a=0}^{\infty} e^{-M\cdot a} \cdot \left(1 - e^{-k\cdot(a-t_0)}\right)^b \, da$$

when a represent each year class in the stock. The shape parameter (m) is given by the length-weight relationship (b)

$$m = \frac{b}{1+b} \tag{7}$$

and when assuming that the individual growth rate, k, equals the natural mortality rate (M) it can be shown that

$$r = -k\,(1+b) \tag{8}$$

General information about the values of k and b are available for a large number of fish species in FishBase (Froese et al., 2019), which has been utilised in this paper.

The methodology is further based on consistency between historical records and equation (1). While parameters r and m could be estimated by available information about k and b, the environmental capacity K remains unknown. While K is difficult to estimate, qualified guestimates on *MSY* may be easier to establish. Indirectly K may therefore be determined by utilising equation (5) and such *MSY*-guestimates.

MSY is in this study expressed in terms of a share (α) of the largest annual catch of the given species (*sp*) during the period 1950-2015:

$$MSY_{sp} = \alpha_{sp} \cdot max_{sp,t=1950-2015}(Y_{sp,t})$$

$$\alpha_{sp} = \frac{MSY_{sp}}{max_{sp,t=1950-2015}(Y_{sp,t})} \tag{9}$$

We assume the initial stock level of species sp in 1950 to be K_{sp}, which is found by inserting equations (7), (8) and (9) into equation (5), solving it for *K*:

$$X_{sp,1950} = K_{sp} = \frac{\alpha_{sp} \cdot max_{sp,t=1950-2015}(Y_{sp,t})}{k \cdot \left(\frac{b}{1+b}\right)^{b}} \tag{10}$$

An initial start at $X_{sp,1950} = K_{sp}$ shows to be a non-critical assumption, since the simulations soon converge to the same values independent of start values. In general, consistency is found when

$$X_{t+1} = X_t + f(X_t) - Y_t \tag{11}$$

And non-negative stock values are obtained for all $t \in (1950, 2015)$.

This paper makes use of three different ways of estimating α_{sp}, for each of the species included in the study. The first estimate (A) simply searches for the lowest possible α_{sp}-value providing positive and consistent stock estimates.

The second α_{sp}-value (B) assumes the current stock biomass to equal the biomass corresponding to *MSY*

$$\frac{X_{2015}}{X_{MSY}} = 1 \tag{12}$$

The last α_{sp}-value (C) searches for the lowest value giving a positive stock increment in 2015, hence assuming the surplus production to be larger than the catch of this year. Such α_{sp}-value is not found for all species, indicating that it is likely to assume stock decline for these species in 2015.

Some of the species included are less data-poor than for others. First of all this is the case for tuna species where *the Indian Ocean Tuna Commission* (IOTC) collects data and each year works out stock assessments. IOTC also issues MSY-estimates and corresponding confidence intervals. MSY-estimates from IOTC have been included for comparison of the results from the suggested method. As mentioned above one important assumption of this study is that all the species included actually can be treated as single stocks. This may be a more valid assumption for tuna species than for some other *Indian Ocean* fisheries. However, the selection of fisheries has not included such considerations.

Data

As seen in figure 1, it has been an amazing increase in registered catches of fish species in the *Indian Ocean* over the last decades. Today the total catch in the *Indian Ocean* is about 10 million tons and close to one third of this is represented by the 25 fish species included here (figure 1). The development of the catches of skipjack tuna serves as a demonstration of the recent development. From a total catch of about 50 thousand tons of skipjack tuna in 1980, the catch of 1990 was five times higher. The catch of 2000 was almost double of the 1990 catch, the catch increased with a factor of ten in two decades. The same pattern is found in all the largest *Indian Ocean* fisheries (figure 2).

However, after year 2000 registered catches display a decline in tuna fisheries, first for the bigeye tuna, thereafter yellowfin, and more recently skipjack. The overall picture displayed in figure 1 also indicates that the growth rate has slowed down and the total catch production may level out. Whether this is due to overfishing and emerging stock collapses, or reaching open access equilibrium due to economic constraints, are not known. However, we assume all these fisheries to be open access fisheries and expect biological, physical (gear technology) and economic constraints to be controlling the development of these fisheries.

Figure 2 shows the development of the nine largest fisheries during the registered period, separated on the eastern and western part of the *Indian Ocean*. In the further analysis we will join the two areas (FAO area 51 and 57), in principle assuming each species to constitute one Indian Ocean stock.

Even though a decline in growth rate of the catch production is visible in the aggregated data (figure 1), table 1 shows that many of the 25 largest *Indian Ocean* fisheries have their largest (or close to largest) catches in 2015, the last year of the time period included in this study. Table 1 displays further individual growth parameters from FishBase and some tuna MSY estimates from the *Indian Ocean Tuna Commission* (IOTC), in addition to catch data retrieved from the FAO database of capture fisheries. As an indicator of how these catches are distributed in the Indian Ocean, the right column of table 1 shows the share of the catch taken in the western part (in percent of catch in the eastern part). This column reveals that some of the species are only caught in the eastern part of the *Indian Ocean* (short mackerel, yellowstripe scad and Bali sardinella), while the largest catches (for example of Indian oil sardine, and yellowfin and skipjack tuna) are found in the western part.

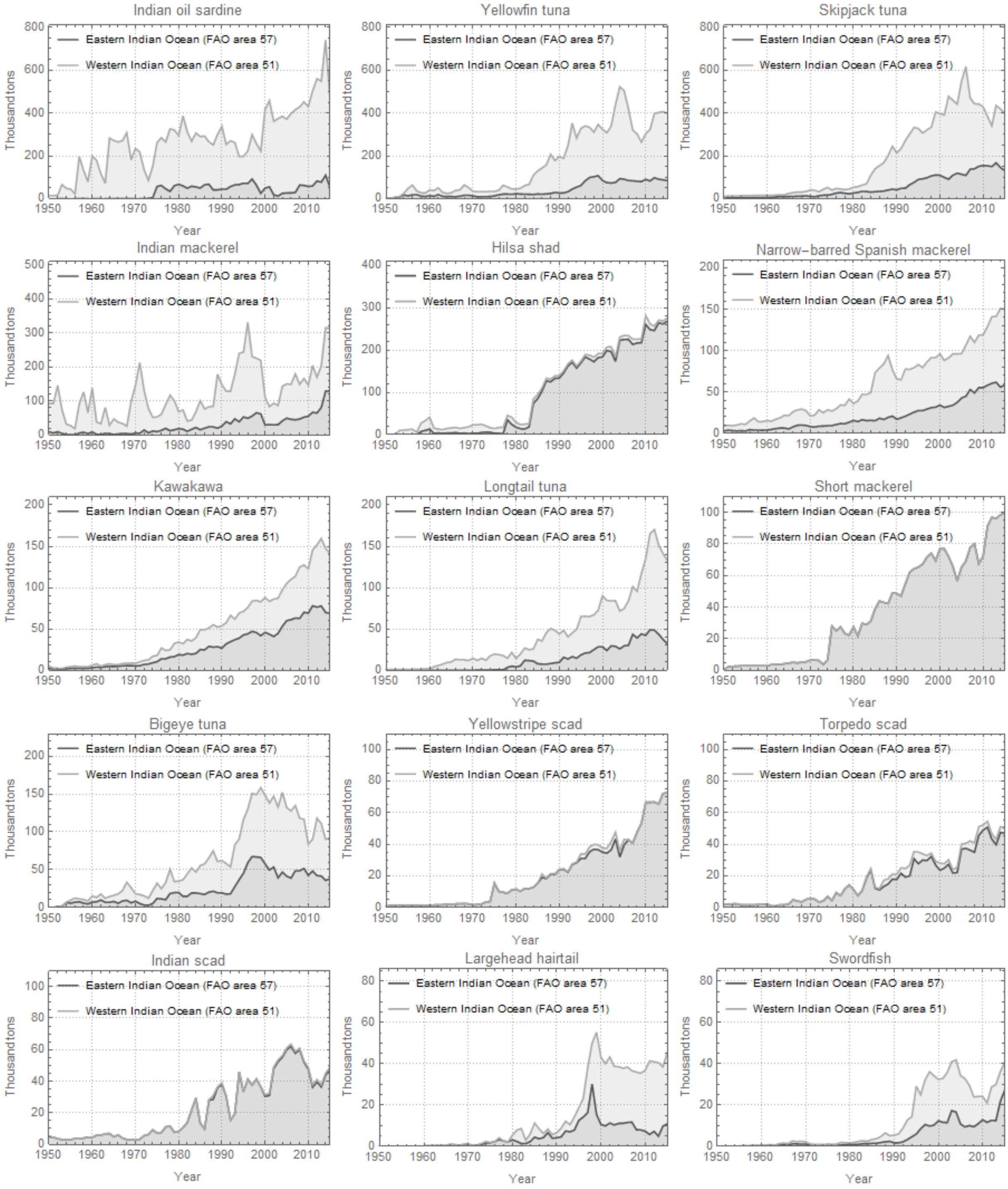

Figure 2*. Aggregated registered catches 1950-2015 in the fifteen largest fisheries in the Indian Ocean in 2015; separated on FAO areas 51 and 57. Catch data have been downloaded from the online FAO database (Anon., 2017a).*

***Table 1.** Individual growth parameters (k and b) from FishBase (Froese and Pauly, 2017), estimated MSY levels for some fish species (MSY estimates by the Indian Ocean Tuna Commission, see Anon., 2017b) and some catch records from the FAO database of capture fisheries (Anon., 2017a). The parenthesis after the MSY estimates gives the corresponding confidence interval. Scientific names of the fish species are provided in Table 3.*

Twenty-five largest Indian Ocean fisheries in 2015	From FishBase		*MSY* estimate by IOTC	Catch 2015	Maximum catch 1950-2015	Western catch in % of eastern catch
	k	*b*				
Indian oil sardine	0.6	2.96		474,058	740,634	767
Yellowfin tuna	0.4	2.94	403(229-436)	398,351	522,466	370
Skipjack tuna	0.8	3.26	563(480-699)	397,289	617,244	205
Indian mackerel	0.9	3.20		313,924	331,946	141
Hilsa shad	0.9	2.92		275,647	281,345	3
Narrow-barred Spanish mackerel	0.4	2.95		150,150	150,974	157
Kawakawa	0.4	3.25		140,938	159,452	104
Longtail tuna	0.3	3.00		133,096	170,221	313
Short mackerel	1.6	3.08		99,630	99,630	0
Bigeye tuna	0.2	3.01	104(87-121)	91,884	158,601	144
Yellowstripe scad	1.4	3.04		72,697	72,697	0
Torpedo scad	0.5	2.75		50,660	54,485	8
Indian scad	0.8	3.05		48,764	63,588	3
Largehead hairtail	0.5	3.14		45,634	55,239	316
Swordfish	0.1	3.17	31(25-46)	40,755	41,924	50
Indo-Pacific king mackerel	0.2	2.94		37,903	45,482	105
Albacore	0.2	2.75	39(34-44)	34,130	43,183	135
Bali sardinella	0.8	3.15		33,060	111,207	0
Blue shark	0.1	3.24		29,948	31,904	33
Black pomfret	0.3	2.98		29,499	29,499	76
Goldstripe sardinella	1.5	2.92		29,000	68,550	0
Silver pomfret	1.0	2.94		26,682	26,682	10
Indo-Pacific sailfish	0.1	2.74	25(16-35)	25,152	25,152	177
Bigeye scad	1.9	3.22		23,526	28,566	0
Indian halibut	0.6	3.22		18,276	18,276	43

Results and interpretations

Series of stock estimates have been calculated for all the twenty-five species by using equation (11), while assuming different α-values (equation 9). Three different α-values have been applied; A: The lowest consistent α-vaule, B: The α-value corresponding to X_{MSY} in 2015, and C: The lowest α-value providing positive stock growth in 2015. Obtained values are displayed in Table 2. In the majority of the fisheries (sixteen cases) α-value C could not be found, which is assumed to indicate overexploitation.

Table 2. *The table shows the parameter m and r (calculated from equations 7 and 8 by inputs from Table 1) and calculated* α*-values (equation 9) based on three different given assumptions. Each assumption is scored according to final position (2015-catches) in the Kobe plots displayed in Figure 3. Each score relates to one of the four rectangles displayed in a Kobe plot; 1: Overfished and overfishing, 2: Overfishing, not overfished, 3: Overfished, not overfishing, and 4: Healthy. Score value zero has been used where no score can be obtained (column C). The average value of the three scores is shown in the right column. Scientific names of the fish species are provided in Table 3.*

Twenty-five largest Indian Ocean fisheries in 2015	m (equation 7)	r (equation 8)	α-values:			Average score
			A lowest valid α-value (score)	**B** giving $\frac{X}{X_{MSY}} = 1$ (score)	**C** α-value giving growth in 2015 (score)	
Indian oil sardine	0.747475	-2.376	0.575 (**1**)	0.699 (**3**)	0.656 (**3**)	**2.3**
Yellowfin tuna	0.746193	-1.576	0.647 (**1**)	0.684 (**1**)	n.a. (**0**)	**0.7**
Skipjack tuna	0.765258	-3.408	0.732 (**3**)	0.736 (**3**)	0.733 (**4**)	**3.3**
Indian mackerel	0.761905	-3.780	0.661 (**1**)	0.662 (**4**)	n.a. (**0**)	**1.7**
Hilsa shad	0.744898	-3.528	0.821 (**1**)	0.896 (**1**)	n.a. (**0**)	**0.7**
Narrow-barred Spanish mackerel	0.746835	-1.580	0.661 (**1**)	0.777 (**1**)	n.a. (**0**)	**0.7**
Kawakawa	0.764706	-1.700	0.655 (**1**)	0.777 (**1**)	1.148 (**4**)	**2.0**
Longtail tuna	0.750000	-1.200	0.546 (**1**)	0.670 (**1**)	1.003 (**4**)	**2.0**
Short mackerel	0.754902	-6.628	0.848 (**1**)	0.937 (**1**)	2.576 (**4**)	**2.0**
Bigeye tuna	0.750623	-0.802	0.641 (**3**)	0.693 (**2**)	0.657 (**3**)	**2.7**
Yellowstripe scad	0.752475	-5.656	0.825 (**1**)	0.906 (**1**)	1.770 (**4**)	**2.0**
Torpedo scad	0.733333	-1.875	0.716 (**1**)	0.809 (**1**)	n.a. (**0**)	**0.7**
Indian scad	0.753086	-3.240	0.818 (**3**)	0.821 (**4**)	n.a. (**0**)	**2.3**
Largehead hairtail	0.758454	-2.070	0.664 (**1**)	0.691 (**2**)	n.a. (**0**)	**1.0**
Swordfish	0.760192	-0.417	0.412 (**1**)	0.510 (**1**)	n.a. (**0**)	**0.7**
Indo-Pacific king mackerel	0.746193	-0.788	0.546 (**1**)	0.649 (**1**)	n.a. (**0**)	**0.7**
Albacore	0.733333	-0.750	0.594 (**1**)	0.682 (**1**)	n.a. (**0**)	**0.7**
Bali sardinella	0.759036	-3.320	0.700 (**4**)	0.700 (**4**)	0.700 (**4**)	**4.0**
Blue shark	0.764151	-0.424	0.325 (**1**)	0.435 (**1**)	n.a. (**0**)	**0.7**
Black pomfret	0.748744	-1.194	0.552 (**1**)	0.646 (**1**)	n.a. (**0**)	**0.7**
Goldstripe sardinella	0.744898	-5.880	0.831 (**4**)	0.831 (**4**)	n.a. (**0**)	**2.7**
Silver pomfret	0.746193	-3.940	0.714 (**1**)	0.831 (**1**)	n.a. (**0**)	**0.7**
Indo-Pacific sailfish	0.732620	-0.374	0.402 (**1**)	0.522 (**1**)	n.a. (**0**)	**0.7**
Bigeye scad	0.763033	-8.018	0.866 (**3**)	0.872 (**4**)	1.059 (**4**)	**3.7**
Indian halibut	0.763033	-2.532	0.677 (**1**)	0.767 (**1**)	n.a. (**0**)	**0.7**

The obtained time series (including three different α-values) of the twenty-five fisheries are evaluated by the use of Kobe plots (see Griffiths et al., 2017). The Kobe plots are displayed in Figure 3 and the scores are given according to which sector the 2015-values are placed. Since the placement of the B-values (Table 2) by definition is on the border between vertically separated sectors, the scores here are given according to the direction of movement. Where no α-value is obtained (in case of C) zero score is given. Sector of *overfishing and overfished* (red sector) gives score 1, *overfishing and not overfished* gives score 2, *overfished and not overfishing* score 3 and *no overfishing and not overfished* score 4.

Table 3. *The table summarises the results of Table 2, categorising each fishery according to the average score in Table 2.*

Twenty-five largest Indian Ocean fisheries in 2015	Catch 2015 (thousand tons)	Evaluation
Bali sardinella (*Sardinella lemuru*)	33,060	Healthy (2%)
Bigeye scad (*Selar crumenophthalmus*)	23,526	
Skipjack tuna (*Katsuwonus pelamis*)	297,289	Overfished, not overfishing (14%)
Bigeye tuna (*Thunnus obesus*)	91,884	
Goldstripe sardinella (*Sardinella gibbosa*)	29,000	
Indian oil sardine (*Sardinella longiceps*)	474,058	Overfishing, not overfished (44%)
Indian scad (*Decapterus russelli*)	48,764	
Kawakawa (*Euthynnus affinis*)	140,938	
Longtail tuna (*Thunnus tonggol*)	133,096	
Short mackerel (*Rastrelliger brachysoma*)	99,630	
Yellowstripe scad (*Selaroides leptolepis*)	72,697	
Indian mackerel (*Rastrelliger kanagurta*)	313,924	
Largehead hairtail (*Trichiurus lepturus*)	45,634	Overfished and overfishing (40%)
Yellowfin tuna (*Thunnus albacares*)	398,351	
Hilsa shad (*Tenualosa ilisha*)	275,647	
Narrow-barred Spanish mackerel (*Scomberomorus commerson*)	150,150	
Torpedo scad (*Megalaspis cordyla*)	50,660	
Swordfish (*Xiphias gladius*)	40,755	
Indo-Pacific king mackerel (*Scomberomorus guttatus*)	37,903	
Albacore (*Thunnus alalunga*)	34,130	
Blue shark (*Prionace glauca*)	29,948	
Black pomfret (*Parastromateus niger*)	29,499	
Silver pomfret (*Pampus argenteus*)	26,682	
Indo-Pacific sailfish (*Istiophorus platypterus*)	25,152	
Indian halibut (*Psettodes erumei*)	18,276	

The final evaluations in terms of Kobe plot positions are provided in Table 3, where also the 2015-catches are shown.

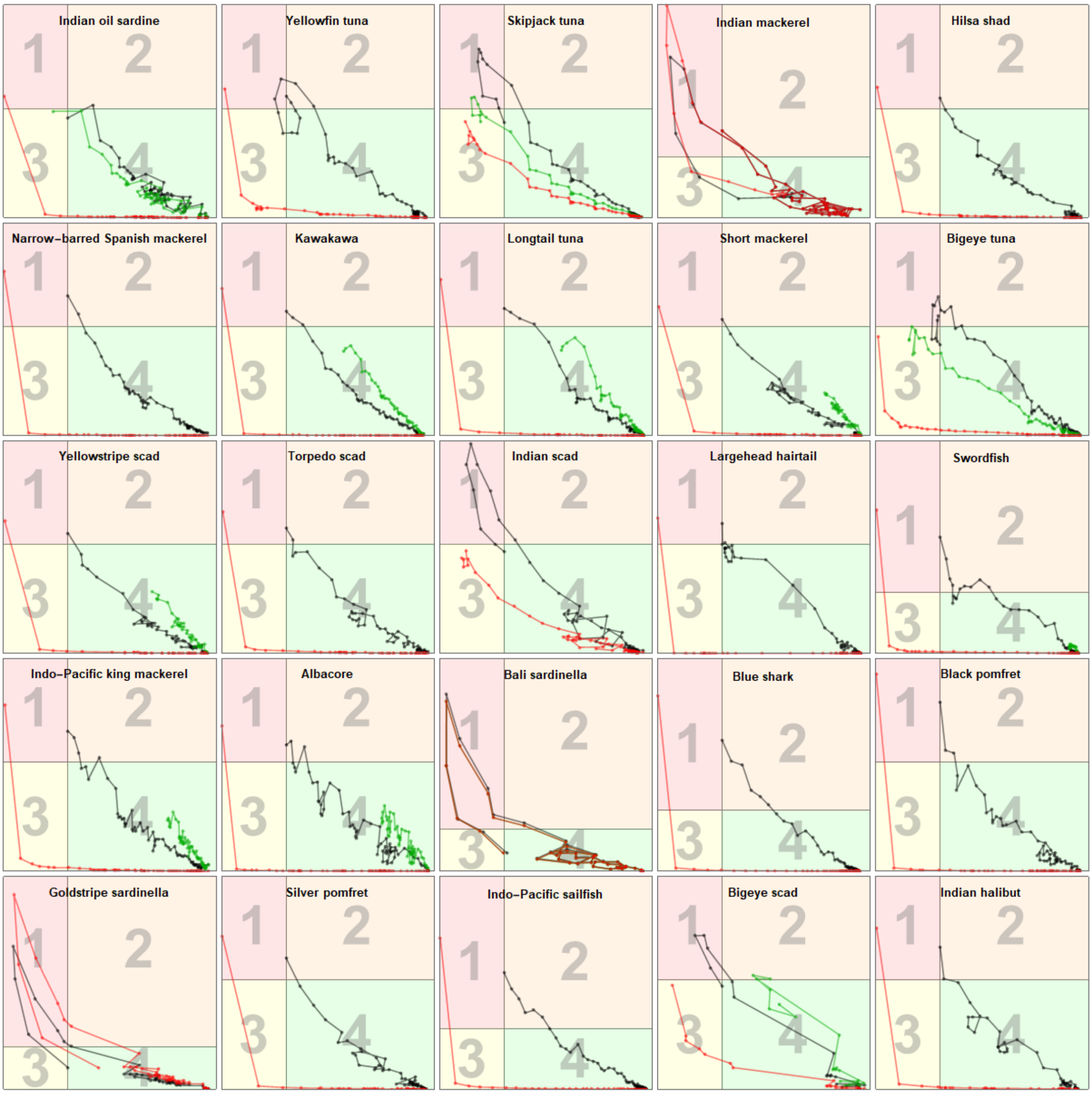

Figure 3. *Kobe plots (phase plots) of the Indian Ocean species included in the study, covering the period 1950 – 2015. The two axes measures* X/X_{MSY} *(horizontal axis) and* F/F_{MSY} *(vertical axis), and the gridlines mark the value of one on each axis. The red, black and green curves represent respectively α-values A, B and C, displayed in Table 2 where the scores are given according to the numbers displayed in the Kobe plots.*

Discussion

The presented results are based on some heavy assumptions regarding the functional relationship between growth and stock biomass. In particular the methodology assumes that core biological and environmental parameters remain constant over the investigated period. If absence of other relevant information, these are necessary assumptions in order to obtain some estimates at all. However, some population analysis have been performed for some of the selected stock, also involving additional fishing effort information.

The IOTC carries out annual stock assessments for some core tuna stocks and there are some references to recent IOTC estimates in Table 1. Selected MSY estimates and state of stock evaluations of five tuna species are presented from the IOTC documents, in order to compare these finding with the results presented here.

The most important tuna species exploited in the Indian Ocean are yellowfin and skipjack tuna. The current IOTC MSY estimate of yellowfin tuna is 403 thousand tons (with a confidence interval of 229 to 436 thousand tons), while the corresponding values of the skipjack is 563 (480 – 699) thousand tons. The corresponding values obtained by the method presented in this paper are considerably lower, utilising the different α-values from Table 2. The yellowfin tuna MSY is found to be within the range of 338 and 357 thousand tons (while the C-value could not be obtained). The corresponding MSY range of the skipjack tuna is even more narrow, 452 – 454 thousand tons. Both these MSY estimates are well below the IOTC MSY-estimates. However, the IOTC stock evaluations of the two species fit quite well the result obtained here: Both agree in yellowfin tuna being overfished and still overfishing, while overfishing still takes place in the skipjack tuna fishery according to the method presented here. IOTC disagree in this, while both methods confirm that skipjack tuna currently is not an overfished stock.

The IOTC estimates an MSY of 104 (87 -121) thousand tons for the bigeye tuna stock, very close to the estimate obtained here, between 102 and 110 thousand tons. Again, the state of the stock is evaluated slightly different by the two methods, as for the skipjack tuna.

A more significant difference are obtained for the swordfish and albacore tuna stock, where the evaluations turn out to be the opposite by the two methods. While IOTC evaluate both stocks to be healthy and not overfished, both are considered overfished and overfishing by the presented method. The MSY estimates also differ considerably, for the swordfish stock IOTC found an average MSY-estimate of 31 thousand tons, while the current analyses finds an MSY estimate between 17 and 21 thousand tons. Similarly for the albacore stock, the IOTC estimate is 39 thousand tons, while the estimate found here is between 26 and 29 thousand tons.

Of the twenty-five investigated stocks, only two may be characterised as healthy and in good shape by the current method. However, two of the most important tuna stock (skipjack and bigeye tuna) are also currently found not to be overfished, although they are below safe limits (overfished). Most stocks are characterised as by overfishing any many of them (thirteen) are also fished down below safe limits.

The method presented represents a biological approach to fisheries analyses and does not take into account any economic framework. A straightforward extension of the current method is to involve rational economic behaviour by identifying stock values by which fisheries become unprofitable unless subsidies are provided. Subsidies are known to play an important role also in developing country surrounding the Indian Ocean (Sumaila et al., 2010), and a further improvement of the method presented here could rather be found in such extensions than in searching more accurate biological information.

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