Assessment of Indian Ocean kawakawa (*Euthynnus affinis*) using data poor catch-based methods

11th May 2015

IOTC Secretariat[1]

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Introduction

Assessing the status of the stocks of neritic tuna species in the Indian Ocean is fairly challenging due to the lack of available data. This includes limited information on stock structure, few standardised CPUE series and a lack of biological information. Nevertheless, a number of approaches have been investigated in the past including A Stock Production Model Incorporating Covariates (ASPIC) which used a CPUE series developed from the Omani gillnet fisheries (Al-Kiyumi et al., 2013; IOTC–2013–WPNT03–32) and a surplus production model using an index of abundance based on the Maldivian pole and line fleet CPUE series (Sharma and Zhou 2013). Since then, a number of data-poor approaches using only catch information have also been considered and used to assess the status of Kawakawa which have provided fairly consistent results (IOTC-2014-WPNT04-26).

In this paper, two data-poor methods were used to assess the status of Indian Ocean Kawakawa, (*Euthynnus affinis*): (i) a Catch-MSY method, based on stock reduction analysis (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012) and (ii) a recently developed posterior-focussed Optimised Catch Only Method, OCOM (Zhou et al., 2013). Other neritic species investigated using the same methods included: Indian Ocean Longtail tuna (*Thunnus tonggol*) (IOTC-2015-WPNT05-22), narrow-barred Spanish Mackerel (*Scomberomorus commerson*) (IOTC-2015-WPNT05-23) and Indo-Pacific king mackerel *(Scomberomorus guttatus)* (IOTC-2015-WPNT05-24). Catch data for Bullet tuna (*Auxis rochei*) and frigate tuna (*Auxis thazard*) were considered too incomplete for the use of catch-based assessment methods.

Basic Biology

The Eastern little tuna or kawakawa, *Euthynnus affinis* (Cantor 1849), is a medium-sized epipelagic, migratory neritic tuna is widely distributed across the Indo-West Pacific region in open waters close to the shore. It has a maximum fork length of 100 cm (Froese & Pauly 2015) and generally forms multispecies schools by size with other scombrid species comprising 100 – 5,000 individuals or more (Collette & Nauen 1983). It is a highly opportunistic predator feeding indiscriminately on small fishes, including clupeoids and atherinids as well as squids, crustaceans, molluscs and zooplankton (Collette 2001; Gupta et al. 2014). The species supports substantial commercial and artisanal fisheries in many countries bordering the Indian Ocean, including Indonesia, India, Iran, Pakistan and Sri Lanka (Pierre et al. 2014). Most research has been focussed in these areas where there are important fisheries for the species, with the most common methods used to estimate growth being through length-frequency studies. Studies on the growth of *E. affinis* indicate that it is a fast growing species, attaining a fork length of 30-49 cm in the first year (IOTC-2015-WPTN05-DATA12).

Catch Trends

Nominal catch data were extracted from the IOTC Secretariat database for the period 1950-2013, given that records for 2014 were still incomplete at the time of writing. Gillnet fleets are responsible for the majority of reported catches of kawakawa, followed by purse seine gear and lines, with the majority of catches taken by coastal country fleets (Figure 1). Figure 2 shows the increase in total catches since 1950, at an increasing rate in recent years, currently reaching approximately 170,000 t across the entire Indian Ocean region (Table 1). Some revisions have been made to the nominal catch series since the assessment that took place in 2014, including an increase in the estimated catch for 2012 from 156 000 t to 159 000 t and a new catch estimate of 170 000 t for 2013. These are shown in Figure 3.

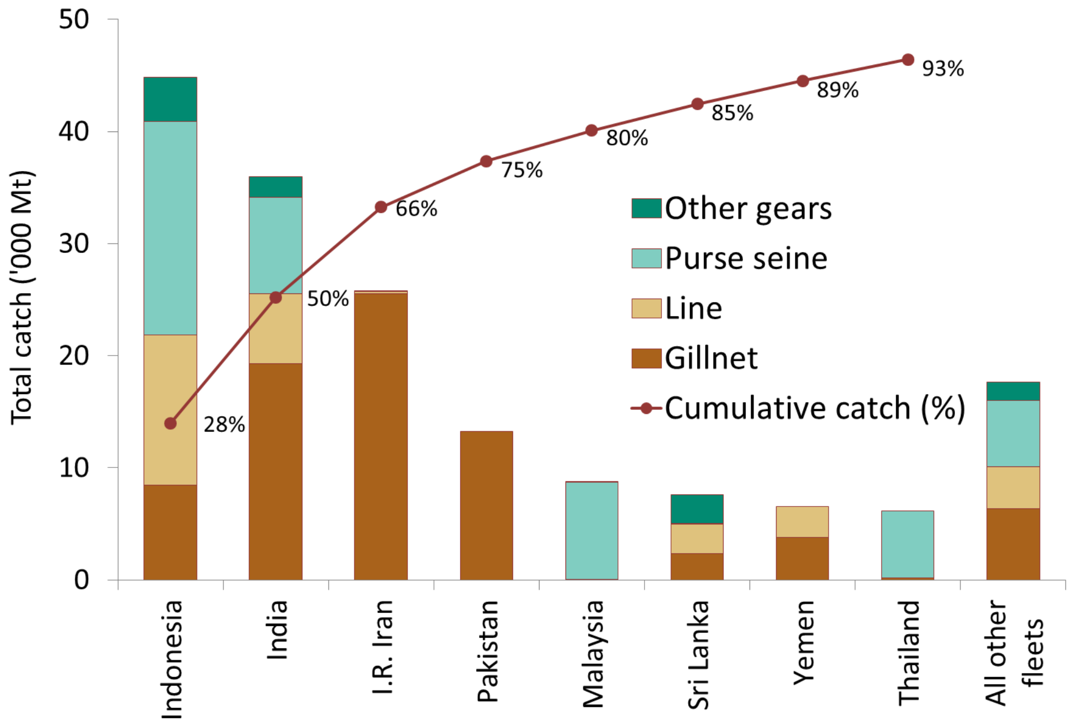

Figure 1. Average catches in the Indian Ocean over the period 2010-2013, by country. Countries are ordered from left to right, according to the level of catches of kawakawa reported. The red line indicates the (cumulative) proportion of catches of kawakawa for the countries concerned, over the total combined catches of this species reported from all countries and fisheries

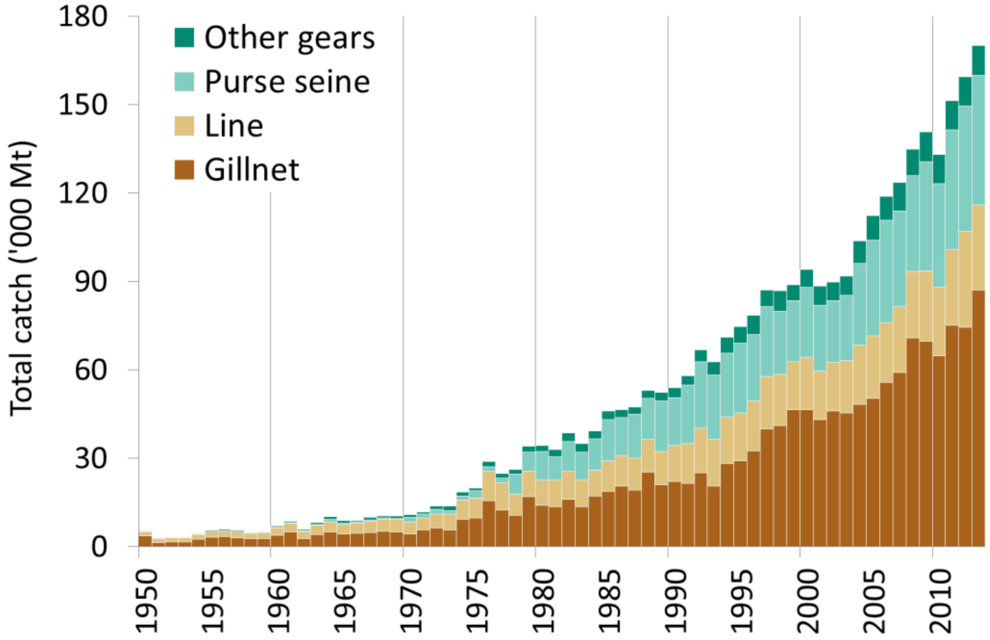

Figure 2. Annual catches of kawakawa by gear as recorded in the IOTC Nominal Catch database (1950–2013)

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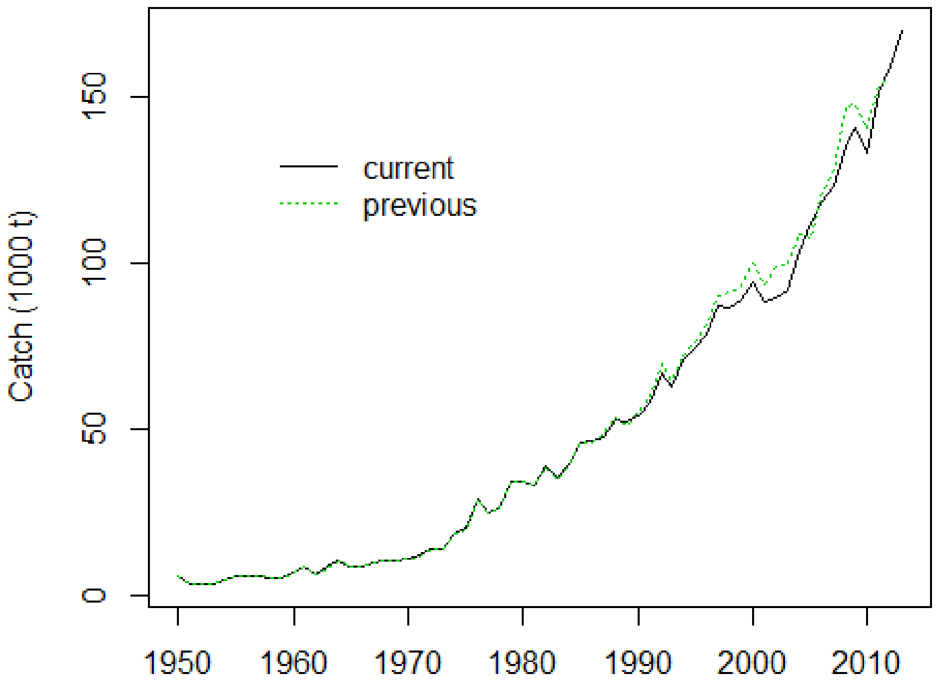

Figure 3. Revisions to Kawakawa nominal catch time series since the assessments in 2014

Table 1. Catch data for *E. affinis* in the Indian Ocean, 1950-2013 (source IOTC Nominal Catch Database)

Year	Catch (t)	Year	Catch (t)
1950	5,575	1982	38,629
1951	3,254	1983	35,092
1952	3,286	1984	39,368
1953	3,244	1985	46,105
1954	4,496	1986	46,524
1955	5,382	1987	47,409
1956	5,863	1988	52,953
1957	5,398	1989	52,302
1958	5,075	1990	53,967
1959	5,277	1991	58,115
1960	6,978	1992	66,866
1961	8,686	1993	62,657
1962	5,996	1994	71,145
1963	8,269	1995	74,692
1964	10,157	1996	78,614
1965	8,781	1997	87,202
1966	8,826	1998	86,842
1967	9,882	1999	88,948
1968	10,498	2000	93,991
1969	10,456	2001	88,555
1970	10,789	2002	89,849
1971	11,861	2003	91,840
1972	13,764	2004	103,687
1973	13,815	2005	112,374
1974	18,556	2006	118,871
1975	20,005	2007	123,652
1976	28,953	2008	134,952
1977	24,880	2009	140,756
1978	26,286	2010	133,127
1979	34,149	2011	151,370
1980	34,435	2012	159,433
1981	33,034	2013	170,181

Methods

1) Catch-MSY method

This method, developed by Martell and Froese (2012) relies on only a catch time series dataset, prior ranges of *r* and *K* and possible ranges of stock sizes in the first and final years of the time series. The Graham-Shaefer surplus production model (Shaefer 1954) is then used (Equation 1), where B_t is the biomass in time step *t*, *r* is the population growth rate, B_0 is the virgin biomass equal to carrying capacity, *K*, and C_t is the known catch at time *t*. Annual biomass quantities can then be calculated for every year based on a given set of *r* and *K* parameters.

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{B_0}\right) - C_t$$

Equation 1.

There are no known prior distributions of the parameters *r* and *K*, so a uniform distribution was used from which values were randomly drawn. A reasonably wide prior range was set for *r* based on the known level of resilience of the stock as proposed by Martell and Froese (2012) where stocks with a very low resiliency are allocated an r value from 0.015 - 0.1, low resiliency 0.05 - 0.5, medium resiliency 0.2 – 1 and high resiliency 0.6 – 1.5. Based on the FishBase classification, *E. affinis* has a high level of resilience and so a range of 0.6 - 1.5 was used.

A reasonably wide prior range was also used for *K*, which ranged from the minimum catch in the times series to the maximum multiplied by 50, i.e. *K* = min(C) – 50*max(C). The ranges for starting and final depletion levels were based on the ratio of starting and final catch to the maximum as in Table 2. This essentially gives a lower initial biomass if the initial catch was large, relative to the maximum, and gives a higher initial biomass if the initial catch was relatively lower. Conversely, in terms of the final biomass, a higher biomass is expected with a high final catch (relative to the maximum) and a lower biomass if the final catch is lower relative to the maximum (Martell and Froese (2012).

Table 2. Rules to determine starting and final biomass levels where B is biomass and k is carrying capacity

	Catch/max catch	*B/k*
First year	<0.5	0.5 – 0.9
	≥0.5	0.3 – 0.6
Final year	>0.5	0.3 – 0.7
	≤0.5	0.01 – 0.4

This resulted in the prior ranges for each species as specified in Table 3. The model worked sequentially through the range of initial biomass depletion level at intervals of 0.05 and random pairs of *r* and *K* were drawn based on the uniform distribution for the specified ranges. A Bernoulli distribution was then used as the likelihood function for accepting each *r*-*k* pair at each given starting biomass level based on the assumptions that the stock has never collapsed or exceeded carrying capacity and that the final biomass estimate which falls within the assumed depletion range. All *r*-*k* combinations for each starting biomass which were considered feasible were retained with the corresponding biomass trajectories.

Table 3. Prior ranges used for each species (Catch–MSY method)

Species	Initial *B/k*	Final *B/k*	*r*	*K (1000 t)*
Kawakawa	0.5 - 0.9	0.3 – 0.7	0.6 - 1.5	170 - 8509

Management quantities were calculated based on geometric means of the standard Schaefer model equations, i.e.:

$$MSY = \frac{rk}{4},\ B_{MSY} = \frac{k}{2} \text{ and } F_{MSY} = -ln\left[1 - \left[\frac{MSY}{(Bmsy+MSY)}\right]\right]$$

2) Optimised Catch Only Method (OCOM)

The Optimised Catch-Only Method was developed by Zhou *et al*. (2013) and also relies on only a catch time series dataset without necessary knowledge of prior distributions. The idea behind this approach is to use unconstrained priors on both *r* and *K*, that is $0 < K < \infty$ and $0 < r < \infty$. Because the two parameters are negatively correlated, the maximum *K* is constrained by $r = 0$ and maximum *r* is constrained by the minimum viable *K*. The aim of this approach is to identify the likely range of both r and *K* and the most likely $r \sim K$ combination on the curve which retain a viable population over time (i.e. where $Bt > Ct$, $Bt \leq K$ *and* $Bt > 0$ always hold true). This approach produces results from a number of trials are produced and the improbable values are then excluded, so the method is referred to as a posterior-focused catch-based method for estimating biological reference points (Zhou *et al.*, 2013).

The approach uses an optimisation model to estimate the feasible *r* value corresponding to a fixed final depletion level and a sampled *K* value by minimising the difference between the final biomass and the given depletion level (i.e. minimising the objective function $|B_{2013}– DK|$ where B_{2013} is the biomass in the final year). All feasible combinations of *r* and *K* are retained and the biomass dynamics model is re-run without any further constraints for a large number of simulations (500). The biomass trajectories are stored and those which are considered unfeasible according to the biomass constraints described above are removed.

Max *K* was set at 50 * max(*C*) and minimum *K* was set at max(*C*). The starting *K* population was set as a logarithmic sequence between these two values to obtain a higher density of low *K* values. Starting depletion levels comprised the range 0.05 to 0.8 in steps of 0.05. A wide prior range of *r* values was used, from 0.1 to 2. A biomass dynamics model was then run with the associated constraints: $Bt \leq K$, $Bt > 0$, $B > C$. The model assumed that the biomass in 1950 was equal to the carrying capacity ($Bt_{1950} = K$). The optimisation routine was then used to retain the *r* values which result in a biomass closest to the fixed final biomass by minimising the difference between B_{2013} and

DK. Where the difference between the final biomass and the specified depletion level was >10% of *K*, the values were considered unfeasible and were not retained. This resulted in a matrix of r values for each combination of K and final depletion level.

As a second step in the method, estimates of the von Bertalanffy parameters L_∞ and K were derived from the literature (IOTC–2015–WPNT05–DATA12). Five different methods were then used to derive possible range for the intrinsic population growth rate *r* as used in paper IOTC-2014-WPNT04-25.

$r = 2\ \omega M$, where $\ln(M) = 1.44 - 0.982 \ln(t_m)$ (Hoenig 1983).

$r = 2\ \omega M$, where $\log(M) = 0.566 - 0.718 Log(L_\infty) + 0.02T$ (www.Fishbase.org);

$r = 2\ \omega M$, where $M = 1.65/t_{mat}$ (Jensen 1996).

$r = 2\ \omega$ M, where $\ln(M) = 0.55 - 1.61 \ln(L) + 1.44 \ln(L_\infty) + \ln(\kappa)$ (Gislason et al. 2010).

$r = 2\ \omega$ M, where $M = (L/L_\infty)^{-1.5}\ \kappa$ (Charnov et al. 2012).

This resulted in a set of estimated *r* values ranging from 1 to 3.17 with a mean of 1.77 ± 0.31 (2 s.d.). Values which were more or less than 2 s.d. removed from the mean were dropped so that ($1.14 \geq r \leq 2$). While depletion levels were originally set ranging up to 0.8, it is fairly unlikely that any tuna stock is only 20% depleted so a range of alternative maximum depletion levels were also explored (Table 4).

Table 4. Prior ranges used for each species (OCOM method)

Species	Initial *B/k*	Final *B/k*	*r*	*K (1000 t)*
Kawakawa	1	0.05 – 0.8	0.1 - 2	170 - 8509
		0.05 – 0.7	1.14 – 2	
		0.05 – 0.6		
		0.05 – 0.5		

As before, median *MSY* was calculated from *r* and *K* $MSY = \frac{rK}{4}$,

While median B_{MSY} and F_{MSY} were calculated from the equations $B_{MSY} = \frac{K}{2}$ and

$$F_{MSY} = -ln\left[1 - \left[\frac{MSY}{(Bmsy + MSY)}\right]\right]$$

The range of *r* and *K* values were further reduced by selecting only those combinations corresponding to the 25th - 75th percentile values of *MSY* and the biomass dynamics simulation model was run again for each retained combination of *r* and *K* values with no constraints on the final depletion level this time. While the three base parameters, r, K and MSY were obtained at the first step, the final biomass and depletion are largely controlled by the limiting conditions (i.e., the assumed depletions levels) imposed at this step so these were instead derived subsequently by re-running the model without a pre-defined depletion level.

Uncertainty was introduced in terms of the variability in values of k and r used in each run as well as each year within model runs. For based runs, the maximum upper depletion level was set at $D \leq 0.7$ which seemed a fairly reasonable assumption.

Results

Catch-MSY method

The feasible *K* values did not reach the maximum available limit, instead ranging from 336 638 – 1 106 170 t while possible r values spanned through the full range possible under the assumptions (0.6 – 1.5). Given that r and *K* are confounded, a higher *K* generally gives a lower *r* value. The range of r values was heavily skewed to the less probable lower values, given that the resiliency of Kawakawa is estimated to be fairly high. Therefore, the upper *K* boundary was reduced to the smallest *K* corresponding to the lowest r values to remove the tail of the distribution (Figure 4 and Figure 5) and the range for *r* was expanded to 1.2 multiplied by the maximum *r* (0.6 - 1.8). The model results from this gave a more normal distribution of *r* (Figure 5) with little change in MSY. This was taken as the base model run and the results for this simulation are presented.

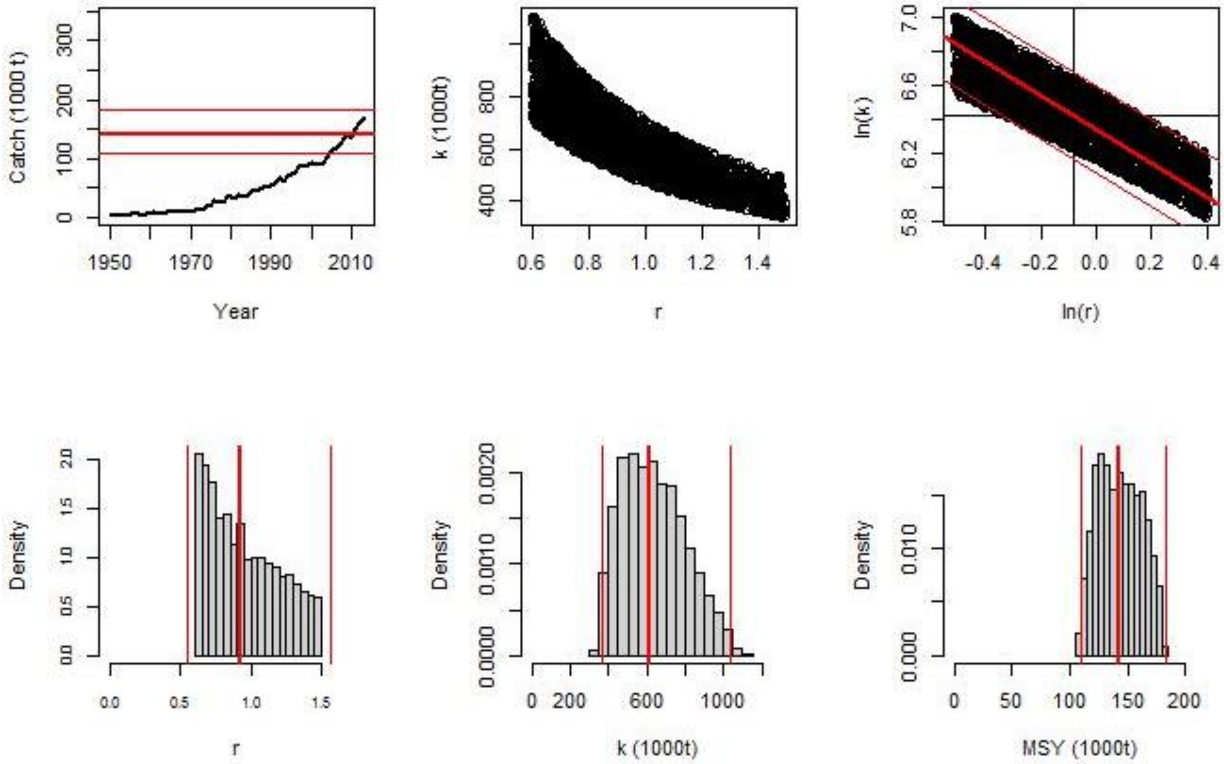

Figure 4. All feasible *r* and *K* combinations resulting from model simulations based on the original parameter constraints

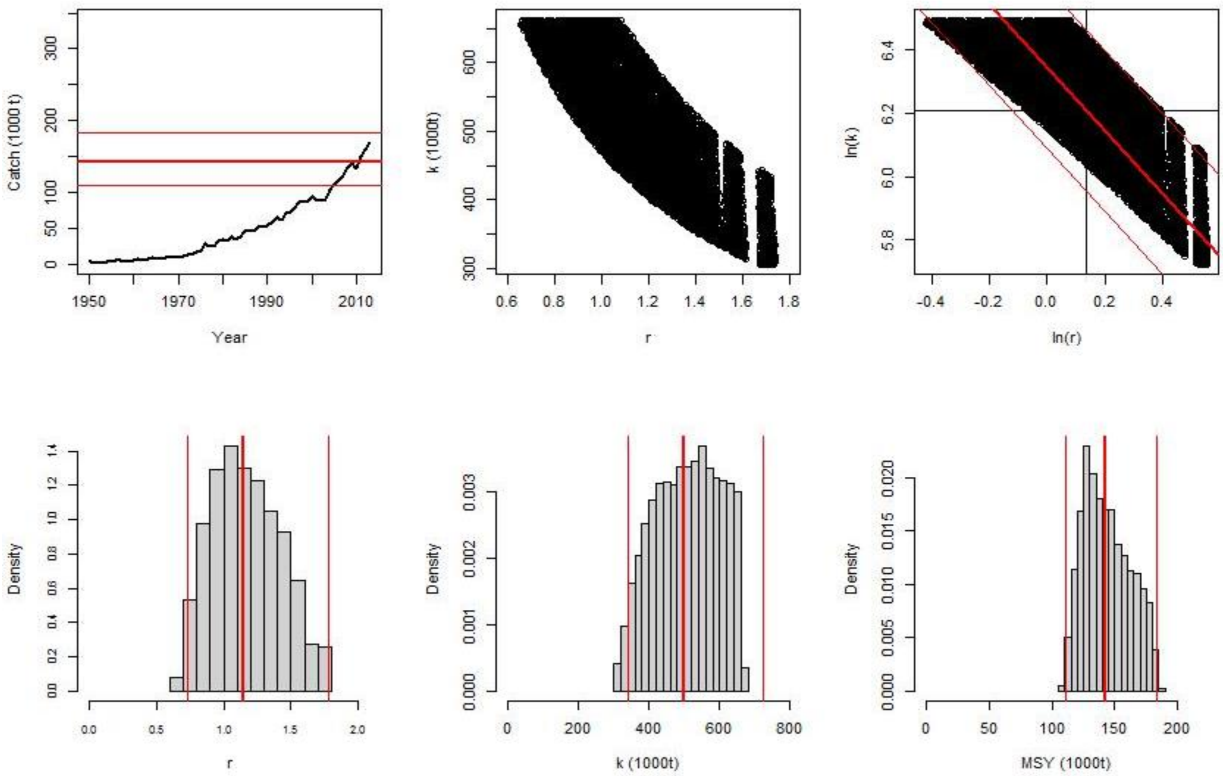

Figure 5. All feasible *r* and *K* combinations with further parameter constraints on max(K)

Results are presented for the simulated biomass trajectories for all plausible *r*, *K* and starting biomass combinations. While the absolute values are highly dependent on the prior ranges set, the results all suggest a relatively rapid decline in biomass since the early 2000s. Table 6 provides a summary of the distributions of the key biological parameters across all feasible runs at all starting depletion levels. Table 7 provides a further breakdown of these results based on the assumed initial biomass level with median values highlighted in bold. The similarity of these results indicates the robustness of this approach to the assumed starting biomass level, particularly with respect to the key reference point median MSY estimate which remains at approximately 135 000 t across all starting biomass levels. Management quantities based on geometric means and plausible ranges are provided in Table 8 which give a slightly higher average MSY, 137 614, than the median. The IOTC target and limit reference points for kawakawa have not yet been defined, so the values applicable for all other IOTC species are used as in Table 5. These are indicated on the KOBE matrix plot which indicates that based on these model results, These are indicated on the KOBE matrix plot which indicates that based on these model results, Kawakawa is currently both overfished (B_{2013}/B_{MSY} = 0.99) and subject to overfishing (F_{2013}/F_{MSY} = 1.19) (Figure 6).

Table 5. IOTC reference points for *E. affinis*

Stock	Target Reference Point	Limit Reference Point
Other IOTC species	B_{MSY}; F_{MSY}	50% of B_{MSY}; 20% above F_{MSY}

Table 6. Key biological parameters for Kawaka for all starting depletion levels (0.5-0.9)

Quantile	K	r	Bmsy	MSY	Bend	Final D
0%	292 837	0.66	146 419	108 223	88 286	0.30
25%	490 202	0.91	245 101	124 392	214608	0.44
50%	**551 277**	**1.04**	**275 638**	**135 426**	**275 660**	**0.50**
75%	604 052	1.15	302 026	151 465	342 442	0.57
100%	657 802	1.74	328 901	185 804	457 636	0.70

Table 7. Key biological parameters for Kawaka under four assumed starting depletion levels

Initial D	Quantile	K	r	Bmsy	MSY	Bend	Final D
0.8	0%	371 767	0.66	185 883	108 224	112 874	0.30
0.8	25%	486 911	0.92	243 455	124 976	215 484	0.44
0.8	50%	546 104	1.06	273 052	136 376	277 864	0.51
0.8	75%	599 414	1.18	299 707	152 824	344 913	0.58
0.8	100%	657 802	1.34	328 901	181 839	457 636	0.70

0.7	0%	333 648	0.66	166 824	108 224	102 248	0.31
0.7	25%	478 463	0.91	239 232	124 381	209 133	0.44
0.7	50%	547 995	1.03	273 997	135 109	269 435	0.49
0.7	75%	605 071	1.14	302 535	150 267	334 206	0.55
0.7	100%	657 802	1.51	328 901	183 789	457 636	0.70
0.6	0%	292 837	0.66	146 419	108 224	88 286	0.30
0.6	25%	494 776	0.90	247 388	123 904	212 808	0.43
0.6	50%	556 413	1.02	278 207	135 033	272 397	0.49
0.6	75%	607 798	1.13	303 899	150 753	340 482	0.56
0.6	100%	657 802	1.74	328 901	185 804	457 636	0.70
0.5	0%	381 665	0.66	190 833	108 224	117 417	0.31
0.5	25%	497 779	0.91	248 889	124 359	216 656	0.44
0.5	50%	553 523	1.04	276 761	135 430	279 812	0.51
0.5	75%	603 527	1.15	301 763	151 824	347 690	0.58
0.5	100%	657 802	1.29	328 901	181 673	457 636	0.70

Table 8. Kawakawa. Key management quantities from the Catch MSY assessment for aggregate Indian Ocean. Geometric means and plausible ranges across all feasible model runs. n.a. = not available.

Management Quantity	**Aggregate Indian Ocean**
Most recent catch estimate (2013)	170,181 t
Mean catch from 2009–2013	155,468 t
MSY (plausible range)	137,614 (108,233–185,804)
Data period used in assessment	1950–2013
F_{MSY} (plausible range)	0.41 (0.29–0.63)
B_{MSY} (plausible range)	268,790 (146,419–328,901)
F_{2013}/F_{MSY} (plausible range)	1.19 (0.78–2.17)
B_{2013}/B_{MSY} (plausible range)	0.99 (0.60–1.40)
SB_{2013}/SB_{MSY} (80% CI)	n.a.
B_{2013}/B_0 (plausible range)	0.50 (0.30–0.70)
SB_{2013}/SB_0 (80% CI)	n.a.
$B_{2013}/B_{0,\ F=0}$ (80% CI)	n.a.
$SB_{2013}/SB_{0,\ F=0}$ (80% CI)	n.a.

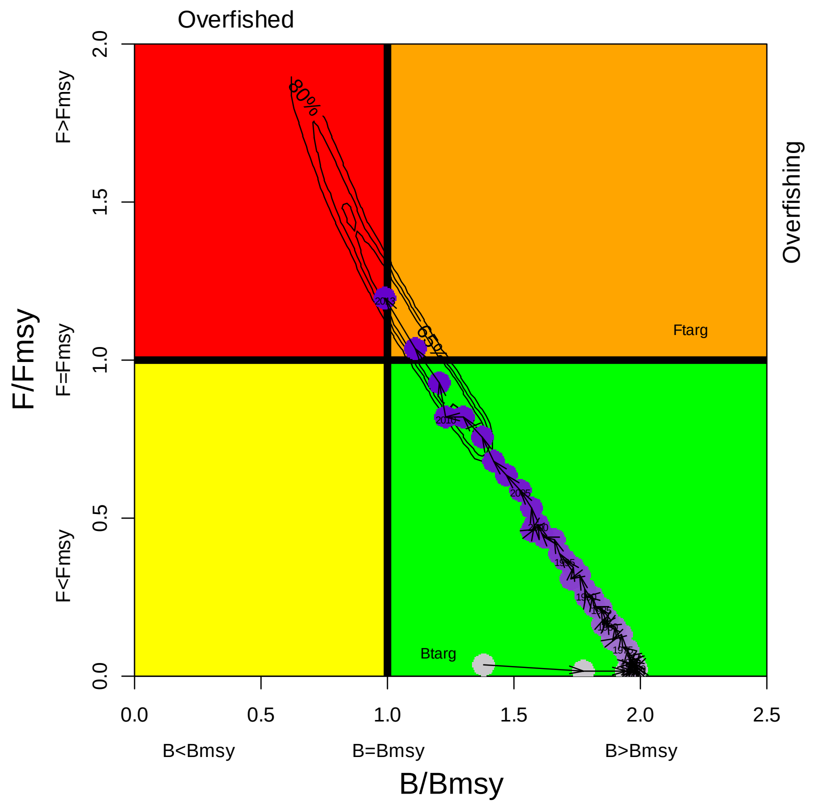

Figure 6. Kawakawa. Catch-MSY aggregated Indian Ocean assessment. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

OCOM method

Figure 7 shows the initial plausible range of *r* and *K* parameter values retained by the biomass dynamics model. This range was further narrowed with the introduction of informative priors based on the literature Figure 8.

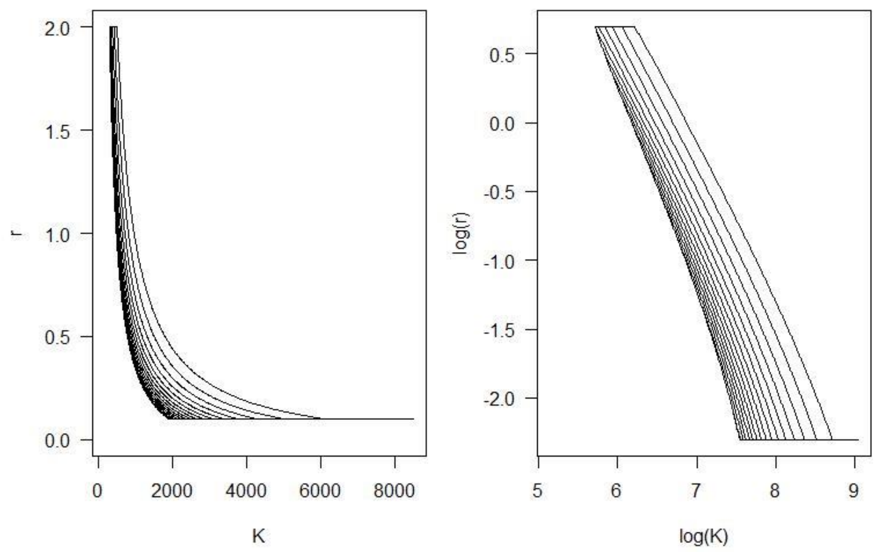

Figure 7. Initial plausible range of r and K values (non-informative priors)

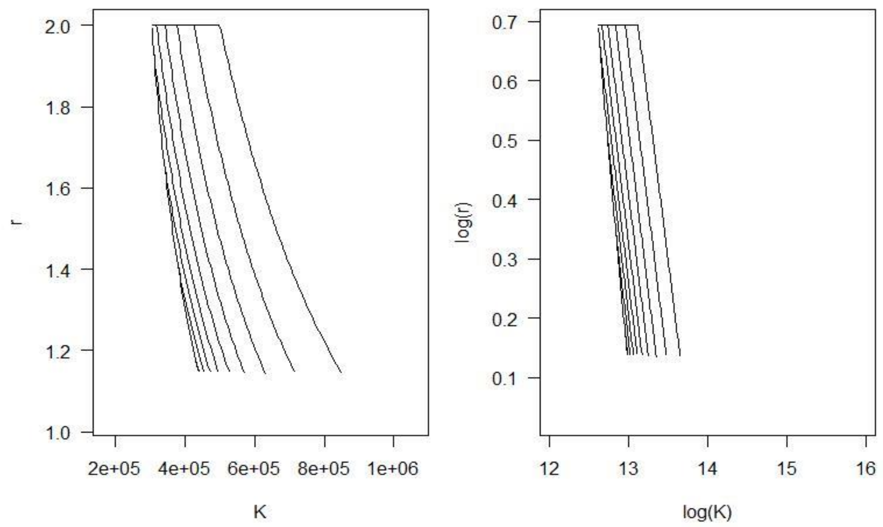

Figure 8. Plausible range of r and K with informative priors on r (1.14 - 2.00)

The range of values was dependent on the level of stock depletion assumed for the final year, with *r*, *K* and *MSY* all positively correlated with the depletion level (Figure 9). There were no feasible solutions found when the depletion level was assumed to be lower than 0.3.

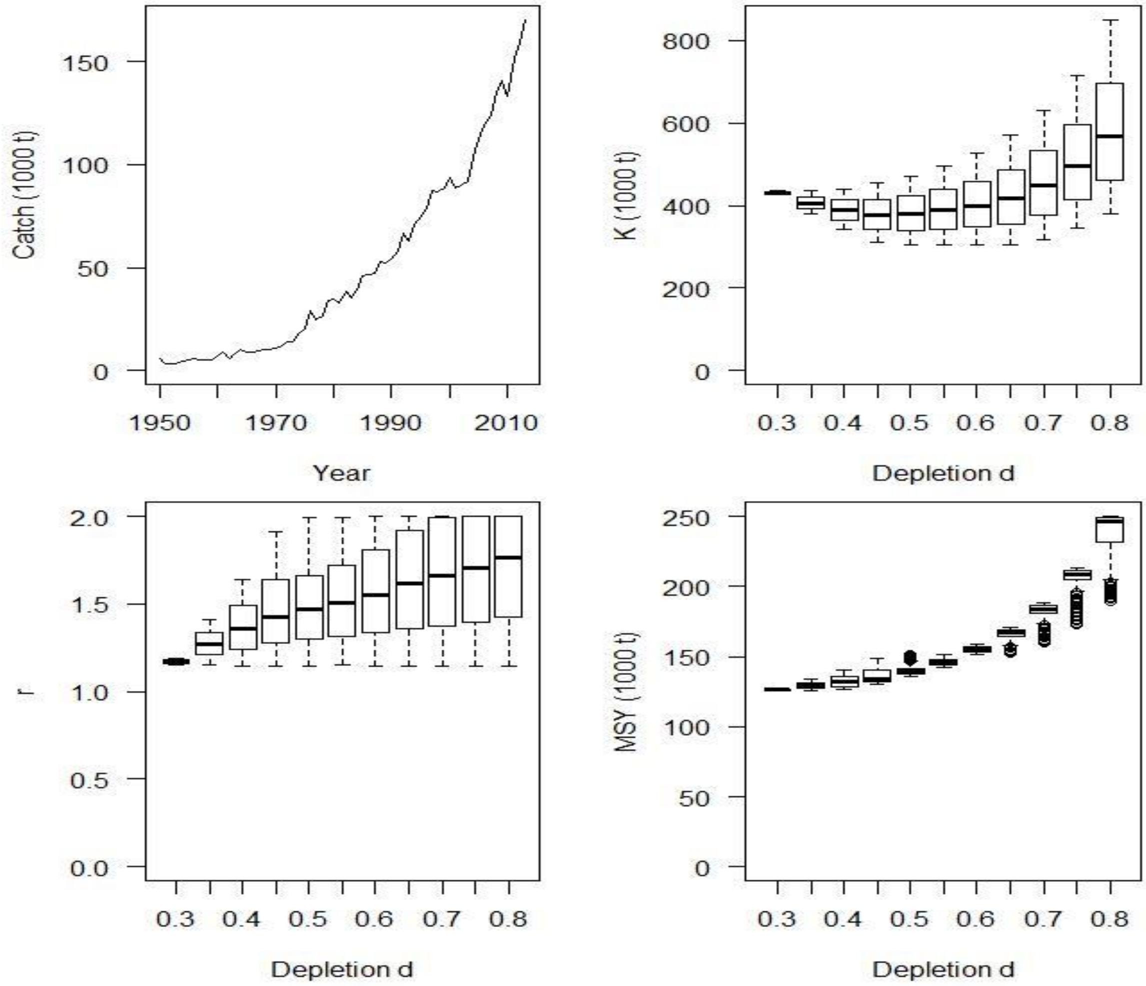

Figure 9. Kawakawa catch history, feasible carrying capacity, population growth rate and MSY at each assumed depletion level. There is no feasible solution when the depletion is assumed to be below 0.3.

Base case model results (for a maximum depletion level of 0.7) indicate that the biomass was approximately 400 000 t in 1950 and declined to approximately 250 000 t in 2013 (Figure 10). The estimated MSY associated with this projection is 151 937 t and ranges from approximately 125 000 t to 188 000 t based on the assumed depletion level (Table 9).

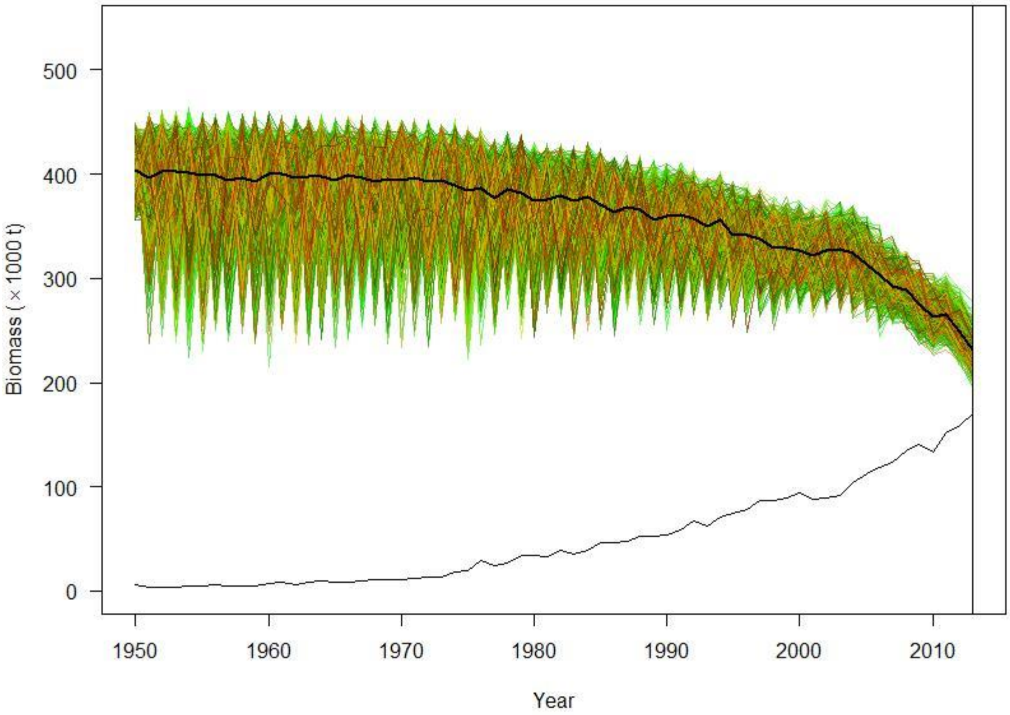

Figure 10. Kawakawa biomass trajectories from 500 simulations with upper depletion = 0.7

Table 9. Posterior key biological parameters for Kawaka under four assumed upper depletion levels[2]

Upper d	Quantile	K	r	MSY	B_{2013}	D
0.8	0%	303 992	1.14	125 467	225 757	0.52
0.8	25%	369 812	1.32	144 547	265 830	0.61
0.8	50%	422 534	1.55	165 627	285 003	0.65
0.8	75%	502 072	1.86	203 938	303 056	0.69
0.8	100%	848 954	2.00	249 875	345 982	0.80
0.7	0%	303 992	1.14	125 467	196 341	0.49
0.7	25%	355 596	1.30	139 261	223 202	0.55
0.7	**50%**	**399 971**	**1.50**	**151 937**	**231 584**	**0.58**
0.7	75%	449 883	1.77	167 242	242 135	0.60
0.7	100%	630 237	2.00	188 191	278 104	0.69
0.6	0%	303 992	1.15	125 467	181 296	0.46
0.6	25%	350 064	1.28	135 432	197 172	0.51
0.6	50%	390 674	1.44	142 937	202 719	0.52
0.6	75%	429 211	1.669	150 496	209 525	0.54
0.6	100%	526 253	2.00	158 791	231 197	0.59
0.5	0%	303 992	1.15	125 467	161 179	0.41

[2] NB While K, R and MSY are derived from the optimisation model, B_{2013} and the final depletion level, D are highly dependent on the fixed assumptions and so the values presented here are from a further, unconstrained model run.

Upper d	Quantile	K	r	MSY	B_{2013}	D
0.5	25%	352 819	1.25	131 268	174 202	0.45
0.5	50%	387 623	1.38	135 981	178 331	0.46
0.5	75%	419 234	1.57	139 606	182 937	0.47
0.5	100%	471 550	1.99	151 376	201 116	0.52

Future projections were run up to 2020 based on two different catch scenarios. The first scenario assumes the future catch remains constant. This was simulated as a constant catch tonnage, equal to the catch in 2013, and resulted in a very rapid decline of the stock (Figure 11). This is an unlikely scenario given that catch rates generally decline with decreasing biomass, so as an alternative this was also simulated as the catch relative to the target biomass level remains at the current level, i.e. a constant catch rate of C_{2013}/B_{MSY}. This is more intuitive than projecting a constant catch level into the future as factors such as changing catchability based on availability are likely to affect the rate at which a stock can decrease, so a catch rate projection provides a more realistic scenario. This projection predicts that the catch decreases from the 2013 level but remains at a relatively high level, resulting in a stock biomass which stabilises somewhat below B_{MSY} (Figure 12).

The second set of projections were based on the assumption that a constant catch of MSY was achieved annually. This was also simulated as a fixed future catch level (Figure 13) as well as a fixed future catch rate equal to the optimum rate for achieving the target biomass, i.e. MSY/ B_{MSY} (Figure 14). While both of these projections result in a biomass which rapidly stabilises at the corresponding B_{MSY} level there is more uncertainty associated with the fixed catch level compared with the fixed catch rate. This is due to the high uncertainty in the biomass level and so here a fixed catch level is more indicative of a management scenario, whereas achieving a fixed catch rate would be extremely difficult to achieve in practice and so provides a less realistic scenario.

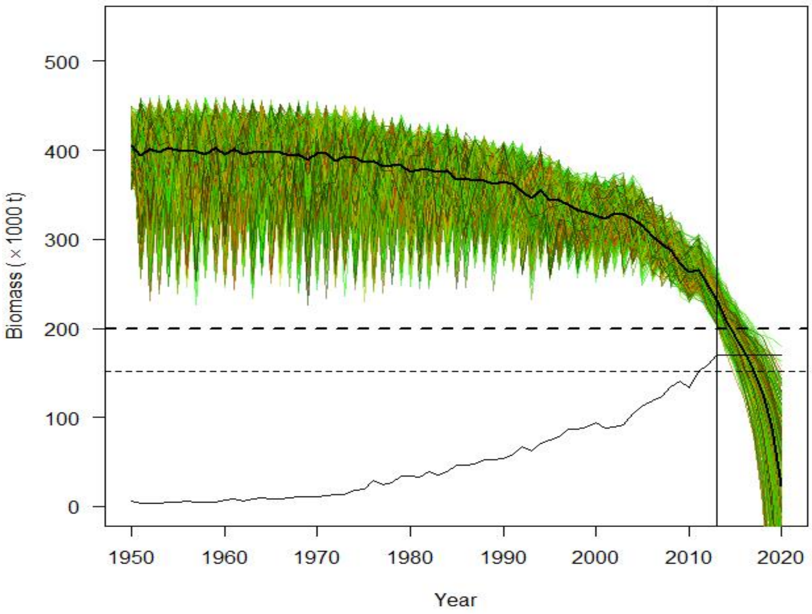

Figure 11. Projected Kawakawa biomass trajectories under hypothetical annual catches equivalent to those of the final year (C_{2013}) until 2020. The vertical line is the last year (2013) for which catch data are available.

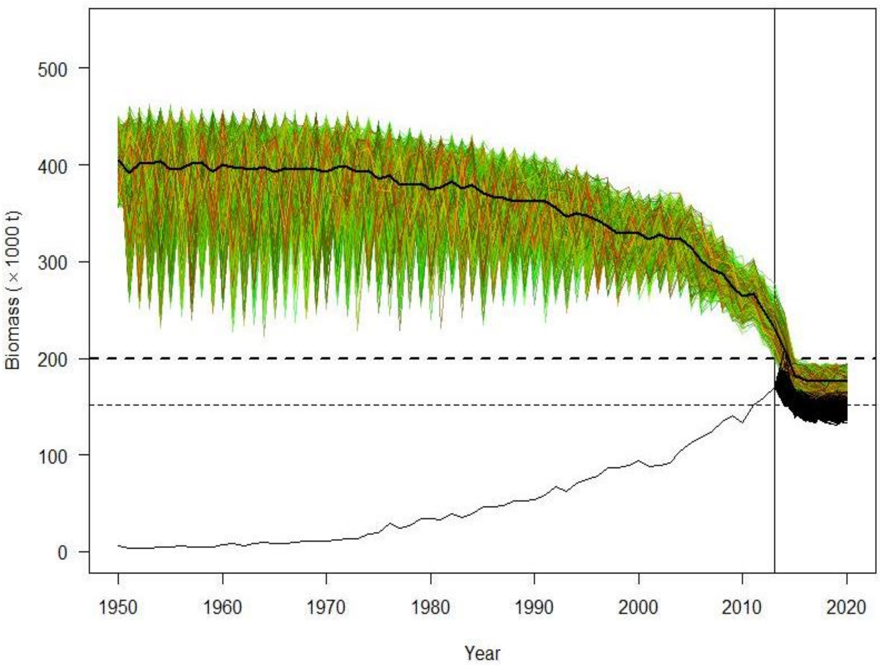

Figure 12. Projected Kawakawa biomass trajectories under hypothetical annual catch rate (C2013/B_{MSY}) at 2013 level until 2020. The vertical line is the last year (2013) for which catch data are available.

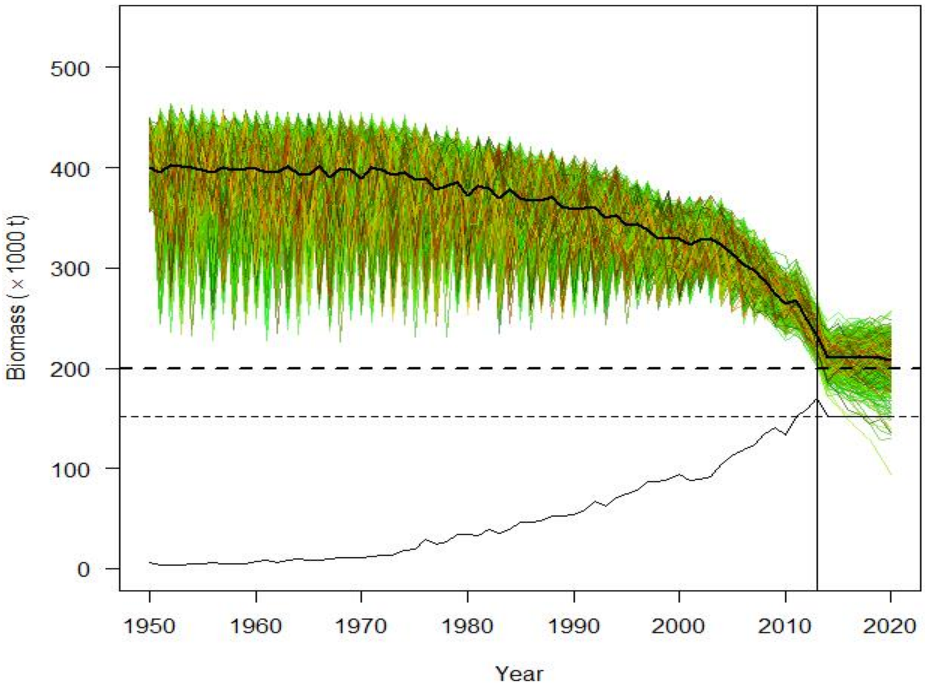

Figure 13. Projected kawakawa biomass trajectories under hypothetical future annual catch equivalent to MSY until 2020. The vertical line is the last year (2013) for which catch data are available.

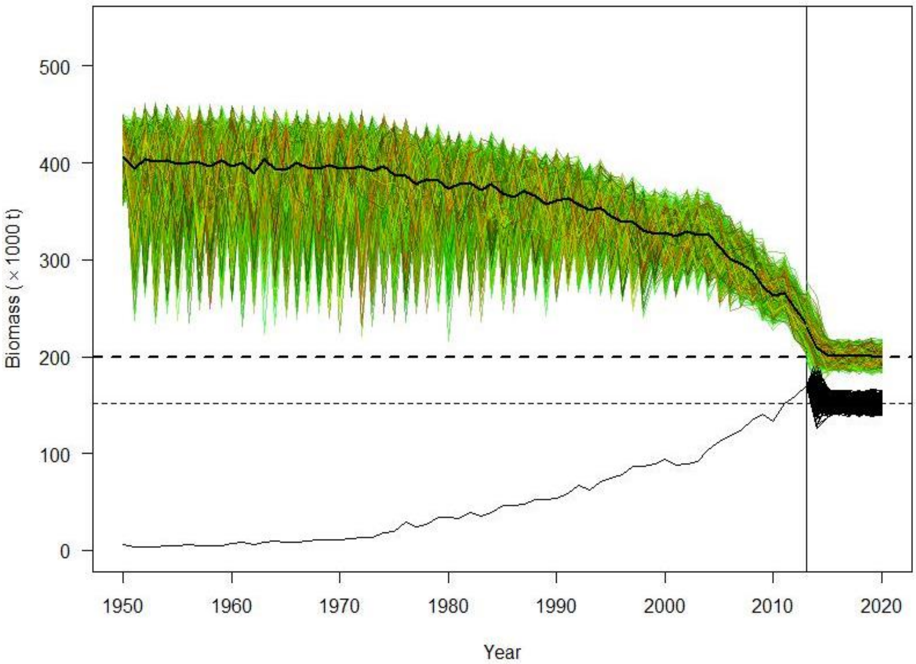

Figure 14. Projected Kawakawa biomass trajectories under hypothetical annual catch rate at MSY level (C_{MSY}/B_{MSY}) until 2020. The vertical line is the last year (2013) for which catch data are available.

Management quantities based on geometric means and plausible are provided in Table 10 which give a higher average MSY, 153 049 t, than the median, 151 937 t. The KOBE matrix plot indicates that based on these model results, Kawakawa is not currently overfished (B_{2013}/B_{MSY} = 1.15) or subject to overfishing (F_{2013}/F_{MSY} = 0.98) (Figure 15).

Table 10. Kawakawa. Key management quantities from the OCOM assessment for Indian Ocean kawakawa, using a base case with maximum depletion of 70%. Geometric means and plausible ranges in brackets. n.a. = not available.

Management Quantity	**Indian Ocean**
Most recent catch estimate (2013)	170 181 t
Mean catch from 2009–2013	155 468 t
MSY (plausible range)	153 049 t (125 466–88 191)
Data period used in assessment	1950–2013
F_{MSY} (plausible range)	0.56 (0.42–0.69)
B_{MSY} (plausible range)	201 957 (1 519 956–351 118)
F_{2013t}/F_{MSY} (plausible range)	0.98 (0.85–1.11)
B_{2013}/B_{MSY} (plausible range)	1.15 (0.97–1.38)
SB_{2013}/SB_{MSY} (80% CI)	n.a.
B_{2013}/B_0 (plausible range)	0.58 (0.33–0.86)
SB_{2013}/SB_0 (80% CI)	n.a.
$B_{2013}/B_{0,\ F=0}$ (80% CI)	n.a.
$SB_{2013}/SB_{0,\ F=0}$ (80% CI)	n.a.

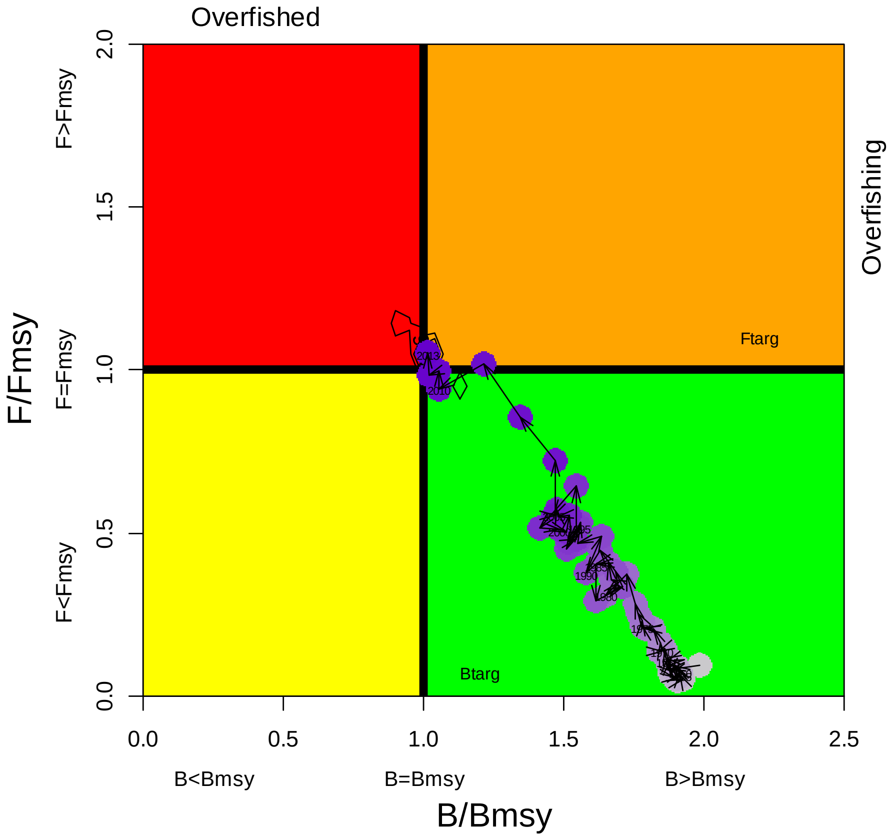

Figure 15. Kawakawa OCOM Indian Ocean assessment Kobe plot. The Kobe plot presents the trajectories for the range of plausible model options included in the formulation of the final management advice. The trajectory of the geometric mean of the plausible model options is also presented.

Discussion

The MSY for kawakawa was estimated at 137 600 t (geometric mean) using the Catch-MSY model and 153 000 t using the OCOM model (geometric means). These estimates are fairly divergent from each other, and also higher than previous assessment results.

Nevertheless, the Catch-MSY model results (137 600 t) are more similar to previous estimates, falling midway between the estimate of 132,000 t from the Catch-MSY assessment carried out in 2014 using data from 1950–2011, (IOTC–2014–WPNT04–26) and the estimate of 145 000 t carried out using data from 1950–2012 (IOTC–2014–WPNT04–25). Previous estimates of MSY using the OCOM model were 128 000 t (data from 1950–2011; IOTC–2014–WPNT04–26) and 140 000 t (data from 1950–2012; IOTC–2014–WPNT04–25). This shows an increase in the estimated MSY year on year, with the highest OCOM estimate this year at 153 000 t. The main difference in OCOM results this year is likely to be due to the priors used on the distribution of *r*. For the 2014 assessment, the limits for the range of *r* were set between 0.97 and 1.83, whereas in this assessment the estimates provided from the literature resulted in a higher range of values used (1.14 to 2) suggesting a higher resilience and therefore providing higher estimates of MSY. This highlights the difference that more informative priors make to model estimates and suggests this is an area for more research.

The model results were also somewhat conflicting in the evaluation of the final status of the stock with the OCOM model again providing a more optimistic outlook than the catch-MSY model. The Catch-MSY model indicates that kawakawa is currently both '*overfished*' (B_{2013}/B_{MSY} = 0.99) and '*subject to overfishing*' (F_{2013}/F_{MSY} = 1.19), while the OCOM model suggests that kawakawa is '*not overfished*' (B_{2013}/B_{MSY} = 1.15) and '*not subject to overfishing*' (F_{2013}/F_{MSY} = 0.98).

The reason for the slightly less optimistic results from the Catch-MSY assessment compared with the previous assessment may be based on the updates to the catch series, as the catch estimates for 2012 have increased as well as catches for 2013 having increased by 10% since the previous estimate. The results from the OCOM assessment were more in line with the previous assessments which estimated F_{2012}/F_{MSY} at 0.97 (0.62‑1.61; OCOM) and 0.99 (0.54–1.45; Catch-MSY) and B_{2012}/B_{MSY} at 1.13 (0.64‑1.4; OCOM) and 1.15 (0.77‑1.50; Catch-MSY), indicating that kawakawa was not overfished and not subject to overfishing (IOTC-2014-WPNT04-R).

In summary, differences in the results may be due to changes in the catch series that have taken place since the previous assessments (Figure 3), the addition of data for another year and due to minor refinements in the model methods. The variation in results across models and years highlights the uncertainty associated with using data-poor methods for stock assessment and so the results should be interpreted with caution and considered in light of the integrated assessment for kawakawa (IOTC-2015-WPNT05-20).

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