Received: 14 June 2013

Stock assessment of two neritic tuna species in Indian Ocean, kawakawa and longtail tuna using catch-based stock reduction methods

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Abstract

We conduct stock assessments for two Indian Ocean neritic tuna species, Kawakawa and Longtail. We used a newly developed posterior-focused catch-based assessment method. The method is based on a classical biomass dynamics model, requires only catch history but not fishing effort or CPUE. Known population growth rate will improve the assessment result. In this paper, we assume that both species in the whole Indian Ocean belong to a single stock and the population size in 1950 is the virgin biomass equal to their carrying capacities. We use recently updated catch data in the analysis.

The preliminary results show that for Kawakawa the median virgin biomass is about 358-408 thousand tonnes depending on the upper depletion level assumed in 2011. The combination of such carrying capacity and growth rate can support a maximum sustainable yield (MSY) of 128-151 thousand tonnes. This means that catch levels in recent year may have exceeded MSY.

The situations are similar for Longtail. The median virgin biomass was about 380 to 440 thousand tonnes, and the intrinsic population growth rate is about 1.14–1.26, somewhat less productive than Kawakawa. The entire stock can support a MSY of nearly 110–140 thousand tonnes. Catch levels in recent year may have been too high, and likely overfishing is occurring on the stock.

Introduction

This is the 3rd WP Neritic Tuna meeting, and the 2nd attempt to conduct a stock assessment on some Neritic Tuna species (in this case longtail and kawakawa). In 2012, attempts made using some nominal CPUE data from India and Thailand were used. Due to short time series of CUPE data and a small fraction of fishing effort, parameter estimation was difficult. Catch trends for both species have gone up drastically in recent years, primarily due to coastal states fishing more in near shore waters than the high seas fisheries (due to piracy scares). As a result, effort has switched from yellowfin, bigeye and skipjack (the Tropical Tunas) to kawakawa and longtail in recent years.

In standard stock assessments conducted in the IO region, a index of abundance is essential to capture trends in biomass over time. In 2012, the CPUE trends were non-informative, and this year a standardized CPUE trend was estimated for kawakawa using the Maldives Pole and Line fleets operational data. However, the assessment conducted using that series (Sharma and Zhou 2013) was non-informative and alternative methods needed to be developed for these species.

Methods developed by CSIRO (draft report "Quantitatively defining biological and economic reference points in data poor fisheries" by Zhou et. al. 2013) highlights some methods developed for data poor fisheries using data rich fisheries as a testing platform. One of the methods developed in the report and improved since then is a posterior-focused catch-based assessment. The basic idea is similar to the Stock reduction Analysis (Kimura and Tagart 1982; Walters et. al. 2006; Martell and Froese 2012). The technique builds on simple surplus production models (like Shaefer, 1954), that uses removal data and some estimate of carrying capacity and population growth rate. Ideally, these models should have some measure of abundance in one or more recent years. However, with a reasonably assumed upper limit on depletion level and population growth rate, it is possible to derive biological parameters using catch data alone, particularly MSY. In this paper we applied this method for Indian Ocean kawakawa, (*Euthynnus affinis*) and Indian Ocean Longtail (*Thunnus tonggol*).

<u>Indian Ocean Kawakawa</u>

Basic Biology

Kawakawa (*Euthynnus affinis*) is found in multiple areas of the Indian Ocean (Figures A1). Kawakawa occurs in open waters but always remains close to the shoreline. They tend to form multi-species schools by size with other scombrid species comprising from 100 to over 5,000 individuals (Collette and Nauen 1983). They are a highly opportunistic predator feeding indiscriminately on small fishes, especially on clupeoids and atherinids; also on squids, crustaceans and zooplankton (Collette 2001, Fish Base). The global distribution is shown in Appendix 1, Figure A1.

Catch Trends

Although primarily distributed in the central Pacific, it is an important fishery for numerous countries in the Indian Ocean region, namely Iran, Indonesia, India, Malaysia, and Thailand. Numerous other countries also catch the species (Appendix 1, Figures A2-A4). The species is primarily caught by Purse Seine and gillnets, but other gears (Appendix 1, Figure A2) are also used to catch the species. The countries that are the primary users of the resource are India, Indonesia and Iran. An attempt to re-estimate the catches across the region is being undertaken in the Indian Ocean region, and it is likely that some of the numbers reported will be revised (Appendix 1 Figure A4).

As is evident from the figures, catch trends have increased in recent years primarily due to increases in effort by Iran and Indonesia. In recent years due the effect of piracy off the coast of Somalia, effort has been concentrated and redirected from Tropical Tunas to local neritic's by the countries of Iran, Pakistan and other Arabian gulf countries. These catches in recent years (2006-2011) have increased by 50%, and thus an attempt to understand the effect of these increased catches on the species is attempted in this Working Party meeting.

Indian Ocean Longtail (***Thunnus tonggol***)

Basic Biology

Longtail (***Thunnus tonggol***) tuna are predominantly neritic species avoiding very turbid waters and areas with reduced salinity such as estuaries. These fish form schools of varying size (source www.fishbase.org). They feed on a variety of fishes, cephalopods, and crustaceans, particularly *stomatopod* larvae and prawns (Collette and Nauen 1983). As evident from the figure below (Appendix 1, Figure A5), the species is distributed around the Indian Ocean and western Central Pacific in large numbers.

Fisheries and catch trends

Longtail tuna is caught mainly by using gillnets and, in a lesser extent, seine nets, and trolling (Appendix 1, Figure A6). Longtail tunas are caught in the western and eastern Indian Ocean areas (Appendix 1, Figure A7). The catch estimates for longtail tuna were derived from small amounts of information and are therefore uncertain[1] (Appendix 1, Fig. A6).

The catches provided are based on the information available at the IOTC Secretariat and the following observations on the catches cannot currently be verified. Estimated catches of longtail tuna increased steadily from the mid 1950's, reaching around 20,000 t in the mid-1970's, over 50,000 t by the mid-1980's, and over 100,000 t in 2000. Catches dropped after 2000, up to 77,000 t in 2005 and have increased since then, with the highest catches ever recorded in 2011, at around 160,000 t (preliminary, Appendix 1, Figure A6).

[1] The uncertainty in the catch estimates has been assessed by the Secretariat and is based on the amount of processing required to account for the presence of conflicting catch reports, the level of aggregation of the catches by species and or gear, and the occurrence of unreporting fisheries for which catches had to be estimated.

Table 1: Catch data on IO Kawakawa and Longtail from 1950-2011 (source IOTC Database)

Year	LOT(t)	KAW(t)		Year	LOT(t)	KAW(t)
1950	2826	5567		1981	20660	30198
1951	2802	3246		1982	30363	34901
1952	3076	3276		1983	26859	31276
1953	3343	3234		1984	31986	35391
1954	3585	4486		1985	36551	41806
1955	3621	5372		1986	38714	43181
1956	3303	5855		1987	52111	45769
1957	4681	5390		1988	56260	49816
1958	3726	5067		1989	50566	46901
1959	4504	5267		1990	43809	52209
1960	4521	6970		1991	49119	56103
1961	4436	8678		1992	42550	66333
1962	5318	5988		1993	47557	59588
1963	6113	8261		1994	51110	66924
1964	7177	10149		1995	69646	70735
1965	7756	8772		1996	63225	74920
1966	9098	8818		1997	64973	83648
1967	9409	9872		1998	71541	86985
1968	9447	10489		1999	72511	88565
1969	8859	10447		2000	89600	93504
1970	8234	10651		2001	81546	87703
1971	7024	11724		2002	77443	93663
1972	8420	13651		2003	78926	94554
1973	7666	13708		2004	70963	102140
1974	12822	18470		2005	66484	101968
1975	14984	19861		2006	80917	114868
1976	15257	28861		2007	95327	119719
1977	15717	24761		2008	96910	136486
1978	17728	23731		2009	114917	136888
1979	19879	31800		2010	133618	131557
1980	19452	31614		2011	164537	143652

In recent years (2009–11), the countries attributed with the highest catches of longtail tuna are Iran (42%) and Indonesia (29%) and, to a lesser extent, Oman, Pakistan, Malaysia, India and Thailand (25%) (Appendix 1, Fig. A8 and Table 1). In particular, Iran has reported large increases in the catch of longtail tuna since 2009. The increase in catches of longtail tuna coincides with a decrease in the catches of skipjack tuna and is thought to be the consequence of increased gillnet effort in coastal waters due to the threat of Somali piracy in the western tropical Indian Ocean.

The size of longtail tunas taken by the Indian Ocean fisheries typically ranges between 15 and 120 cm depending on the type of gear used, season and location. The fisheries operating in the Andaman Sea (coastal purse seines and troll lines) tend to catch longtail tuna of small size (15–55cm) while the gillnet fisheries operating in the Arabian Sea catch larger specimens (40–100cm).

As stated earlier, in 2012, a preliminary surplus production assessment was conducted on these stocks using nominal CPUE data from Thailand and east-coast of India. The data indicated that the fishery was probably approaching overfishing levels in recent years, but due to high uncertainty in the data, and confounding in the r and K parameters, and the fact that the CPUE data used was not very informative (Sharma et. al. 2012). The current approach is using some data poor techniques (Zhou et. al. 2013) that have been developed and tested on Australian stocks and are being applied for the 1st time on resilient Indian Ocean neritic tuna stocks.

Methods

We use a newly developed stock assessment method in this paper. This method is based on catch data and does not require fishing effort or CPUE data. The method involves several steps. It applies a simple population dynamics model, starts with wide prior ranges for the key parameters, and includes the available catch data in the model. Then the model systematically searches through possible parameter spaces and retains feasible parameter values. Mathematically and biologically unfeasible values are excluded from the large pool of data. We progressively derive basic parameters, and carry out stochastic simulations using these base parameters to get biomass trajectories and additional parameters. Finally, we project to future biomass to explore alternative harvest policies.

We use following Graham-Shaefer surplus production model (Shaefer 1954):

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

Where B_t is biomass in time step *t*, *r* is the population growth rate, B_0 is the virgin biomass equal to carrying capacity K, and C is the known catch.

This simple model has two unknown parameters, r and K. We set reasonably wide prior range, for example, *K* between C_{max} and 500 * C_{max}. We use six methods to derive possible range for the intrinsic population growth rate r.

r from literature (fishbase.org).

$r = 2\,\omega M$, where *M* is obtained from literature and $\omega = 0.87$ is a scale linking Fmsy to M for teleosts (Zhou et al. 2012).

$r = 2\,\omega M$, 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).

In these equations, *r* is the intrinsic population growth rate, □ and L_∞ are von Bertalanffy growth parameters, *T* = average annual water temperature, t_m = maximum reproductive age, and t_{mat} = average age at maturity. The range (min to max) from these methods is used as prior for Model 1. Further, we set up a series of assumed depletion level $D = B_T/K$, e.g., D = 0.02 to 0.80. Here B_T is the assumed true biomass at the end of the time series. It is unlikely that the any tuna stock has biomass greater than 80% of unfished virgin population size.

We run model (1) to find all mathematically feasible *r* values by searching through wide range of Ks for all depletion levels. Optimization routine is used by minimizing objective function $|B_{end} – DK|$, where B_{end} is the simulated final year biomass (i.e., at the end of time series t).

Biological parameters, including K, r, MSY, are derived from the retained pool of [r, K] values. Using these K, r, and known catch, stochastic simulations are carried out by re-running Model (1) without any further restrain. From a large number of simulations (e.g., 1000), biomass trajectories, as well as ending biomass and depletion level are stored. Not all iterations may be viable. Some simulations may result in $B_t \leq 0$ (extinction) before the end of the time series. These iterations are removed while the remaining viable quantities are used for parameter references.

Results

Kawakawa

The six methods results in a range of r from 1.056 to 2.04 for kawakawa. We first explored how assumed depletion may affect the result. We used eight assumed depletion level in 2011: 0.1, 0.2,…0.8 (Figure 1). The results indicate that with the r range used, the population must have been greater than 30% of unfished level in 2011. Typically, the key parameters (i.e., K, r, MSY) have to be larger to maintain a higher population (i.e., larger D).

We then used depletion level between 0.02 and 0.80 at a step of 0.02 in Model 1 and combined all feasible results (Figure 2). The possible unfished population may range from about 300 thousand ton to nearly 800 thousand ton (Figure 2). The lowest possible depletion level is 0.38. At this depletion level, 2 data points are retained: r = 1.11, K = 393617, and r = 1.06, K= 409353.

Table 2. Posterior key biological parameters for Kawaka under three assumed upper depletion level.

Upper D	Param	Mean	5%	25%	50%	75%	95%
0.8	*K*	406.02	350.84	376.13	**408.12**	434.72	458.6
0.8	*r*	1.5	1.32	1.39	**1.48**	1.61	1.72
0.8	MSY	155.32	117.68	132.92	**150.96**	171.8	205.16
0.8	B_{2011}	266.14	243.36	255.37	**265.15**	276.48	290.8
0.8	D_{2011}	0.66	0.56	0.61	**0.65**	0.71	0.77
0.7	*K*	368.01	327.36	346.52	**366.84**	387.5	407.86
0.7	*r*	1.48	1.33	1.4	**1.48**	1.56	1.66
0.7	MSY	136.17	115.63	126.96	**135.47**	146.83	157.28
0.7	B_{2011}	214.75	203.08	208.11	**213.46**	220.14	228.83
0.7	D_{2011}	0.59	0.51	0.55	**0.58**	0.62	0.67

0.6	*K*	358.05	322.45	337.65	**358.04**	377.72	394.55
0.6	*r*	1.43	1.29	1.35	**1.43**	1.51	1.58
0.6	MSY	126.42	113.16	120.92	**127.57**	132.48	136.37
0.6	B_{2011}	192.03	181.29	187	**191.81**	196.55	203.82
0.6	D_{2011}	0.54	0.48	0.51	**0.54**	0.57	0.6

Since within the assumed depletion levels the upper limit has some effect on the result, we tested the sensitivity by three alternative upper limits: *D* = 0.80, 0.70, and 0.60. Again, assuming a higher D results in a higher r, K, MSY, B_{2011}, and D_{2011} (Table 2). However, the magnitude appears to be relatively small. For example, for the three assumed upper depletions, MSY is about 151, 135, and 128 thousand tons, respectively.

While the catch increases over time, biomass continues to decline (Figure 3). To evaluate management strategy, we investigated two hypothetic harvest levels for the next 10 years. This exercise is based on the conservative upper depletion level **D = 0.6**. First, we assumed catch remains at 2011 level from 2012 to 2021 (Figure 4). The projected biomass trajectories show a quick depletion of the population. Hence, the catch level in 2011 appears to be unsustainable. We then assumed that annual catch is 100 thousand tonnes for the next 10 years (Figure 5). This results in a very different picture. The population recovers to a higher level and becomes stable after about 7 or 8 years.

Longtail tuna

The six methods results in a range of r from 0.75 to 1.76 for Longtail tuna. Again, we used depletion level between 0.02 and 0.80 at a step of 0.02 in Model 1 and combined all feasible results (Figure 6). The possible unfished population may range from about 280 thousand ton to nearly 540 thousand ton (Figure 6). The lowest possible depletion level is 0.46. At this depletion level, 3 data points are retained, with r between 0.84 and 1.06, and K between 360 and 430 thousand tons.

Table 3. Posterior key biological parameters for Longtail under three assumed upper depletion levels.

Upper D	Param	Mean	5%	25%	50%	75%	95%
0.8	*K*	441.64	373.47	406.71	**443.16**	477.16	506
0.8	*r*	1.27	1.1	1.17	**1.26**	1.37	1.49
0.8	MSY	143.21	99.45	120.13	**139.38**	166.22	194.53
0.8	B_{2011}	301.56	221.91	261.37	**303.06**	344.11	375.52
0.8	D_{2011}	0.68	0.58	0.64	**0.68**	0.72	0.75
0.7	*K*	396.8	350.41	370.48	**396.21**	423.2	444.01

0.7	*r*	1.26	1.12	1.17	**1.25**	1.34	1.41
0.7	MSY	123.41	95.87	110.2	**123.84**	135.03	150
0.7	B_{2011}	247.47	190.08	217.39	**247.97**	277.12	303.11
0.7	D_{2011}	0.62	0.54	0.59	**0.63**	0.66	0.69
0.6	*K*	380.8	338.11	356.71	**380.57**	404.63	424.64
0.6	*r*	1.16	1.03	1.08	**1.15**	1.23	1.3
0.6	MSY	109.45	94.27	102.25	**109.75**	118.06	123.8
0.6	B_{2011}	211.35	152.42	183.11	**211.89**	241.64	268.46
0.6	D_{2011}	0.55	0.44	0.51	**0.56**	0.6	0.64

We applied three assumed upper depletion limits: D = 0.80, 0.70, and 0.60 (Table 3). Corresponding to these levels, the median MSY varies between 110 and 140 thousand tons, and the depletion level between 0.56 and 0.68, respectively. Like kawakawa, we assumed catch remains at 2011 level from 2012 to 2021 (Figure 7). The projected biomass trajectories show a quick depletion of the population. Hence, the catch level in 2011 appears to be unsustainable. We then assumed that annual catch is 100 thousand tonnes for the next 10 years (Figure 8). This results in a very different picture. The population recovers to a higher level and becomes stable after about 7 or 8 years.

Discussion

Given that the fishery has been operational for the last 60 years (and likely before that), it seems unlikely that the depletion levels would be above 60%. However, based on the r-K combinations and the fitting procedures, the lowest value of depletion attainable is 0.38. In all likelihood then Kawakawa appears to be healthy and fishing at optimal levels. In recent years with the increased level of catches (Table 1), the fishery catches are probably unsustainable (Figure 4). Yield targets are probably in the vicinity of 113-136 k tons (Table 2, assuming depletion in 2011 is 60%). It is however, likely that depletion is probably around 50% -60% in 2011. Using catch targets of 100k tons over the entire Indian Ocean gives us a population that is sustainable (Figure 5).

For longtail, a similar conclusion could be reached (Table 3). Here the optimal yield targets are slightly lower 94k-123k tons, with depletion assumed to be around 60%. Once again it appears that the in 2011, the resource is fully utilized (around 50% depletion levels). Catches in recent years (around 164k tons in 2011) are probably too high and if fishing is kept at these levels the population will be severely depleted in 10 years (Figure 7).

At the current knowledge of the catch history, and based on the stock reduction with optimization process pursued here, we suggest that the target yields not exceed 120k for kawakawa and 110k for longtail tuna in the Indian Ocean.

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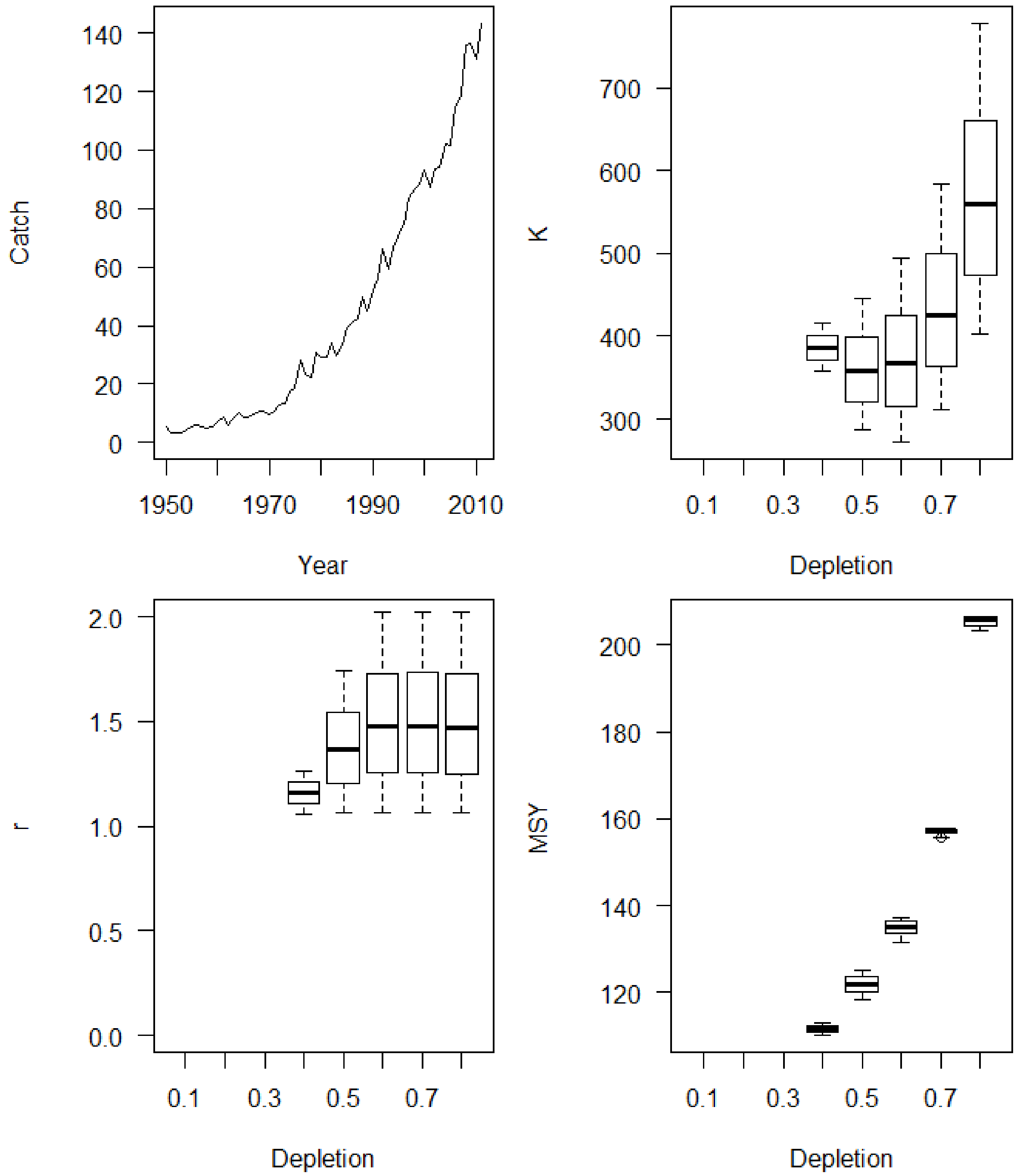

Figure 1. Kawaka catch history, feasible carrying capacity, population growth rate, and maximum sustainable yield at each assumed depletion level. There is no feasible solution when the depletion is assumed to be smaller than 0.4. The unit is thousand tonnes, except for population growth rate r.

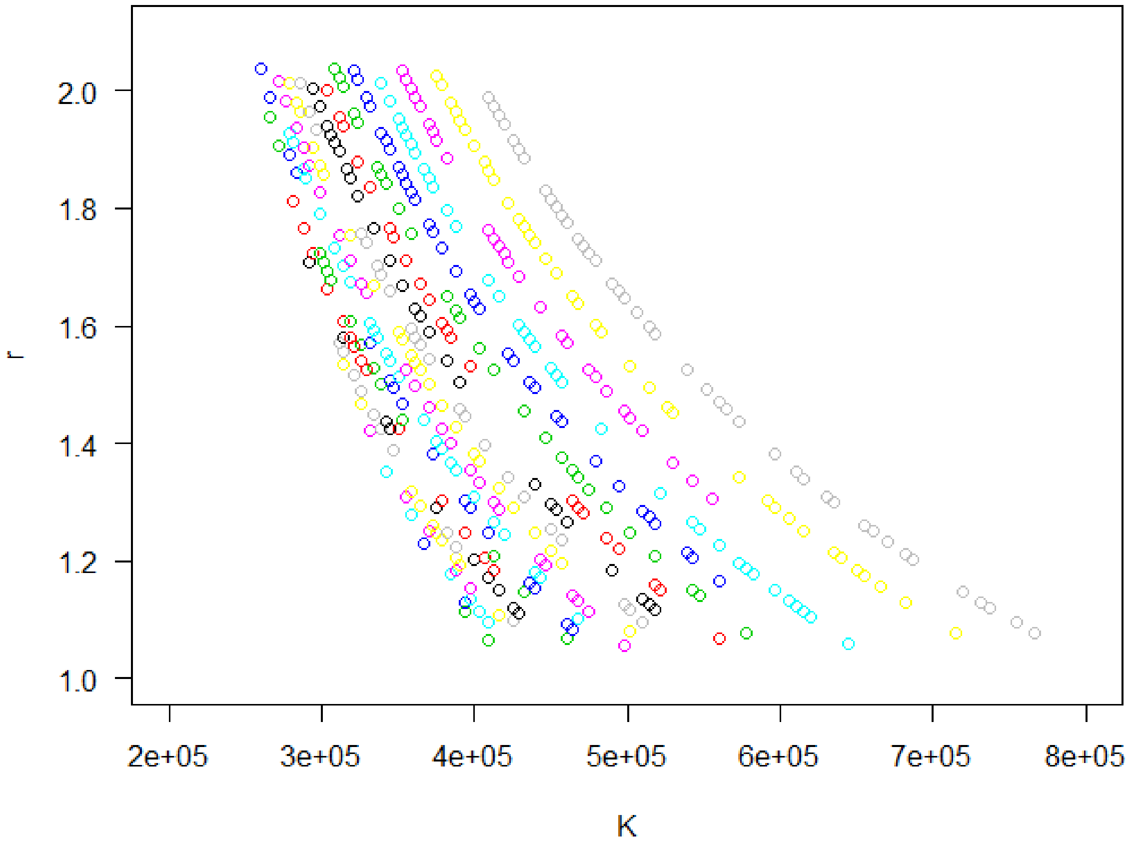

Figure 2. Possible combination of [r, K] from assumed depletion level [0.02, 0.80] for kawakawa. Prior r range is [1.056, 2.04]. Each line is an assumed depletion level. There is no feasible [r, K] pairs when depletion is lower than 0.38.

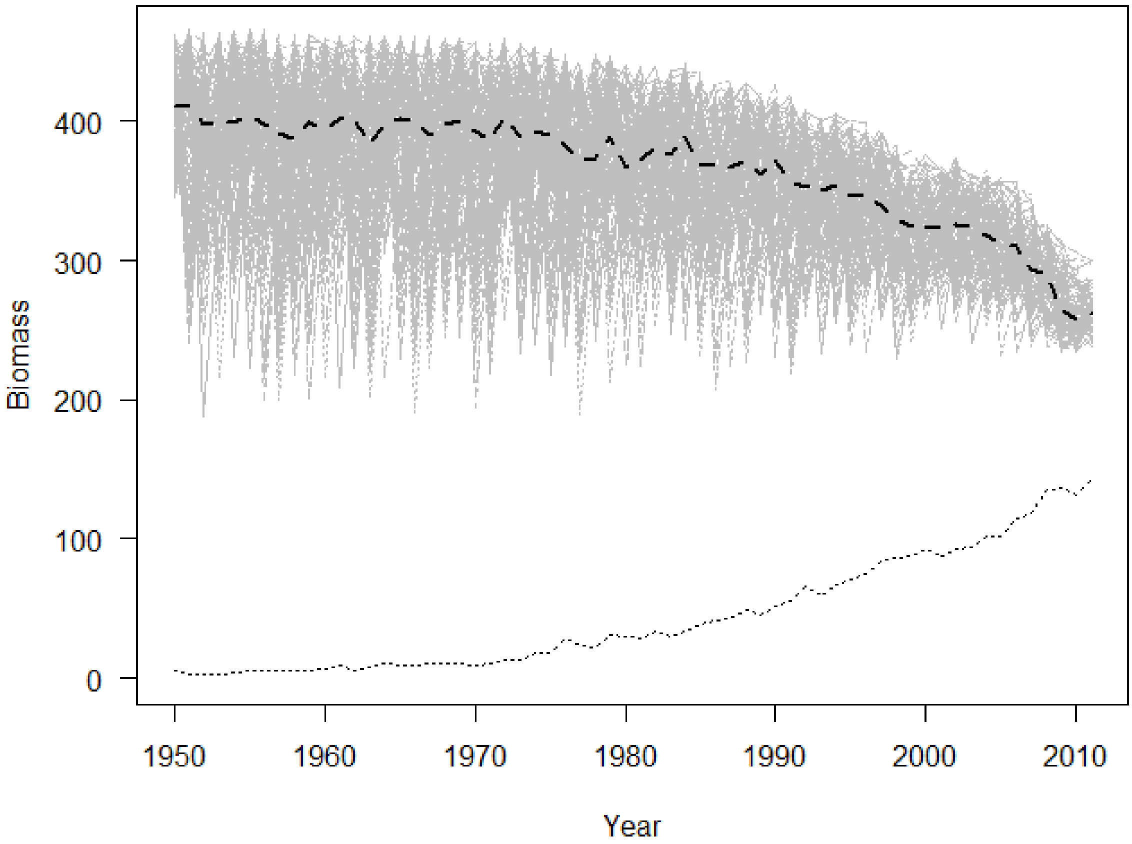

Figure 3. Kawakawa biomass (in thousand tonnes) trajectories from 100 simulations. The dark dashed line is the median biomass and the thin dotted line is the catch.

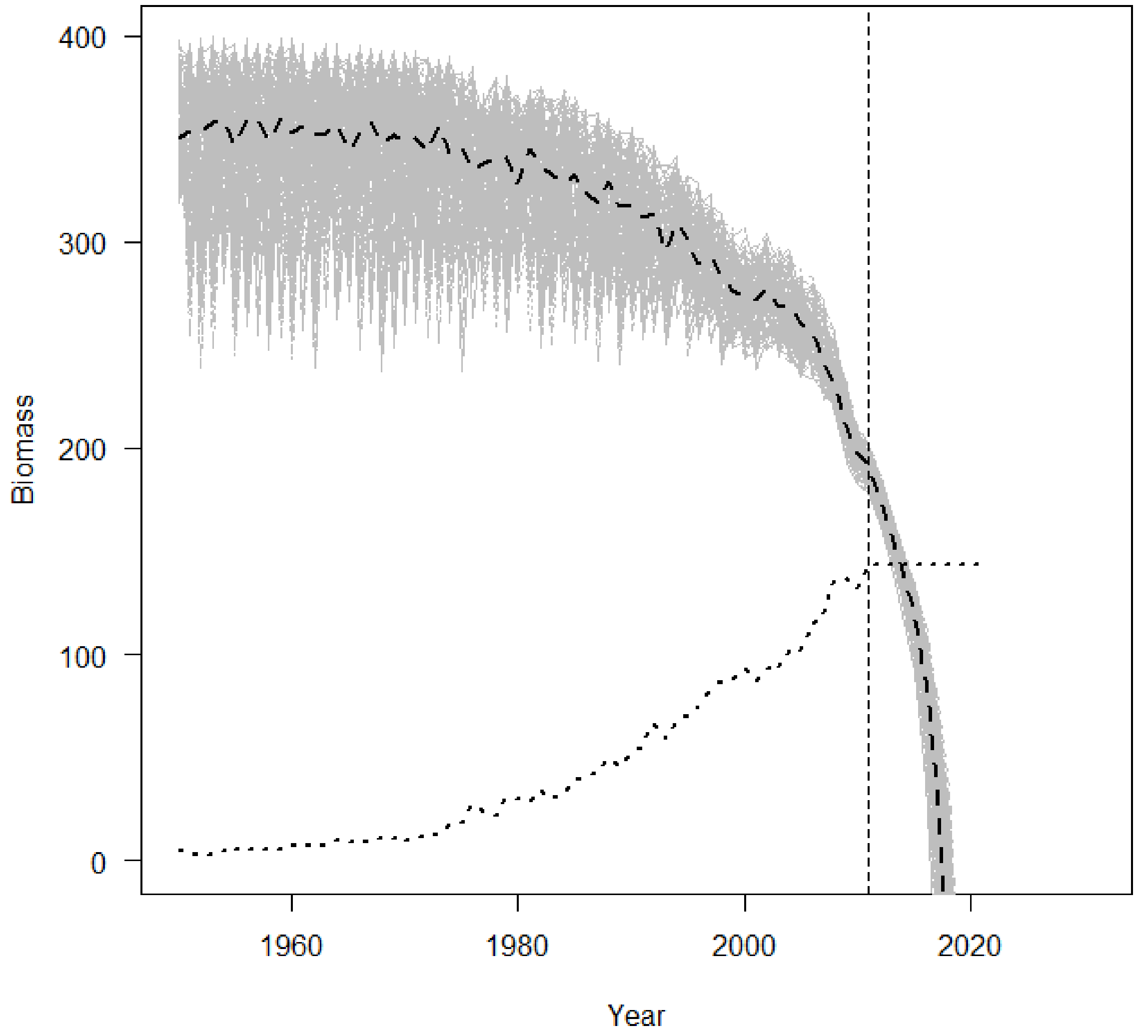

Figure 4. Projected biomass trajectories under hypothetic annual catch level at 2011 for 10 years. The vertical line is the last year (2011) when catch data are available.

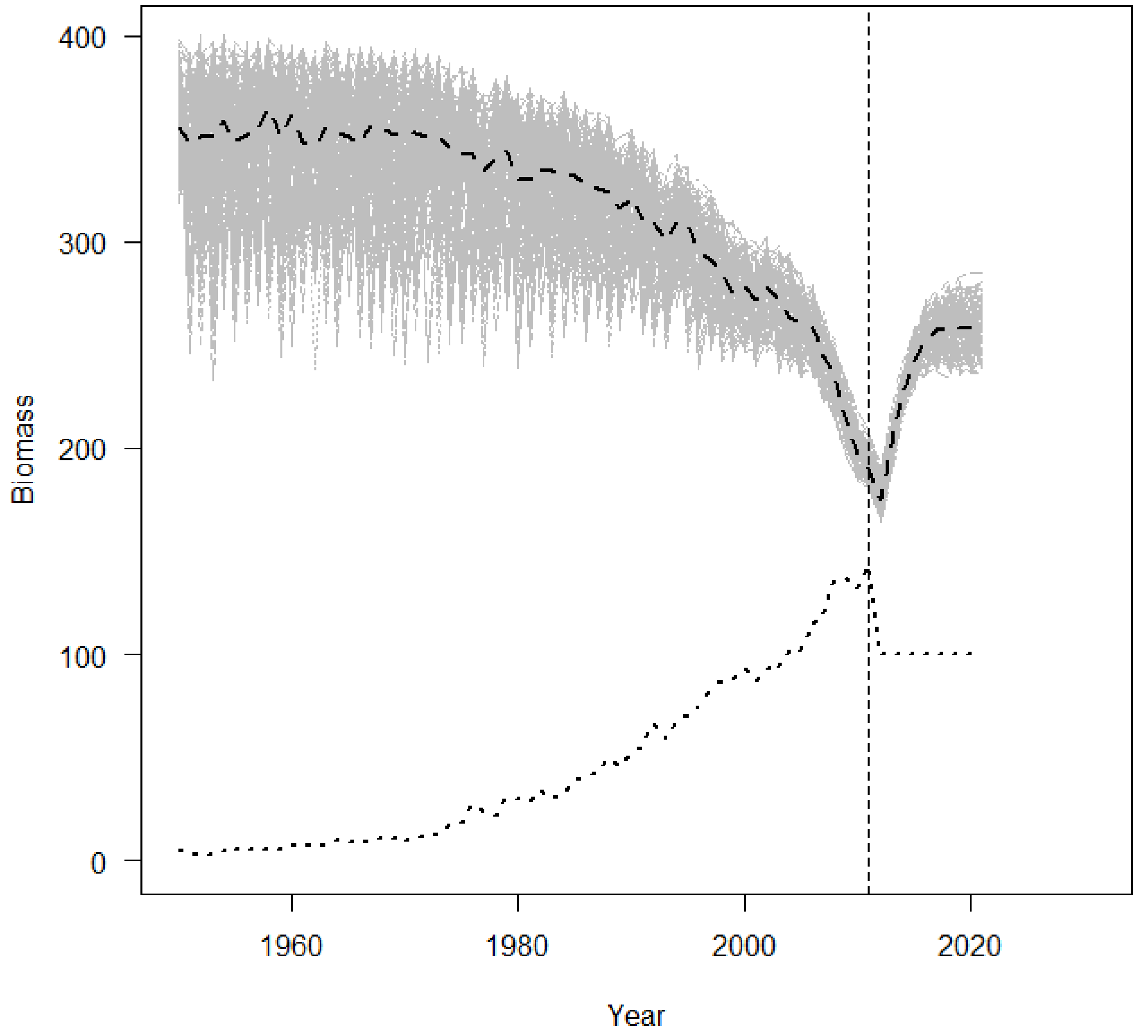

Figure 5. Projected biomass trajectories under hypothetic annual catch level at 100 thousand tonnes for 10 years. The vertical line is the last year (2011) when catch data are available.

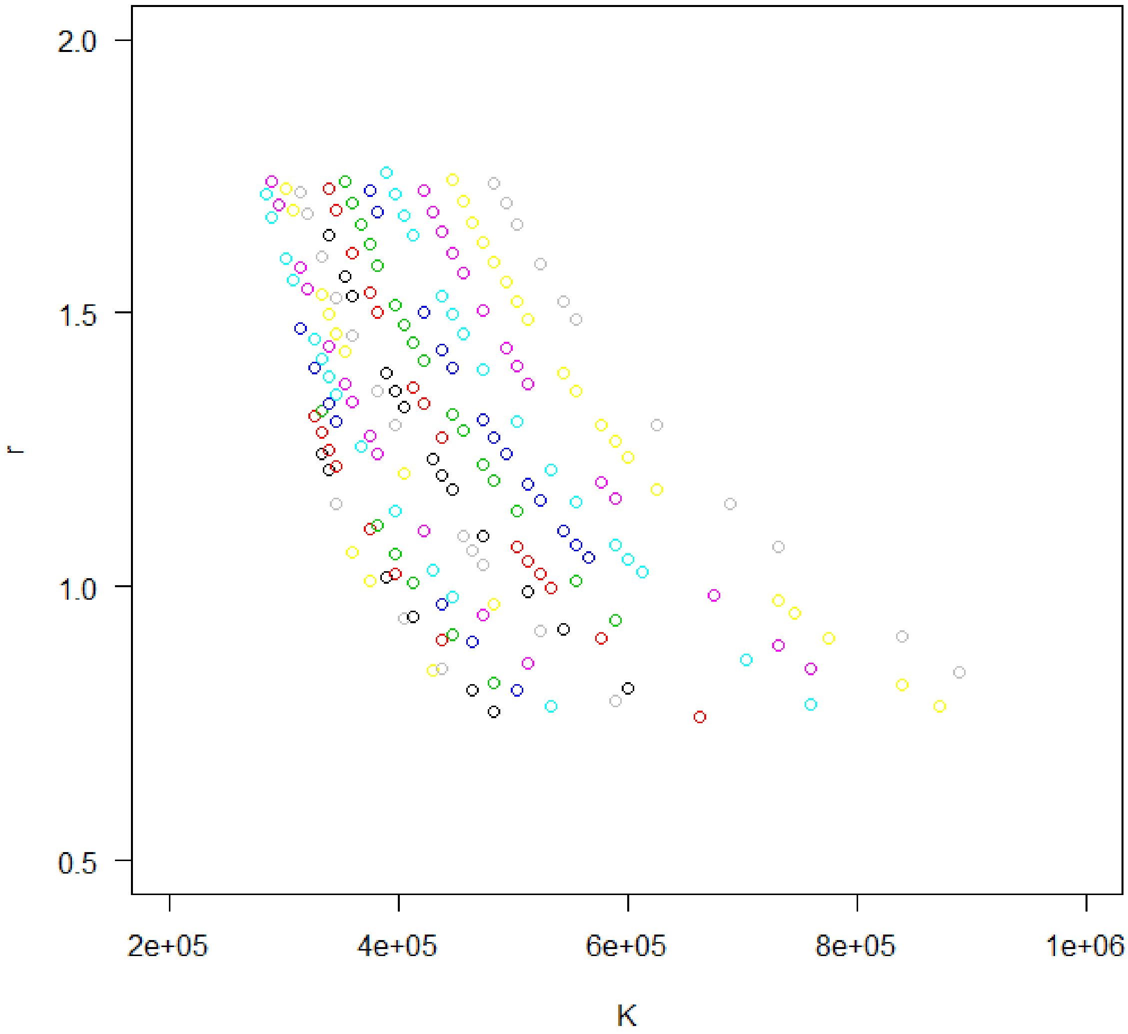

Figure 6. Possible combination of [r, K] from assumed depletion level [0.02, 0.80] for Longtail tuna. Prior r range is [0.75, 1.76]. Each line is an assumed depletion level. There is no feasible [r, K] pairs when depletion is lower than 0.46.

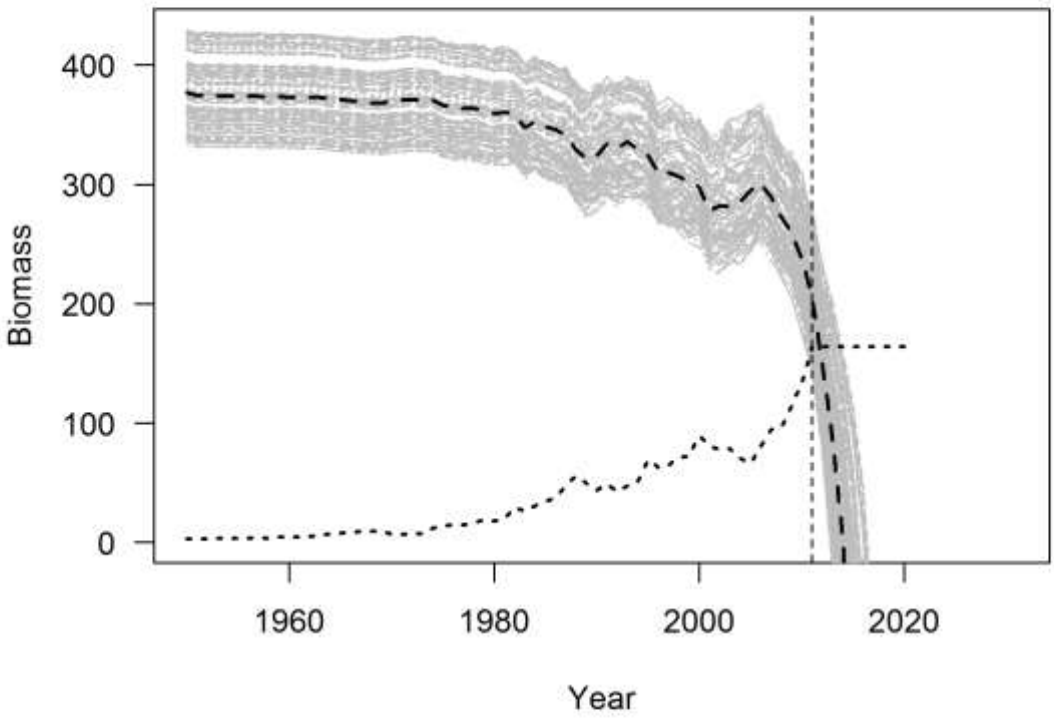

Figure 7. Projected Longtail biomass trajectories under hypothetic annual catch maintaining at the level in 2011 for 10 years. The assumed upper depletion level is 0.6. The vertical line is the last year (2011) when catch data are available. The dark dashed line is the median biomass.

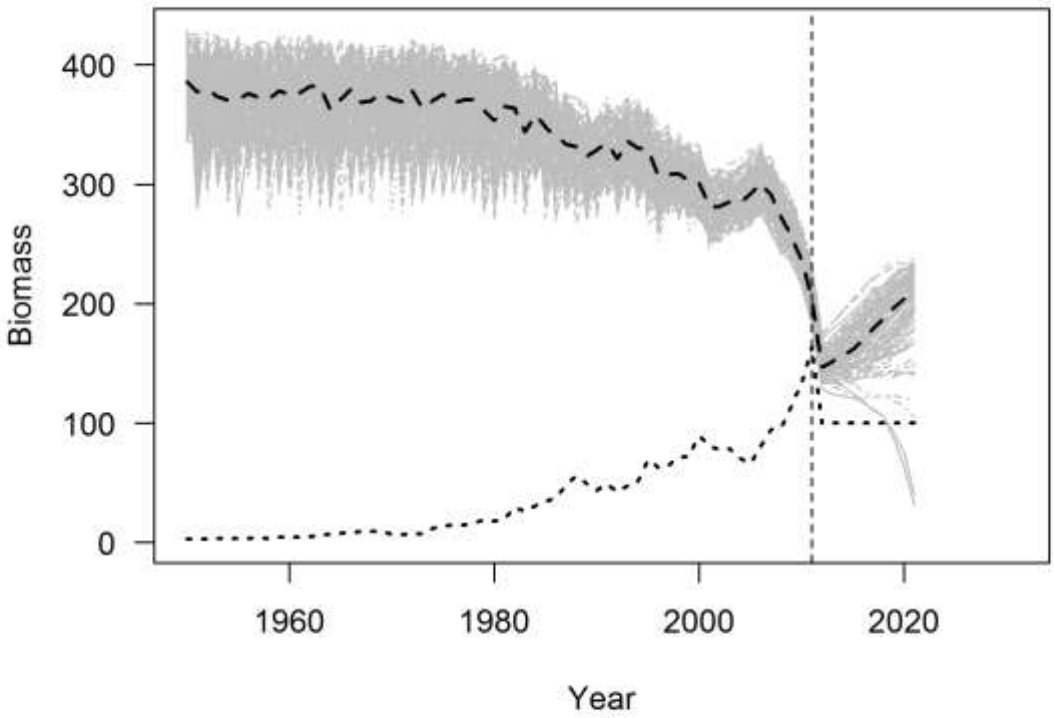

Figure 8. Projected Longtail biomass trajectories under hypothetic annual catch level at 100 thousand tonnes for 10 years. The assumed upper depletion level is 0.6. The vertical line is the last year (2011) when catch data are available. The dark dashed line is the median biomass.

Appendix 1: Basic fishery and life history data of Kawakawa and Longtail

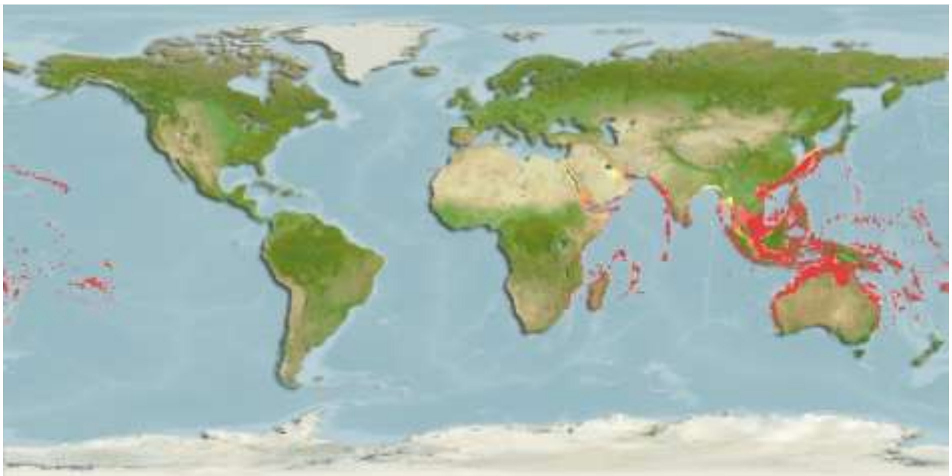

Figure A1: Kawakawa Global distribution (source: www.fishbase.org)

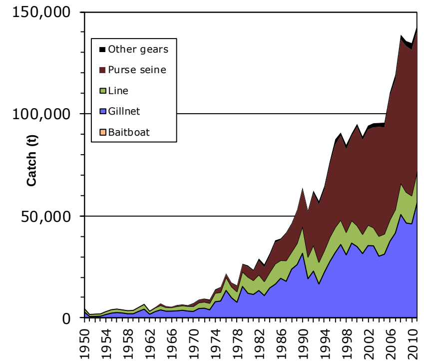

Figure A2. Kawakawa: Annual catches of kawakawa by gear recorded in the IOTC database (1950–2011)

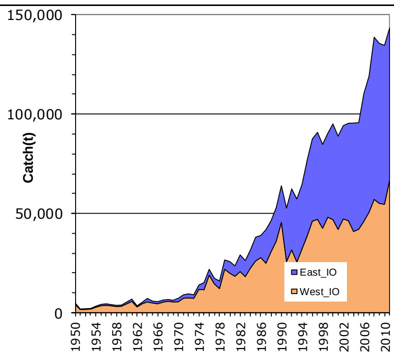

Figure A3. Kawakawa: Annual catches of kawakawa by IOTC area recorded in the IOTC database (1950–2011)

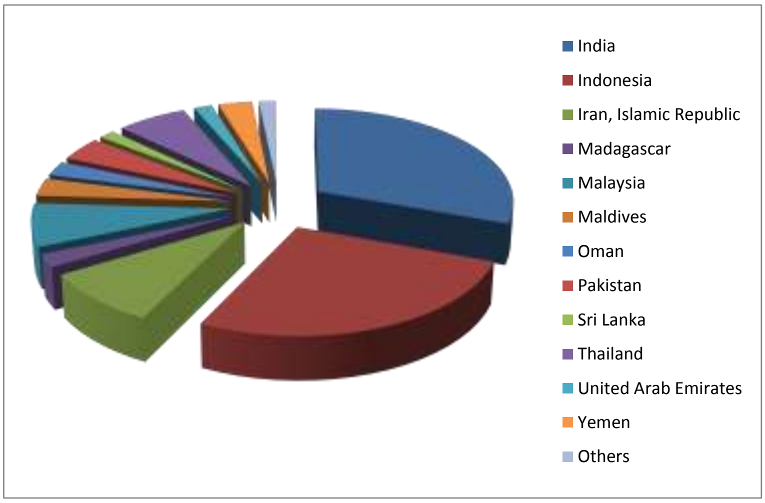

Figure A4: Proportion of the Catch accounted (1950-2011) for the Indian Ocean countries

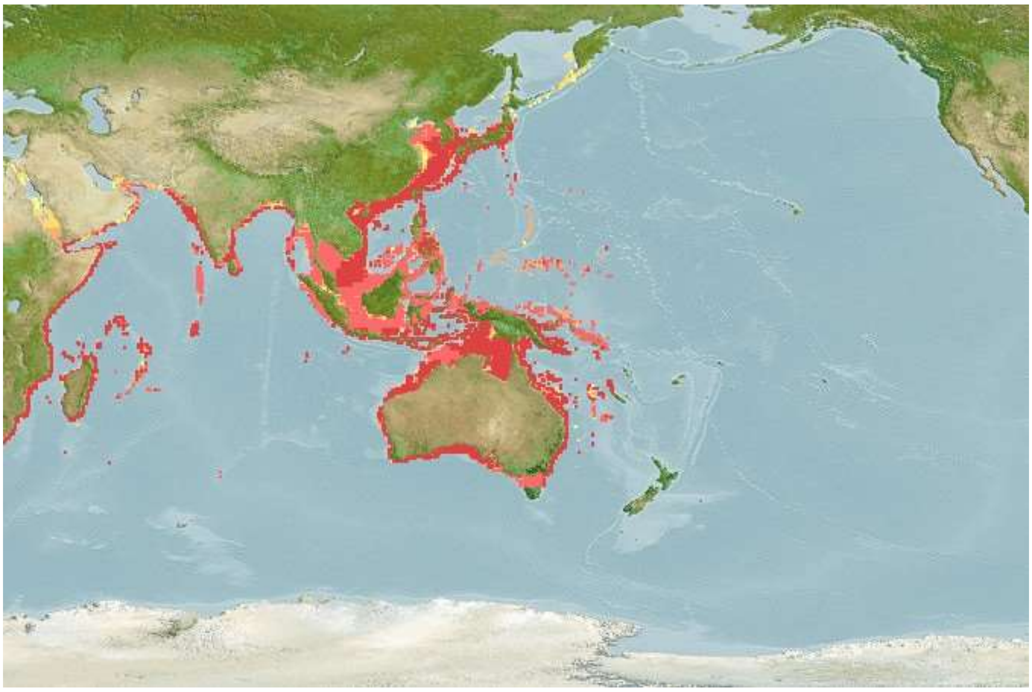

Figure A5: Indo-Pacific Species distribution for Longtail Tuna (source www.fishbase.org)

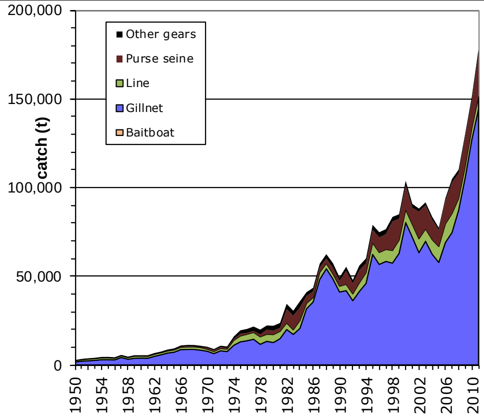

Figure A6. Longtail tuna: Annual catches of longtail tuna by gear recorded in the IOTC Database (1950–2011)

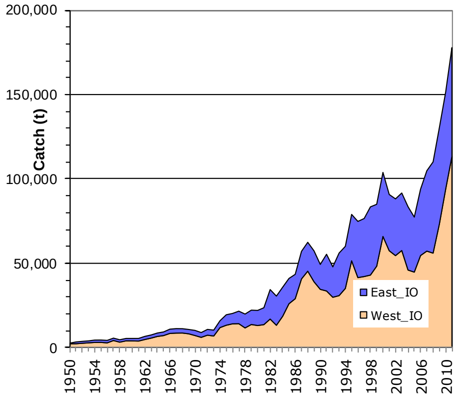

Figure A7. Longtail tuna: Annual catches of longtail tuna by IOTC area recorded in the IOTC Database (1950–2011)

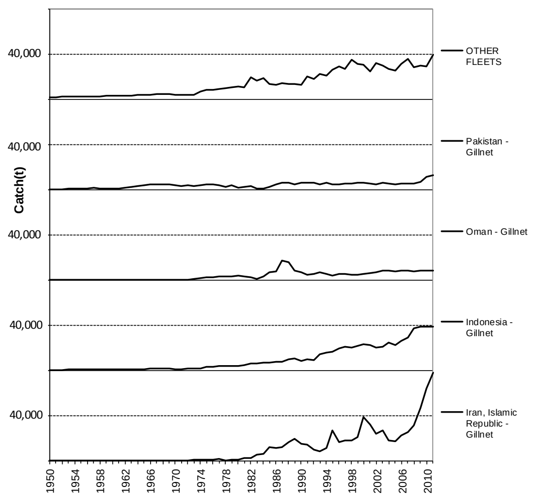	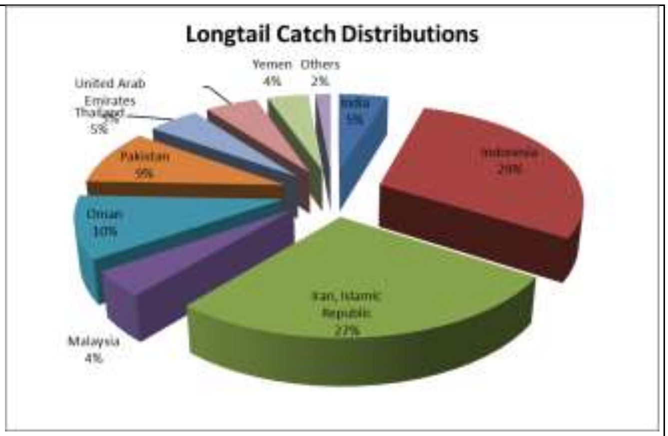
Figure A8 a: Catches of longtail tuna recorded in the IOTC Database for main fishing fleets (1950–2011). Broken lines representing 40,000 t each)	Figure A8b:Proportion of catch accounted by major Indian Ocean countries (1950-2011) for Longtail