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Stock assessment of neritic tuna species in Indian Ocean: kawakawa longtail, and narrow-barred Spanish Mackerel tuna using catch-based stock reduction methods

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Abstract

We conduct stock assessments for three Indian Ocean neritic tuna species, Kawakawa and Longtail. We used a newly developed posterior-focused catch-based assessment method, and compared them to the traditional SRA approach developed by Kimura et. al. 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 363-469 thousand tonnes depending on the upper depletion level assumed in 2012. The combination of such carrying capacity and growth rate can support a maximum sustainable yield (MSY) of 127-146 thousand tonnes. This means that catch levels in recent year may have exceeded MSY, or is fully exploited.

The situations are similar for Longtail. The median virgin biomass was about 443 to 595 thousand tonnes, and the intrinsic population growth rate is about 0.8–1.11, somewhat less productive than Kawakawa. The entire stock can support a MSY of nearly 106–141 thousand tonnes. Catch levels in recent year may have been too high, and likely overfishing is occurring on the stock.

For narrow-barred Spanish Mackerel, the median virsgin biomass is between 380-543 thousand tonnes, and MSY levels are between 112-133 thousand tonnes. Catch levels in recent years indicate that these stocks are also fully exploited.

These results are compared across two approaches, and similar results are concluded, i.e. Yield levels are similar across approaches, though tighter precision is observed with the optimal yield and current biomass levels using a newly developed Posterior focussed Catch Reduction Approach (PFCRA) versus the traditional Stock Reduction Approaches (SRA). With respect to fishing based reference points, the results are similar across both approaches. Stock status advice is similar across bothe approaches.

Introduction

In standard stock assessments conducted in the IO region, a index of abundance is essential to capture trends in biomass over time. In 2013, 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 (IOTC–2014–WPNT04–26: Sharma &Zhou)

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*), Indian Ocean Longtail (*Thunnus tonggol*), and narrow-barred Spanish Mackerel (*Scomberomorus commerson*).

Traditional Stock Reduction analysis approaches (SRA's) were compared to the Posterior Focussed Catch Reduction Approach (PFCRA)

<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).

In recent years (2010–12), 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).

Narrow-barred Spanish Mackerel (*Scomberomorus commerson*)

Basic Biology

[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.

Spanish mackerel are found in most of the countries on the shelf in the Indian ocean region (Figure A9). Spawning takes place on the edge of the reef, in warmer temperatures so that larvae experience conditions that are optimal and grow rapidly. They are known to undertake lengthy long-shore migrations, but permanent resident populations also seem to exist. Generally they are found in small schools (Collette 2001), and feed primarily on small fishes like anchovies, clupeids, carangids, squids and penaeoid shrimps.

Fisheries and Catch Trends

Catches have significantly increased in recent years (Figure A10). Prior to 2000, the catches were less than 100k T, and these have significantly increased in recent years (~141K t in the last 3 years). In recent years, the countries attributed with the highest catches of Spanish mackerel are Indonesia (28%) and India (22%) and, to a lesser extent, Iran, Myanmar, the UAE and Pakistan (26%) (Fig.A12).

The size of Spanish mackerel taken by the Indian Ocean fisheries typically ranges between 30 and 140 cm depending on the type of gear used, season and location. The size of Spanish mackerel taken varies by location with 32–119 cm fish taken in the Eastern Peninsular Malaysia area, 17–139 cm fish taken in the East Malaysia area and 50-90 cm fish taken in the Gulf of Thailand. Similarly, Spanish mackerel caught in the Oman Sea are typically larger than those caught in the Persian Gulf.[2]

[2] The IOTC Secretariat did not find any data in support of this statement.

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

Year	LOT(t)	KAW(t)	COM(t)
1950	2826	5567	9187
1951	2802	3246	9827
1952	3075	3276	9707
1953	3342	3234	9686
1954	3585	4486	11054
1955	3620	5372	10059
1956	3303	5855	14290
1957	4681	5390	13740
1958	3726	5067	12552
1959	4503	5267	13076
1960	4521	6970	13262
1961	4435	8678	15324
1962	5318	5988	16869
1963	6113	8261	17599
1964	7176	10149	19765
1965	7756	8772	19617
1966	9098	8818	23353
1967	9409	9872	25326
1968	9447	10489	26429
1969	8859	10447	25042
1970	8244	10645	23469
1971	7031	11760	25385
1972	8427	13645	30453
1973	7670	13756	27369
1974	12827	18466	36179
1975	14993	19854	36269
1976	15263	28856	41448
1977	15724	24756	49981
1978	17384	26004	49523
1979	19546	33975	55825
1980	19093	34023	53914
1981	20248	32899	56930
1982	29807	38508	65710
1983	26324	34794	57651
1984	31434	39022	64553
1985	35985	45577	79156
1986	38197	46067	87148
1987	51614	48669	93077
1988	55592	53423	99998
1989	49849	50849	83778
1990	43239	55291	74415
1991	48447	59738	76624
1992	41938	69644	83290
1993	46649	64501	81457
1994	50112	72323	87160
1995	68628	76238	97670
1996	62053	81261	88325
1997	63752	90252	95674
1998	73414	91567	101575
1999	74462	93337	100052
2000	90828	99769	104729
2001	82739	93799	97258
2002	78479	98959	100570
2003	79989	100008	103420
2004	72215	108529	103478
2005	67581	107569	93747
2006	82243	121634	115068
2007	96879	127910	119487
2008	98924	147271	127467
2009	116979	148010	134116
2010	132849	141090	135406
2011	165896	153597	145261
2012	160532	156017	143333

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), this approach was abandoned. In 2013, SRA approaches were pursued and used for stock status advice for Longtail, and Kawakawa. The SC adopted one of these approaches. The current approach extends the analysis to another species and also compares results of the Posterior focussed catch reduction based approach to the traditional approaches (Zhou et. al. 2013).

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 five methods to derive possible range for the intrinsic population growth rate r.

$r = 2\,\omega M$, 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, κ 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., $D = 0.05$ 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.

Surplus production Model using Catch data Only (Stock Reduction Model).

This simple model (eq. 1) was also used in this analysis. It has two unknown parameters, r and K. We set reasonably wide prior range, for example, *K* between C_{max} and 500 * C_{max}. We used the approach proposed in Martell and Froese (2012) for "resiliency" estimates that tied to the productivity parameter r (low resiliency levels indicated r between 0.05-0.5, medium resiliency indicated a r between 0.2-1, and high between 0.5-1.5). These were compared to values obtained in the literature and alternative methods.

We run model (eq. 1) to find all mathematically feasible *r* values by searching through wide range of Ks for all depletion levels. The model begins at K in 1950 (eq.1). If the feasible choice of r and k chosen meets the intermediate (0.1 and 1 level of depletion in 1980), and last point depletion levels (the range specified was 0.3-0.7 level of depletion for all 3 species) it is kept. The summary of all runs which meet these criteria are then used, and geometric mean values are reported to be the better representation of yield targets (Martell and Froese 2012). Biological parameters, including K, r, MSY, are derived from the retained pool of [r, K] values. The geometric mean values of these are then used to assess the stock dynamics over time and reported using a phase plot.

Results

Posterior Focussed Catch Reduction Approach (PFCRA)

<u>Kawakawa</u>

The five methods results in a range of *r* from 0.97to 1.84 for kawakawa. We first explored how assumed depletion may affect the result. We used 16 assumed depletion level in 2012: 0.05, 0.1,…0.8 (Figure 1). The results indicate that with the r range used, the population must have been greater than 25% of unfished level in 2012. 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 0.05 and 0.80 at a step of 0.05 in Model 1 and combined all feasible results . The possible unfished population may range from about 300K ton to nearly 800 K ton . The lowest possible depletion level is 0.25.

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

Upper d	Quantile	K	r	MSY	Bend	D
0.8	0%	310,445	0.98	117,639	234,195	0.49
0.8	25%	400,842	1.12	133,340	271,449	0.57
0.8	50%	459,976	1.30	148,024	283,575	0.60
0.8	75%	551,726	1.53	177,585	299,303	0.63
0.8	100%	951,973	1.83	242,681	356,312	0.74
0.7	0%	310,445	0.98	117,639	205,151	0.47
0.7	25%	385,388	1.12	131,324	232,739	0.53
0.7	**50%**	**433,634**	**1.30**	**140,168**	**241,506**	**0.55**
0.7	75%		1.52			0.57

		497,606		158,656	251,910	
0.7	100%	708,862	1.83	179,964	283,682	0.65
0.6	0%	310,445	0.98	117,639	171,844	0.41
0.6	25%	370,529	1.10	127,819	194,838	0.46
0.6	50%	416,915	1.28	135,505	202,211	0.48
0.6	75%	469,108	1.50	142,986	209,619	0.50
0.6	100%	593,914	1.83	153,434	239,518	0.57
0.5	0%	310,445	0.98	117,639	146,897	0.36
0.5	25%	363,317	1.09	125,408	166,587	0.40
0.5	50%	412,857	1.25	130,657	173,188	0.42
0.5	75%	459,976	1.46	134,897	181,233	0.44
0.5	100%	538,314	1.81	140,676	206,859	0.51

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, 0.60, and 0.50. Again, assuming a higher D results in a higher r, K, MSY, B_{2012}, and D_{2012} (Table 2). However, the magnitude appears to be relatively small. For example, for the three assumed upper depletions, MSY is about 148, 140, 136, and 131 thousand tons, respectively.

While the catch increases over time, biomass continues to decline (Figure 2). Based on some projections run, the 2012 level of catch maybe too high, and should be reduced.. When, we assumed that annual catch at MSY tonnes for the next 10 years (Figure 3), the population will become stable. However, if the catch continues at the 2012 level, the population will decline quickly (Figure 4).

<u>Longtail tuna</u>

The five methods results in a range of r from 0.69 to 1.34 for Longtail tuna. Again, we used depletion level between 0.05 and 0.80 at a step of 0.05 in Model 1 and combined all feasible results (Figure 5). The possible unfished population may range from about 460 thousand ton to 540 kt (Figure 5). The lowest possible depletion level is 0.25. Similar to Kawakawa there is declining trend in abundance (Figure 6).

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

Upper d		K	r	MSY	Bend	D
0.8	0%	357,109	0.69	89,595	260,096	0.44
0.8	25%	461,093	0.81	109,493	308,916	0.53
0.8	50%	539,621	0.94	128,466	333,776	0.57

0.8	75%	703,666	1.12	167,061	357,954	0.61
0.8	100%	1,256,617	1.34	251,926	412,946	0.71
0.7	0%	357,109	0.69	89,595	216,129	0.41
0.7	25%	443,316	0.80	106,339	261,782	0.50
0.7	**50%**	**508,717**	**0.94**	**119,576**	**275,661**	**0.53**
0.7	75%	595,356	1.11	141,282	287,281	0.55
0.7	100%	899,632	1.34	181,037	334,105	0.64
0.6	0%	357,109	0.69	89,595	188,003	0.39
0.6	25%	426,225	0.80	102,928	217,053	0.45
0.6	50%	479,583	0.93	113,335	225,078	0.47
0.6	75%	529,117	1.11	124,374	233,755	0.49
0.6	100%	710,582	1.34	145,954	262,642	0.55
0.5	0%	357,109	0.69	89,595	158,075	0.35
0.5	25%	409,792	0.79	99,372	185,881	0.41
0.5	50%	461,093	0.93	106,968	192,618	0.42
0.5	75%	503,766	1.09	114,647	198,945	0.44
0.5	100%	619,230	1.34	126,545	224,374	0.49

We applied four assumed upper depletion limits: D = 0.80, 0.70, 0.6, and 0.50 (Table 3). Corresponding to these levels, the median MSY varies between 128, 120, 113, and 107 thousand tons, and the median depletion levels are 0.57, 0.53, 0.47, and 0.42, respectively. Like kawakawa, we explored two catch scenarios for the next 10 years: catch at MSY (119,576 t) (Figure 7) and catch remains at 2012 level from 2013 to 2022 (Figure 8). Clearly, the current catch level is unsustainable, while reducing catch to MSY level would make the population stable.

Spanish Mackerel

The five methods results in a range of r from 0.70 to 1.67 for Spanish mackerel. The possible unfished population may range from about 454 to 511 thousand ton (Figure 9). The lowest possible depletion level is 0.20. Similar to the other two tuna species there is declining trend in abundance (Figure 10).

MSY levels are near 120K t, based on D=0.8, 0.7, 0.6, and 0.5 respectively (Table 4). Catch trends that are increasing indicate a downward trend in biomass (Figure 10). Catch needs to be reduced to at least MSY level to stabilize the stock (Figure 11).

Table 4. Posterior key biological parameters for Spanish Mackerel under three assumed upper depletion levels.

Upper d	Quantile	K	r	MSY	Bend	D
0.8	0%	306,603	0.71	100,918	240,780	0.46
0.8	25%	419,930	0.86	116,584	280,530	0.54
0.8	50%	511,154	1.05	130,991	297,375	0.57
0.8	75%	622,196	1.30	161,914	315,280	0.60
0.8	100%	1,190,326	1.67	227,207	387,055	0.72
0.7	0%	306,603	0.71	100,918	203,957	0.42
0.7	25%	403,740	0.85	113,973	236,130	0.49
0.7	50%	**481,880**	**1.04**	**124,367**	**247,484**	**0.51**
0.7	75%	563,949	1.29	141,244	257,346	0.53
0.7	100%	886,345	1.67	169,147	296,079	0.62
0.6	0%	306,603	0.71	100,918	156,450	0.34
0.6	25%	388,174	0.84	111,462	196,971	0.42
0.6	50%	463,302	1.03	119,788	206,538	0.44
0.6	75%	542,206	1.28	128,462	217,320	0.47
0.6	100%	742,617	1.67	143,220	257,088	0.55
0.5	0%	306,603	0.71	100,918	134,142	0.30
0.5	25%	384,396	0.83	108,909	168,187	0.37
0.5	50%	454,283	1.00	115,231	176,811	0.39
0.5	75%	521,302	1.25	121,076	183,814	0.41
0.5	100%	659,994	1.66	129,638	206,568	0.46

Traditional Stock Reduction Approaches (SRA approach outlined in Martell and Froese 2012).

Based on the assumptions used in the simulations (describe in methods), i.e. all three stocks are highly resilient (r between 0.5-1.5), and if the feasible choice of r and k chosen meets the intermediate (0.1 and 1 level of depletion in 1980), and last point depletion levels (the range specified was 0.3-0.7 level of depletion for all 3 species) it is kept. Results using these criteria, and the a limit on K being 500 times the maximum catch seen, the results for all three species are summarized in Table 5 (Figure 12 for Kawakawa, Figure 13 for Longtail and Figure 14 for Spanish Mackerel).

Table 5: Traditional SRA Approaches and reference points for the three stocks

	KAW		LOT		COM	
Pars	**Geo. Mean**	**CI (95%)**	**Geo. Mean**	**CI (95%)**	**Geo. Mean**	**CI (95%)**
r	1.13	0.73 - 1.76	1.16	0.757 - 1.77	1.19	0.734 - 1.92
K	511020	351159 - 743654	464874	338493 - 638442	458973	304532 - 691737
MSY	144995	114748 – 183215	134697	98964 – 183334	136344	107926 – 172245
B_{MSY}	255510	175580-371827	232437	169246-319221	229487	152266-345869
B_{2012}	295866	144220-447510	260303	142993-389612	270146	126698-413594
B_{2012}/B_{MSY}	1.15	0.77-1.5	1.12	0.81-1.43	1.17	0.79-1.49
F_{2012}/F_{MSY}*	0.99	0.54-1.45	1.08	0.59.1.58	0.98	0.53-1.41

* Arithmetic Mean reported

Sensitivity with Measurement Error and Process Error

Measurement Error Effects

Simulations were run with uncertainty in the catch data with a CV of 0.2, 0.4 and 0.6. Results indicate that if the data is imprecise (but not biased), the results (median estimates) remain the same. The skew in the distribution widens, but not by an amount greater than 10% in the case of the situation with the measurement error being greater than a CV of 0.5.

Process Error Effects

If there is a lot more noise in the stock recruit relationship, then the PE gets larger in equation 1 (above). Situations indicating that with a process error CV of 0.05 (results shown for COM in Figure 15), the r values decline by ~25% while k values increase by ~20%., thereby having a reduction in Yield targets of 10-15%, raising the B_{MSY} values by 20%, and thereby giving a bleaker picture of the stock.

Kobe Plots with Uncertainty

Stock trajectories are provided for the three stocks with uncertainty in the last point in Figure 16. While both kawakawa and Spanish-Mackerel appear healthy, though at full exploitation levels, longtail appears to be experience overfishing, but not yet overfished.

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 135 k tons (Table 2, assuming maximum depletion in 2012 is 60%). It is however, likely that depletion is probably around 50% -60% in 2012. Using catch targets of 135k tons over the entire Indian Ocean gives us a population that is sustainable (Figure 4).

For longtail, a similar conclusion could be reached (Table 3). Here the optimal yield targets are slightly lower 115k t-120k tons, with depletion assumed to be around 60%. Once again it appears that the in 2012, the resource is fully utilized (around 50% maximum depletion levels). Catches in recent years (around 160k tons in 2012) are probably too high and if fishing is kept at these levels the population will be severely depleted in 10 years. Catches around 119k T (optimal yield levels) seems to keep the stock sustainable for the long term.

For Spanish Mackerel, we have a similar conclusion where MSY is around 120K t, depending on the maximum levels of depletion assumed. Current catch levels of 140K t, appear to be too high and need to be reduced as well to keep the stock sustainable.

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 130k for kawakawa, 110k for longtail tuna and Spanish Mackerel in the Indian Ocean respectively.

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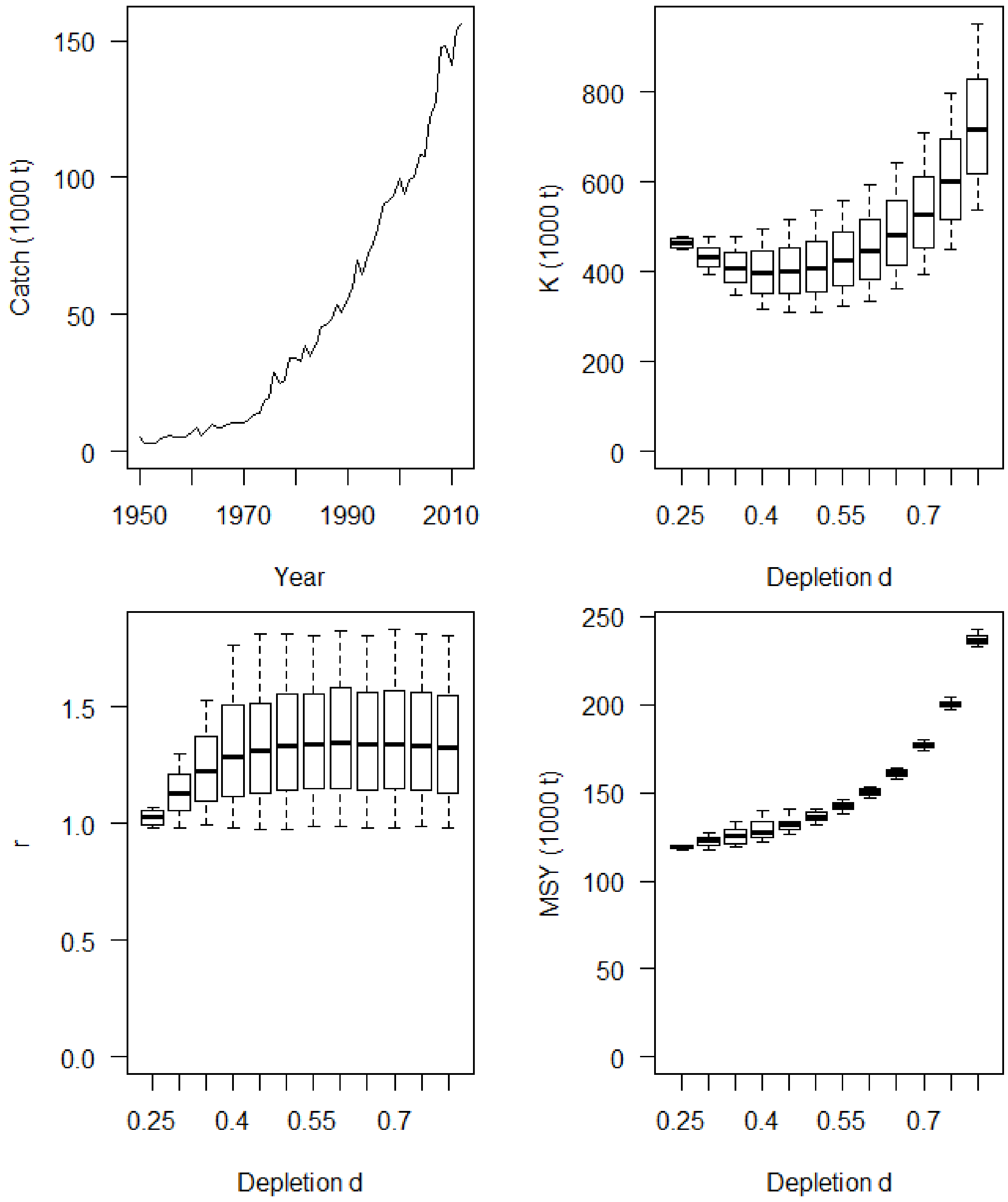

Figure 1. Kawaka catch history, feasible carrying capacity, population growth rate, and maximum sustainable yield at each assumed depletion level. There is no feasible solution when the depletion is assumed to be smaller than 0.25.

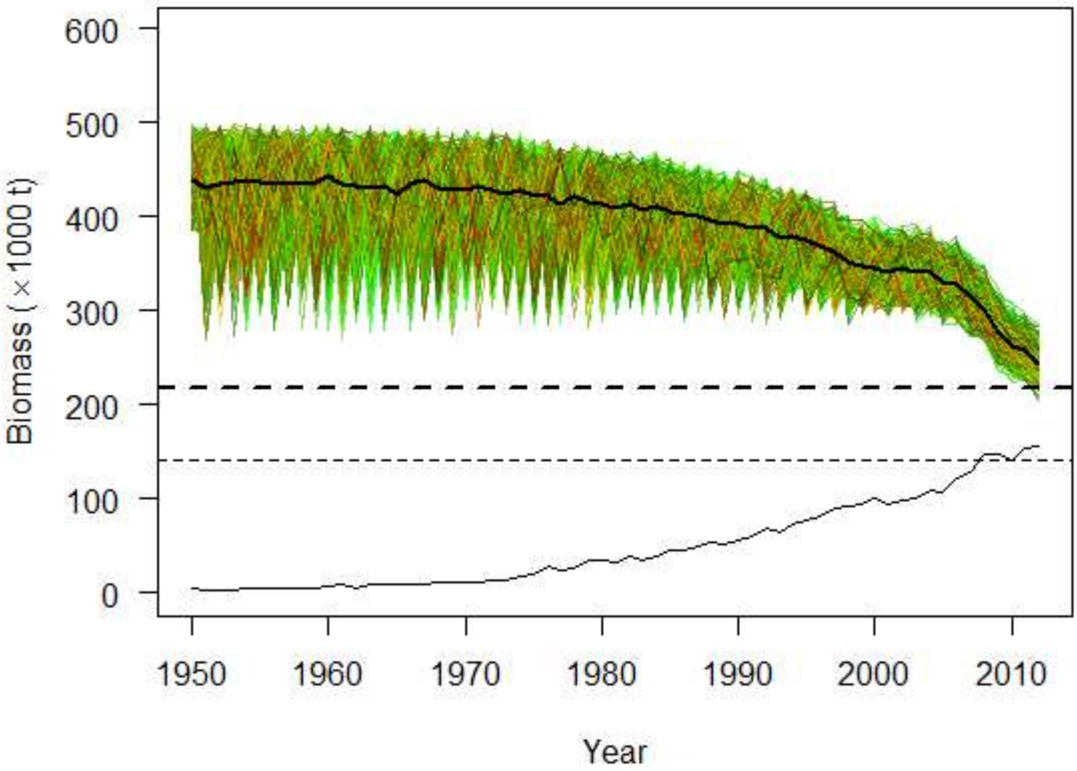

Figure 2. Kawakawa biomass (in thousand tonnes) trajectories from 500 simulations with upper depletion d = 0.7. The dark line is the median biomass and the thin line is the catch. The thick dashed line is the target biomass B_{MSY} and the thin dashed line is the optimal yield MSY.

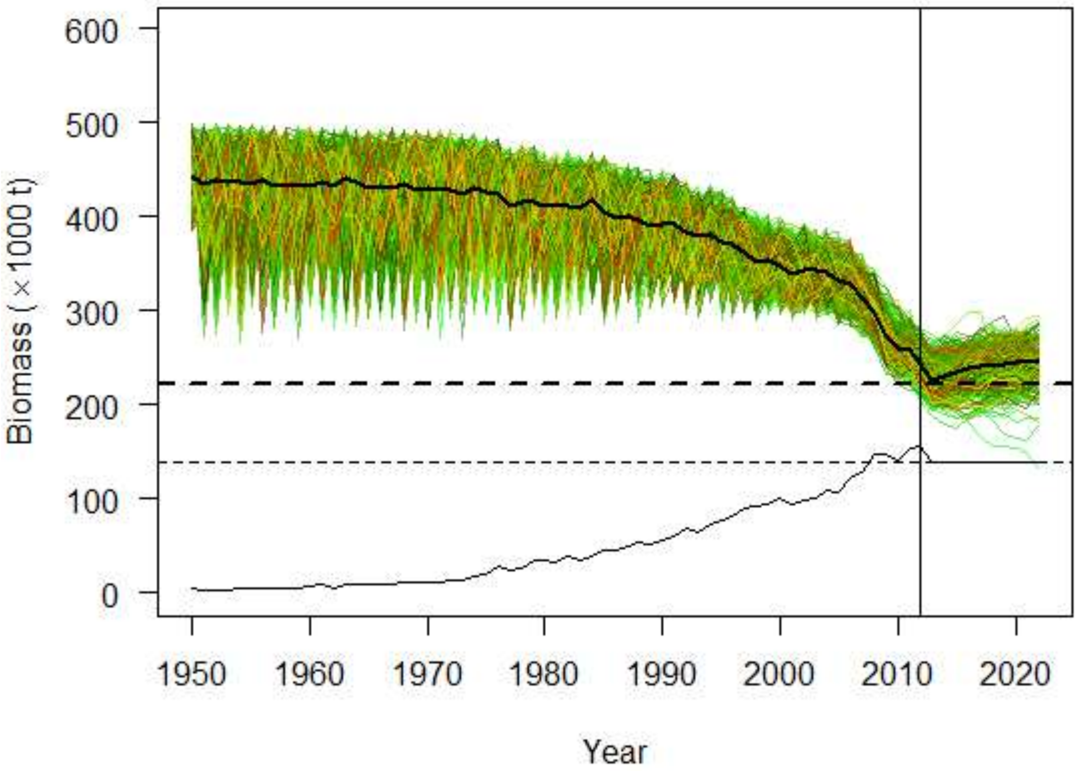

Figure 3. Projected kawakawa biomass trajectories under hypothetic annual catch level at MSY (139,754 tonnes) for 10 years. The vertical line is the last year (2012) when catch data are available.

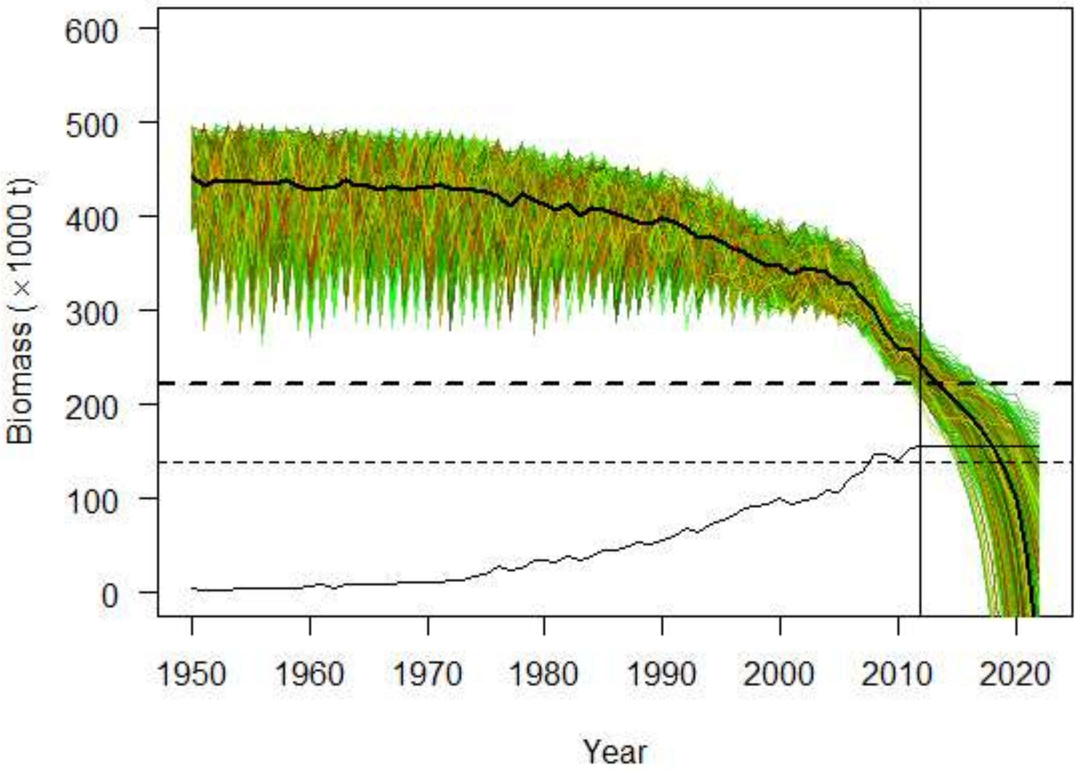

Figure 4. Projected kawakawa biomass trajectories under hypothetic annual catch at 2012 level (156,017 tonnes) for 10 years. The vertical line is the last year (2012) when catch data are available.

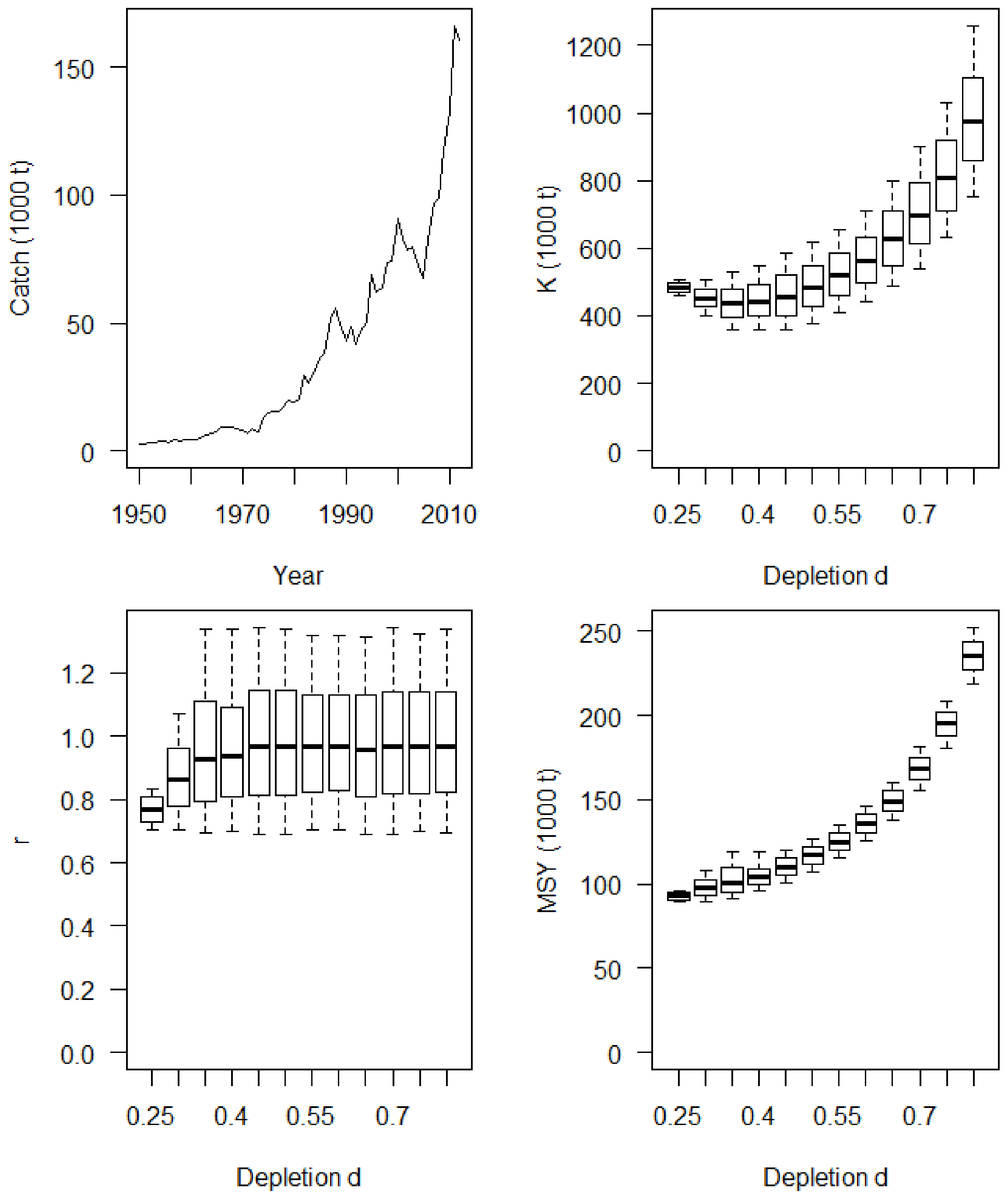

Figure 5. Longtail tuna catch history, feasible carrying capacity, population growth rate, and maximum sustainable yield at each assumed depletion level. There is no feasible solution when the depletion is assumed to be smaller than 0.25.

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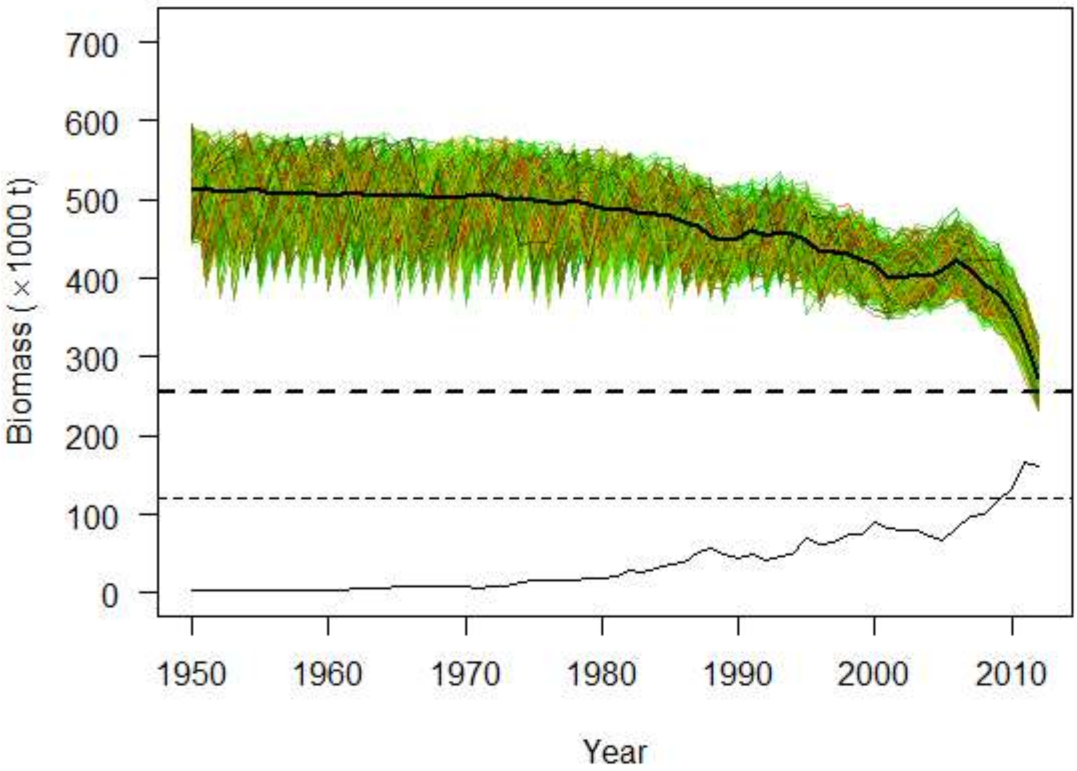


Figure 6. Longtail biomass trajectories from 500 simulations with upper depletion d = 0.7. The dark line is the median biomass and the thin line is the catch. The thick dashed line is the target biomass B_{MSY} and the thin dashed line is the optimal yield MSY.

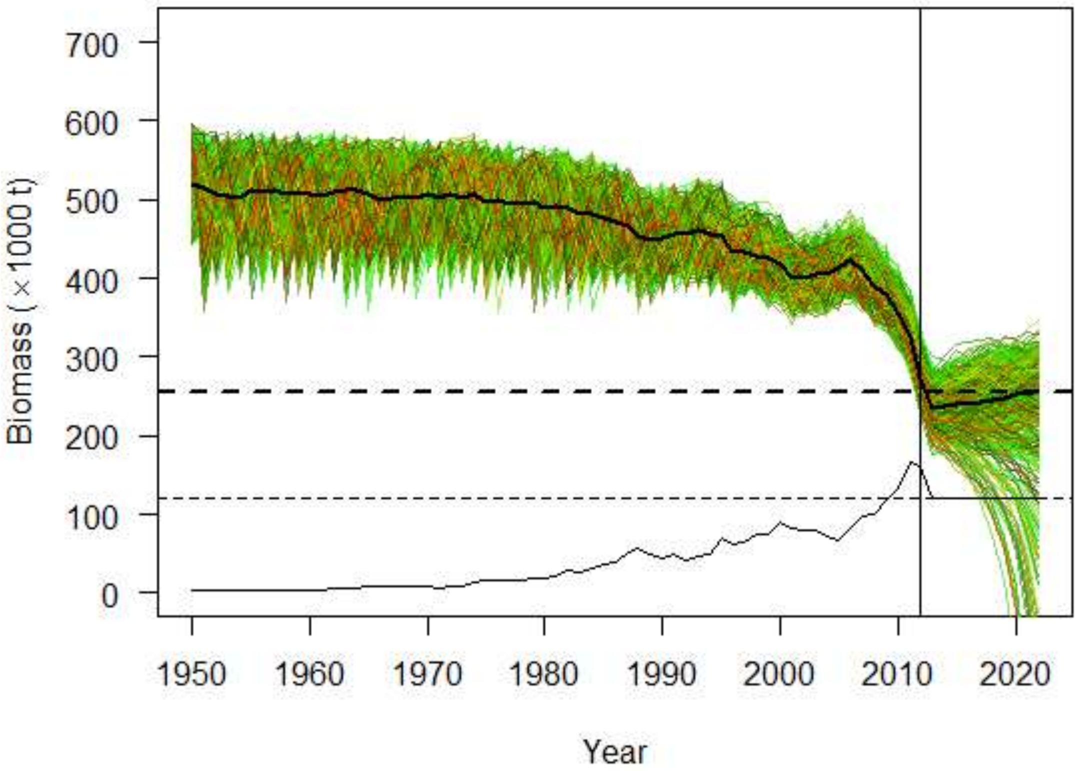


Figure 7. Projected Longtail biomass trajectories under hypothetic annual catch level at MSY (119,576 tonnes) for 10 years. The assumed upper depletion level is 0.7. The vertical line is the last year (2012) when catch data are available. The dark line is the median biomass.

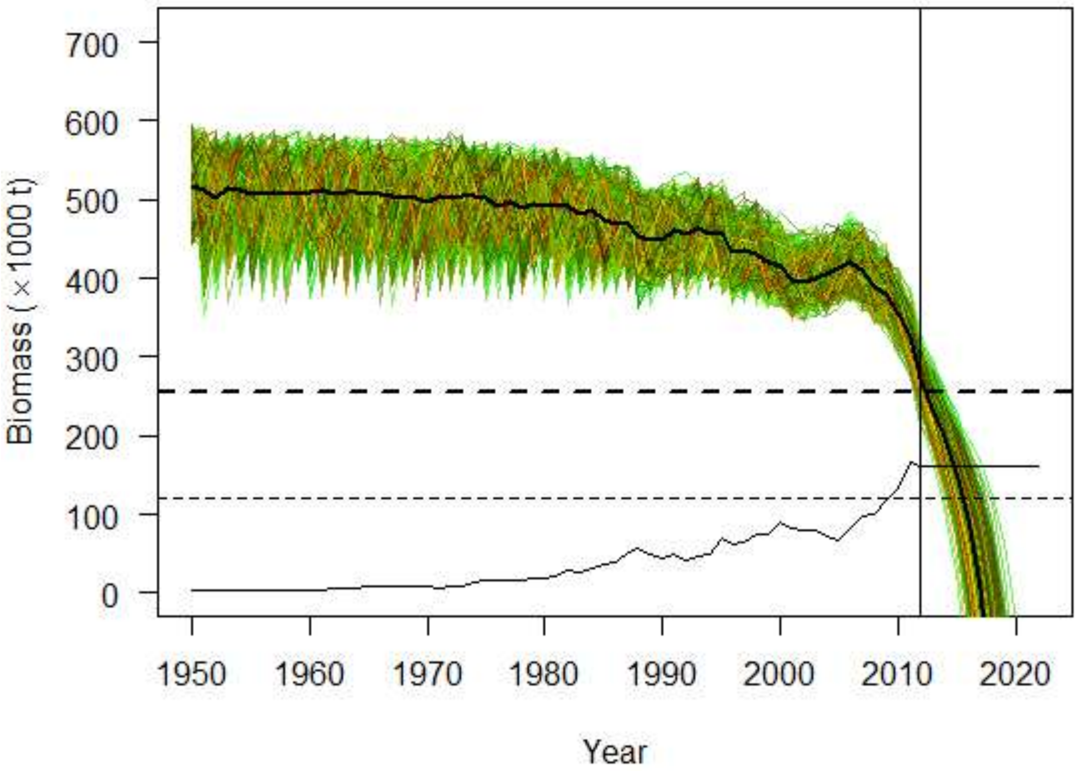


Figure 8. Projected Longtail biomass trajectories under hypothetic annual catch at 2012 level (160,532 tonnes) for 10 years. The vertical line is the last year (2012) when catch data are available.

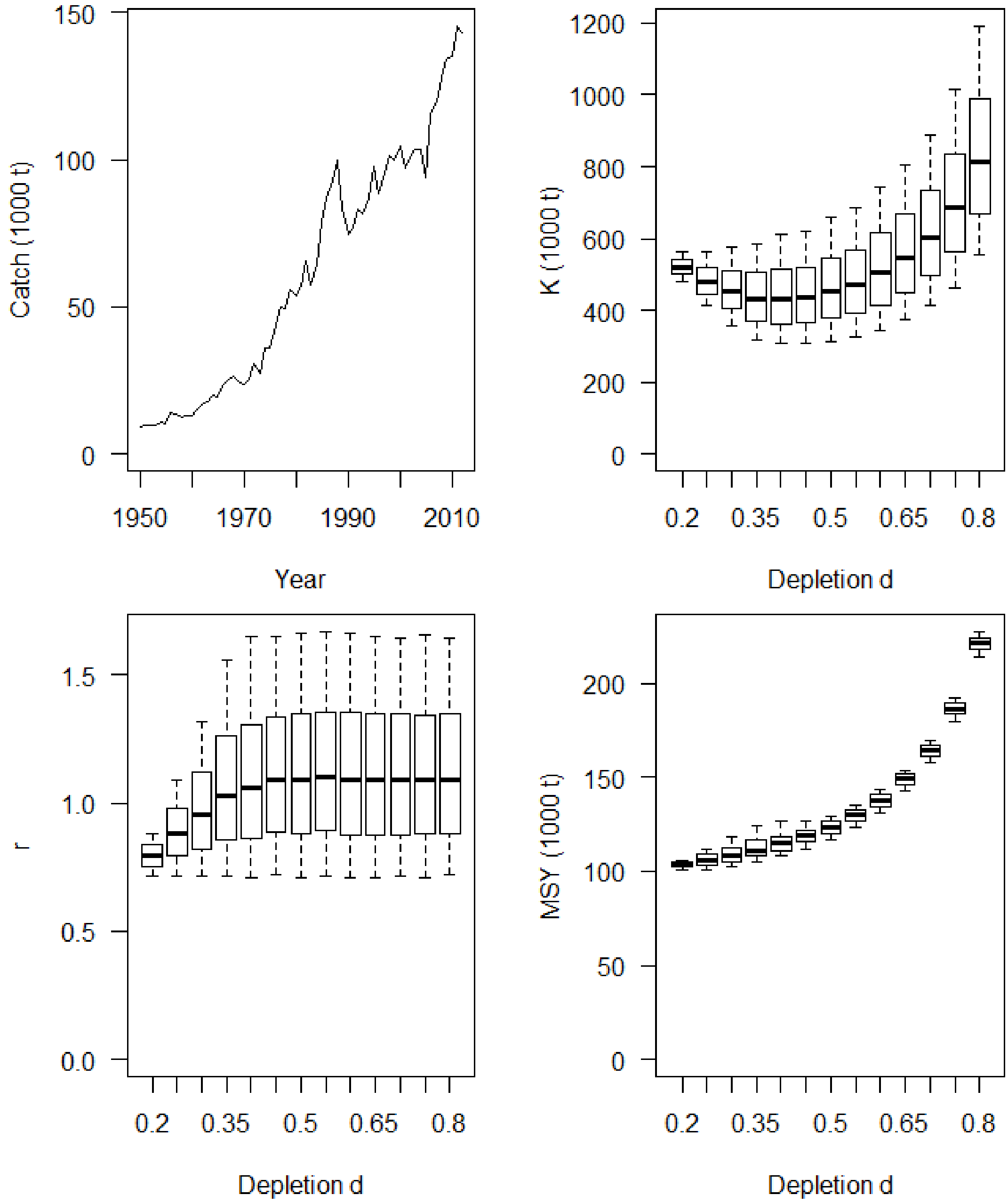


Figure 9. Spanish Mackerel catch history, feasible carrying capacity, population growth rate, and maximum sustainable yield at each assumed depletion level. There is no feasible solution when the depletion is assumed to be smaller than 0.20.

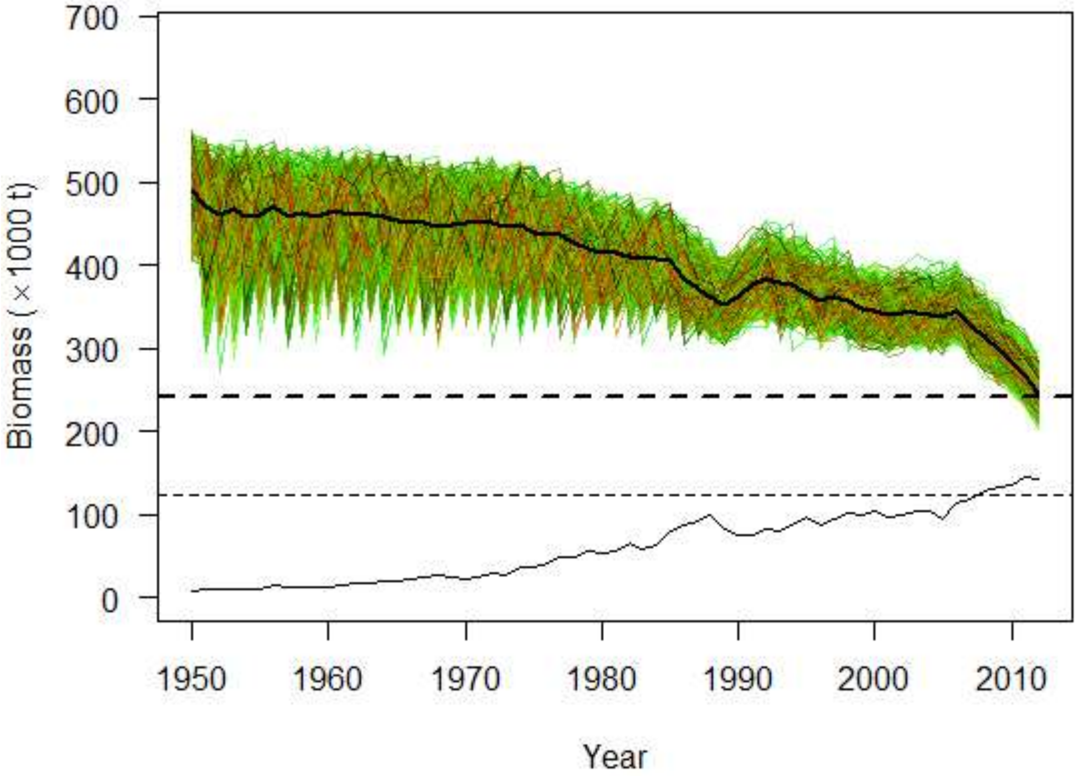


Figure 10. Spanish Mackerel biomass trajectories from 500 simulations with upper depletion d = 0.7. The dark line is the median biomass and the thin line is the catch. The thick dashed line is the target biomass B_{MSY} and the thin dashed line is the optimal yield MSY.

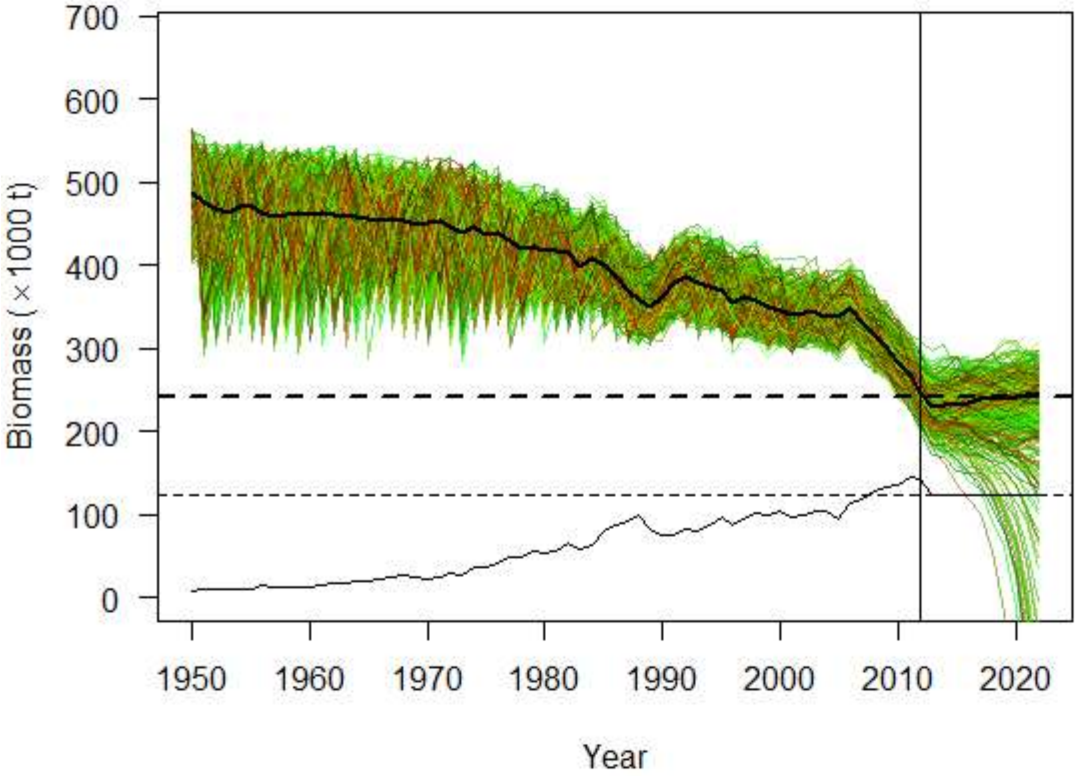


Figure 11. Projected Spanish Mackerel biomass trajectories under hypothetic annual catch level at C = MSY= 124367 tonnes for 10 years. The assumed upper depletion level is 0.7. The vertical line is the last year (2012) when catch data are available. The dark dashed line is the median biomass.

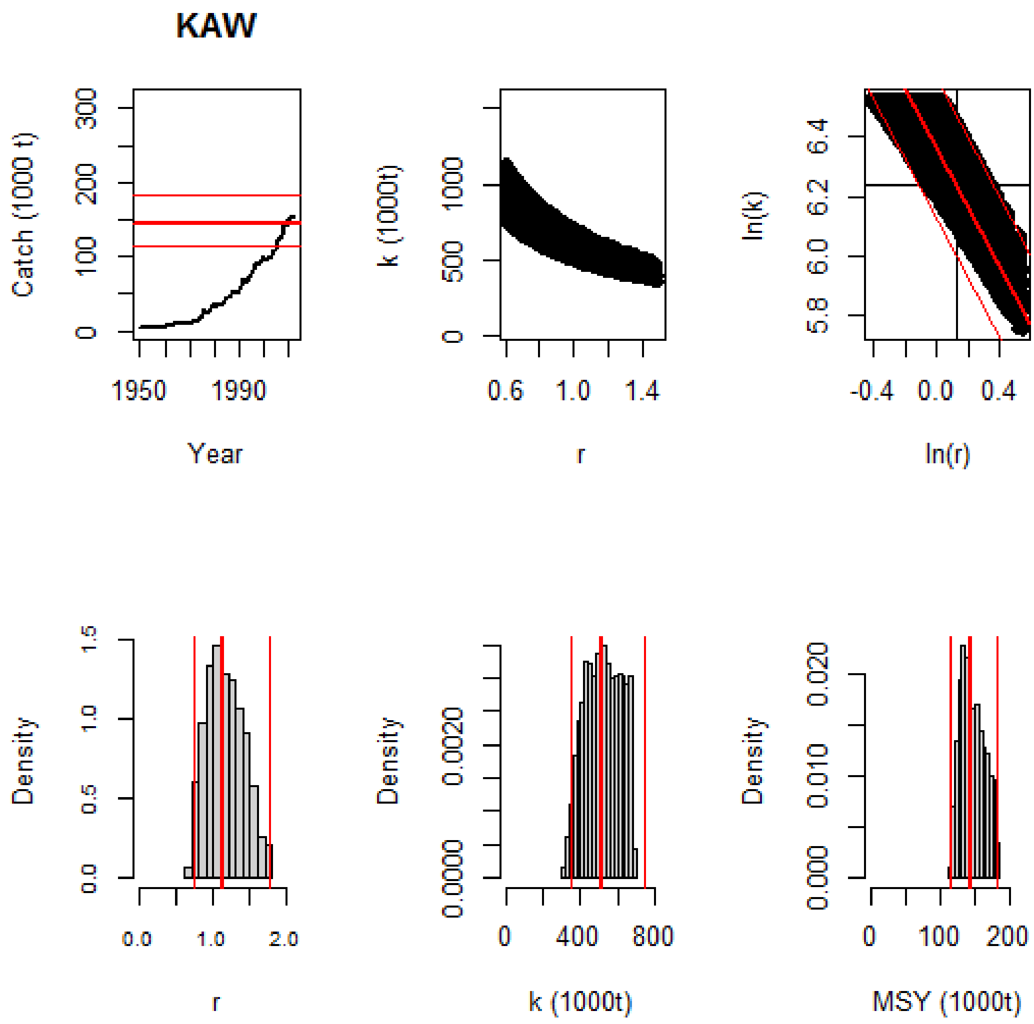


Figure 12: SRA Approaches adopted from Martell and Froese (2012) applied on Kawakawa. The upper three panels show the catch trajectory, the correlation between r and k in real and log space, and the bottom 3 panels show the distribution of r, K and MSY.

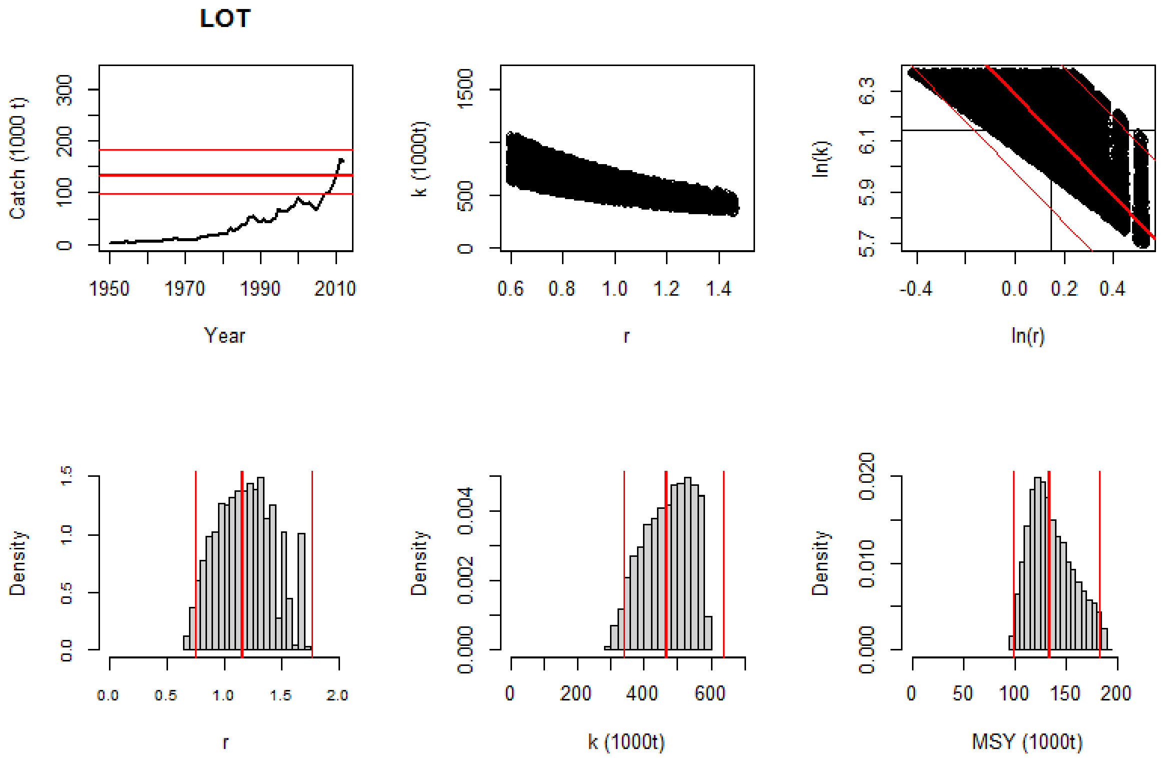
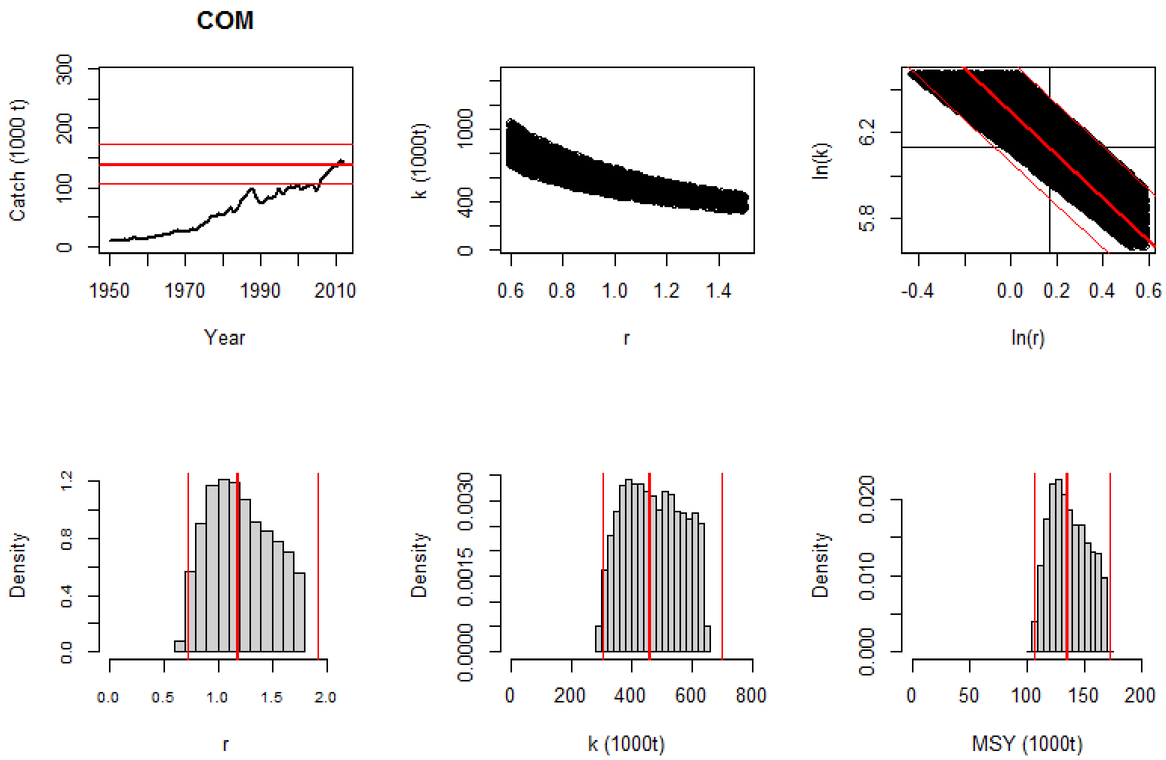


Figure 13: SRA Approaches adopted from Martell and Froese (2012) applied on Longtail. The upper three panels show the catch trajectory, the correlation between r and k in real and log space, and the bottom 3 panels show the distribution of r, K and MSY.



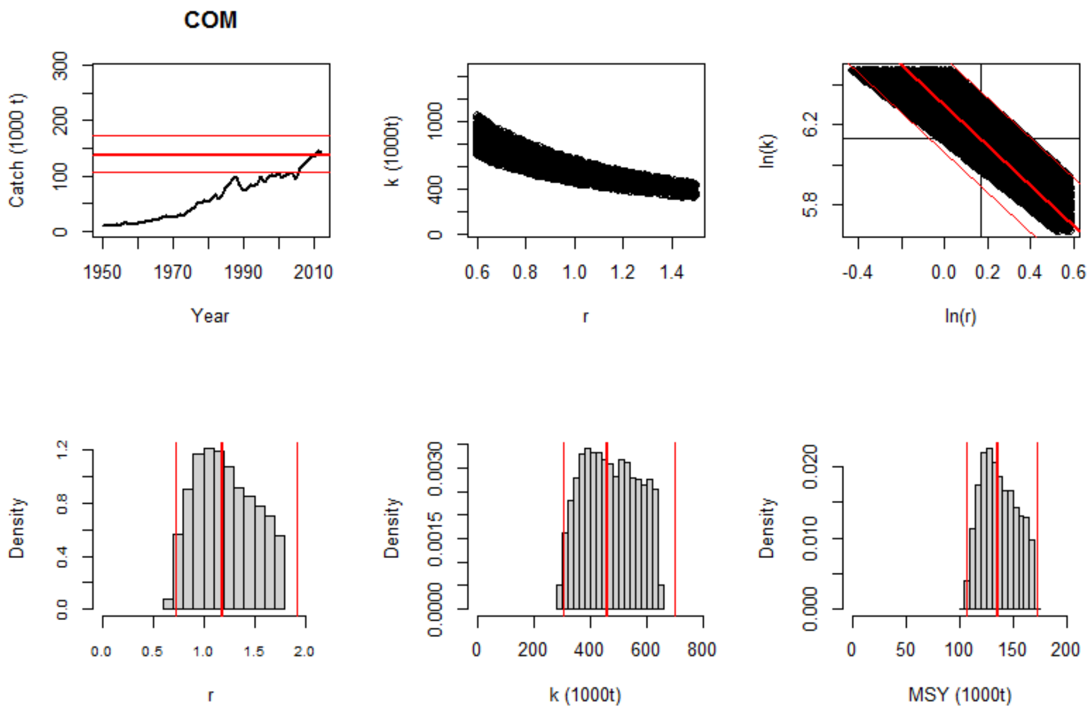


Figure 14: SRA Approaches adopted from Martell and Froese (2012) applied on Spanish-Mackerel. The upper three panels show the catch trajectory, the correlation between r and k in real and log space, and the bottom 3 panels show the distribution of r, K and MSY.

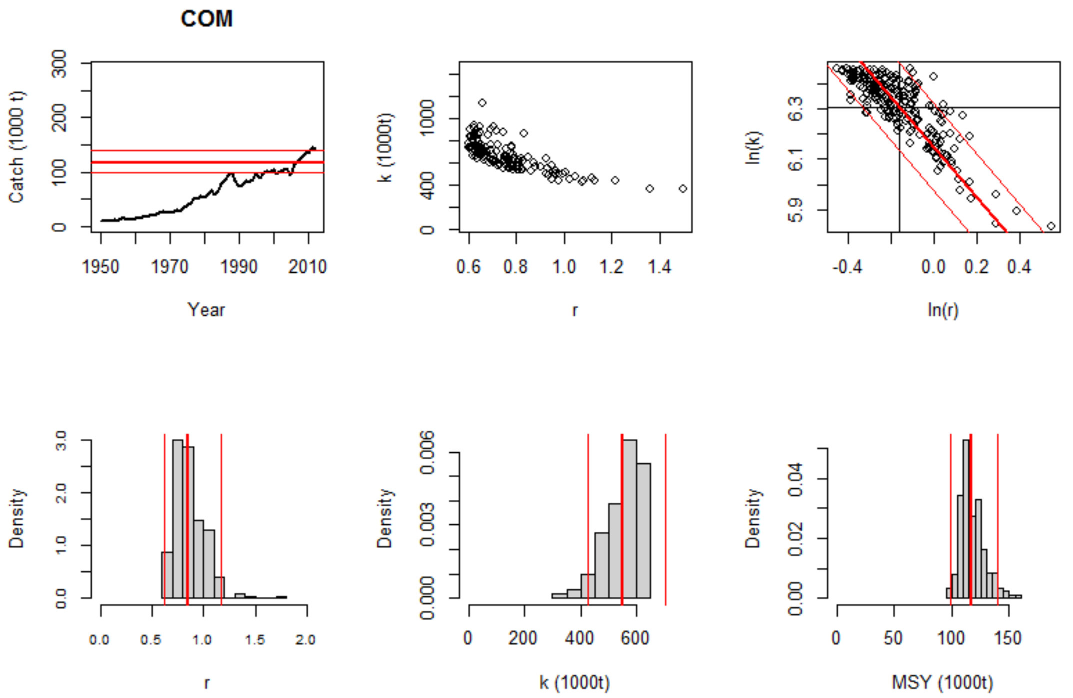


Figure 15: SRA Approaches adopted from Martell and Froese (2012) applied on Spanish-Mackerel with a process error of 0.05. The upper three panels show the catch trajectory, the correlation between r and k in real and log space, and the bottom 3 panels show the distribution of r, K and MSY.

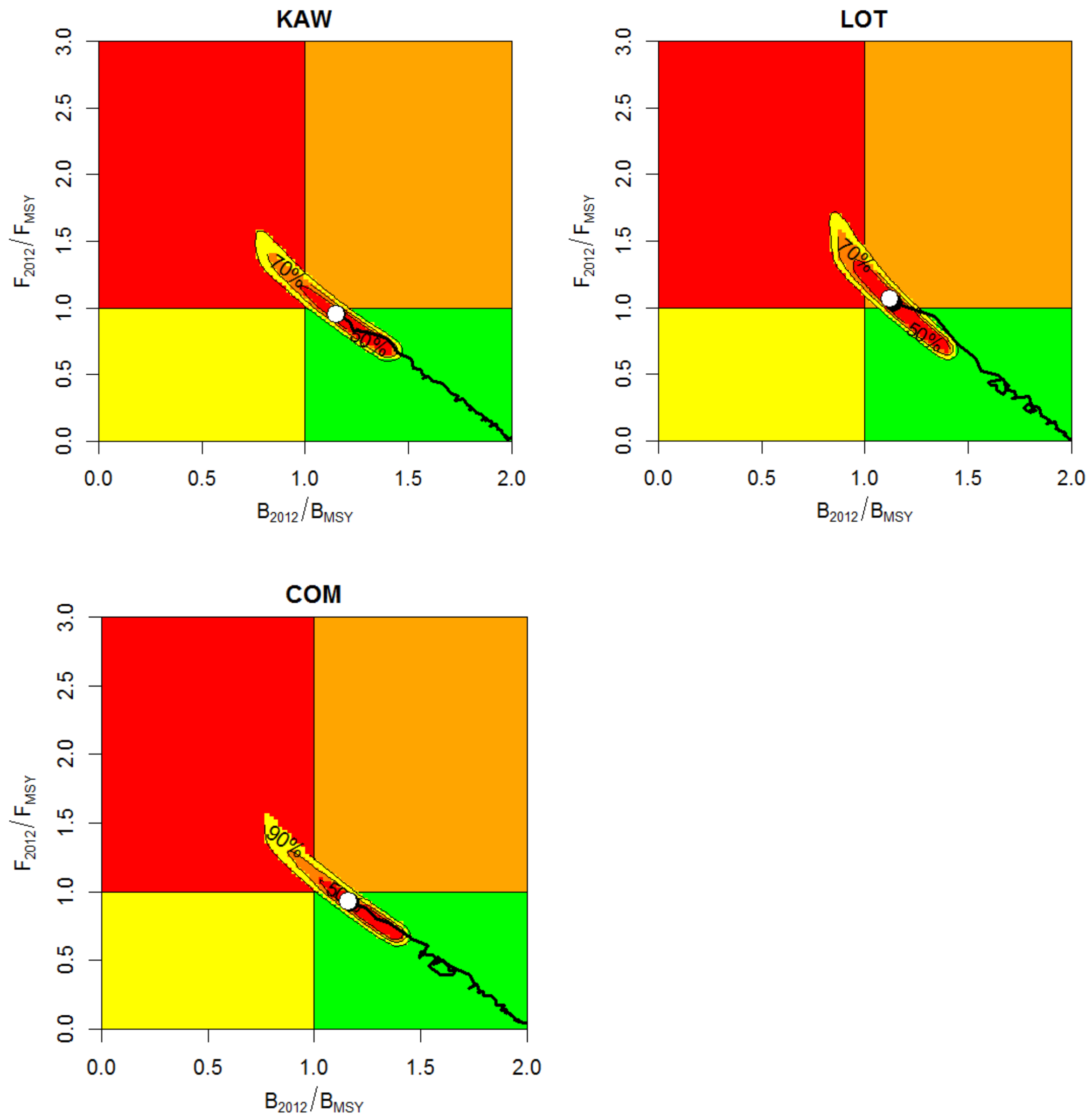


Figure 16: Kobe plots with uncertainty on the last point for KAW, LOT and COM respectively using the SRA approaches (Martell and Froese 2012).

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

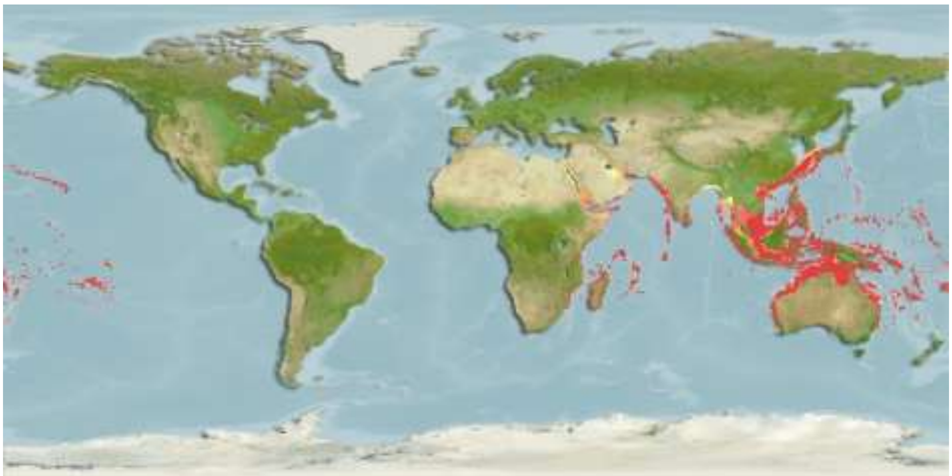


Figure A1: Kawakawa Global distribution (source: www.fishbase.org)

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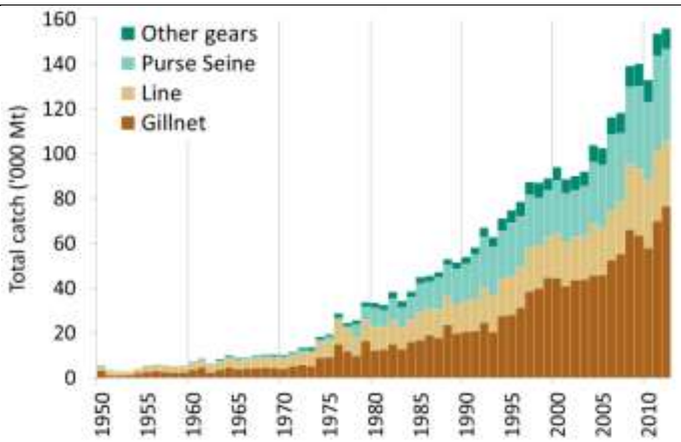


Figure A2. Kawakawa: Annual catches of kawakawa by gear recorded in the IOTC database (1950–2012)

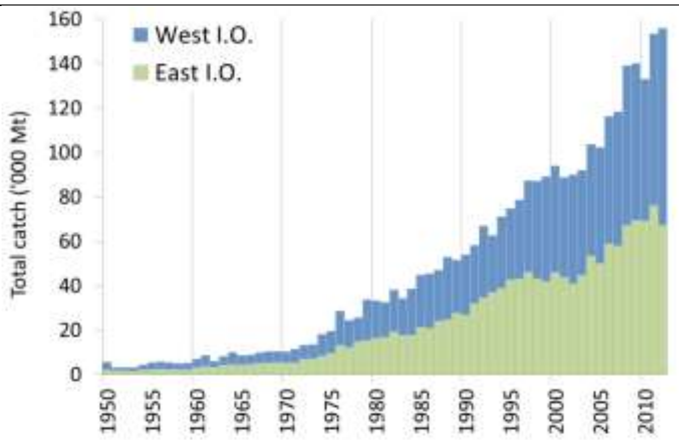
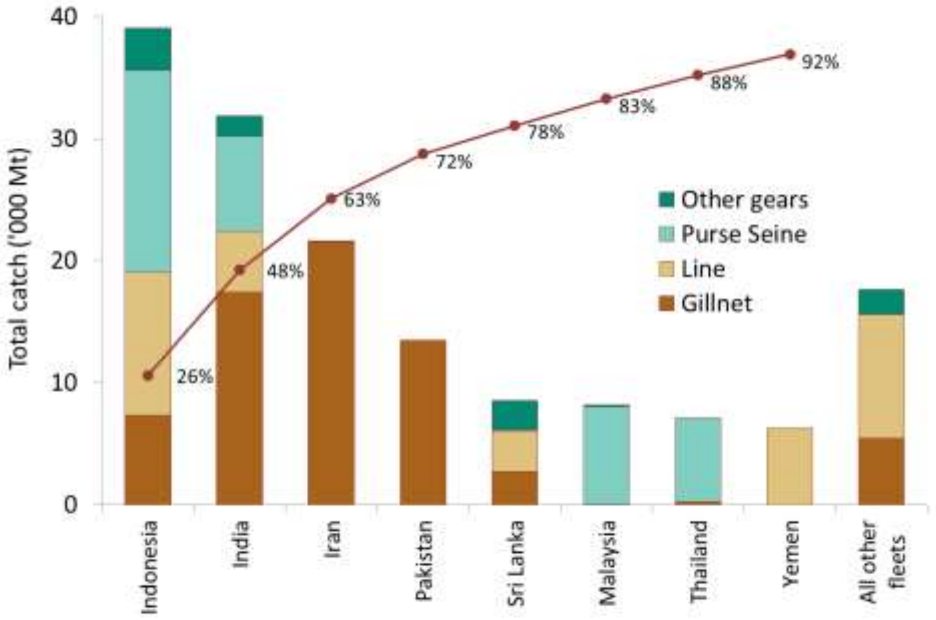
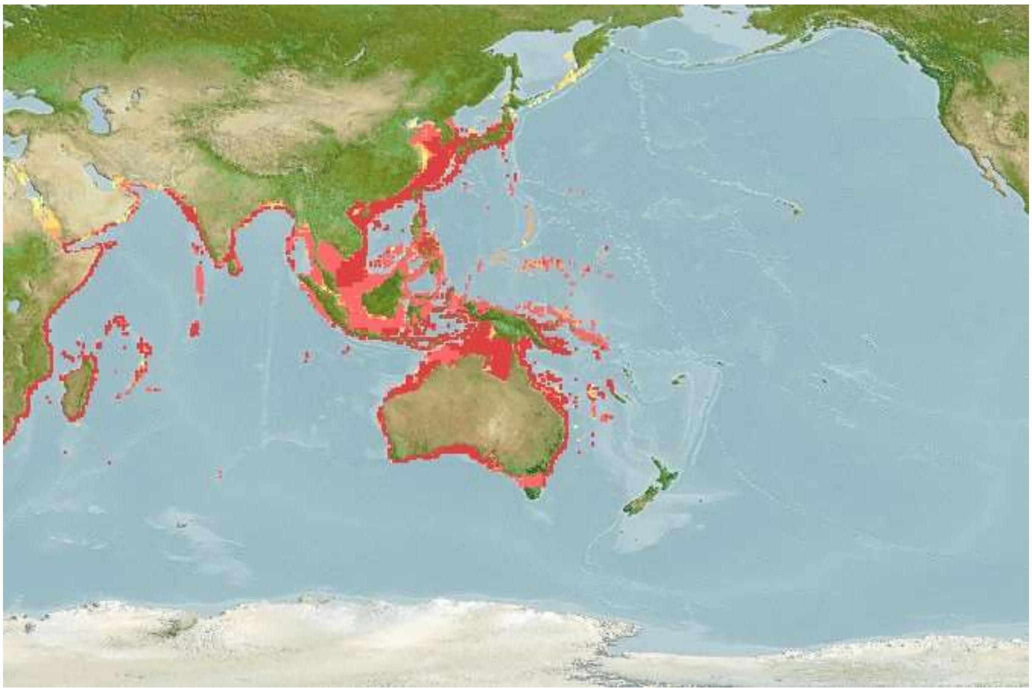


Figure A3. Kawakawa: Annual catches of kawakawa by IOTC area recorded in the IOTC database (1950–2012)



<u>Figure A4:</u> *Kawakawa***: *average catches in the Indian Ocean over the period 2010-2012, by country. Countries are ordered from left to right, according to the importance 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.***



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

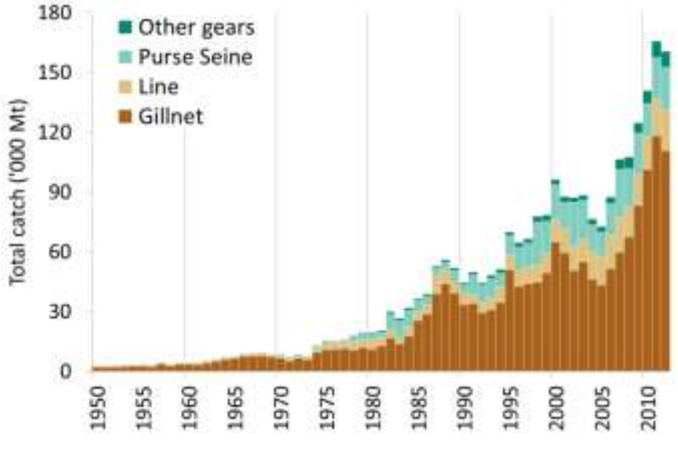


Figure A6. Longtail tuna: Annual catches of longtail tuna by gear recorded in the IOTC Database (1950–2012)

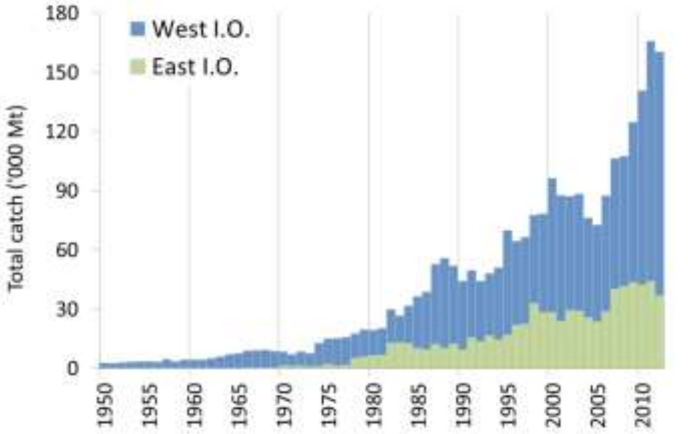


Figure A7. Longtail tuna: Annual catches of longtail tuna by IOTC area recorded in the IOTC Database (1950–2012)

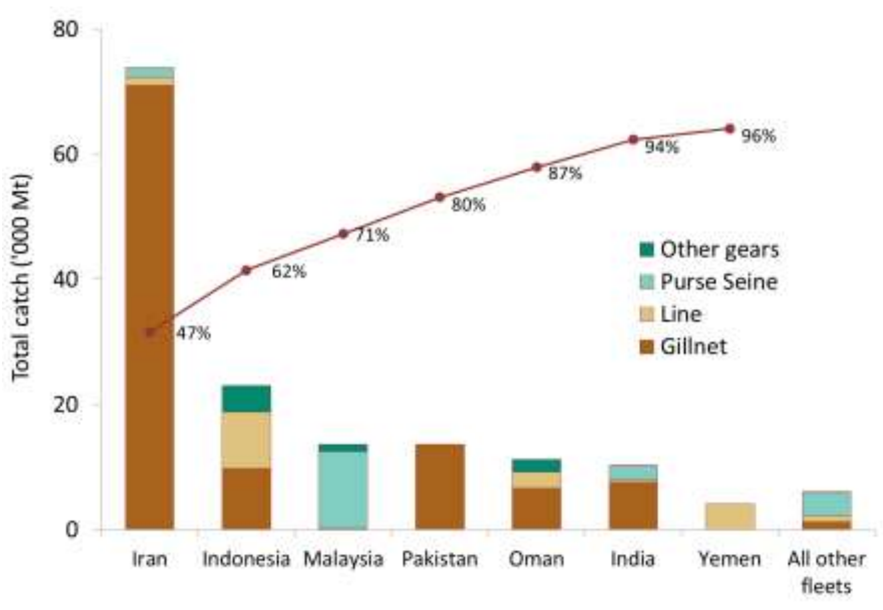


Fig. A8: Longtail tuna: Average catches in the Indian Ocean over the period 2010–12, by country.
Countries are ordered from left to right, according to the importance of catches of longtail reported. The red line indicates the (cumulative) proportion of catches of longtail tuna for the countries concerned, over the total combined catches of this species reported from all countries and fisheries.

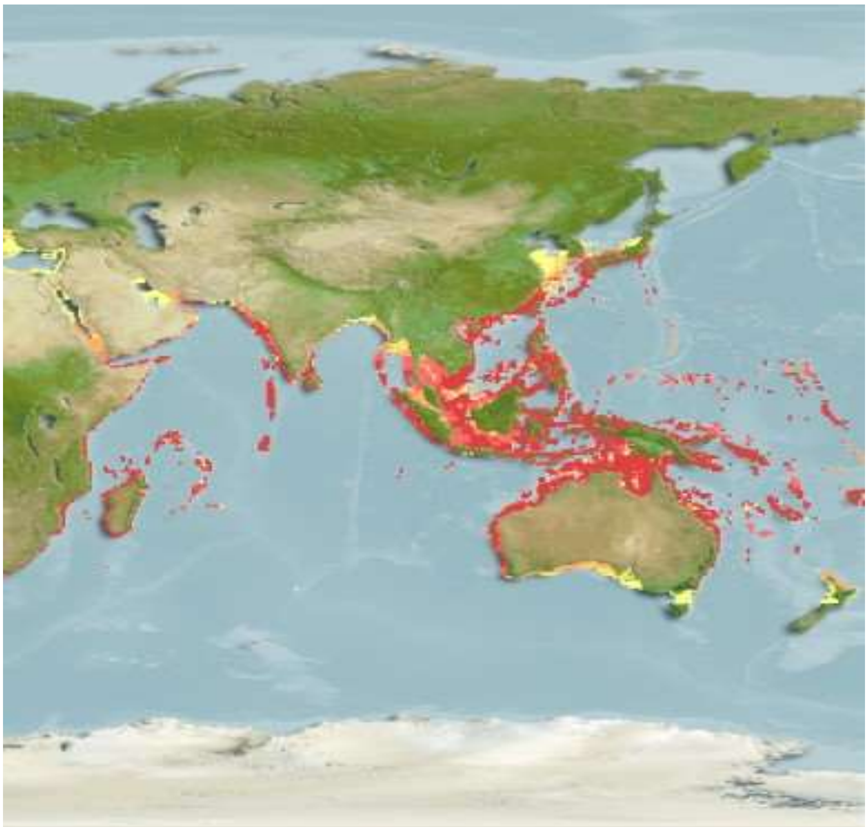


Figure A9: Indian Ocean Species distribution for narrow-barred Spanish Mackerel (source www.fishbase.org)

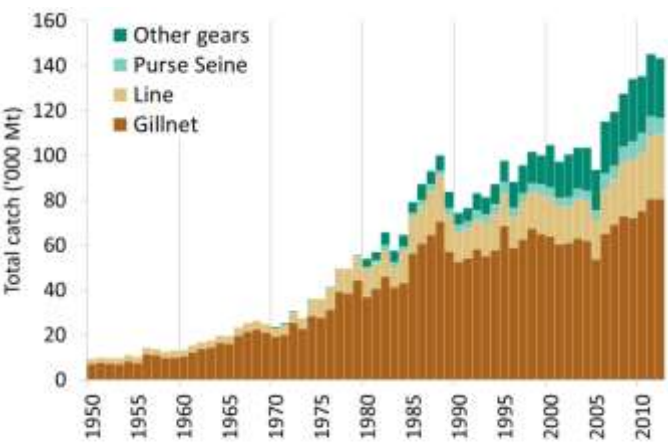
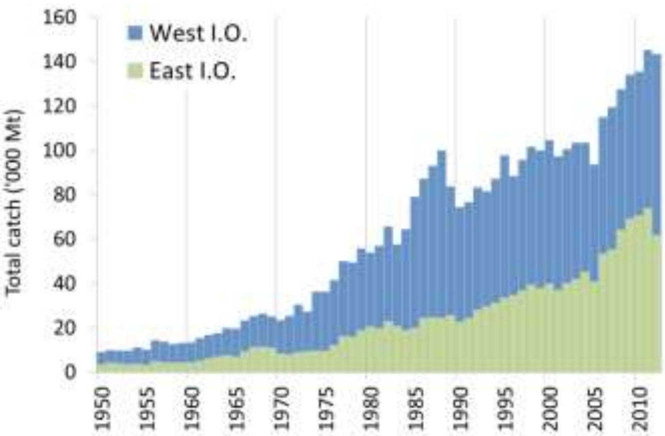
	

Fig. A10. Narrow-barred Spanish mackerel: Annual catches of narrow-barred Spanish mackerel by gear recorded in the IOTC database (1950–2012).	**Fig. A11.** Narrow-barred Spanish mackerel: Annual catches of narrow-barred Spanish mackerel by IOTC area recorded in the IOTC database (1950–2012).

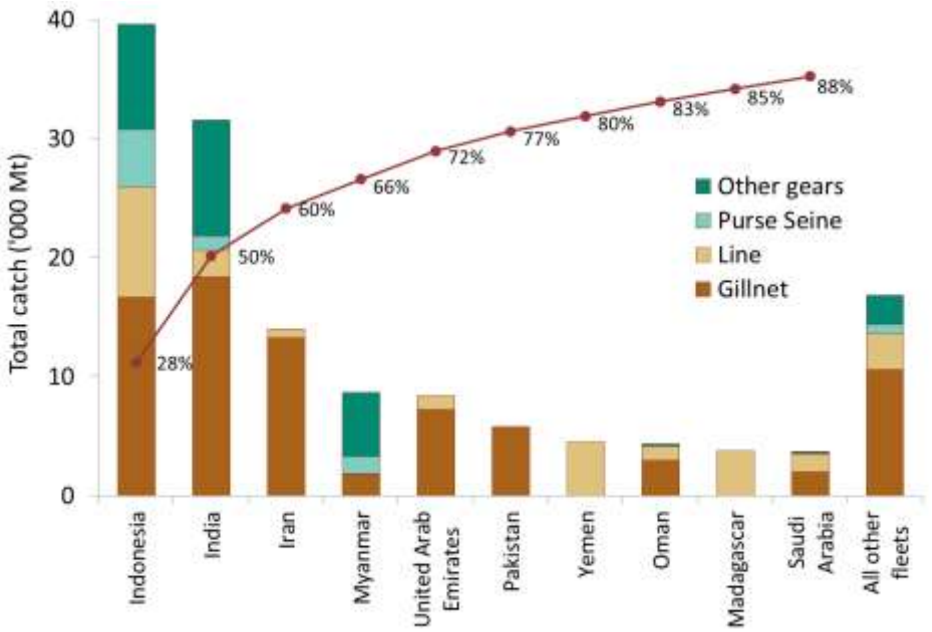


Fig. A12. Narrow-barred Spanish mackerel: average catches in the Indian Ocean over the period 2010-2012, by country. Countries are ordered from left to right, according to the importance of catches of narrow-barred Spanish mackerel reported. The red line indicates the (cumulative) proportion of catches narrow-barred Spanish mackerel for the countries concerned, over the total combined catches of this species reported from all countries and fisheries.