Ministry for Primary Industries
Manatū Ahu Matua

Characterisation and catch per unit effort of striped marlin in New Zealand

New Zealand Government

Growing and Protecting New Zealand

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This project updates the available data from the commercial and recreational fisheries for striped marlin caught in New Zealand waters.

Two datasets are available for investigation of commercial catch and effort; commercial tuna longline mandatory reporting information and observer reports. The total number of striped marlin reported is small; a total of 3597 striped marlin have been reported by commercial tuna longliners since 2000, and just 421 striped marlin have been observed since 1990. The overwhelming majority of sets catch no marlin.

The commercial catch reporting data are compromised by the failure of many vessels to report catch of striped marlin, which they are required to release. Despite this the standardised series of positive catches shows some promise as an index of relative abundance. The observer database has limited coverage of the striped marlin catch, which is largely a bycatch of bigeye and swordfish in the northern New Zealand, because observer coverage is focused on the charter fleet that fishes for southern bluefin tuna further south.

Two signals of relative abundance are potentially available from each dataset; the probability of capture (presence-absence) and the catch rate from positive sets. These can be combined but in this study they are considered separately, because the binomial part is either unreliable (as in the case of the commercial catch reporting data) and/or it dominates the combined index because of the very high proportion of unsuccessful sets (both datasets). The binomial and combined series are presented for completeness without detailed diagnostics.

Positive catches usually comprise a single fish and rarely more than two fish per set. There is thus little contrast in catch rate in positive sets, but the standardised series suggests an overall decline in abundance. The fit of positive catches to the lognormal assumption is poor and is improved slightly by assuming an inverse Gaussian error distribution. The effect of the alternative error distribution on the annual indices is to steepen the decline slightly in recent years. The series based on observed catches has large error distribution around each point due to the small number of records.

These CPUE analyses are undertaken using the data that were groomed and submitted to WCPFC. In respect of some potential explanatory variables these datasets are not complete, and there is some potential to improve the analyses in future with dedicated data extracts. The shortened time series of commercial data used reflects the period for which we have confidence that striped marlin were being reported consistently by fishers.

The New Zealand Sport Fishing Council (NZSFC, formerly NZ Big Game Fishing Council) compiles annual sport fish tallies for the main species from 56 game fishing clubs around New Zealand. These records contain a reasonably complete record of striped marlin catch from a long-established target fishery and were used to provide an estimate of the national landed recreational catch. The tagging database was used to provide the number of striped marlin recorded as tagged and released and these data were used to undertake further analyses.

The individual weights of recreationally caught marlin are recorded by gamefish clubs, with some records going back to the start of the fishery in the 1920s. Prior to 1988 a high proportion of the recreational catch was landed and accurately weighed. Since the early 1990s 60% of all striped marlin caught by recreational anglers have been tagged and released. Recreational fishers estimate weight for fish brought alongside the boat and the accuracy of these estimates cannot be assured. The average

annual striped marlin weights for four of the oldest deep sea angling clubs has declined since the late 1950s with higher inter annual variability.

Northland charter boat catch and effort information has been collected in a relatively coarse form (average catch per vessel per day for the season) since 1977. A subset of the detailed daily logbook data has been used to extend this data series since 2007. There are few informative variables available to use in standardising charter boat CPUE. Vessel technology, equipment and fishing techniques have changed significantly over this time series. Despite this, a standardised charter vessel CPUE index was developed.

Recreational CPUE was standardised using a Lognormal GLM. Fishing year was forced as the first variable and explained most of the variance in the catch (33.5%). The effort term *days fished* entered the model second, explaining an additional 24% of the variance and was followed by *vessel* (11.7%). The final model explained 69% of the variance. Overall there is an increasing trend in CPUE following the introduction of the billfish moratorium in 1987 to the mid-1990s and a decreasing trend since then. The 2010 and 2011 values were relatively low.

While the recreational index of positive catches is considered to be the most reliable index, the three final standardised CPUE indices showed similar trends with high CPUE in the mid-1990s, a peak in 1999 and a declining trend over the last decade. All of these indices suffer from limited spatial coverage of the data used and a limited number of records. There are some quite large changes in availability of striped marlin from year to year which appear in all indices. This may be indicative of changes in abundance or recruitment in some part of the south western Pacific stock but the scale may be amplified by annual variability in oceanographic conditions.

1. INTRODUCTION

1.1 Objectives

Overall objectives:
1. To update the characterisation of fisheries for striped marlin in New Zealand and develop CPUE indices for the relevant fisheries.

Specific objectives:
1. To characterise the fisheries for striped marlin in the New Zealand fisheries waters and analyse existing commercial and recreational catch and effort data to the end of 2010 fishing season and undertake a CPUE standardisation.
2. To collate size data for recreational fisheries in New Zealand waters.

1.2 Description of the Fishery

Striped marlin (*Kajikia audax*) is a highly migratory species widely distributed through the Pacific and Indian Oceans and is the most commonly encountered of the five istiophorid billfishes caught in New Zealand. New Zealand has a long established and internationally recognised recreational fishery for large striped marlin. Recreational sport fishing clubs have kept catch records for pelagic gamefish for many years, in some cases since 1925. Many gamefish clubs have kept detailed catch records of fish weighed and tagged and released.

Japanese surface longline vessels began targeting pelagic species, including striped marlin, north of New Zealand in the late 1950s. Large numbers of vessels were attracted to New Zealand waters during the 1960s to catch southern bluefin tuna (*Thunnus maccoyii*). During the 1970s some of the fleet, along with vessels from Korea, took up licences to fish part of the year in northern New Zealand waters where bigeye and albacore tuna were the main target species.

There was a rapid expansion in New Zealand domestic surface longline effort in the 1990s targeting bigeye and southern bluefin tuna. Foreign licences were no longer issued but New Zealand companies chartered vessels from Japan, Philippines and Australia for particular fisheries (Table 1).

After three very poor years in the recreational striped marlin fishery, regulations and foreign licence conditions were passed in 1987 prohibiting commercial vessels from retaining billfish caught in the Auckland Fisheries Management Area (referred to as the Billfish Moratorium). In 1991 the Billfish Moratorium was replaced with amendments to the regulations that allowed commercial vessels to retain broadbill swordfish, but prohibited the retention of istiophorid billfish throughout the EEZ.

Tuna fisheries in New Zealand were the last significant free-entry fisheries left outside the Quota Management System (QMS) in New Zealand waters. Tunas and swordfish, except for southern bluefin tuna, were not subject to any catch restrictions up to October 2004. All retained catch from surface longlining was required to be reported on Tuna Longline Catch Effort Returns (TLCER) (Table 1).

In October 2004, bigeye, Pacific bluefin, southern bluefin, and yellowfin tunas, and swordfish were introduced into the QMS, with swordfish becoming a legal target species. Several key bycatch species, namely mako, blue, and porbeagle sharks, moonfish and Ray's bream were also introduced to the QMS at this time. The number of vessels targeting tunas had already declined markedly with the expected rationalisation of the fleet, and these changes mark a regime shift that will affect most time series of nominal tuna CPUE, especially where it is based on fisher nominated target species. By 2008 the number of longline vessels operating in New Zealand had declined to 35. Despite the fact that the domestic longline fleet mainly targets bigeye and southern bluefin tuna, the greatest part of the catch consists of albacore and swordfish. Blue shark is the most common non-tuna bycatch species in the longline fishery followed by Ray's bream.

New Zealand longline vessels fishing for tuna or swordfish in New Zealand fishery waters may only set their lines at night unless using line weighting as a seabird mitigation measure, and that, combined with active targeting of swordfish, might be expected to have had an effect on the bycatch of those pelagic sharks that surface at night and may reduce the bycatch of striped marlin.

A requirement to report marlin caught and released by commercial vessels was introduced in the mid 1990s (Francis et al. 2004). Despite this, striped marlin have been under-reported by some commercial fishers (Francis et al. 2000). Some catch data from the surface longline fishery is available, including some data collected by observers.

Table 1: Commercial landings and discards of striped marlin (numbers of fish) in the New Zealand EEZ reported by fishing nation (CELRs and TLCERs), and recreational landings and numbers of fish tagged, by fishing year (1 October to 30 September).

Fishing Year	Japan Landed	Japan Discarded	Korea Landed	Philippine Discarded	Australia Discarded	Domestic Discarded	NZ Recreational Landed	NZ Recreational Tagged	Total
1979–80	659						692	17	1 368
1980–81	1 663		46				792	2	2 503
1981–82	2 796		44				704	11	3 555
1982–83	973		32				702	6	1 713
1983–84	1 172		199				543	9	1 923
1984–85	548		160				262		970
1985–86	1 503		19				395	2	1 919
1986–87	1 925		26				226	2	2 179
1987–88	197		100				281	136	714
1988–89	23		30			5	647	408	1 113
1989–90	138					1	463	367	969
1990–91		1				6	532	232	771
1991–92		17				1	519	242	779
1992–93						7	608	386	1 001
1993–94						59	663	929	1 651
1994–95						182	910	1 206	2 298
1995–96						456	705	1 104	2 265
1996–97						441	619	1 302	2 362
1997–98						445	543	898	1 886
1998–99						1 642	823	1 541	4 006
1999–00		2				798	398	791	1 989
2000–01						527	422	851	1 800
2001–02						225	430	771	1 426
2002–03		3		7		205	495	671	1 381
2003–04		1				423	592	1051	2 067
2004–05						307	834	1 348	2 489
2005–06						203	630	923	1 756
2006–07						9	152	688	964	1 813
2007–08		1				231	485	806	1 523
2008–09						242	731	1 058	2 030
2009–10						197	597	809	1 603
2010–11							529	698	

2. DATA SOURCES AND METHODS

2.1 Commercial tuna catch and effort returns

In the New Zealand commercial fishery, striped marlin is mainly caught by surface (tuna) longline gear. Effort in this fishery has declined from a peak of 8600 sets in 2002, to less than 3000 sets per year by 2007 (sets average about 1200 hooks), and the catch of striped marlin consequently declined from over 700 fish in 2000 to fewer than 350 fish per year by 2005.

Catch rates calculated across all surface longline effort average less than 0.1 fish per set in most years (Figure 1) but largely reflect the encounter rate (proportion of positive sets) which has varied similarly between 1 and 7% over the same period (Figure 2), because catches generally comprise a single fish and rarely more than 2 fish per set (Figure 3).

There is little contrast in catch rate for successful sets, and while presence/absence data might be expected to be more informative, vessels have been required to discard all striped marlin and may not have always recorded their catches, although they are required to do so. It is thought likely that reporting has improved since 2000, but any estimate of catch rate based on total effort will reflect variations in reporting practice.

A total of 3597 striped marlin have been reported by commercial vessels since 2000, mostly in sets targeted at swordfish and bigeye tuna during the first six months of the year (Table), by the small ice boats of the domestic fleet (99.4%). Much of the longline effort in New Zealand waters however, is targeted at southern bluefin tuna (27% of records/sets), and striped marlin bycatch rates in this fishery are low (Table 3).
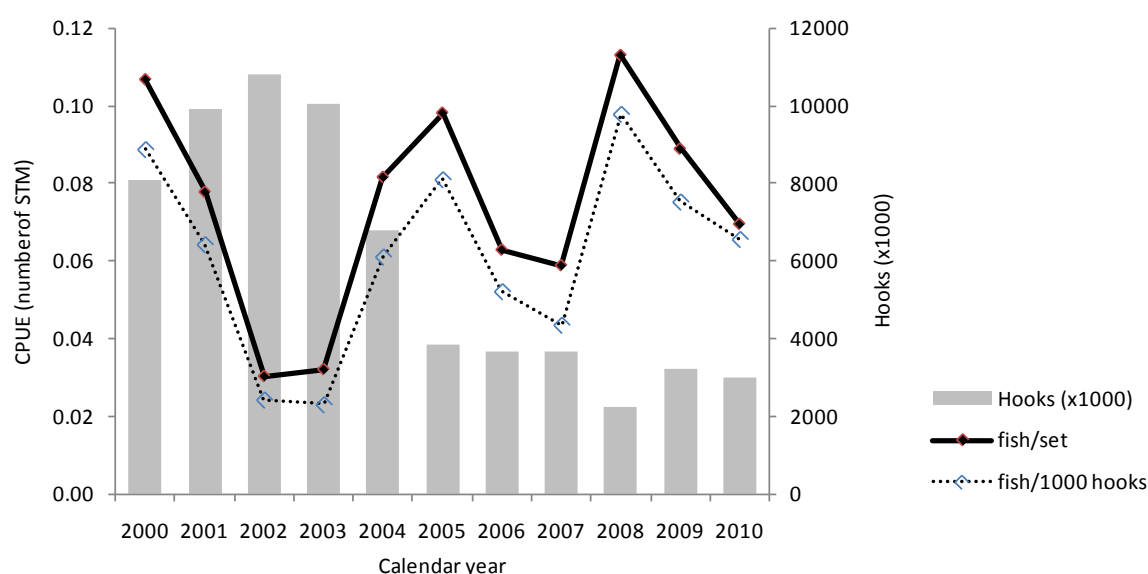
Figure 1: Total effort expended by the surface longline fleet in the New Zealand EEZ (bars) and simple annual catch rate of striped marlin (number of fish/ set or thousand hooks) calculated across all effort.
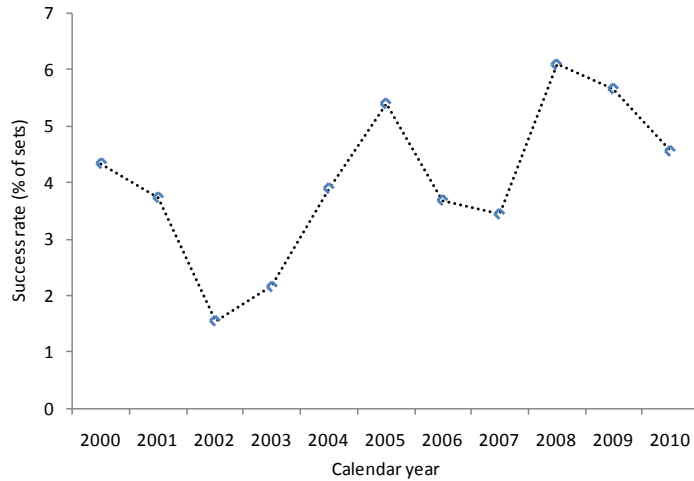
Figure 2: Annual striped marlin success rate in the surface longline fishery (percentage of sets that caught striped marlin).
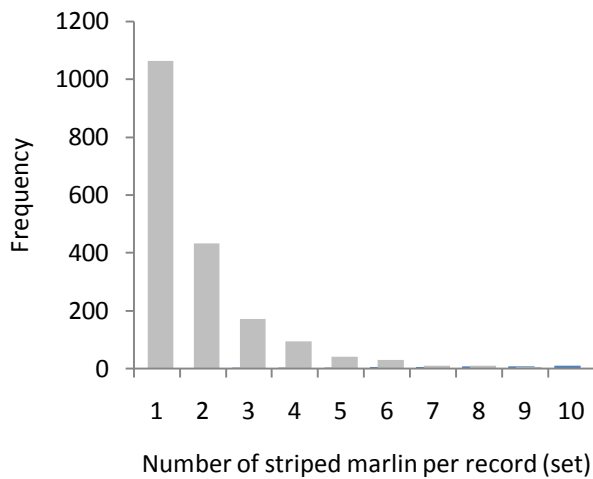
Figure 3: The number of striped marlin per set in non-zero records from commercial reporting for surface longline effort in New Zealand waters.

Table 2: Number of striped marlin caught in the New Zealand EEZ and reported by commercial longline vessels, by month and year. All vessels and form types combined. The year/months inside the border describe data that was offered to the model.

| Calendar Year	1	2	3	4	5	6	7	8	9	10	11	12	Total STM
2000	171	106	250	105	17	5	22	28	4	8	3		719
2001	30	212	242	57	21	14	31	17	4	5	2	5	640
2002	24	58	138	18	1	6	3	4	1	8	0	2	263
2003	7	45	21	43	24	12	24	34	18	0	3	2	233
2004	70	117	145	56	4	2	5	11	5	0	0	0	415
2005	84	48	75	49	37	1	2	10	5	2	0	0	313
2006	15	72	64	32	5	1	1	0	1	0	2	0	193
2007	6	26	38	50	16	5	4	5	4	0	0	7	161
2008	57	70	57	11	9	1	13	2	1	0	0	0	221
2009	13	40	101	52	12	1	7	12	1	0	0	3	242
2010	32	65	64	25	4	1	2	1	1	0	0	2	197
Total						3260							3597

Table 3: Number of surface longline sets and the number of striped marlin reported in each year in the New Zealand EEZ, by target species, for 2000–2010 from commercial reporting. Also the overall percentage of sets and number of striped marlin by target species.

Target	Number sets (records)							Number STM						
	BIG	STN	ALB	SWO	TOR	YFN	Other	BIG	STN	ALB	SWO	TOR	YFN	Other
2000	5 244	946	464	1		60	14	636	3	70			10	0
2001	6 191	1 173	576	2	8	209	59	542	6	9	3	0	78	2
2002	5 691	1 914	844		101	69	30	244	6	6		0	7	0
2003	3 761	2 309	1 017	2	119	15	15	172	8	38	0	10	5	0
2004	2 591	1 939	388		105	11	46	401	2	7		2	3	0
2005	1 682	1 100	130	177	63	30	4	272	1	0	32	0	8	0
2006	1 687	994	64	291	25	4	0	142	0	0	48	3	0	0
2007	1 518	954	17	198	31	4	9	131	0	0	29	0	1	0
2008	1 060	725	2	131	25	6	5	161	15	0	28	9	8	0
2009	1 721	922	11	47	14		5	231	0	0	9	2		0
2010	1 328	1 300	25	154	22	1	0	167	8	0	22	0	0	0
Percent	62.0	27.2	6.8	1.9	1.0	0.8	0.4	86.2	1.4	3.6	4.8	0.7	3.3	0.1

Previous work (Holdsworth & Kopf 2011) analysed standardised CPUE from successful sets only in order to eliminate the large proportion of effort that is unproductive as well as the vessels that may not have been reporting their catch. The indices were, not surprisingly, effectively flat over the study period. In this update we further constrain the fishery definition to effort north of 40° S, targeted at swordfish, bigeye, albacore or yellowfin tunas, in the months January to June. This reduced the number of longline sets by 60% but retained 87% of the catch of striped marlin (by number). While the main reason for this was to better define effective effort in an attempt to extract a meaningful signal from success rate, it also removed much of the contrast in the explanatory variables available to the models with some anomalous trips consequently excluded. For example, trips by two Philippine flagged ships that targeted albacore in the northern part of the zone in the later part of 2003 enabled the previous analysis to describe the significant effects of latitude on catch, but also caused the dataset to be severely unbalanced with respect to month and vessel across year. They were excluded by this

fishery definition. The Highly Migratory species Working Group subsequently requested an additional analysis be done including all months.

2.2 Core vessels

The dataset was further reduced to a core fleet defined as vessels that completed at least three successful longline trips (with respect to striped marlin) per year in at least two years. Once a vessel was selected, all data for that vessel were included in an attempt to extract a signal from the presence/absence of striped marlin in the catch. This further reduced the dataset to 15% of the total effort (sets) while retaining 61% of the total catch of striped marlin (Figure 4, Table A1). The participation of the core fleet was examined for adequate overlap over the study period (Figure 5).
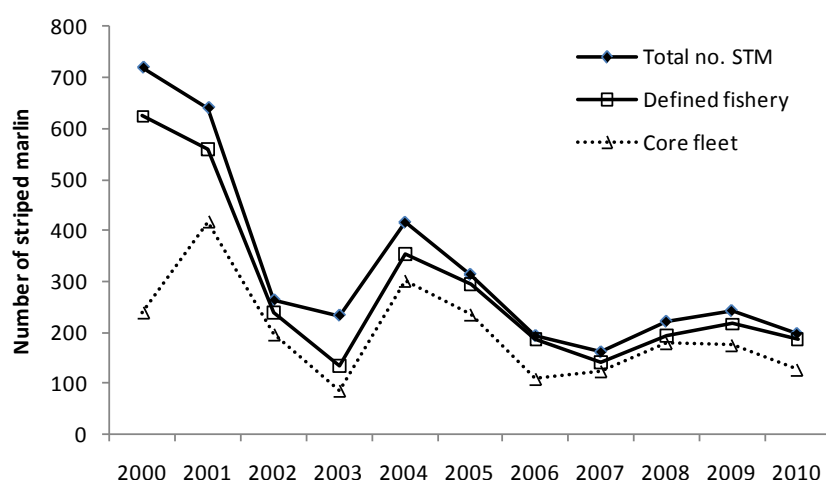

Figure 4: The effect on the number of striped marlin retained in the analysis dataset in each year of defining effective effort and of selecting a core fleet.
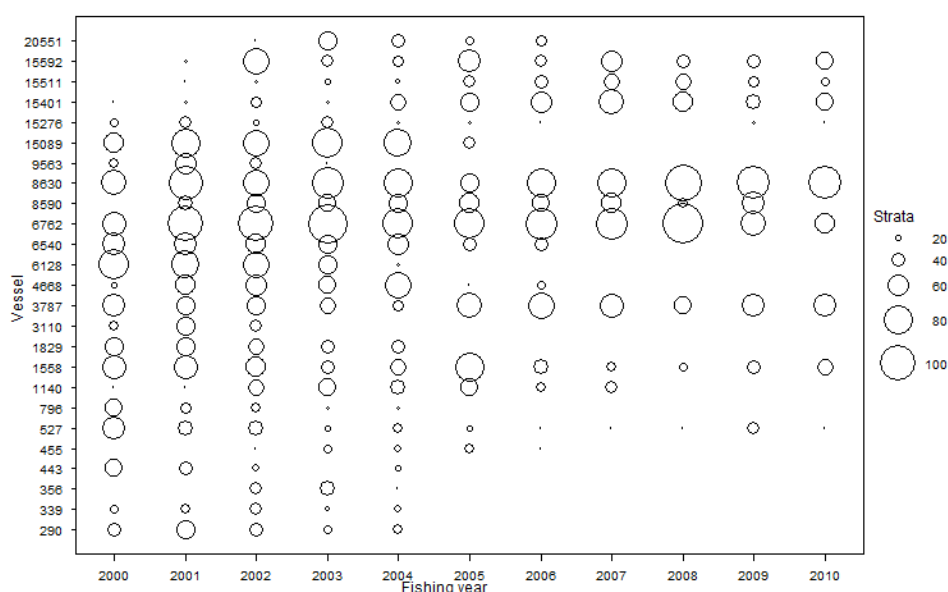

Figure 5: Distribution of records (sets) by fishing year for core vessels. Area of circles is proportion of the number of sets over all fishing years and vessels.

2.3 Observer records

A subset of the surface longline effort in which catches of striped marlin should be accurately reported over a longer time period, and the presence/absence signal therefore more informative, is available from observer records. However, the focus of observer coverage in New Zealand is on larger vessels of the charter fleet that target southern bluefin tuna in waters south of 40° S. Observer coverage of the domestic fleet, in contrast, has been less than 10% in most years, and a total of just 421 striped marlin have been observed since 1990. Previous work has focused on this dataset for describing the effect of gear and environmental factors on the expected catch of striped marlin, and this has been informative, but is unlikely to produce an index of abundance due to the poor spatial representativeness of the fishery (Francis et al. 1999, 2000, 2004).

Table 4: Distribution of observed surface longline sets north of 38°S and striped marlin caught, by nationality and calendar year. JAP, Japan (charter); NZ, New Zealand (domestic); PHL, Philippines (charter). AUS, Australia (charter).

Calendar year	Number of records (sets) Nationality				Number of STM observed Nationality			
	JAP	NZ	PHL	AUS	JAP	NZ	PHL	AUS
1990	74				10			
1991	122				4			
1992	84	16						
1993	114				9			
1994	27	10			10	1		
1995	13	43				40		
1996		60				44		
1997	43	96				33		
1998	93	58			15	27		
1999	29	15				33		
2000	22	21			2	8		
2001		183				69		
2002	4	57				11		
2003	27		190		5		12	
2004	16	40				4		
2005	38	125				24		
2006	17	32		24	1	2		2
2007	52	127		20		10		7
2008		136				5		
2009	23	167				9		
2010		117				24		

Fleet and *nation* were not offered to the model due to their unbalanced distribution across year (Table 4). Vessel ID was not available to the analysis and *Minimum hook depth* was not offered because it was dominated by a single year in which depths recorded were much deeper than in other years and the data were suspect.

The dataset for observed sets north of 38°S was trimmed to 1993 onwards, and to the months of January to August, which reduced the number of fish in the analysis dataset to 385 (Table 5). No core vessel selection was done to further reduce the observer dataset, as it is already a small subset of the fishery, involving few vessels, and there is confidence that unsuccessful (with respect to striped marlin) effort is perfectly identified. The distribution of number of striped marlin in non-zero sets closely resembles that from commercial reporting, with most catches comprising a single fish and rarely more than two fish (Figure 6).

Table 5: Number of striped marlin observed caught on tuna longlines north of 38°S by month and calendar year. The data described by the cells inside the border (months January to August) were included in the analysis dataset. -, no effort observed; 0, no striped marlin (STM) observed.

| Calendar Year	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total STM
1990	-	-	-	-	-	0	1	9	-	-	-	-	10
1991	-	-	-	-	-	0	0	4	-	-	-	-	4
1992	-	-	-	-	0	0	0	-	-	-	-	-	0
1993	-	-	-	-	-	7	1	1	-	-	-	-	9
1994	-	-	-	-	-	10	-	-	-	-	-	1	11
1995	23	7	-	-	-	0	0	2	0	-	-	8	40
1996	24	15	-	-	2	3	0	-	-	-	-	-	44
1997	9	17	2	3	2		0	-	-	-	-	-	33
1998	-	15	5	0	-	12	3	1	-	-	-	6	42
1999	33	-	-	-	-	-	0	0	-	-	-	0	33
2000	6	2	-	-	-	0	2	-	-	-	-	0	10
2001	16	39	7	-	-	2	5	-	0	0	0	0	69
2002	4	5	2	-	0	-		0	0	-	-	-	11
2003	-	-	-	-	0	2	10	5	0	-	-	-	17
2004	-	-	0	3	0	1	0	0	-	-	-	-	4
2005	18	3	-	1	1	0	0	0	1	0	0	-	24
2006	-	-	-	-	-	0	1	-	1	0	3	-	5
2007	1	6	7	1	1	0	0	1	-	-	-	-	17
2008	1		2	0	1	0	0	1	-	0	0	-	5
2009	2	3	-	0	1	0	0	2	1	0	0	0	9
2010	20	0	3	-	-	0	0	0	1	0	0	0	24
Total								385					421
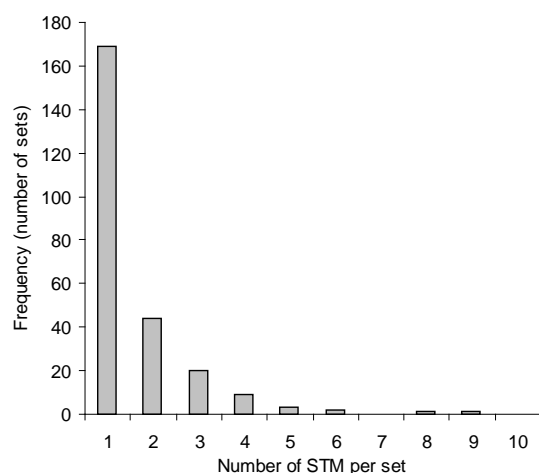
Figure 6: Distribution of catch rates (number of striped marlin per set) observed in tuna longlines north of 38°S between 1989–90 and 2009–10.

2.4 Recreational catch and effort

The New Zealand Sport Fishing Council (NZSFC formerly NZ Big Game Fishing Council) compiles annual sport fish tallies for the main species from 60 gamefishing clubs around New Zealand. These records were used to provide an estimate of the national landed recreational catch of striped marlin in New Zealand waters. Since the 1990s over 60% of all striped marlin caught by recreational anglers

have been tagged and released (Table 1). The tagging database was used to provide the number of striped marlin recorded as tagged and released (Holdsworth & Saul 2011). There has been a significant increase in total recreational catch of striped marlin since the late 1980s (Table 1, Figure 7).

Catch records of individual billfish including weight, vessel and capture date were collected from four long established gamefish clubs. These are Bay of Islands Swordfish Club, Whangaroa Big Gamefish Club, Whangarei Deep Sea Anglers Club, and Tauranga Game Fishing Club. A time series of club records has been collected as part of earlier striped marlin projects. Trends in annual club catch tallies have not changed as much as the NZSFC national tallies (Figure 7). In fact 1949 still has the second highest annual striped marlin catch for the Bay of Islands Swordfish Club. More clubs have fishers targeting marlin since 1990.
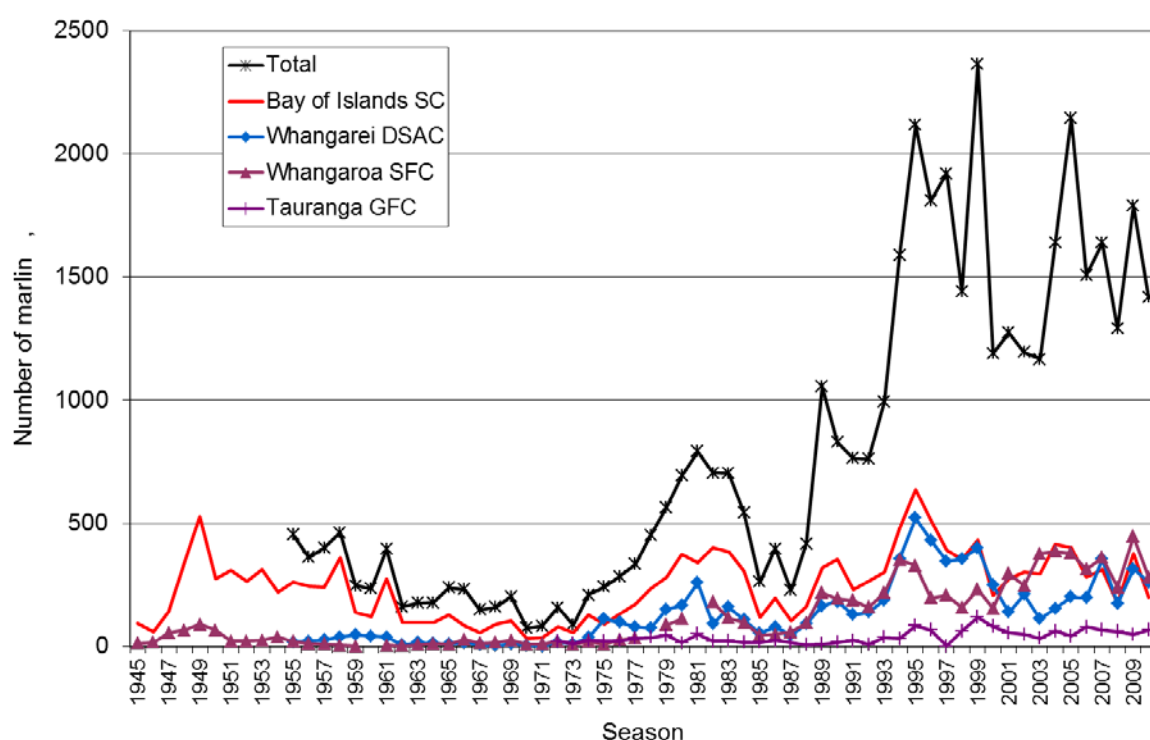

Figure 7: Recreational striped marlin catch (landed and tagged) for all New Zealand (NZSFC club tallies, Total) and for four large clubs with long term record of catch.

Club records have been used to estimate the mean weight for striped marlin in New Zealand by season (Figure 8). The fishing season used by clubs is 1 July to 30 June. Almost all club catch is taken between January and June so calendar year and season are effectively the same. The estimated total weight of the recreational landed catch was calculated using the mean weight from four main clubs multiplied by the national tally from all NZSFC affiliated clubs. The total weight of fish tagged by recreational fishers was estimated using mean weight of fish tagged by the same four clubs and the tagging database tally of fish released by recreational fishers (Table E1).
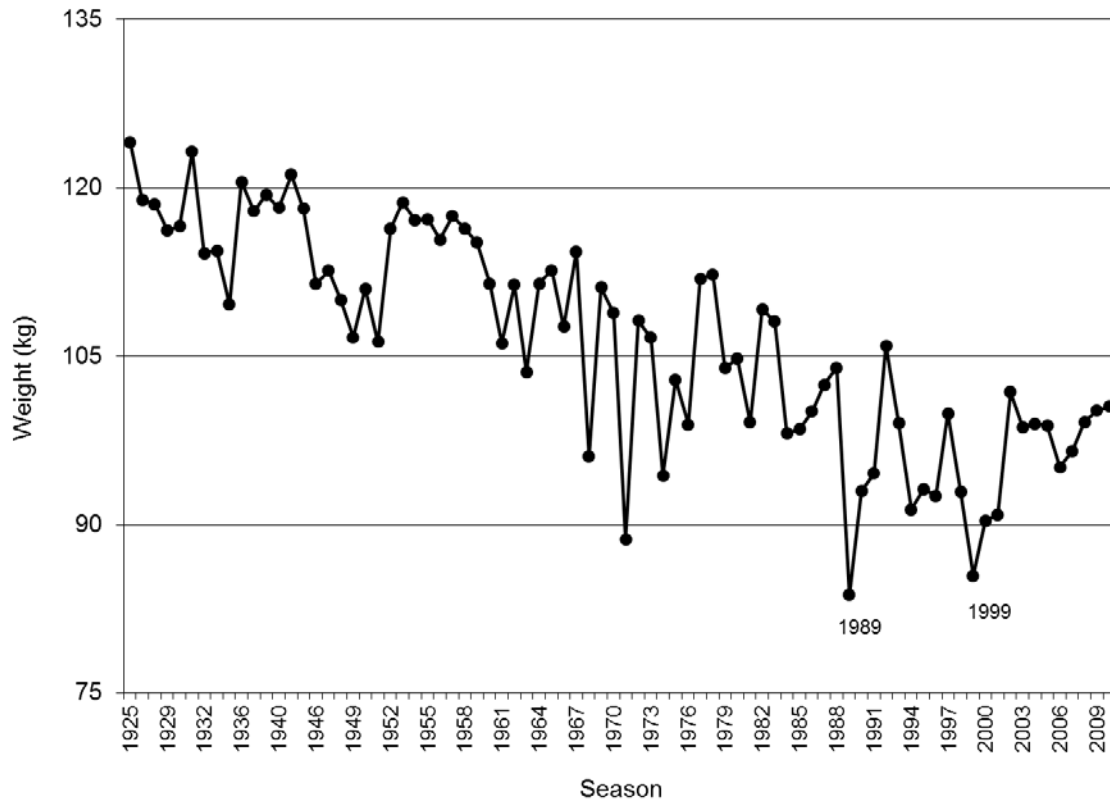
Figure 8: Average annual weight of striped marlin (landed and tagged) by season from the main sport fishing clubs combined.

An annual postal survey of Northland gamefish charter skippers was conducted by the Ministry of Agriculture and Fisheries between 1977 and 1996. This survey provided information on the number of days fishing for marlin per vessel (whether under charter or fishing with friends) for each season. With support from various organisations including Ministry of Fisheries and the New Zealand Marine Research Foundation the postal survey was maintained between 1997 and 2006. In 2006–07 a national billfish logbook scheme was introduced to collect daily catch and effort information as well as detailed location and environmental data as part of a Ministry of Fisheries project (STM2005-01) (Holdsworth et al. 2007). A subset of these fishers, the Northland recreational charter fleet, was used to extend the existing time series from the postal survey. The dataset was reduced to a core of vessels that had reported at least five years catch and effort for use in GLM standardisation of charter CPUE. This reduced the total data set used in the Lognormal model to 4535 striped marlin (84%) from 27 705 fishing days. The participation of the core fleet was examined for adequate overlap over the study period (Figure 9). The distribution of the raw mean annual striped marlin catch per day by charter vessels shows a mode at 0.15 and a tail to the right (Figure 10).
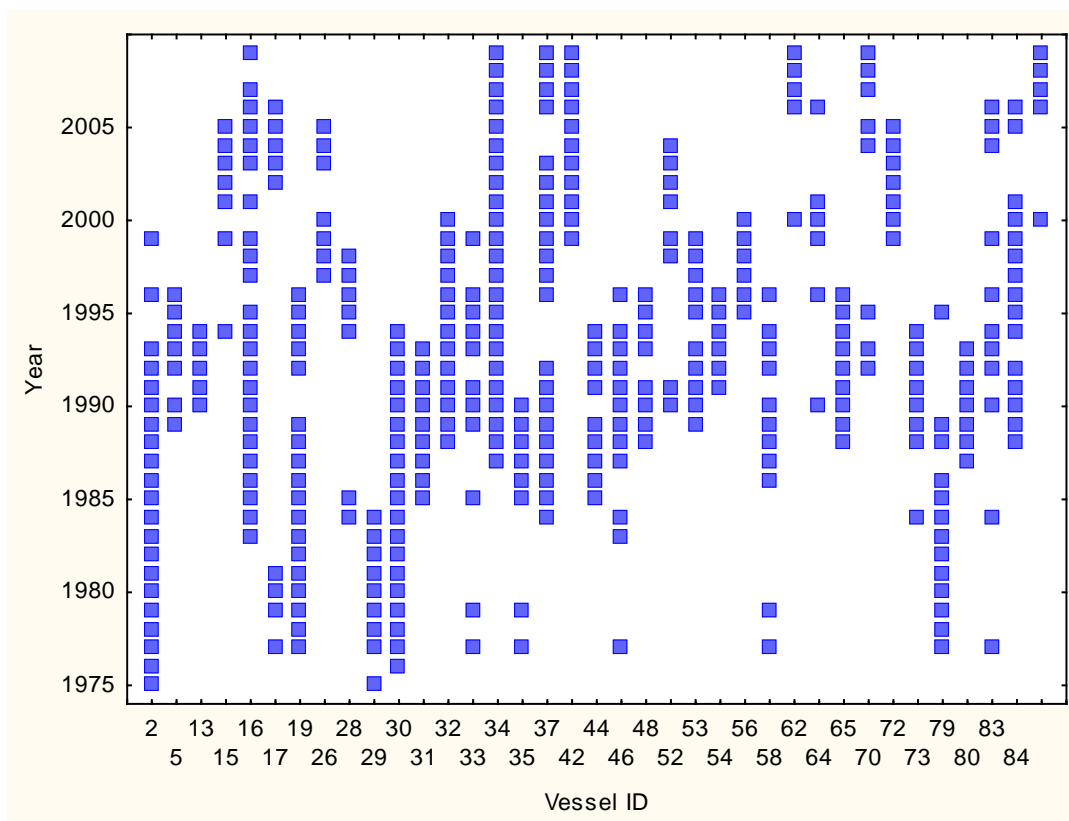
Figure 9: Reporting history of core vessels by season for the east Northland charter boat CPUE survey (postal and logbook survey data). Core vessels are those having provided five or more years' data.
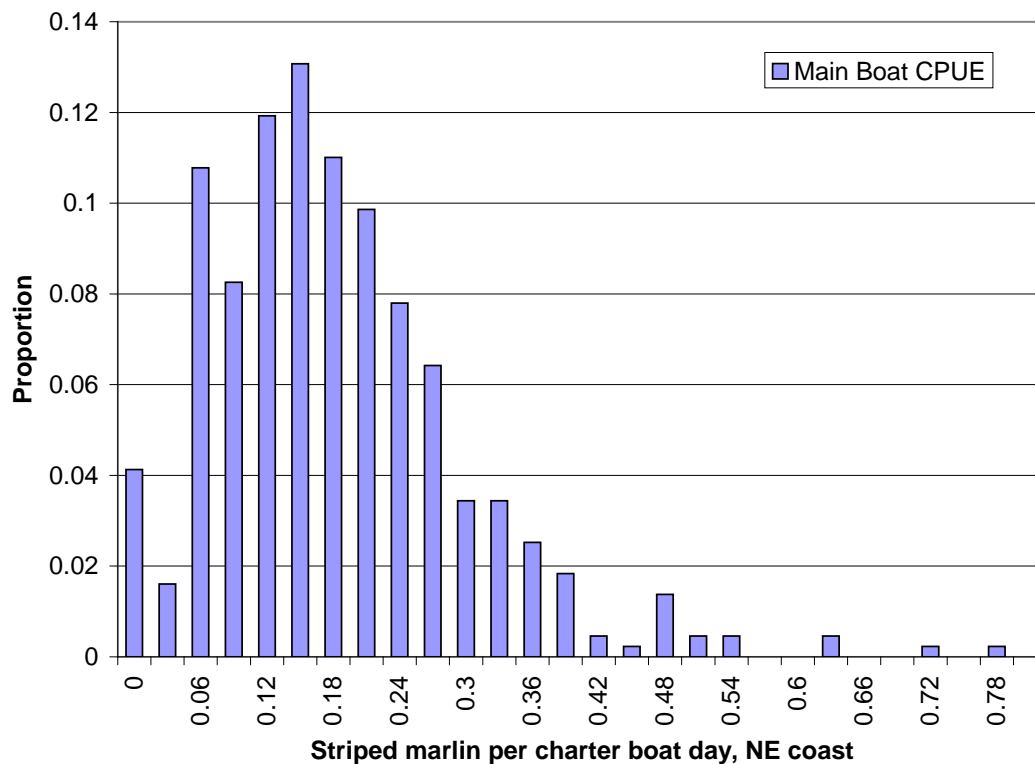

Figure 10: Distribution of CPUE for core vessels all years in the east Northland charter surveys.

2.5 Models of commercial CPUE

Two potential signals of abundance in the data are standardised. A binomial model which predicts the success or failure of striped marlin catch is fit to the total dataset including records that reported a zero catch of striped marlin. A lognormal linear model is fit to just successful catches of striped marlin, excluding zero catches. Success and catch rates (by set) were standardised against variation in the potential explanatory variables (Table 6) using a stepwise multiple regression procedure, selecting each explanatory variable until the improvement in model R^2 was less than 0.01. The year effects were extracted as canonical coefficients so that confidence bounds could be calculated for each year. The previous study reported a very poor fit of the data (positive catches) to the lognormal assumption and this study includes a comparison of log likelihoods and residual distribution plots for alternative error distributions from the exponential dispersion family, including log-logistic, gamma, weibull, and inverse Gaussian.

The effect of the variables accepted into the non-zero models is examined with the aid of Coefficient-Distribution-Influence (CDI) plots (Bentley et al. 2011). These plots consider the combined effect of the coefficients for each level of the factor and the distribution of the underlying data across time to calculate the influence of a variable on moving the standardised index away from the nominal CPUE.

The dependent variable for the binomial model was a binary variable set to '1' for records which had associated striped marlin catch and set to '0' for records with no catch. The potential explanatory variables included the log of hooks set. The dependent variable for the lognormal model was the log of the number of striped marlin per set. This model was offered the same explanatory variables as the binomial model.

The two models are combined after Vignaux (1994) as follows:

$$C_i = \frac{L_i}{\left(1 - P_0\left[1 - \dfrac{1}{B_i}\right]\right)}$$

where C_i = combined index for year i
L_i = lognormal index for year i
B_i = binomial index for year i
P_0 = proportion zero for base year 0

A bootstrap procedure is the appropriate way to estimate the variability of the combined index, but this was not done for this paper. The step of combining the two series is rarely done in New Zealand fisheries because of the unequal quality of the two signals, but each series is routinely examined separately. In this instance, the presence-absence information from commercial catch reporting is likely to be compromised by ambivalent reporting of released fish, while the observed fishery catches very few striped marlin, and in each case, the combined series is distorted by the overwhelming influence of the binomial part.

Table 6: Description of potential explanatory variables offered to the models.

Factor	Description	Observer dataset	Commercial Dataset
Calendar year	Categorical	1993 to 2010	2000–2010
Vessel	Categorical	Not available	Core fleet
Month	Categorical	January - August	January – June
Day/Night set	Categorical	Time of set D, ; N,	Time of set D, ; N,
Target species	Categorical	BIG, SWO, STN, ALB	BIG, SWO, ALB, YFN
Latitude	Continuous	3rd order polynomial	3rd order polynomial
Longitude	Continuous	3rd order polynomial	3rd order polynomial
Temperature (vessel)	Continuous	3rd order polynomial	3rd order polynomial
Backbone length (km)	Continuous	Not available	3rd order polynomial
Buoy line length	Continuous	3rd order polynomial	Not available
HBF	Continuous	Hooks between baskets 3rd order polynomial	Hooks between baskets 3rd order polynomial
LBH	Continuous	Not available	Lightsticks per 1000 hooks
Log (Hooks)	Continuous	Number of hooks observed 3rd order polynomial	Number of hooks set 3rd order polynomial
Month:Latitude	Interaction	Interaction	Interaction

3 RESULTS

3.1 Commercial tuna longline catch and effort returns

The poor fit of the positive catches to the lognormal assumption was identified as a problem by Holdsworth & Kopf (2011) and other error distributions of the exponential dispersion family were investigated as part of this update. They included weibull, log-logistic, inverse Gaussian, and gamma distributions. Diagnostics used to evaluate the alternative models are shown in Figure B1 and include the maximum likelihood fit to observed catches and quantile-quantile plots of the standardised residuals. There was some improvement obtained with an inverse Gaussian model and there was also an associated effect on the annual indices (Figure B2) so the non-zero GLM for commercial data reported here assumes inverse Gaussian distributed errors. The diagnostic plots of the residuals are given in (Figure C1) and nevertheless show a poor fit to the assumed error distribution. The Working Group suggested that future work should also consider a negative binomial distribution which would be more appropriate for count data.

The final non-zero model explained almost 25% of the variance in log catch (Table 7), largely by standardising for changes in the core fleet and in the month fished, both of which are predicted to have improved observed catches over the study period. No measure of effort entered the model.

Log(number STM per set) = fishing year + vessel + month

Changes in the core fleet had a positive influence on catch rates overall (Figure 11) with the loss of many of the poorer performing vessels. The coefficients for month described a strong seasonal effect with catch rates predicted to be greatest between January and March, although catches did occur throughout the year and the model had to adjust for low observed catch rates in 2002–03 when less of the catch was taken in those months (Figure 12). The effect of the standardisation was to lift early points and drop recent points, and the annual indices describe a slight but reasonably well determined decline (Figure 13) with a particularly poor year in 2003. An interaction term (month × Latitude) was offered in an attempt to account for the seasonal movement of striped marlin in New Zealand waters but was not accepted.

The binomial model explained about 21% of the variance in success and included latitude as the variable with the greatest explanatory power, followed by month and vessel (Table 7). The annual indices from the binomial model vary from year to year in a pattern that is similar to the encounter rate, and the combined model indices reflect the binomial series. Overall it is flat, and it also corroborates the non-zero series in describing a very poor year in 2003 (Figure 14).

The annual indices from the final models are given in Table A1.

Table 7: Summary of final models (inverse Gaussian and binomial) of commercial catch and effort data. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, Proportion of deviance explained, Final: Whether or not variable was included in final model.

Inverse Gaussian Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (%)	Final
fyear	11	-1 453	2 930	6.99	*
vessel	35	-1 371	2 814	20.96	*
month	40	-1 336	2 755	26.25	*
poly(lat, 3)	43		2 746	26.99	

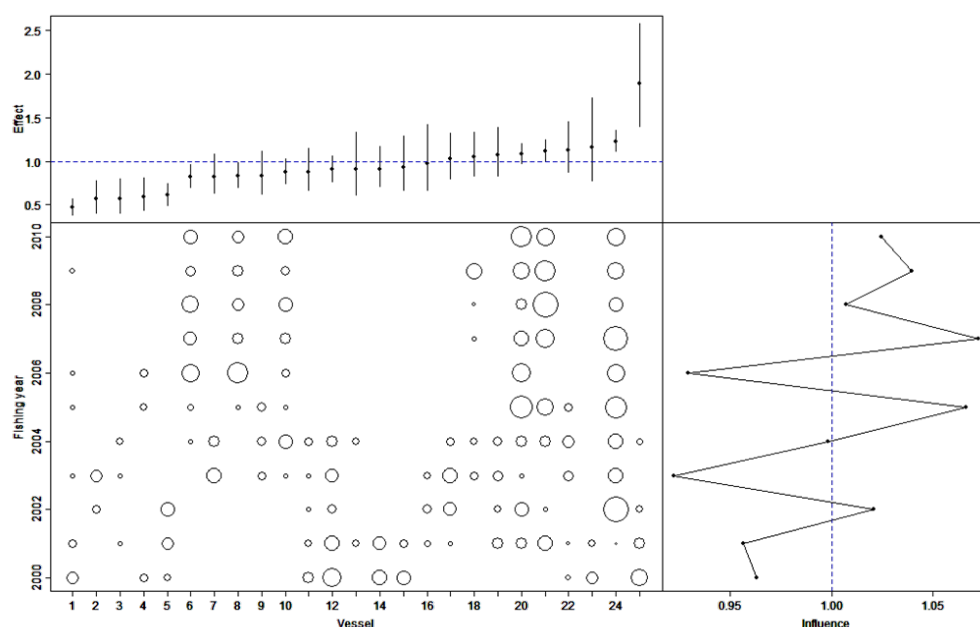| Binomial term	DF	Deviance	AIC	R^2	Final
None	0	6 391	6 393	0.0000	
fyear	11	6 218	6 240	0.0271	*
poly(lat, 3)	14	5 563	5 591	0.1296	*
month	19	5 222	5 260	0.1829	*
vessel	43	5 009	5 095	0.2162	*
poly(log(hooks), 3)	46	4 975	5 067	0.2215	
target	49	4 955	5 053	0.2247	
poly(lat, 3):month	64	4 923	5 051	0.2298	

Figure 11: Effect of vessel in the model of non-zero catches for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
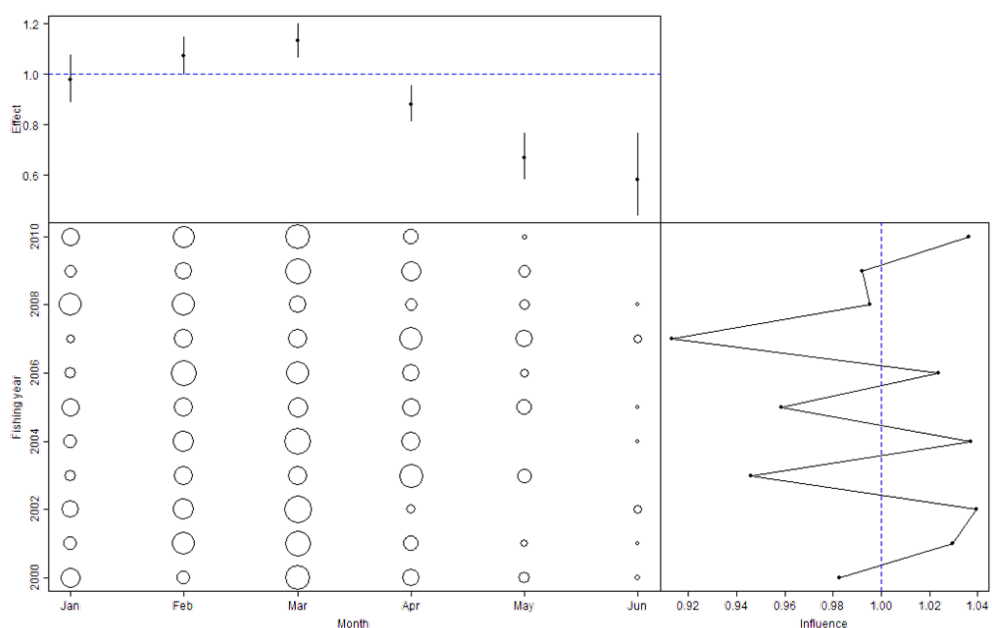
Figure 12: Effect of month in the model of non-zero catches for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
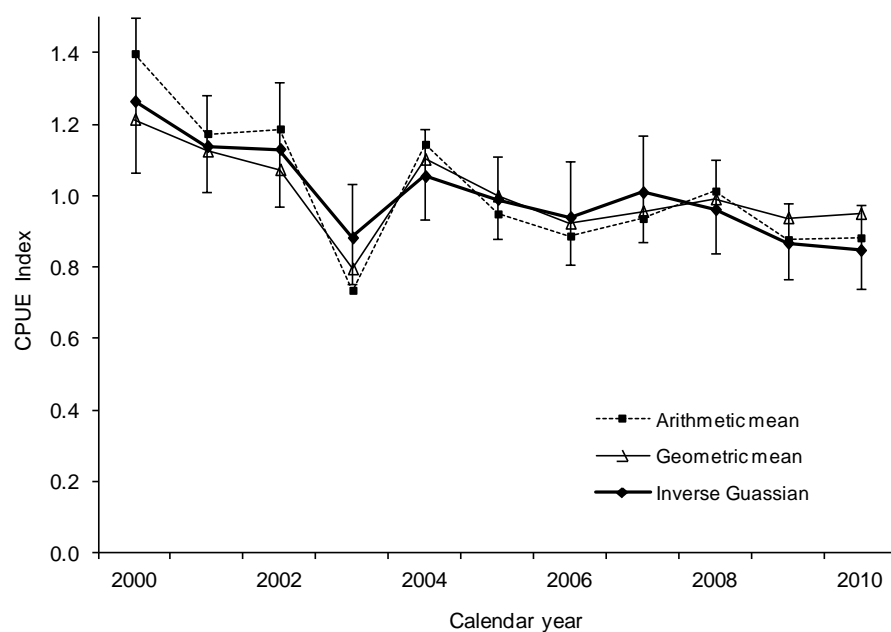

Figure 13: Unstandardised CPUE (arithmetic and annual geometric mean number of striped marlin per set), standardised CPUE (year effects from the inverse Gaussian model of non-zero catches) for commercial catch reporting (± 2 s.e.).
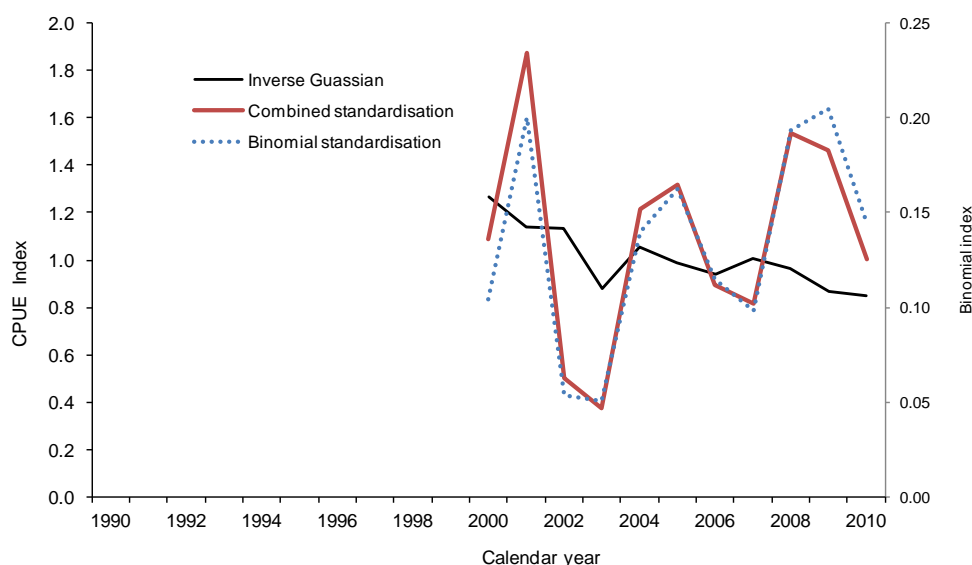
Figure 14: Comparison of annual indices from the non-zero (inverse Gaussian) model, the binomial model, and the combined model for commercial catch reporting of core vessels north of 40°S targeting swordfish, bigeye, yellowfin or albacore.

The Highly Migratory Species Working Group requested an additional analysis be done that included all months and this is summarised in Appendix F. The main difference was that latitude was accepted into the model (Table F1), but it made little difference to the annual indices (Figure F1). The full year model is the preference of the Working Group for future work.

3.2 Observer records

The final non-zero model of observer data explained 30% of the variance in catch rate. Fishing year was forced as the first variable, and did in fact explain most of the variance in catch (16%). Sea surface temperature entered the model as the second most important variable explaining an additional 5% of the variance and it was followed by longitude, buoy_line length, and longline length, each with little additional explanatory power (Table 8).

Log(number STM per set) = fishing year + temperature + longitude + buoy-line length + length

The diagnostic plots of the residuals from the fit of this model to the data show a poor fit to the log normal assumption (Figure C2). A comparison of alternative error distributions also suggested a better fit could be achieved by assuming inverse Gaussian distributed errors, however the improvement was not marked, nor was the effect on the annual indices, so that the analysis presented here is the more traditional lognormal model.

The relation between SST and catch is positive over the range in which most of the data occur (18 – 22°C) but with some downturn predicted above 22°C that is driven by some anomalous trips in 1996 and 2010. The model accounts for year to year variance and adjusts catch upwards to account for the first two years (1993, 1994) during which all the observed trips were carried out in cold water (Figure). Likewise the significant effect of longitude is largely driven by a single year in which fishing outside the normal longitudinal range yielded high catches (

Figure). The influence of buoy line length is more interesting because it shows the negative relation between length of buoy-line (a proxy for depth), and catch, and also because there has been a trend over the study period towards shorter buoy-lines that is predicted to have increased the catch of

striped marlin (Figure 7). This is countered by a trend towards shorter longlines which is predicted to have reduced the catch. The relation between length of line and catch per set is complex, being negative over most of the range but increasing for both very short and very long lines, and it is likely to be a proxy for vessel (Figure 818).

The effect of standardisation is marked because of the unbalanced nature of the dataset that the model attempts to account for. The standardised series is smoother than the unstandardised with most of the anomalous peaks removed. The first two years in the series consist entirely of sets in cool water which the model accounts for by lifting the standardised CPUE in those years relative to the unstandardised, but the error bars around each point are nevertheless large and the overall trend is essentially flat (Figure 919).

The binomial model included Sea Surface Temperature (SST) and longline length and explained 35% of the variance in the success (Table 8). The annual indices from this model decline over the study period with the main features being high points in the first two years (1993, 1994) and in 1999. In this respect it can perhaps be considered to offer some corroboration of the indices from the lognormal model (Figure 1020).

The annual indices for the final models are given in Table A2.

Table 8: Summary of final models (Lognormal and binomial) of observer data. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion R^2: Proportion of deviance explained Final: Whether or not variable was included in final model.

Lognormal Term	DF	Deviance	AIC	R^2	Final
None	0	57.2	339	0.000	
fyear	18	48.3	333	0.155	*
poly(SST, 3)	21	45.0	323	0.213	*
poly(long, 3)	24	43.1	318	0.247	*
poly(buoy, 3)	27	41.3	314	0.278	*
poly(log(length), 3)	30	40.2	314	0.297	*

Binomial Term	DF	Deviance	AIC	R^2	Final
None	0	1 338	1 340	0.000	
fyear	18	1 170	1 206	0.126	*
poly(SST, 3)	21	885	927	0.339	*
poly(log(length), 3)	24	870	918	0.350	*
poly(lat, 3)	27	860	914	0.357	

Figure 15: Effect of Sea surface temperature in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

Figure 16: Effect of Longitude in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
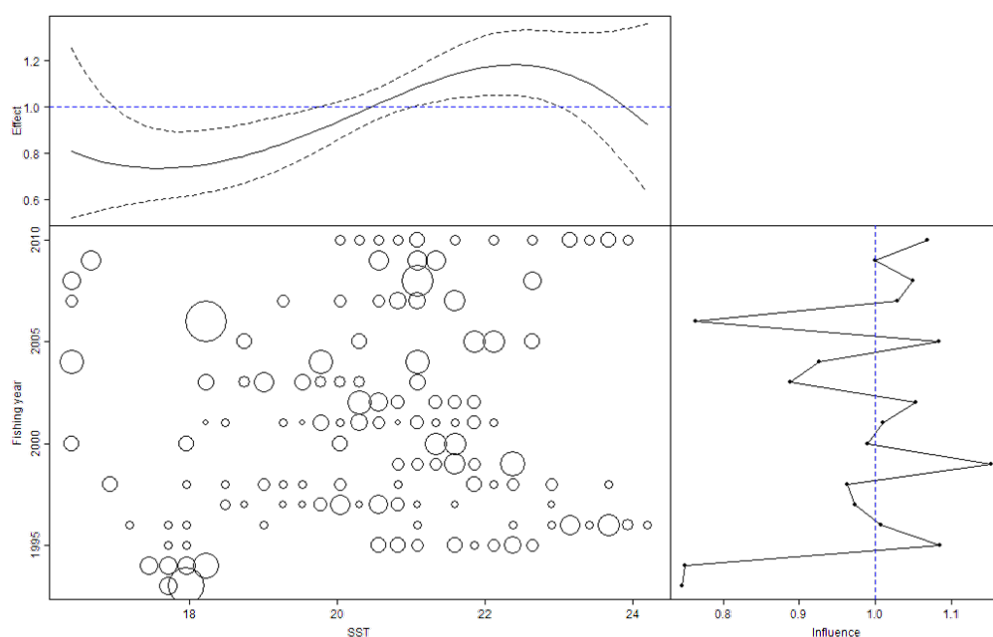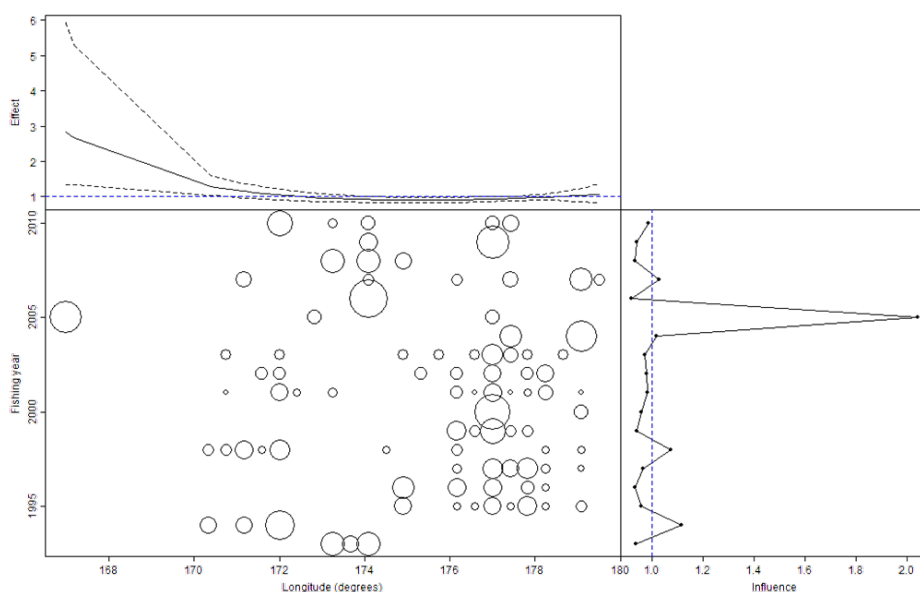
Figure 7: Effect of buoy-line length in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
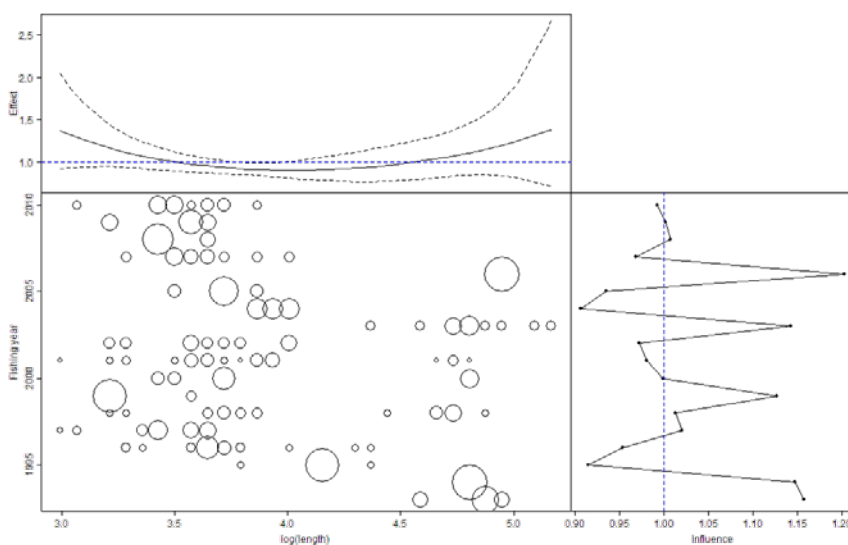
Figure 8: Effect of long-line length in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
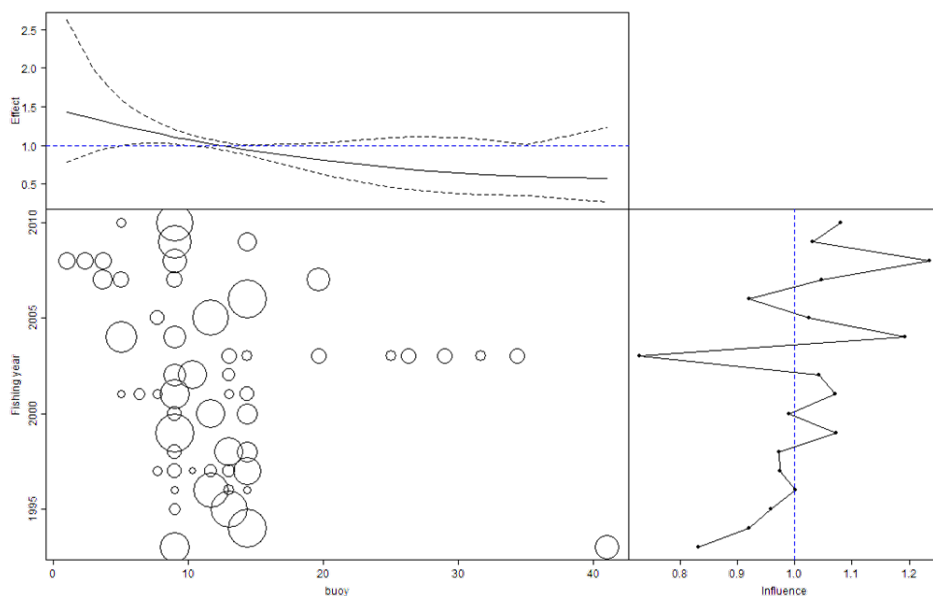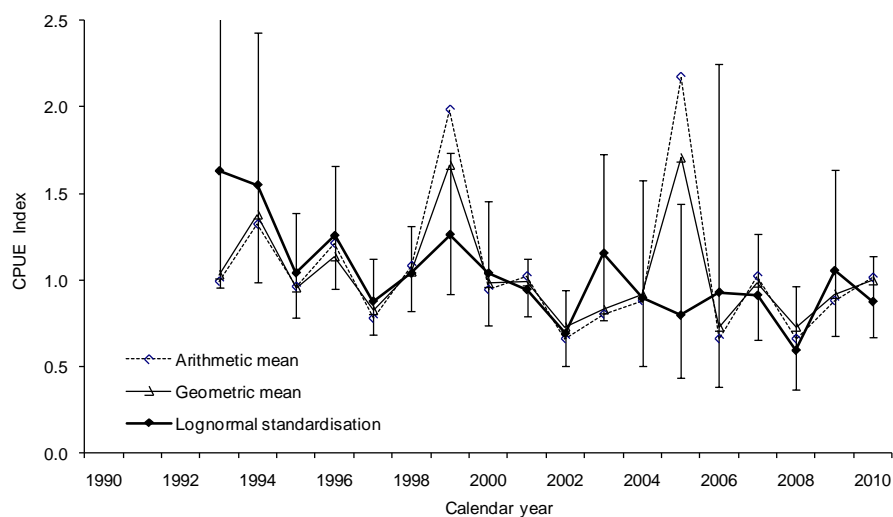
Figure 9: Unstandardised CPUE (arithmetic and geometric mean numbers of striped marlin per set) and the year effects from the lognormal model of catch rates in successful sets (± 2 s.e.).
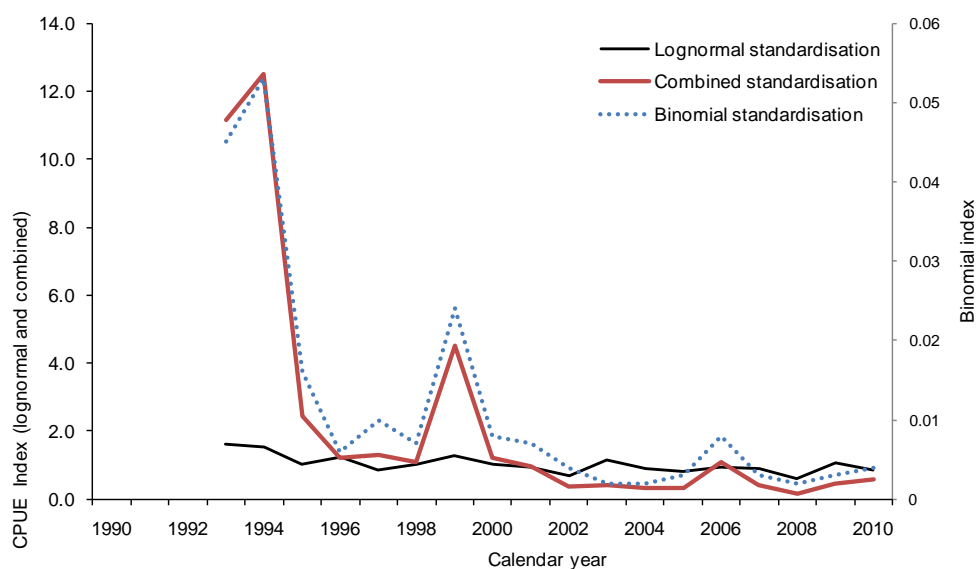
Figure 10: Comparison of annual indices from the non-zero (lognormal) model, the binomial model, and the combined model from observer reports for tuna longline vessels targeting southern bluefin tuna, swordfish, bigeye, yellowfin or albacore north of 40°S.

3.3 Models of recreational charter CPUE

Annual average catch per recreational fishing vessel for the whole season was a relatively coarse measure of catch per unit effort (CPUE) which could not effectively be modelled against spatial and environmental variables. Since 2006–07 a national billfish logbook scheme has collected daily method, catch and effort from recreational fishers. Participation in the logbook scheme is voluntary and open to charter and private skippers. To be consistent with data collected in the previous survey only recreational charter vessel data is used in this analysis. These boats have professional skippers, which generally ensure a high standard of fishing tackle and knowledge.
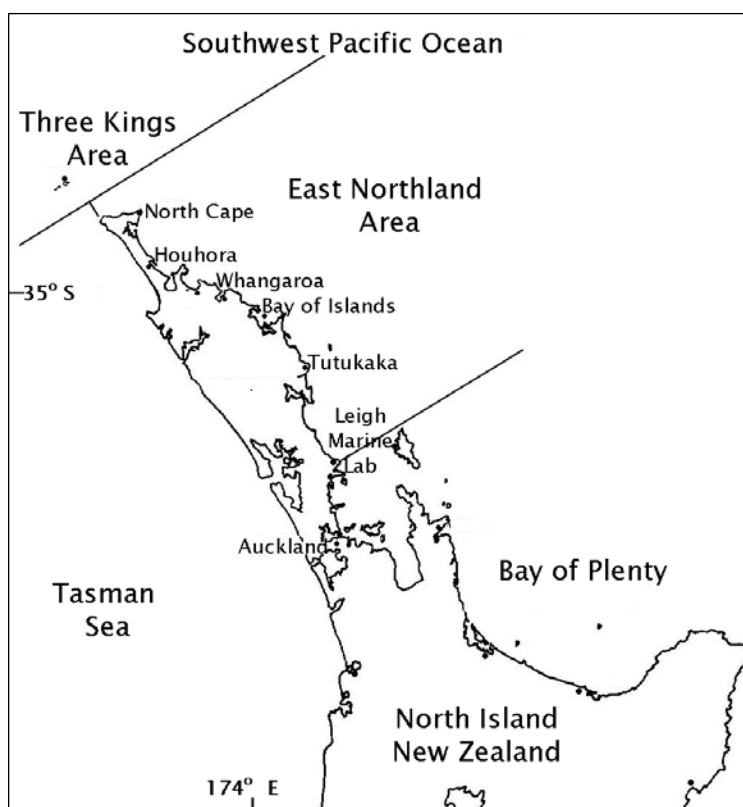
A total of 5422 striped marlin have been reported in the surveys of charter vessels in East Northland survey area

Figure 21: Boundaries of the East Northland area used in charter CPUE collection.

(Figure 21) since 1975 from a total of 32 505 fishing days. Core vessels were selected if they had reported at least 5 years in the time series and only positive catches for the season were included. This reduced the total data set used in the Lognormal model to 4535 striped marlin (84%) from 27 705 fishing days. Fishing year was forced as the first variable but nevertheless explained most of the variance in the catch (33.5%). The effort term (log of days fished) entered the model second, explaining an additional 24% of the variance and was followed by vessel with an additional 11.7% of the variance (Table 9). The final model that explained 69% of the variance in catch is:

Log(number STM per season) = fishing year + log(days fished) + vessel

A plot of model indices at each step of variable selection is shown in Figure 22. There has been a marked change in the operation of the fleet over the survey period with a decline in the number of days fished in a season. Prior to 1987 most charter boats fished over 50 days per season, but this has steadily declined. Since 2004, few charter boats fished more than 50 days per year in the survey area (Figure 23). For many years the top charter boats fished local waters from tourist ports like Bay of Islands using baits trolled at 4 knots. The top boats in the 1990s were large fast vessels that fished a wider area and trolled plastic lures at 8 knots or more. They fished a large number of days in a season but many of these were outside the survey area, north of New Zealand and in the Three Kings area. Boats that remained doing day trips from popular ports lost customers to the long range boats and to an ever increasing pool of private launches and trailer boats that were equipped to target marlin. The influence of days fished shows a positive relation between fishing more days per season and catch (Figure 23).

Table 9: Summary of final Lognormal model for the fishery. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, R²: Proportion of deviance explained, Final: Whether or not variable was included in final model, See text for explanation of influence measures.

Term	DF	Deviance	AIC	R^2	Final
None	0	330	1,151	0.000	
fyear	37	219	1,037	0.335	*
days	38	149	864	0.547	*
vessel	84	108	808	0.672	*
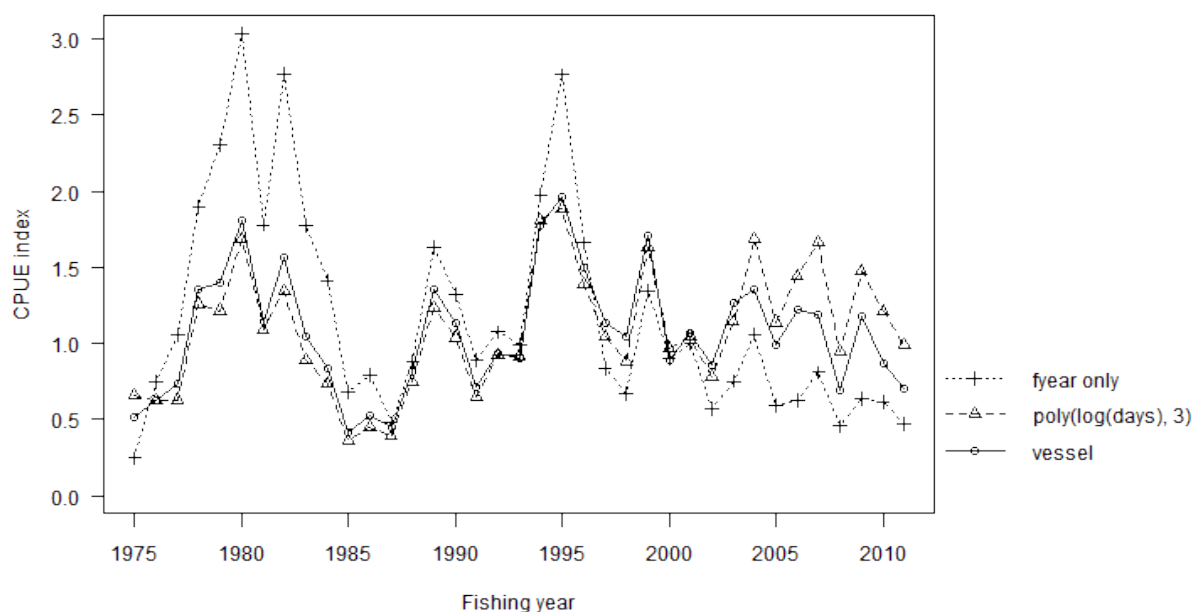
Figure 22: Annual indices from the Lognormal model at each step in the variable selection process.

Changes to the core fleet had a positive influence on catch rates overall (Figure 24) with the inclusion of better performing vessels over the last 7 or 8 years. These were mostly large new boats run by experienced skippers employed by the vessel owner. In this situation earning a living and getting a return on investment are less dependent on the number of charter days fished than with owner/operator boats. The model adjusts for the number of higher performing vessels in the survey in the last 8 years and adjusts the CPUE index downwards (Figure 24). Home port of vessel was also offered to the model but was not selected as an explanatory variable, although most likely vessel is a proxy for area fished. Various attempts have been made in previous years to include environmental variables in a GLM with these data but without better temporal resolution in CPUE they are not useable.

The diagnostic plots of the residuals from the fit of this model to the data show an adequate but not good fit to the log normal assumption (Figure C3).

Over all there is an increasing trend in standardised CPUE following the introduction of the billfish moratorium in 1987 to the mid 1990s and a decreasing trend since then (Figure 25). The 2009–10 and 2010–11 seasons were relatively poor years for the recreational striped marlin fishery in New Zealand. The peak years in the late 1970s are about equivalent to the best years in the 1990s. A table of CPUE indices are provided in the appendix (Table D3).

Figure 23: Effect and influence of recreational charter days fished in the Lognormal model. Top: relative effect by level of variable (left-axis: log space, additive; right-axis: natural space, multiplicative). Bottom-left: relative distribution of log (days) by fishing year (3.91 is the log of 50 days). Bottom-right: influence of variable on unstandardised CPUE by fishing year (bottom-axis: log space additive; top-axis: natural space, multiplicative).

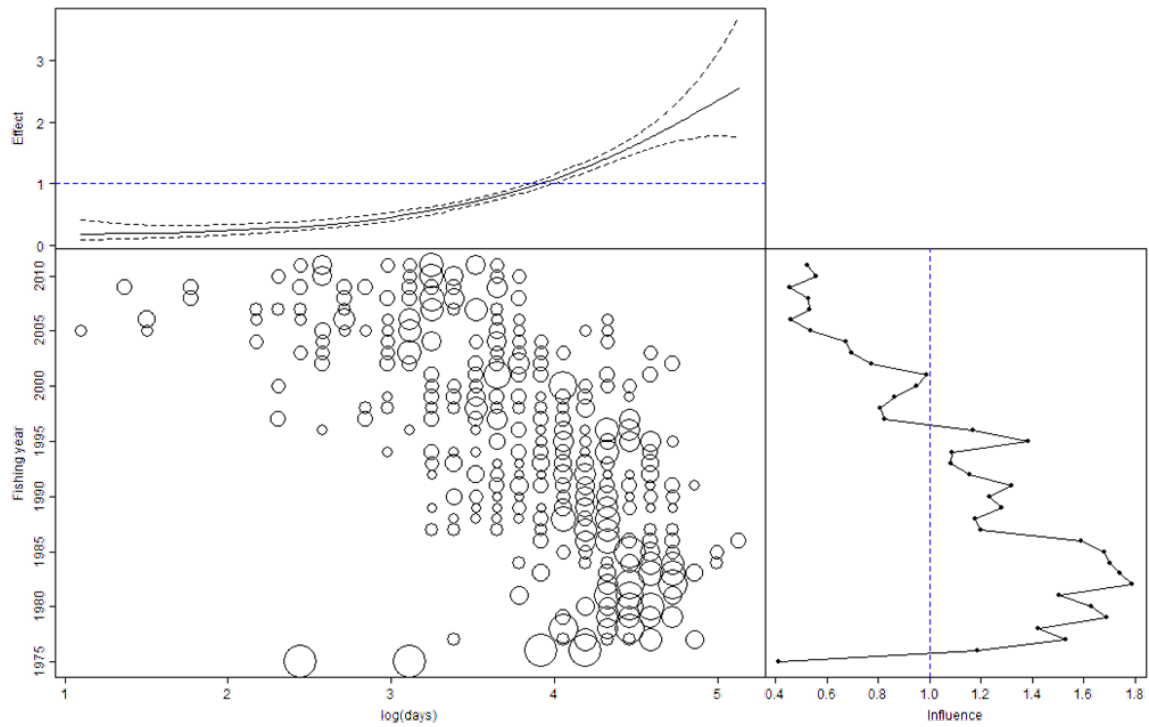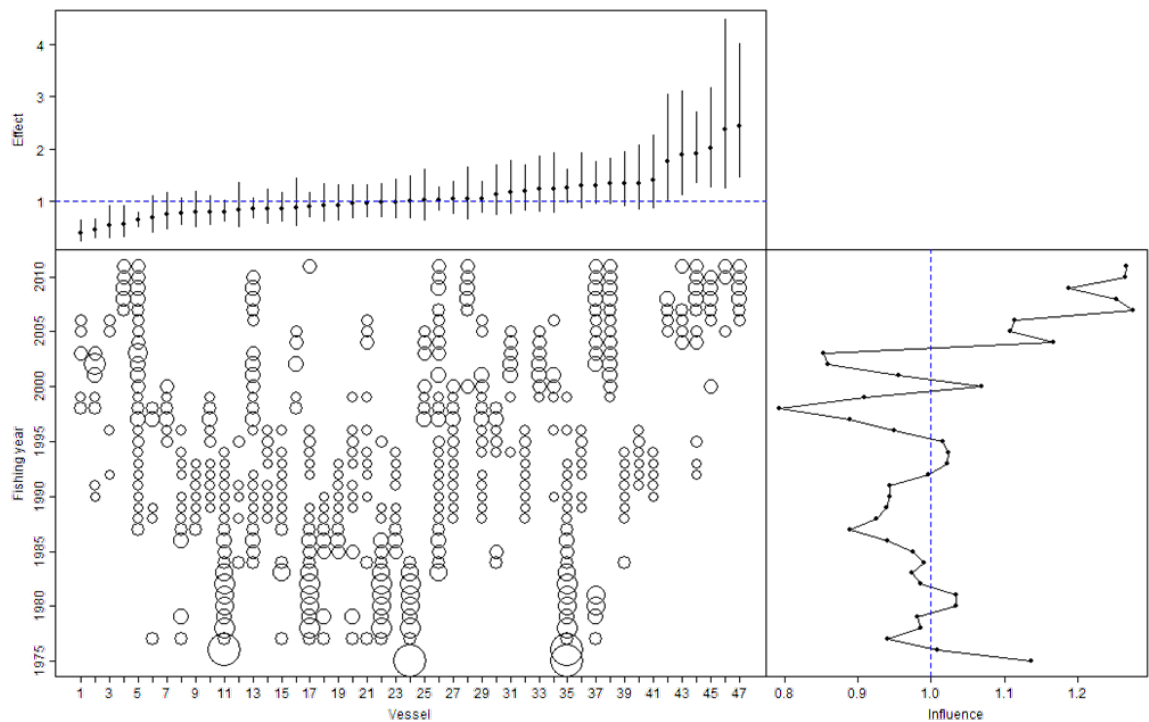**Figure 24: Effect and influence of charter vessel in the Lognormal model. Top: relative effect by level of variable (left-axis: log space, additive; right-axis: natural space, multiplicative). Bottom-left: relative distribution of variable by fishing year. Bottom-right: influence of variable on unstandardised CPUE by fishing year (bottom-axis: log space additive; top-axis: natural space, multiplicative).**
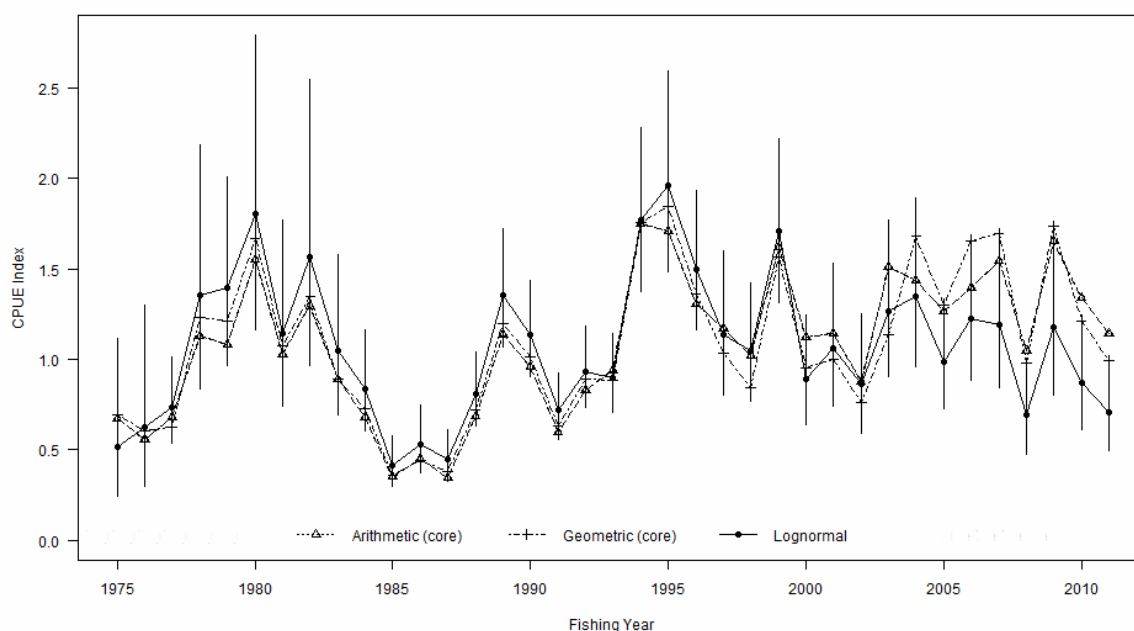
Figure 25: Unstandardised recreational charter boat CPUE (arithmetic and geometric mean number of striped marlin per vessel season) and the year effects from the model of non-zero catches (± 2 s.e.).

3.4 Comparison of models

The standardised series of observed non-zero commercial catches shows considerable interannual variance due to the small number of records, but does not disagree with the better estimated series for the core longline vessels reporting in commercial catch reporting, in describing a flat or maybe slightly declining trajectory over the last decade. The binomial series from observer records is also overlaid for comparison though on a secondary axis. It agrees reasonably well with the observer lognormal series in describing a decline from a high starting point, a peak in 1999, and a flat or slightly decreasing trajectory in the last decade (Figure 26).
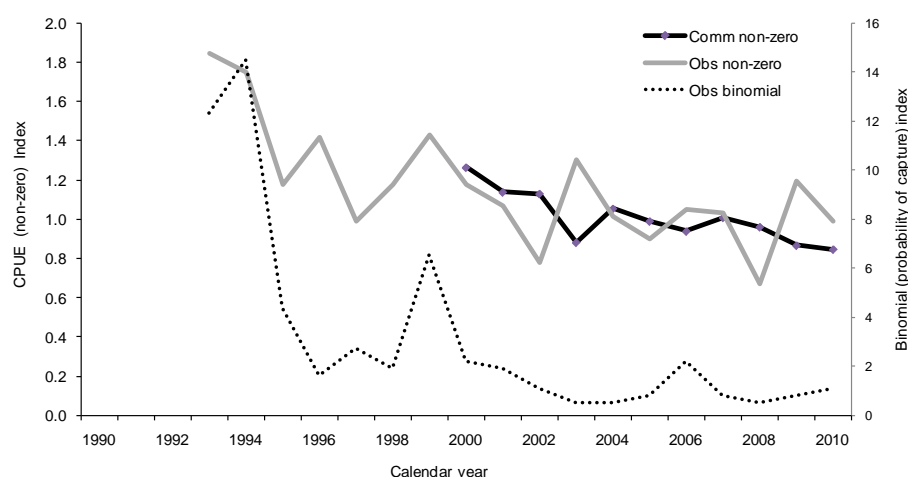
Figure 26: Comparison of standardised CPUE from non-zero models of commercial and observer records. Also shown is the binomial index of success rate from observed longline sets. The observer series have been rescaled relative to the geometric mean of the years they have in common with the commercial data series, note that the binomial is plotted on a different scale for clarity.

Standardised CPUE from the recreational charter fishery has been overlaid in Figure 27. There is considerable interannual variability but trends are similar to the non-zero commercial and observer time series with high CPUE in the mid-1990s, a peak in 1999 and a declining trend over the last decade (Figure 27). Although not part of the analysis dataset commercial reported catch in 1999 was double any other year in the series (Table 1). Striped marlin were available in high numbers in all areas of northern New Zealand that year.

One explanation for the increase in availability of striped marlin in 1999 and in 1989 was the presence of a large number of relatively small marlin of 60 to 75 kg in weight (see annotation Figure 8). Fish of this size are not common in most seasons, probably staying in warmer latitudes to the north in those years. These were also strong La Nina years and changes in oceanographic structures may affect the range of some highly migratory species. The Multivariate ENSO Index (MEI), an indicator of large climatic shifts affecting the South Pacific, has also been shown to index availability of small albacore to the troll fishery in New Zealand waters (Kendrick & Bentley 2010), with very good years for that fishery corresponding with strong La Nina years.

All the New Zealand CPUE data sets suffer from a limited spatial scale and limited number of records. There are some quite large changes in availability from year to year which appear in all indices. These may be indicative of changes in abundance or recruitment in some part of the south western Pacific stock but the scale may be amplified by annual variability in oceanographic conditions.

Figure 27: Comparison of standardised CPUE from the non-zero models of recreational charter vessel records with non-zero models of commercial and observer logbook records.

The Highly Migratory Species Working Group recommended**;**

That the commercial positive and observer trends should, at this stage, not be included in the assessments.

That future work done on commercial catch effort should;

- Be done with the benefit of dedicated data extracts (not the data submitted to WCPFC);
- explore the negative binomial error distribution model for positive commercial catches;
- select the core fleet independently of the STM catch (effort based and independent of success or failure);
- include data for all months.

4 ACKNOWLEDGEMENTS

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APPENDIX A. Analysis Datasets

Table A1: Summary of dataset of TLCER for core vessel fleet defined as having completed 3 trips per year in at least two years.

Year	Vessels	Sets	Catch (number STM)	Zero catch (% sets)
2000	19	859	239	89.6
2001	22	1 064	417	82.6
2002	25	1 111	196	92.3
2003	23	957	86	93.6
2004	23	886	301	84.5
2005	16	706	235	81.7
2006	15	609	109	89.5
2007	10	540	124	87.2
2008	9	466	179	80.3
2009	10	491	175	78.8
2010	9	387	127	80.6

Table A2: Summary of dataset of observed surface longline sets north of 38°S.

Year	Trips	Sets	Catch (number STM)	Zero catch (% sets)
1993	5	114	9	94.7
1994	3	27	10	81.5
1995	4	50	32	56.0
1996	4	60	44	60.0
1997	9	139	33	79.9
1998	10	136	36	83.8
1999	5	40	33	72.5
2000	6	34	10	79.4
2001	11	134	68	67.2
2002	8	54	11	79.6
2003	8	215	17	93.5
2004	9	52	4	94.2
2005	13	154	23	95.5
2006	7	36	1	97.2
2007	16	186	17	94.1
2008	14	118	5	95.8
2009	13	131	8	95.4
2010	11	83	23	81.9

Table A3: Summary of dataset of east northland recreational core vessel catch and national club and tagging database striped marlin records.

Year	Vessels	Effort (days fished)	Catch (number STM)	Total recreational catch recorded	Proportion of catch by core vessels
1975	3	63	4	242	0.02
1976	3	143	11	284	0.04
1977	12	1 084	119	334	0.36
1978	5	385	70	452	0.15
1979	9	862	150	565	0.27
1980	6	545	136	709	0.19
1981	6	508	84	794	0.11
1982	5	513	107	715	0.15
1983	7	718	103	708	0.15
1984	12	1 196	131	552	0.24
1985	11	1 057	60	262	0.23
1986	12	982	67	397	0.17
1987	12	815	45	228	0.20
1988	20	1 255	138	417	0.33
1989	22	1 567	286	1 055	0.27
1990	23	1 623	250	830	0.30
1991	20	1 488	143	764	0.19
1992	22	1 398	186	761	0.24
1993	21	1 268	191	994	0.19
1994	19	1 165	328	1 592	0.21
1995	16	1 243	342	2 116	0.16
1996	19	1 258	264	1 809	0.15
1997	12	520	89	1 921	0.05
1998	13	553	91	1 441	0.06
1999	18	828	216	2 364	0.09
2000	12	601	107	1 189	0.09
2001	12	513	90	1 273	0.07
2002	10	422	56	1 201	0.05
2003	11	450	107	1 166	0.09
2004	14	437	92	1 643	0.06
2005	16	477	97	2 179	0.04
2006	14	343	77	1 552	0.05
2007	12	314	78	1 638	0.05
2008	12	293	43	1 201	0.04
2009	12	240	61	1 789	0.03
2010	11	301	65	1 416	0.05
2011	11	277	51	1 227	0.04

APPENDIX B. Alternative Error distributions
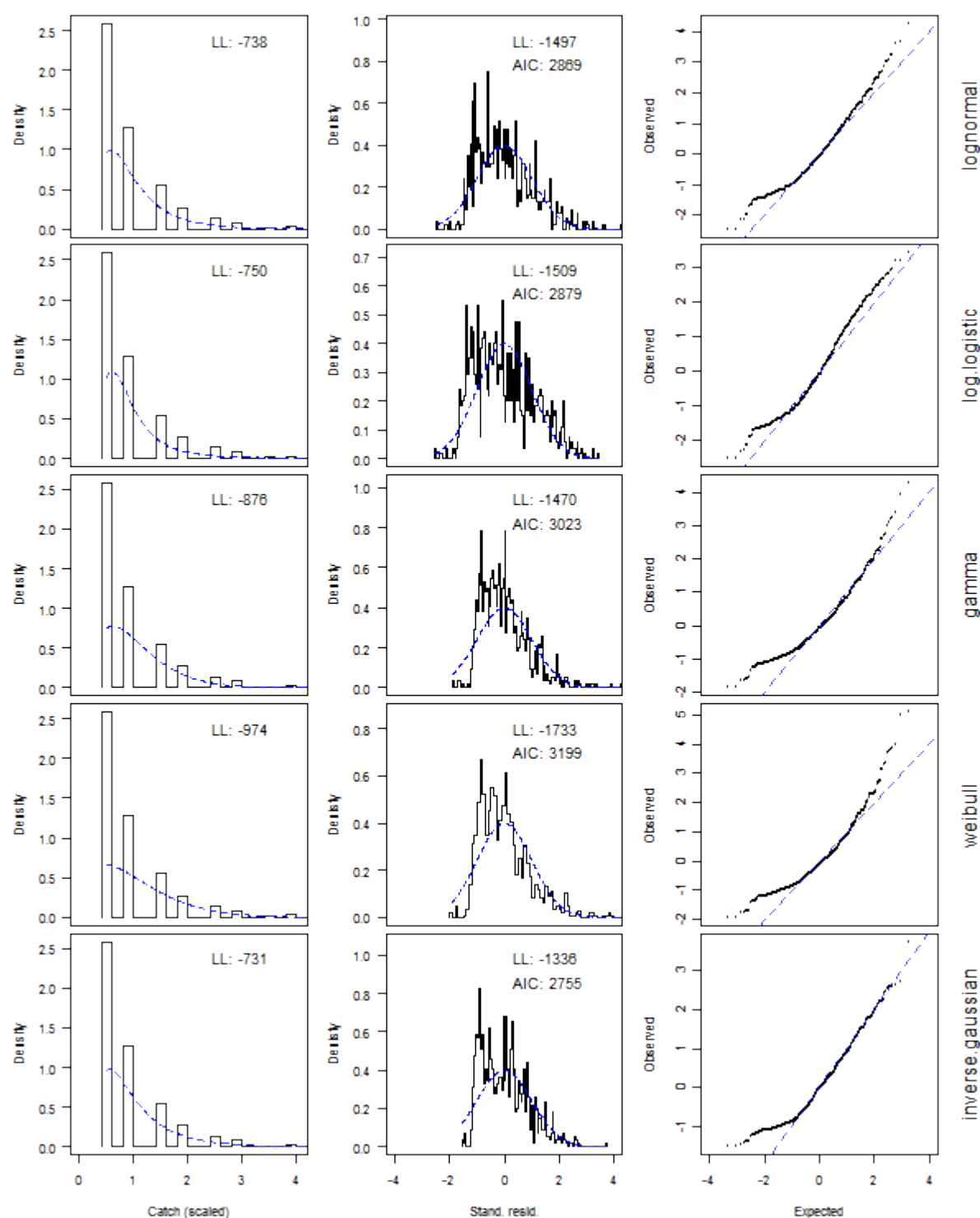
Figure B1: Diagnostics for alternative distributional assumptions for commercial positive catches. Left: maximum likelihood fit (dotted) to observed catches (solid, scaled by their mean); Middle: standardised residuals from a simplified model catch~fyear +vessel+month; Right: quantile-quantile plot of standardised residuals of model. LL = log-likelihood of fit.
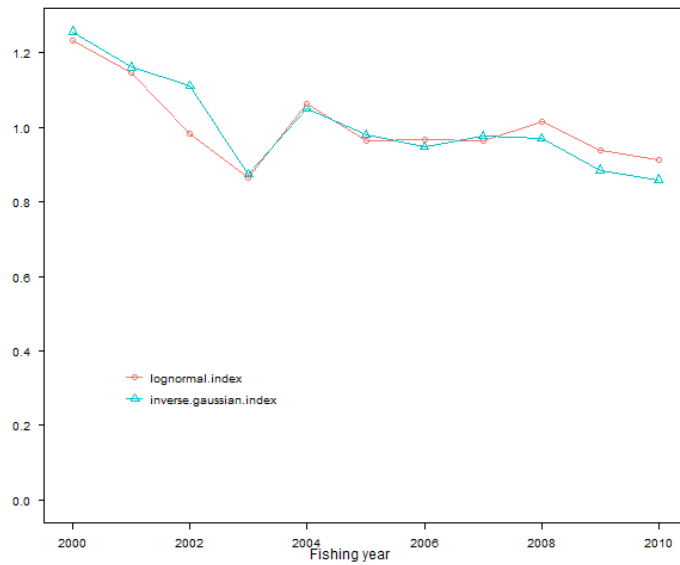
Figure 11: Comparison between CPUE indices obtained from model catch~fyear+vessel+month assuming lognormal and inverse gaussian distributions.

APPENDIX C. Model residual plots
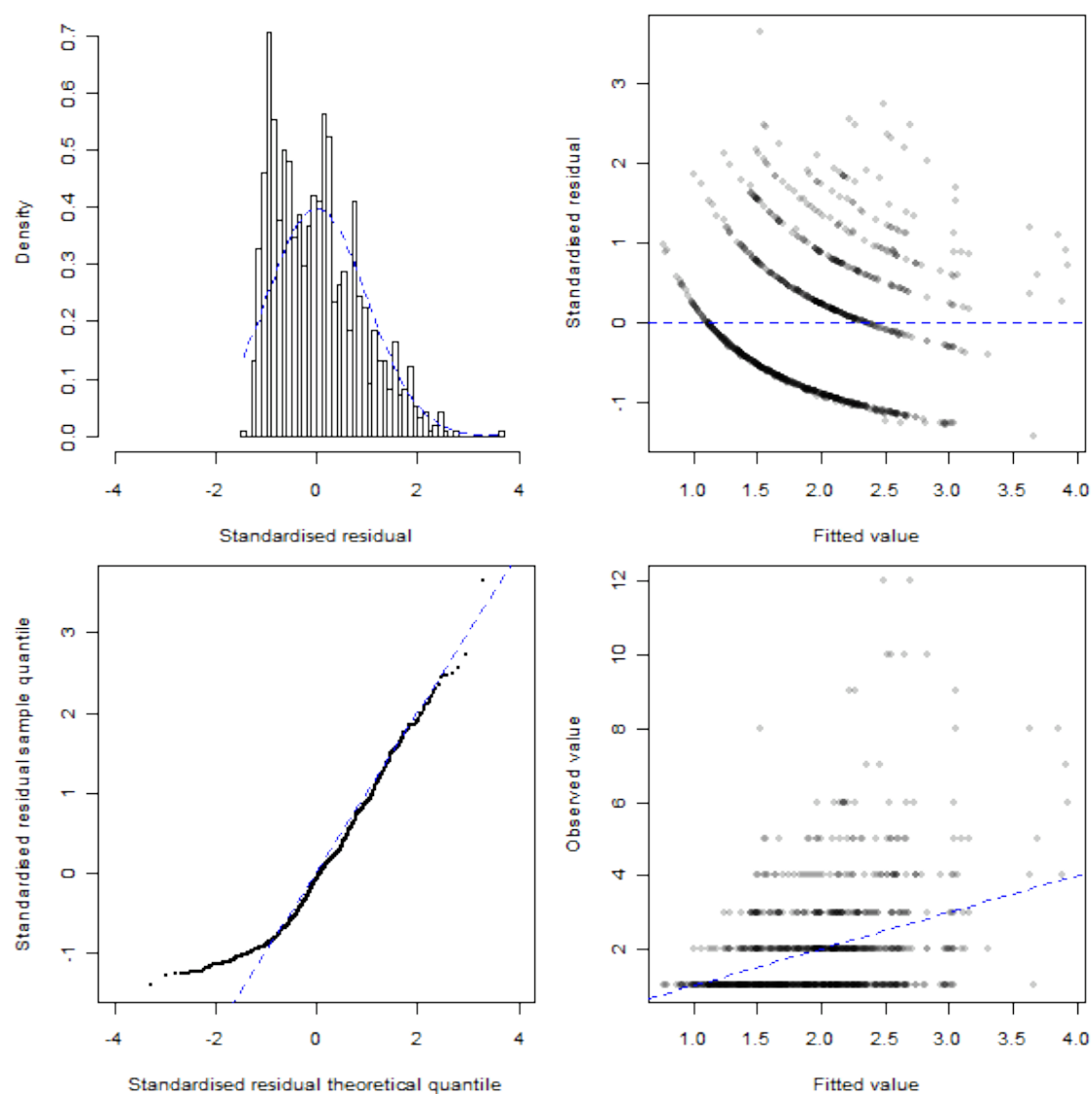
Figure 12: Residual diagnostics. Top left: histogram of standardised residuals compared to the inverse gaussian distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.
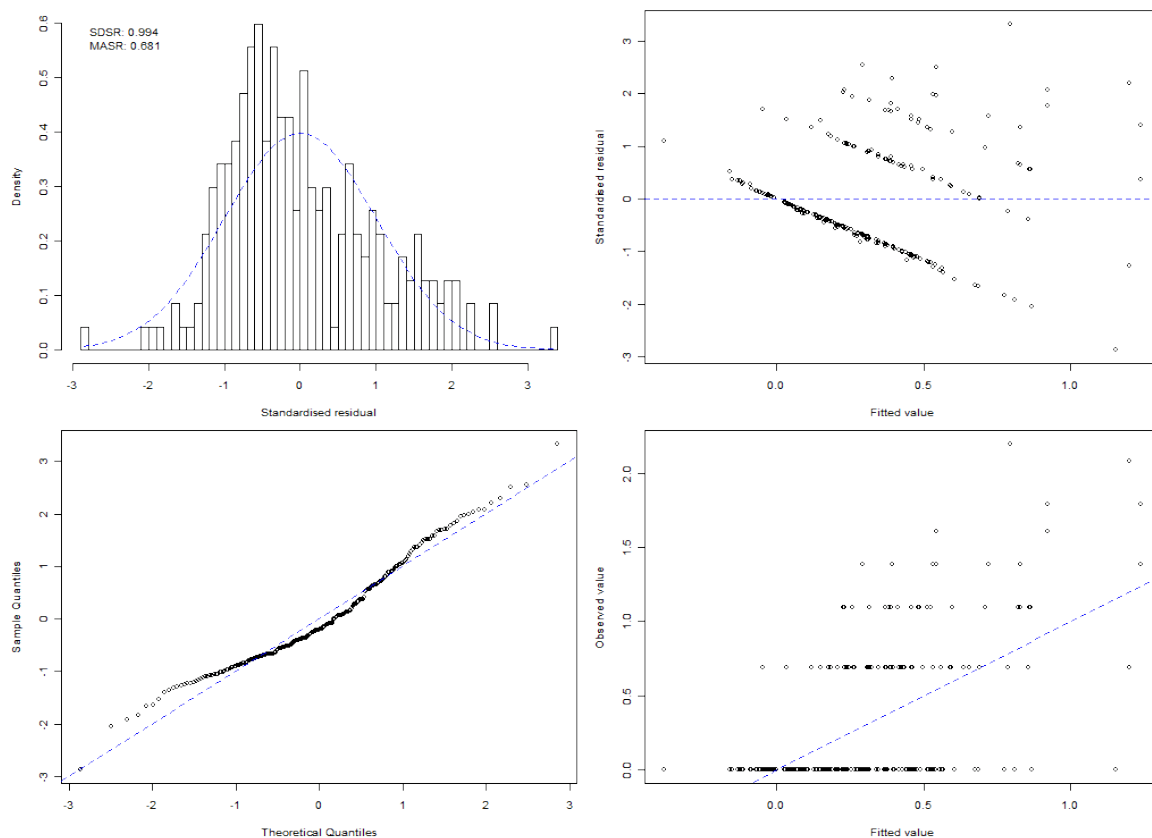
Figure C2: Plots of the fit of the standardised CPUE model to successful catches of striped marlin in the observed longline sets. [Upper left] histogram of the standardised residuals compared to a lognormal distribution (SDSR: standard deviation of standardised residuals. MASR: median of absolute standardised residuals); [Upper right] Q-Q plot of the standardised residuals; [Lower left] Standardised residuals plotted against the predicted model catch per trip; [Lower right] Observed catch per record plotted against the predicted catch per record.
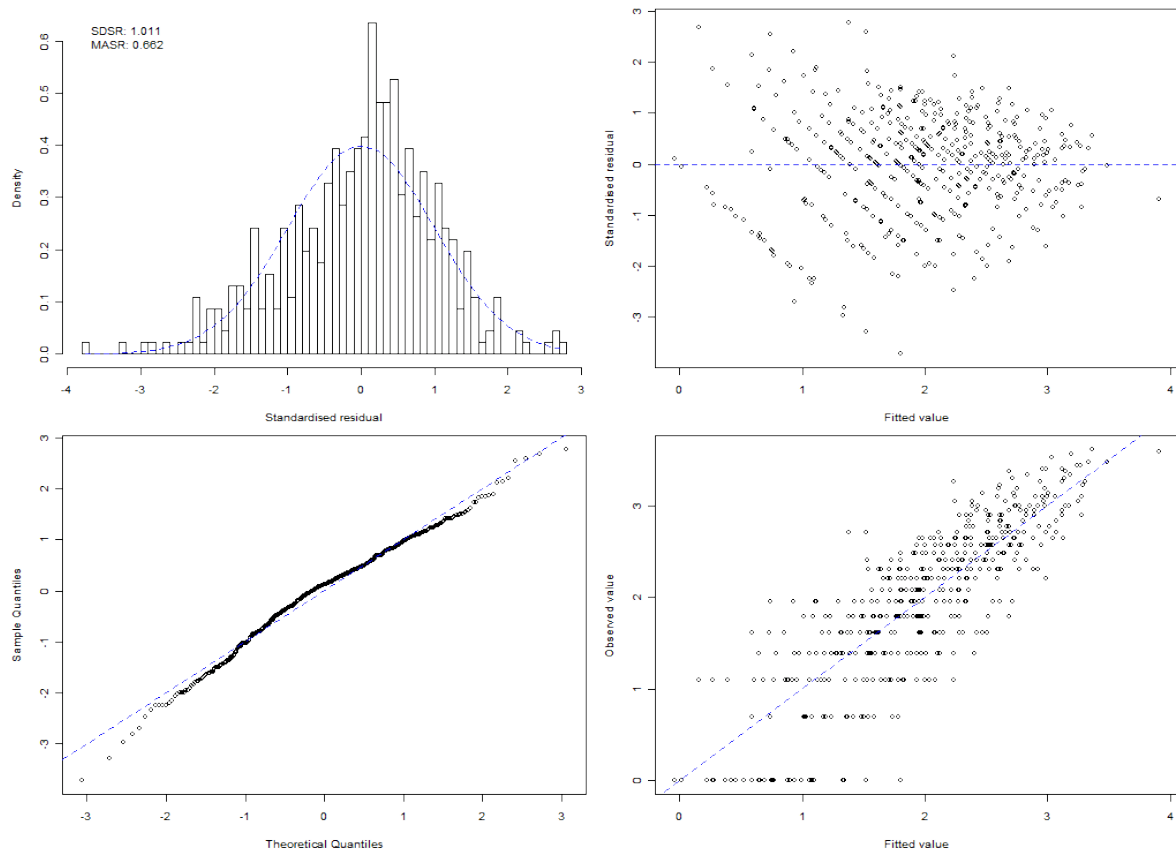
Figure C3: Diagnostic plots for the Lognormal model for the recreational fishery. Top left: histogram of standardised residuals compared to standard normal distribution. (SDSR: standard deviation of standardised residuals. MASR: median of absolute standardised residuals.) Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

APPENDIX D. CPUE Indices

Table 1: Indices (± 2 s.e.) from the models fit to commercial catch and effort data.

| Calendar year	Arithmetic mean	Geometric mean	Inverse Gaussian standardisation	Binomial standardisation	Combined standardisation
2000	1.397	1.214	1.264 (1.066–1.500)	0.104	1.085
2001	1.173	1.125	1.138 (1.010–1.284)	0.200 (0.156–0.252)	1.873
2002	1.186	1.073	1.130 (0.970–1.316)	0.054 (0.039–0.075)	0.504
2003	0.734	0.795	0.882 (0.753–1.033)	0.051 (0.035–0.074)	0.374
2004	1.143	1.102	1.054 (0.935–1.188)	0.140 (0.104–0.185)	1.212
2005	0.948	0.999	0.990 (0.881–1.111)	0.162 (0.119–0.217)	1.320
2006	0.886	0.923	0.939 (0.806–1.095)	0.115 (0.080–0.164)	0.893
2007	0.935	0.956	1.009 (0.870–1.171)	0.098 (0.067–0.140)	0.813
2008	1.012	0.991	0.961 (0.839–1.100)	0.193 (0.140–0.260)	1.532
2009	0.876	0.938	0.867 (0.767–0.979)	0.205 (0.151–0.272)	1.462
2010	0.881	0.950	0.847 (0.738–0.973)	0.144 (0.100–0.201)	1.003

Table 2: Indices (± 2 s.e.) from the models fit to observer data.

Calendar year	Arithmetic mean	Geometric mean	Lognormal standardisation	Binomial standardisation	Combined standardisation
1993	0.992	1.032	1.631 (0.958–2.779)	0.045	11.139
1994	1.322	1.379	1.549 (0.989–2.428)	0.053 (0.012–0.209)	12.516
1995	0.962	0.957	1.042 (0.781–1.390)	0.016 (0.003–0.068)	2.455
1996	1.212	1.137	1.257 (0.951–1.663)	0.006 (0.001–0.029)	1.220
1997	0.779	0.826	0.878 (0.686–1.123)	0.010 (0.002–0.038)	1.283
1998	1.082	1.049	1.039 (0.822–1.314)	0.007 (0.002–0.026)	1.097
1999	1.983	1.666	1.263 (0.918–1.737)	0.024 (0.006–0.094)	4.526
2000	0.944	0.983	1.040 (0.741–1.460)	0.008 (0.002–0.035)	1.215
2001	1.022	0.992	0.946 (0.795–1.126)	0.007 (0.002–0.025)	0.953
2002	0.661	0.730	0.692 (0.508–0.944)	0.004 (0.001–0.017)	0.387
2003	0.803	0.830	1.155 (0.772–1.729)	0.002 (0.001–0.009)	0.413
2004	0.881	0.920	0.896 (0.509–1.575)	0.002 (0.000–0.013)	0.322
2005	2.172	1.708	0.798 (0.441–1.444)	0.003 (0.001–0.013)	0.324
2006	0.661	0.730	0.930 (0.384–2.248)	0.008 (0.001–0.080)	1.097
2007	1.022	0.985	0.913 (0.659–1.264)	0.003 (0.001–0.013)	0.426
2008	0.661	0.730	0.595 (0.368–0.963)	0.002 (0.000–0.009)	0.165
2009	0.881	0.920	1.055 (0.680–1.637)	0.003 (0.001–0.015)	0.437
2010	1.014	0.998	0.876 (0.672–1.141)	0.004 (0.001–0.019)	0.579

Table D3: Striped marlin catch per unit effort indices for core recreational charter vessel data.

Fishing year	Arithmetic mean	Geometric mean	Lognormal standardisation
1975	0.672	0.696	0.519 (0.241–1.120)
1976	0.556	0.602	0.622 (0.297–1.302)
1977	0.683	0.622	0.735 (0.535–1.012)
1978	1.131	1.234	1.353 (0.838–2.186)
1979	1.082	1.211	1.393 (0.968–2.007)
1980	1.552	1.67	1.803 (1.164–2.794)
1981	1.028	1.077	1.145 (0.741–1.770)
1982	1.297	1.348	1.569 (0.966–2.549)
1983	0.892	0.889	1.047 (0.692–1.583)
1984	0.681	0.729	0.839 (0.606–1.161)
1985	0.353	0.359	0.416 (0.299–0.578)
1986	0.451	0.443	0.528 (0.375–0.745)
1987	0.343	0.378	0.447 (0.328–0.610)
1988	0.684	0.718	0.810 (0.630–1.042)
1989	1.135	1.197	1.357 (1.070–1.722)
1990	0.958	1.013	1.138 (0.901–1.437)
1991	0.598	0.632	0.718 (0.559–0.923)
1992	0.828	0.891	0.932 (0.735–1.182)
1993	0.937	0.887	0.897 (0.704–1.142)
1994	1.751	1.755	1.774 (1.378–2.283)
1995	1.711	1.846	1.964 (1.488–2.593)
1996	1.305	1.362	1.498 (1.161–1.932)
1997	1.17	1.034	1.136 (0.805–1.602)
1998	1.023	0.846	1.045 (0.768–1.421)
1999	1.623	1.565	1.708 (1.313–2.221)
2000	1.12	0.955	0.893 (0.641–1.245)
2001	1.145	1	1.065 (0.741–1.529)
2002	0.877	0.761	0.861 (0.592–1.251)
2003	1.509	1.137	1.267 (0.906–1.770)
2004	1.434	1.684	1.350 (0.962–1.894)
2005	1.265	1.302	0.987 (0.730–1.336)
2006	1.396	1.653	1.224 (0.885–1.692)
2007	1.545	1.695	1.189 (0.843–1.677)
2008	1.049	0.978	0.690 (0.474–1.005)
2009	1.657	1.738	1.179 (0.803–1.733)
2010	1.343	1.21	0.870 (0.609–1.243)
2011	1.145	0.991	0.706 (0.495–1.008)

APPENDIX E. Mean weight of recreational catch

Table E1: The recorded number, average weight of weighed fish landed, estimated average weight of fish tagged, and estimated total weight of striped marlin caught by recreational fishers in New Zealand fisheries waters based on club records. Almost all catch is taken between January and June so Year and Season are effectively the same.

Year	Season	Numbers of striped marlin		Average weight (kg)		Total weight (tonnes)	
		Landed	Tagged	Landed	Tagged (est.)	Landed	Tagged
1945				118.17			
1946				111.41			
1947				112.64			
1948				110.02			
1949				106.71			
1950				111.02			
1951				106.26			
1952				116.34			
1953				119.06			
1954				117.09			
1955	1954–55	454		117.20		53.2	
1956	1955–56	361		115.39		41.7	
1957	1956–57	400		117.46		47.0	
1958	1957–58	462		116.46		53.8	
1959	1958–59	246		115.13		28.3	
1960	1959–60	234		111.46		26.1	
1961	1960–61	396		106.12		42.0	
1962	1961–62	161		111.93		18.0	
1963	1962–63	176		103.08		18.1	
1964	1963–64	178		111.47		19.8	
1965	1964–65	239		113.23		27.1	
1966	1965–66	231		102.47		23.7	
1967	1966–67	149		110.31		16.4	
1968	1967–68	160		106.05		17.0	
1969	1968–69	202		111.66		22.6	
1970	1969–70	75		108.86		8.2	
1971	1970–71	82		86.61		7.1	
1972	1971–72	158		105.35		16.6	
1973	1972–73	88		106.65		9.4	
1974	1973–74	209		94.38		19.7	
1975	1974–75	242		102.91		24.9	
1976	1975–76	281	3	98.91		27.8	0.3
1977	1976–77	332	2	111.93		37.2	0.2
1978	1977–78	445	7	112.28		50.0	0.8
1979	1978–79	547	18	103.96		56.9	1.9
1980	1979–80	675	17	104.77		70.7	1.8
1981	1980–81	790	2	99.09		78.3	0.2
1982	1981–82	693	11	109.18		75.7	1.2
1983	1982–83	696	6	108.09		75.2	0.6

		Numbers of striped marlin		Average weight (kg)		Total weight (tonnes)	
Year	Season	Landed	Tagged	Landed	Tagged (est.)	Landed	Tagged
1984	1983–84	534	9	98.15		52.4	0.9
1985	1984–85	262		98.48		25.8	
1986	1985–86	395	2	100.08		39.5	0.2
1987	1986–87	226	2	102.46		23.2	0.2
1988	1987–88	320	97	107.88	96.40	34.5	9.4
1989	1988–89	684	371	88.19	79.15	60.3	29.4
1990	1989–90	463	365	95.17	90.42	44.1	33.0
1991	1990–91	532	229	97.70	87.96	52.0	20.1
1992	1991–92	519	239	111.57	92.98	57.9	22.2
1993	1992–93	608	385	102.97	95.10	62.6	36.6
1994	1993–94	663	928	99.94	87.97	66.3	81.6
1995	1994–95	910	1202	102.73	88.57	93.5	106.5
1996	1995–96	705	1102	98.48	91.10	69.4	100.4
1997	1996–97	619	1301	105.78	98.13	65.5	127.7
1998	1997–98	543	895	102.75	89.12	55.8	79.8
1999	1998–99	823	1541	88.58	85.03	72.9	131.0
2000	1999–00	398	787	100.19	88.87	39.9	69.9
2001	2000–01	422	851	102.75	89.44	43.4	76.1
2002	2001–02	430	771	106.34	101.95	45.7	78.6
2003	2002–03	495	671	110.01	97.31	54.5	65.3
2004	2003–04	592	1051	102.70	98.23	60.8	103.2
2005	2004–05	834	1348	103.84	97.43	86.6	131.3
2006	2005–06	630	923	96.48	92.98	60.8	85.8
2007	2006–07	688	964	98.14	96.86	67.5	93.4
2008	2007–08	485	806	100.31	98.89	48.6	79.7
2009	2008–09	731	1058	100.82	98.63	73.7	104.4
2010	2009–10	607	809	103.93	98.29	63.1	79.5

APPENDIX F. Sensitivity of commercial catch effort analysis to inclusion of all months

The commercial catch and effort data was re-analysed by including data for all months in the year. The same core fleet was used, and the inverse Gaussian error distribution was again selected as the most appropriate. The model included latitude as having significant explanatory power and a comparison of annual indices with the base model shows very little change as a result of accounting for the additional data. This was the analysis preferred by the Working Group.

Table F1: Summary of final models (inverse Gaussian and binomial) of commercial data. Independent variables are listed in the order of acceptance to the model. AIC: Akaike Information Criterion, Proportion of deviance explained, Final: Whether or not variable was included in final model.

Inverse GaussianTerm	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (%)	Final
fyear	11	-1 563	3 149	4.78	*
month	22	-1 484	3 015	17.05	*
vessel	46	-1 407	2 907	27.84	*
poly(lat 3)	49	-1 388	2 875	30.26	*

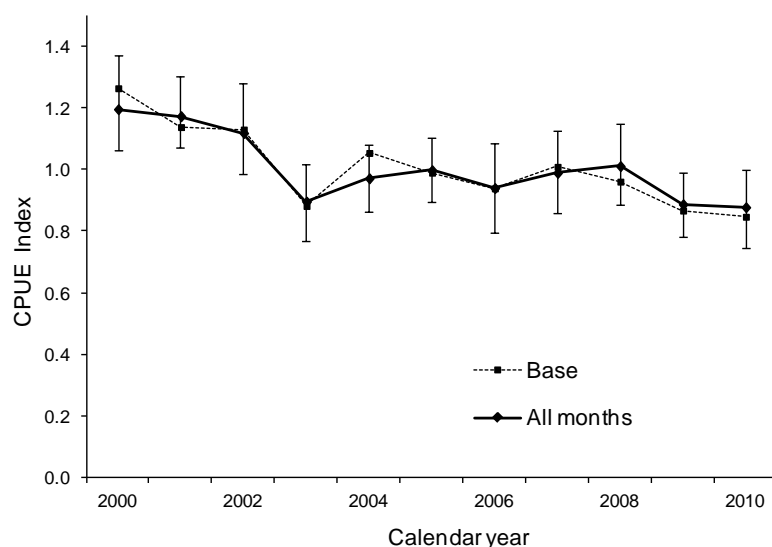| Binomial Term	DF	Deviance	AIC	R^2	Final
None	0	8 260	8 262	0.0000	
fyear	11	8 071	8 093	0.0228	*
month	22	7 200	7 244	0.1284	*
vessel	46	6 429	6 521	0.2217	*
poly(lat 3)	49	6 192	6 290	0.2504	*
poly(log(hooks) 3)	52	6 159	6 263	0.2543	
target	55	6 137	6 247	0.2571	

Figure F1: Comparison between CPUE indices obtained from the base model of positive commercial catches and an alternative model that included all months. Both models assumed inverse gaussian error distributions.
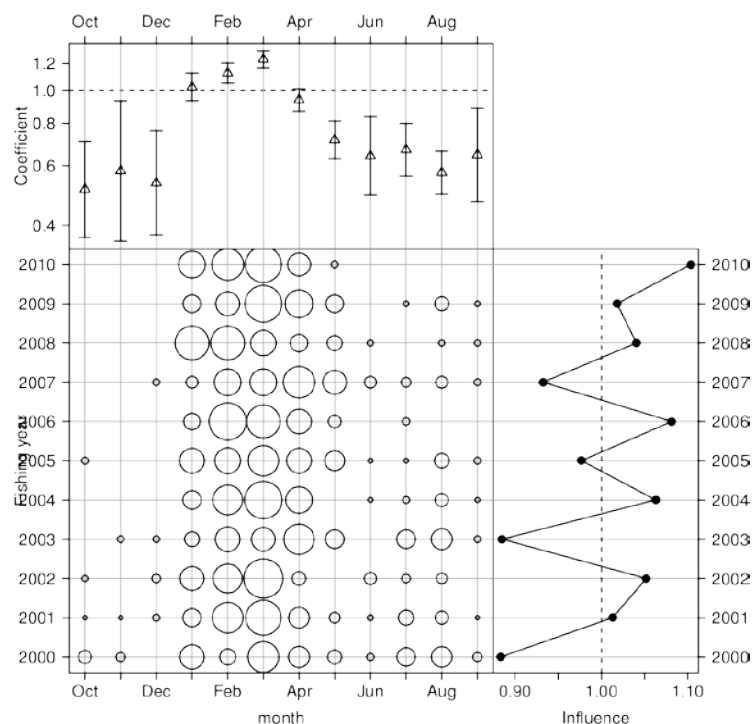
Figure F2: Effect of month in the model of non-zero catches for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
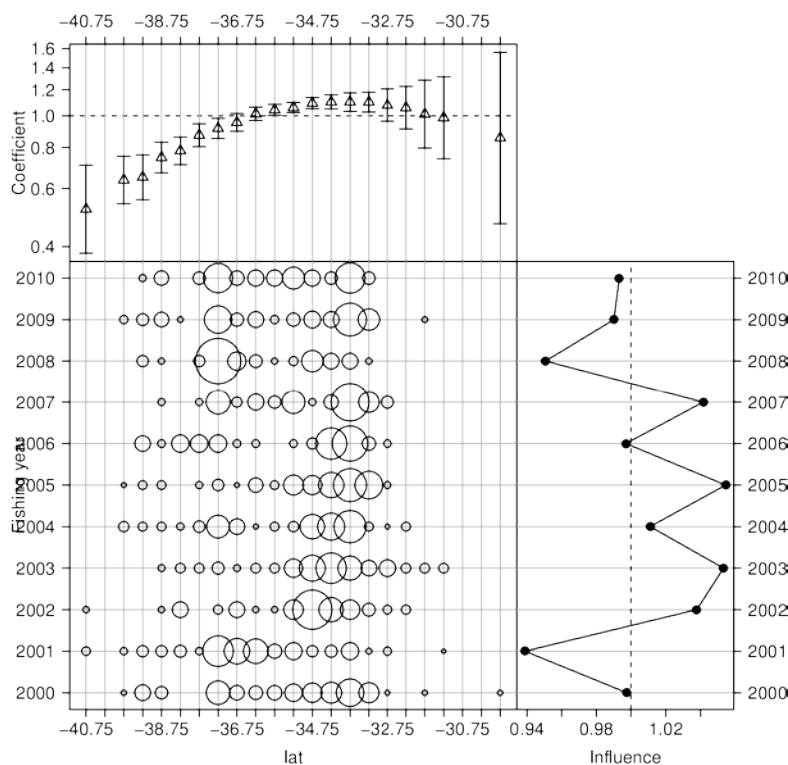

Figure F3: Effect of latitude in the model of non-zero catches for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.
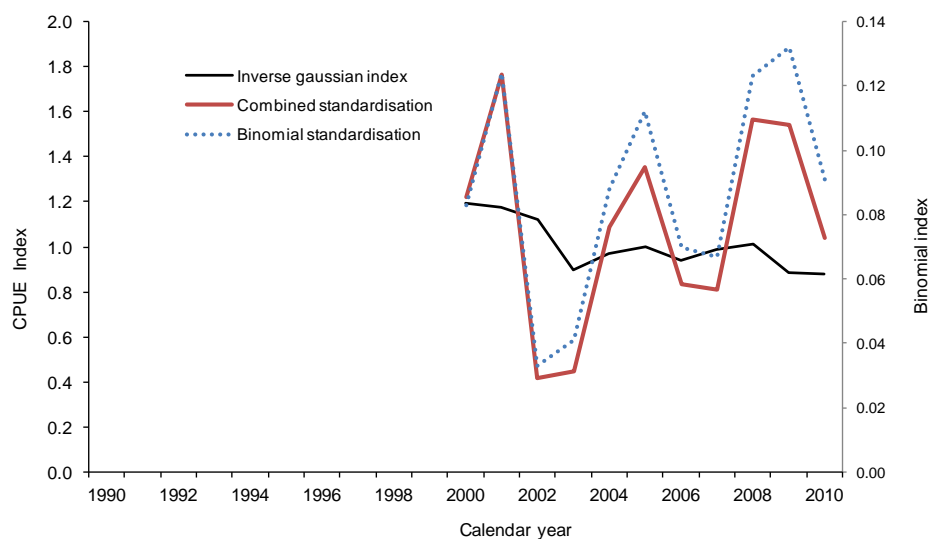
Figure F4: Different standardised annual cpue_indices for the fishery. Top: Binomial index representing probability of capture. Middle: inverse gaussian index representing magnitude of catch. Bottom: Combined index representing expected catch.