New Zealand Fisheries
Assessment Report
2011/22
May 2011
ISSN 1175-1584 (print)
ISSN 1179-5352 (online)

Characterisation of striped marlin fisheries and biology in New Zealand and wider southwest Pacific Ocean

J. C. Holdsworth
R. K. Kopf

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J. C. Holdsworth
R. K. Kopf

Blue Water Marine Research
P O Box 402081
Tutukaka
Northland 0153

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Published by Ministry of Fisheries
Wellington
2011

ISSN 1175-1584 (print)
ISSN 1179-5352 (online)

Holdsworth, J.C.; Kopf, R.K. (2011).
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New Zealand Fisheries Assessment Report 2011/22.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Holdsworth, J.C.; Kopf, R.K. (2011). Characterisation of striped marlin fisheries and biology in New Zealand and wider southwest Pacific Ocean.

New Zealand Fisheries Assessment Report 2011/22.

Striped marlin (*Kajikia audax*) is a highly migratory species widely distributed across the Pacific and Indian Oceans and is the most commonly encountered of the five istiophorid billfishes caught in New Zealand. Striped marlin usually arrive in New Zealand, along with warm oceanic water, during December or January. By late summer they may range as far south as Gisborne on the east coast and New Plymouth on the west coast.

Striped marlin in the southwest Pacific Ocean (SWPO) is managed as a semi-independent population. Commercial catch in the region has averaged about 2500 t per year since 1980 from an annual world catch estimated at 12 000 t. It is hard to get precise historical catch statistics because istiophorid billfishes were frequently grouped together without individual species recognition.

Japanese surface longline vessels were the first to fish in the SWPO in the mid 1950s and targeted blue and striped marlin. Later, yellowfin and bigeye tuna became the primary catch in subtropical waters. Domestic longline fleets in New Zealand, Australia's east coast, and other Pacific Island countries and territories have expanded since the mid 1990s. Most catch in the region comes from the Coral and Tasman Seas. Taiwanese vessels now land the majority of striped marlin in the region. The most recent stock assessment of striped marlin in the SWPO suggested that the status of the fishery was largely uncertain and recommended no further increase in fishing mortality. Regional management by the Western Central Pacific Fisheries Commission and national management by member states affect striped marlin abundance in the SWPO and availability in New Zealand waters.

The New Zealand EEZ is the only area in the SWPO where retention of commercially caught striped marlin is prohibited. Longline bycatch in New Zealand waters declined from 65.1 t in 2000 to 23.9 t in 2009. This 63% reduction in reported catch of striped marlin during this period coincides with a decrease in effort of 8.2 million to 3.1 million hooks or 62%. In the 1990s there were indications that there was under-reporting of catch and release of striped marlin in commercial catch returns. Observer records show that 74% of striped marlin were alive when brought to the boat, but there is no available information on the survival rate of these released fish.

The observer database provides catch and effort from 2226 surface longline sets north of 38° S since 1990. These contain accurate records of striped marlin catch but there is not good spatial or temporal overlap with the striped marlin fishery. In the early 1990s the records of striped marlin catch are sparse.

Two potential signals of abundance were investigated from New Zealand observer catch effort data and two standardised models were applied to the dataset (397 fish). Vessel was not identified in the data and was not offered to the model. Sea surface temperature and latitude entered the binomial model as the most important factors after fishing year was forced as the first variable. Overall 35% of the variance in success rate was explained by the model. A lognormal linear model fitted to just successful catches of striped marlin (excluding zero catches) accepted sea surface temperature, longitude, and buoy line length as the most important factors, explaining 28% of variance.

The two series of year effects from observer data each describe a very similar pattern which is probably because of the lack of contrast in the catch rate data (most catch rates are of a single fish per set). The lognormal series is flatter than the binomial and the error bars around each point are smaller. The first two points in each series are entirely the prediction of the models for years when very few striped marlin were observed caught.

Reported commercial catch from tuna longline catch effort returns were investigated with a lognormal model of positive catches from core vessels since 1990–2000. The series modelled for the core fleet reporting on TLCERs agrees with the observer lognormal series in describing a relatively flat trajectory. There is an indication of a slight step down since the late 1990s, but given the precision of the year effects, the trend in each series can generally be described as flat for the last decade at least. There are a number of issues with the commercial data used in CPUE analysis. The observer data are well reported but contain relatively few marlin and in most years there is poor coverage of effort between January and April. The TLCER for released and discarded fish has not been consistently reported by all vessels; there was a change to the data form and a major decline in the number of vessels fishing in 2003.

Some potential measures to reduce the bycatch of striped marlin in New Zealand were investigated. A time/area closure in FMAs 1, 9, and 10 between January and March would reduce catches of striped marlin by about 70% but would have significant effects on commercial fisher access to other species they target, particularly swordfish and bigeye. Weighted buoy lines 100 m long trailed in Hawaii have successfully reduced the catch rate of marlin but also affect the catch rate of target species. There, elimination of hooks in the top 100 m of the water column reduced catches of individual striped marlin by nearly 63%. Bigeye catch increased by 22% but the catch of most other species declined.

The recreational fishery for striped marlin in New Zealand has a long history. Fishing clubs have published detailed catch records, in some cases since the 1920s. There was a decline in total catch and mean weight of striped marlin from the late 1950s through to the late 1970s, which coincided with the development and expansion of the large scale surface longline fishery in the region.

Recreational catch and fishing effort targeting marlin has increased significantly since the 1970s, now with far more private boats than recreational charter boats participating. Over this period the annual striped marlin catch in club records has fluctuated between 1200 and 2400 fish per season. Recreational CPUE from the east Northland charter fleet has remained at or above the long-term average in recent years. Some potential problems with the time series are creep in vessel and gear technology and the relatively small area fished in relation to the habitat available for striped marlin in New Zealand.

Conventional and electronic tagging has shown that striped marlin, show some regional site fidelity, with little mixing between New Zealand and east Australian tagged fish. New Zealand fish disperse to, and presumably draw from, a wide area of the southwest Pacific from New Caledonia to French Polynesia (6500 km wide at 20^{o} S) and the EEZs of at least seven Pacific Island nations. New Zealand is at the southern edge of the striped marlin range and domestic access to this stock is reliant on a portion of the population, including the largest fish, travelling to the cooler waters at the southern extent of their distribution. It appears New Zealand is a foraging ground for striped marlin following spawning, mainly in the Coral Sea and French Polynesia in November and December.

A recent study aged 425 striped marlin from the SWPO. Fish from this analysis ranged from 130 days old (estimated from a 4 kg whole weight 1120 mm, Lower Jaw–Fork Length, LJFL, fish) to 8 years old (estimated from a 168 kg 2871 mm, LJFL, fish). New Zealand fish were aged from 2 to 8 years in fish ranging in length from 2000 mm to 2871 mm LJFL. The median age of striped marlin landed in the New Zealand recreational fishery was 4.4 years for females and 3.8 years for males. Females matured between the ages of 1.5 and 2.5 years old (L_{50}=2026 mm; A_{50}=1.9 years), while males matured (L_{50}%=1898 mm LJFL; A_{50}=1.4 years) about six months earlier and at a shorter length than females.

Despite the relatively rapid growth rate, early maturity, and high fecundity of striped marlin, there is some uncertainty over the resilience of the species to fishing pressure in the SWPO. The most recent stock assessment for striped marlin in the SWPO indicated a long-term decline in stock abundance but relatively stable catches over the past 15 to 20 years. A preliminary stock assessment of striped marlin in the North Pacific has suggested that the stock may be overfished.

1. INTRODUCTION

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. Adult striped marlin are known to spawn between 10 and 25 degrees latitude in late spring and early summer before moving to feeding grounds in higher latitudes during summer and autumn. They usually arrive in New Zealand, along with warm oceanic water, during December. By late summer they may range as far south as Gisborne on the east coast and New Plymouth on the west coast.

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. Each season the number of marlin caught by an angler, vessel, and club has been of interest to participants in the fishery. A high proportion of avid anglers belong to fishing clubs, but such is the mystique of billfish among New Zealand anglers, that even anglers who do not belong to fishing clubs tend to bring their fish to club weigh stations to have the fish weighed and recorded. For example, in the 2008–09 fishing season, 16% of striped marlin recorded by east Northland fishing clubs were caught by non-members. Often, these people are fishing on vessels that are owned by club members, or on charter vessels associated with the clubs and using their facilities. There are anecdotal reports that small numbers of marlin, especially some caught by non-club members on the Northland west coast from trailer boats launched off beaches in favourable weather, do not enter the club system, but the numbers of such fish are certainly very small compared to those that are recorded.

The New Zealand Sport Fishing Council (NZSFC, formerly New Zealand Big Game Fishing Council) publishes annual tallies of landed gamefish from 37 affiliated sportfishing clubs. Since 1975 New Zealand anglers have been encouraged to tag and release striped marlin as part of a Ministry of Fisheries research project. For the last 15 years over 60% of all striped marlin caught by recreational anglers have been tagged and released. The tagging database contains a good record of where and when these fish were tagged, but only estimated weights are available for these fish (Holdsworth & Saul 2004).

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 waters where bigeye and albacore tuna were the main target species. There are some catch records for these years that indicate striped marlin was a significant bycatch and occasional target species in northern New Zealand (Bailey et al. 1996).

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 FMA (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 marlin species (striped, blue, and black marlin) throughout the EEZ.

A requirement to report marlin caught on domestic commercial vessel was introduced in the mid 1990s (Francis et al. 2004). Despite this, striped marlin have been under-reported by commercial fishers (Francis et al. 2000). Although some catch data from the surface longline fishery are available, under-reporting and a lack of observer data suggest that these data are probably not representative of the actual striped marlin catch.

Ministry of Fisheries (MFish) research project STM2003/01 provided a characterisation of the New Zealand striped marlin fisheries using MFish data and recreational gamefish club records (Holdsworth & Kopf 2005). This study noted that commercial catch records for the surface longline fishery in New Zealand began in 1980. At first only Japanese and Korean vessels used surface longline gear under licence in New Zealand. Domestic fishers started using this method to target large tunas in the late 1980s and there was a significant increase in domestic surface longline effort in the late 1990s.

Tuna fisheries in New Zealand waters were described for the fishing years 2002–03 and 2003–04 in detail, and in context of the six most recent fishing years from 1998–99 by Kendrick (2006). That report described a period during which the domestic fleet expanded rapidly to replace licensed foreign vessels fishing in the New Zealand Exclusive Economic Zone (EEZ), and tuna fisheries 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 or to compulsory reporting requirements up to October 2004, except that all retained catch from longlining, targeted at tuna species, was required to be reported on Tuna Longline Catch Effort Returns (TLCER), but the commercially valuable species that are the focus of this report were generally well reported. Swordfish were a valuable component of the catch but could not legally be targeted.

The domestic longline fleet increased in numbers exponentially after the start of the tuna fishery in 1991, and from 1998–99 to 2001–02 the number of longline vessels continued to increase from about 80 vessels in 1998–99 to a peak of about 155 vessels in 2001–02. The increase during those years largely included vessels that fished more than one method, switching between troll gear and longline gear, but the number of dedicated longline vessels also peaked in 2000–01 at 100. There was some spurious reporting of albacore as an important target species by the domestic fleet that was prompted by the promise of imminent quota allowances.

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 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.

Recent reductions in domestic longline effort have resulted in reductions in catches of the major bycatch species. A further driver for rationalisation in the tuna longline fleet has been the allocation of southern bluefin tuna quota and the shift way from the “Olympic” system was also responsible for changes to the spatial and temporal distribution of effort. 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.

Stock assessment

The Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) has attempted to combine all commercial tuna catch and effort data since the surface longline fishery began in the South Pacific in 1952. These data were used to undertake the first southwest Pacific striped marlin stock assessment in 2006. The most recent and plausible stock assessment suggested a sharp decline in biomass during the late 1950s and 60s with catch rates remaining relatively stable since the 1980s (Figures 4 and 5). Standardised peak quarterly catch rates declined from 4 to 14 striped marlin/1000 hooks (see Figure 5) to fewer than 4 striped marlin/1000 hooks (see Figure 4) in most regions between the 1950s and subsequent years (see Figure 5). The stability of catches since the early 1980s tentatively suggests that current exploitation rates are not reducing the productivity of the stock, but some stock assessment model scenarios suggested that spawning biomass may “approximate or be below” the level required to support maximum sustainable yield (Langley et al. 2006). The WCPFC Scientific Committee commented on the results:

“Several of the plausible model scenarios investigated indicate that current levels of fishing mortality may approximate or exceed the reference level F_{MSY} and current spawning biomass levels may approximate or be below the biomass based reference point B_{MSY}. On the basis of this preliminary assessment, it is recommended as a precautionary measure that there should be no increase in fishing mortality (i.e. fishing effort) on striped marlin in the south western Pacific.” (Source WCPFC Scientific Committee 2 Executive Summary, Manila 2006).

The information reported in recent biological studies (Kopf 2010) is cautiously encouraging and generally falls within the more productive range of values explored in the preliminary stock assessment model for striped marlin in the SWPO (Langley et al. 2006). Uncertainty in the stock status of striped marlin may be reduced by applying the newly acquired biological information to update a stock assessment model.

The International Scientific Committee (ISC) recently indicated that catches of striped marlin in the North Pacific have undergone a significant decline in CPUE and that fishing mortality rate should not be increased (Piner at al. 2007). Estimates suggest that biomass has declined to about 6–16% of pre-industrial fishing levels. The ISC will be updating the stock assessment in 2011. The Pelagic Fisheries Research Programme has funded an age and growth study on striped marlin in the Hawaii-based pelagic longline fishery in order to address some of the uncertainties in the stock assessment model.

Conservation and management measures

In 2006 the Western and Central Pacific Fisheries Commission (WCPFC) adopted a Conservation and Management Measure (CMM) for striped marlin in the southwest Pacific Ocean (WCPFC 2006). The CMM was implemented in response to uncertainty in stock abundance (Langley et al. 2006) and was aimed at preventing increases in fishing mortality until the population status of striped marlin could be estimated with greater certainty. The CMM represents an important first step to ensuring the long-term sustainability of fisheries for striped marlin, although in its current form it does not directly limit total fishing mortality on the stock; it has attempted to restrict effort through limits on the number of commercial vessels targeting striped marlin. Very few vessels outside Australian waters and the Coral Sea target striped marlin, so the effort limits in this measure have not had any practical effect on fisher behaviour.

New Zealand is specifically exempt from any mandates of the CMM due to the presence of a commercial moratorium on striped marlin landings. However, all member countries and territories that are not exempt from the CMM are required to cooperate on research to reduce uncertainty with regard to the status of striped marlin stocks. Substantial research achievements focused on the biology and ecology of striped marlin have been made since the stock assessment was conducted in 2006 (Langley et al. 2006). Areas of improved knowledge include population genetics (McDowell & Graves 2008), age, growth, and reproduction (Kopf 2010), movements and migration (Domeier 2006, Sippel et al. 2007, Holdsworth et al. 2009) (see Section 3.5). A stock assessment for striped marlin was proposed in 2010 by CSIRO, but funding was not secured and an assessment is now planned for 2012.

2 DATA SOURCES AND METHODS

2.1 Commercial longline catch, effort, and CPUE

Commercial catch from surface longline vessels has been reported on Catch, Effort & Landing Returns (CELR) and the method specific Tuna Longline Catch & Effort Return (TLCER). From March 2003, a completely redesigned TLCER has been in use, and, along with clearer instructions to fishers, has markedly improved the quality of data available from longlining. Data verification standards administered by the MFish data management group have also greatly improved the quality of all catch effort data since about 2000. Striped marlin catches from the TLCER and CELR databases were sourced and groomed for the fishing years 2000–09. Catch information was summarised and plotted temporally and spatially, within and across seasons.

Data from New Zealand observer records collected between 1990 and 2009 north of 38° S latitude were extracted and groomed. This area includes almost all striped marlin catch and excludes effort south of 38^{o} S mainly targeted at southern bluefin tuna. Two potential signals of abundance were investigated in the observer catch effort data and two standardised models were applied to the dataset. One was a binomial model which predicted success or failure of striped marlin catch and was fitted to the total dataset including records that reported a zero catch of striped marlin. A lognormal linear model was fitted to just successful catches of striped marlin, excluding zero catches.

Success and catch rates were standardised against variation in the explanatory variables 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 dependent variable for the binomial model was a binary variable set to '1' for records which had associated striped marlin catch and to '0' for records with no catch. The potential explanatory variables offered to the models include the number 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.

Fleet and nation were not offered due their unbalanced distribution across year. Vessel ID was not available to the analysis and there was no selection of core vessels done; all records in the observer database were considered valid. 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.

A similar approach was taken to analysis of the commercial catch records of striped marlin discards. Positive catches of striped marlin reported on the tuna longline form (TLCER) were extracted from the MFish catch effort database "warehou" for the fishing years 2000–01 to 2008–09. The analysis dataset was restricted to a core fleet of vessels that had completed at least three trips in at least two years and this reduced the number of vessels in the dataset from about 110 to 27, and reduced the catch of striped marlin by about 30% (by number). A summary of the TLCER catch and effort data used in the analysis is given in Table 9 and potential explanatory variables offered to the model are in Table 10. Sea surface temperature was incompletely reported for the period and was not offered to the model.

The Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) has maintained a catch and effort database for tuna and billfish in the western and central Pacific Ocean since its inception in 1981. Catch, effort, and nominal CPUE of striped marlin in the SWPO were summarised for 1980 to 2006 using a 5°x5° latitude/longitude extract from the OFP database. Catch and effort information for the years 2007–09 were excluded from analyses because information from some fleets was incomplete. Catch and effort information were restricted to the SWPO boundaries defined in the most recent stock assessment for striped marlin (0°-40° S and 140° E-130° W) (Langley et al. 2006). Langley et al. (2006) standardised commercial longline CPUE of striped marlin in the SWPO between 1952 and 2003 and these data are presented herein, courtesy of the Secretariat of the Pacific Community.

2.2 Gear configuration and operational measures to reduce commercial longline catch of striped marlin

Publications and reports on billfish bycatch were reviewed. Generalised Linear Models were used to standardise longline CPUE for striped marlin in the New Zealand EEZ. The potential explanatory variables offered to the model are listed in Tables 6 and 9. The dataset was trimmed down to include just the main months (for striped marlin) of January to May to restrict the range of sea surface temperatures in the dataset. Alternative models were fitted to this data subset in the hope of learning more about the relation between catch and gear configuration, without the effect of temperature overwhelming the analysis.

2.3 Recreational catch, effort and CPUE

The recreational catch of striped marlin has been recorded by gamefish clubs and published in their annual reports. Clubs provide weigh stations with certified scales, and recognition of landed catch and fish tagged and released is an important part of gamefishing culture for anglers and skippers. Most clubs will also weigh and record fish caught by non-members. The New Zealand Sport Fishing Council (NZSFC, formerly the New Zealand Big Game Fishing Council) is an umbrella group for gamefish clubs and produces a yearbook with New Zealand line class records and catch tallies for all affiliated clubs. These records are used as the best estimate of national recreational landed catch for billfish.

The Bay of Islands has been a highly regarded tourist and sport fishing area for many years. The Bay of Island Swordfish Club (BOISC) has published annual catch records since 1925. Records from 1926 and 1928 have been lost and there are gaps in the early 1930s (Great Depression) and the early 1940s (World War II). Individual catch records have also been captured from Whangaroa Big Gamefish Club since 1927, Whangarei Deep Sea Anglers Club since 1955, and Tauranga Game Fishing Club since 1972. The electronic database includes individual fish weights for 34 244 striped marlin, date of capture and name of vessel, and in recent years fishing area and fish tagged and released. The New Zealand Gamefish Tagging Programme started in 1975 and the database includes all fish reported as tagged and released. Catch and weight have been summarised by season.

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 fished per vessel where marlin was the target species (whether under charter or fishing with friends) and the catch of billfish by species for the season. With support from various organisations including MFish and the New Zealand Marine Research Foundation the postal survey was continued for a further 11 years. 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 an MFish project (STM2005-01) (Holdsworth et al. 2007). A subset of these fishers included the same Northland charter skippers who had been involved in the postal survey. Core vessels with five or more years data were selected and their catch and effort data for the east Northland survey area were modelled in a GLM using year, vessel, and port as explanatory variables (Holdsworth & Saul 2010).

2.3 Age, growth, and reproduction

A variation to the MFish project STM2005/01 supported the collection of striped marlin hard parts and gonad tissue from the New Zealand recreational fishery. These samples were analysed along with samples from around the SWPO as part of a PhD project at Charles Sturt University in Australia (Kopf 2010). Growth was modelled using a standard von Bertalanffy growth curve (VBGC) (von Bertalanffy 1938) and a generalised VBGC (Richards 1959). A sex-specific age-length model was used to convert size frequency information into sex-specific age frequencies (Kopf 2010). The age-length model was developed from fin spine and otolith age estimates from 425 striped marlin sampled in the SWPO between 2006 and 2009. Sampled fisheries included the Australian commercial longline and recreational fisheries, longline fisheries in Pacific Island countries, and 133 samples from the New Zealand recreational fishery.

The striped marlin age composition from the New Zealand recreational fishery was estimated from 778 whole weight measurements (± 0.5 kg) collected by recreational fishing clubs during 2006 and 2007. A voluntary minimum size limit of 90 kg was imposed at recreational fishing clubs in New Zealand, which may influence weight measurements and therefore age composition. However, the mean converted LJFL of 784 striped marlin that were weighed (2355 ± 242 mm) in the New Zealand recreational fishery was not significantly different from the mean LJFL estimated from 1143 tag-and-release estimates (2356 ± 141 mm) made between 2006 and 2007.

Gonads were excised from female and male striped marlin caught in recreational and commercial longline fisheries. Two 1–2 cm thick transverse sections were removed from the cranial and caudal third of the largest gonad and preserved in 10% neutral buffered formalin. The most advanced single oocyte and the most advanced mode of developing oocyte were recorded for each histological section of ovaries. The most advanced gametes in histological sections of testes were classified into four categories following the classification schemes used by Merrett (1970) and Grier (1981). Batch fecundity estimates were made on paired ovaries of four striped marlin with unovulated hydrated oocytes, no atresia, and no post-ovulatory follicles using the gravimetric method (Hunter et al. 1985). The spawning interval was estimated by the 'hydrated oocyte method' (Hunter & Macewicz 1985). The LJFL (mm) (L_{50}) and age (A_{50}) at which 50% of the population was sexually mature was estimated for females and males by fitting the proportion mature in 100 mm LJFL and 1-year age classes to a four parameter sigmoidal regression. A model was developed to estimate the proportion of mature and immature fish in the New Zealand recreational fishery using 778 whole weight measurements from recreational catch.

3 RESULTS

The southwest Pacific Ocean (SWPO) represents a semi-independent population of striped marlin (McDowell & Graves 2008) and fisheries within this area are assessed and managed separately from other regions of the Pacific (Langley et al. 2006). The majority of striped marlin catch in the region comes from commercial longline fisheries in subtropical and temperate latitudes (Bromhead et al. 2004, Langley et al. 2006).

3.1 Commercial longline fisheries

Overview

The accuracy of historical catch statistics for striped marlin worldwide is uncertain because istiophorid billfishes have frequently been grouped together without individual species recognition (Bromhead et al. 2004). It is estimated that over 12 000 t of striped marlin have been harvested each year in longline fisheries from the Pacific and Indian Oceans since the 1990s (Bromhead et al. 2004). Most striped marlin catch in the Pacific Ocean comes from longline fisheries in the northwest and eastern central Pacific but the large individual size and flesh quality of striped marlin from the SWPO is highly valued as sushi and sashimi in Japan.

Longline fisheries in the western and central Pacific Ocean make up less than 11% (Williams &Terawasi 2008) of the total catch of tuna by weight and generate about half the economic output of the much larger purse seine fishery. Longline caught species including bigeye, yellowfin, albacore, and to a lesser extent striped marlin are sold fresh and frozen to markets in Japan and other countries. Striped marlin is the most commercially valuable istiophorid species (including marlin, sailfish, and spearfish). The mean ex-vessel price of fresh striped marlin sold at major sushi markets in Japan during 2003 was about $6.30/kg compared to $9.98/kg for swordfish and $16.26/kg for bigeye tuna (FFA 2004). Although the average annual price of striped marlin is comparatively low, the price fluctuates with season and monthly prices have exceeded $17.50/ kg, outstripping prices for bigeye and yellowfin tuna. High seasonal prices for striped marlin coincide with the spring spawning season in the SWPO and particularly the southern Coral Sea (Kopf 2010).

Southwest Pacific Ocean

The commercial longline catch of striped marlin in the SWPO peaked at over 12 000 t a year in the 1950s. It has since declined to less than 2500 t annually since the 1980s (Figure 1). The majority of catch (70%) in the region comes from the tropical and subtropical waters (Regions 1 and 2, Figure 2) with total catches exceeding 12 800 t and 20 600 t from these regions for the 26 years between 1980 and 2006 (Figure 2). In Regions 1 and 2 longline catch has been greatest in the third and fourth quarter of the year. Longline catch in temperate waters of Region 3, which includes the Tasman Sea and New Zealand, are highest in the first and second quarters of the year and very low in the fourth quarter. Striped marlin are caught in the central Pacific zone (Region 4) in all quarters but catch is consistently lower than other regions of the SWPO (Figure 2).

Distant water Japanese fleets historically caught the majority of striped marlin in the SWPO but domestic fleets on the east coast of Australia and other Pacific Island Countries and Territories (PICTs) have expanded since the 1990s with the development of exclusive economic zones (EEZs) (see Figure 1). Overall, SWPO reported catch has remained between 1000 and 3000 t since 1980, with peaks in the early 1980s and 1999.

Since 1990, the mean annual harvest of striped marlin from the Region 2 (656 t) has exceeded the other areas of the SWPO. Taiwan has replaced Japan as the principal foreign licensed vessel nation catching striped marlin in the region. However, the majority of harvest in the Coral Sea region and, therefore the SWPO, comes from the Australian longline fleet which harvested an average of 622 t per year between 1990 and 2006. Striped marlin has become one of the top five species landed in the Eastern Tuna and Billfish Fishery of Australia (ETBF). Catches in this fishery peak during the fourth quarter of the year off Mooloolaba, Queensland, followed by sporadically high catches on the south coast of New South Wales during the first and second quarters of the year.

Longline fish effort increased to a peak of over 400 million hooks in 2003 and declined in the subsequent 3 years (see Figure 1). Longline fishing effort has increased year round in tropical areas (Region 1) of the SWPO (Figure 2). Effort in subtropical areas (Region 2) is also spread across all quarters for the years 1980 to 2006 combined. Region 3 has the least effort with proportionally more hooks in the second quarter (Figure 2).

Mean CPUE of striped marlin for the Australian fleet has been consistently above CPUE of other longline fleets in the SWPO since 1993 (see Figure 1). Overall there has been a significant decline in CPUE for the Japanese fleet since 1998 despite 1999 being the peak year of catch. Overall Japanese longline effort in the SWPO has declined, with less than a third of the number of hooks set in 2006 as were set in 1981.

During the first quarter of the year, catch rates of striped marlin are highest in Region 3, encompassing New Zealand and the south coast of New South Wales (Figure 3). Catch rates in this region decline during the second quarter of the year but remain higher than in most other regions of the SWPO. The majority of catch and highest catch rates of striped marlin occur in Region 2 during the third and fourth quarters of the year. Catch rates of striped marlin in the SWPO are highest during the fourth quarter of the year in the Coral Sea region (Region 2) (Figure 3). The region around French Polynesia (Region 4) has a comparatively low level of longline effort and striped marlin catch per unit effort compared to the Coral and Tasman Seas (Figure 3). However, matching trends in CPUE between Regions 2 and 4 during the fourth quarter of the year suggest the presence of spawning activity in both the Coral Sea and French Polynesia (Figure 3). No such increase in the fourth quarter is seen in the tropical region (Region 1). Observer size data combined with maturity schedules (Kopf 2010) suggest that a high proportion of striped marlin harvested in Region 1 are immature.

The decline in CPUE of striped marlin by most fleets in the SWPO since 1999–2000 may be interpreted to suggest that increasing levels of effort have supported the relatively stable levels of total catch since the early 1980s. However, the decline in CPUE may also reflect temporal changes in recruitment, which have fluctuated on 5-yearly cycles since the early 1950s (Langley et al. 2006). It is noted that catch data used in the present study did not match all records reported by Langley et al. (2006) (Appendix 1). Some records have been updated since the most recent stock assessment. In particular, Japanese longline catches reported by Langley et al. (2006) were inflated due to database errors that have subsequently been amended (P. Williams, SPC, pers. comm. 2010). The New Zealand EEZ is the only area in the SWPO where retention of commercially caught striped marlin is prohibited (Holdsworth et al. 2003).

New Zealand commercial catch

Commercial longline catches of striped marlin in the New Zealand EEZ peak in the Bay of Plenty and off the coast of Northland between January and May each year (Figures 6 and 7). Reported catch declined from 65.1 t in 2000 to 23.9 t in 2009 (Tables 1 and 2). The 63% reduction in catch of striped marlin during this period coincides with a decrease in effort of 8.2 million to 3.1 million hooks or 62% (Figure 8). All catches of striped marlin by commercial longline operators in the EEZ are released whether alive or dead. Observer records show that 74% of striped marlin were alive when brought to the boat, but there is no available information on the survival rate of released fish.

High seas catch of striped marlin was reported by New Zealand vessels between 2004 and 2006 but the reliability of these data are uncertain and may be influenced by incomplete reporting (Table 1). However, it is clear that the high seas catch is very small in comparison to that reported within the EEZ. Only 2.1 tonnes were reported in total for the 10 year period 2000–09. These fish can be landed in New Zealand, unlike those caught by vessels fishing exclusively within the EEZ. The number of striped marlin reported in TLCER forms has ranged from 161 to 721 fish per year between 2000 and 2009 with an average of 324 fish per year (Table 2). In New Zealand, domestic longline vessels catch most (95%) of the reported striped marlin within in the EEZ with the remaining catch reported as unknown or from vessels registered to Australia, Japan, or the Philippines (Table 2).

Over the past 10 years commercial longline effort has peaked in May and June when most striped marlin catch is declining (Figure 9). During this period most longline effort in the New Zealand EEZ occurs north of 38° S where catches of striped marlin would be expected but attention is turning toward southern bluefin tuna south of East Cape at this time. The top 10 vessels reported in TLCER forms accounted for 67% of striped marlin caught, with most vessels reporting fewer than 20 fish in total, between 2000 and 2009 (Figure 10). A lot of vessels left the fishery in the early 2000s with relatively few fishing right through this period.

The proportion of catch by weight and species by quarter of the year and for sets where striped marlin were reported on TLCERs are plotted in Figure 11. It shows that swordfish, albacore, and bigeye tuna are the species most often caught in association with striped marlin. Striped marlin and swordfish catch show a similar declining trend from the first to the third quarter. Albacore and bigeye tuna catch declines in autumn but increases slightly in the winter quarter.

The species composition of longline catch recorded by scientific observers also shows that albacore, bigeye, and yellowfin are more likely to be caught in sets where billfish are also caught than for all sets (Figure 12), while blue shark and southern bluefin tuna made up a smaller proportion of catch. The catch of swordfish and mako shark was about equal when billfish were caught and for all sets.

New Zealand observer data

Since the late 1980s scientific observers have been placed on selected longline vessels operating in the New Zealand EEZ to obtain reliable, accurate, and independent catch, effort and biological data. The number of surface longline sets observed and striped marlin observed caught is summarised by nationality and fishing year in Table 3. The target coverage rate is 10% of effort. Even for observer data collected north of 38° S there has not been a good overlap of observed trips and the striped marlin season (Table 4, Figure 13). This is largely because the focus on observer coverage for many years was the southern bluefin tuna catch.

The catch rate of striped marlin was highest when bigeye was the target species and lowest when albacore and southern bluefin were targeted (Figure 14). Even though bigeye was the main target species in this time and area, the minimum hook depth estimated by observers was mainly less than 50 m. Striped marlin catch rate was high with minimum hook depth of 16 to 30 m and declined at depths between 31 and 60 m (Figure 14). There was a marked increase in catch rate deeper than 60 m although the sample size is low and many of these fish (8) were caught on a single trip.

Binomial standardisation of the probability of capture from observer data

Two potential signals of abundance were investigated in the observer catch effort data and two standardised models were applied to the dataset (Table 5). One model was a binomial model which predicted success or failure of striped marlin catch and was fitted to the total dataset including records that reported a zero catch of striped marlin. A lognormal linear model was fitted to just successful catches of striped marlin, excluding zero catches.

The potential explanatory variables offered to the models are described in Table 6 and include the number 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.

Catches of striped marlin rarely exceed one fish per set so that catch rate in this instance is unlikely to be much more informative than the binomial (presence-absence) analysis (in contrast to most other New Zealand fisheries that are monitored with catch per unit effort).

Fishing year was forced as the first variable in the binomial model and explained 13% of the variance in success rate. Sea surface temperature entered as the most important factor, explaining an additional 20% of the variance and latitude entered the model last. The final model explained 35% of the variance in success rate (Table 7).

P(Catch>0) = fishing year + temperature + latitude

The success rate of a longline set with respect to striped marlin is predicted to increase with sea surface temperature above 18 °C (see Figure 1, Appendix 2). Most of the data occurred below that temperature, and in the first two years of the series, all of the observed sets were in water cooler than that. The model had to account for high success rates in a few years in which relatively more sets were carried out in warmer water (1994–95 and in 2000–01 and 2001–02), but the influence of temperature on success rate was neutral overall and did not contribute to a trend up or down

Success rate is also predicted to increase with latitude over the range in which most of the data occurred (38 to 33° S). The relation appears to reverse North of 33° S (see Figure 2, Appendix 2) but that is because the only data further north than about 30° S are for the Philippine-flagged vessels that fished around the Kermadecs in 2002–03, targeting albacore by setting deeper lines on longer buoy lines.

The effect of standardisation is quite marked with the first few years lifted so that they become the highest for the series, whereas in the unstandardised series they are low points of the series. This is the effect of the model adjusting a low success rate upwards because of the unusually low latitudes and associated water temperatures that were fished in those years. The series is essentially flat. Although the year effects describe a decreasing trend the error bars around each point are large and the trend is not significant. The initial high points are particularly dubious (Figure 15).

Lognormal standardisation of catch rate in successful sets from observer data.

Fishing year was forced as the first variable in the lognormal model but did in fact explain most of the variance in catch rates (16%). Sea surface temperature entered the model second, explaining an additional 6% of the variance and was followed by longitude and buoy-line length. The final model explained 28% of the variance in catch rate (Table 8). The diagnostic plots of the residuals from the fit of this model to the data show a poor fit to the log normal assumption (see Figure 3, Appendix 2). Some alternative error structures including negative binomial and poisson were tried, but these distributions did not provide a better fit to the data.

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

The number of striped marlin per set is predicted to increase with sea surface temperature over the range in which most of the data occur, but declines above 22 ^{o}C (based on very few observations) (see Figure 4, Appendix 2). The highest temperatures are those reported in 2005–06, when most of the catch of striped marlin was taken in January and February. The correlation between month and temperature is obvious, and is the reason that month doesn't enter either model. A trend towards warmer waters is predicted to have had a positive influence on observed catch rates over the time series.

There is very little contrast in catch rate through the longitudinal range in which most of the data occur, but higher catch rates in 2004–05 were made in sets west of 168^{o} E and have been attributed by the model to longitude (see Figure 5, Appendix 2). Apart from adjusting catch rates in that year downwards, the effect of longitude in the standardisation is minimal.

The negative effect of buoy-line length on catch rate is well described through the whole range of the data and is not just determined by the data in 2003, when longer than typical lines were used by the charter fleet targeting albacore (see Figure 6, Appendix 2). There is also a trend through the time series towards shorter buoy-lines which is predicted to have influenced observed CPUE upwards.

The effect of standardisation is marked largely 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 comprise 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 16).

Lognormal standardisation of catch rate in successful sets from TLCER data.

Positive catches of striped marlin reported on TLCERs were extracted for the fishing years 2000–01 to 2008–09. The analysis dataset was restricted to a core fleet of vessels that had completed at least three trips in at least two years and this reduced the number of vessels in the dataset from about 110 to 27, and reduced the catch of striped marlin by about 30% (by number). Core vessel numbers, sets, catches and effort are summarised in Table 9.

Catch rates were standardised against variation in the explanatory variables using a stepwise multiple regression procedure, selecting each explanatory variable until the improvement in model R^2 was less than 0.01. The potential explanatory variables offered to the model are described in Table 10. Sea surface temperature was incompletely reported for the analysis period and was not offered to the model.

Fishing year was forced as the first variable but explained very little of the variance in catch rate. Month, vessel, and latitude were accepted into the model in that order (Table 11) and the final model explained 19% of the variance in catch rate. No measure of effort entered the model. A interaction term (month x latitude) was offered in an to attempt to account for the migratory nature of striped marlin availability in New Zealand waters, but was not accepted into the model despite both month and latitude entering as main effects.

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

The coefficients for month described a strong seasonal effect with catch rates predicted to be greatest in January to 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 (see Figure 7, Appendix 2). Changes to the core fleet had a positive influence on catch rates overall (Figure 8, Appendix 2) with the loss of many of the poorer performing vessels. The exception was a year when there were no data from one of the better performing vessels (with respect to striped marlin) which the model had to account for.

The relationship with latitude is positive over the range in which most of the data occur and the model had to account for two years in which more of the catch was taken in higher latitudes, but overall the influence of latitude was neutral, in that it did not contribute to any trend up or down (see Figure 9, Appendix 2).

The effect of standardisation was not great, and the standardised series is not markedly different from the unstandardised series (Figure 17). The year effects describe an initial decline and are then flat with reasonably small error bars around each point. The fit of the data to the lognormal assumption was poor (see Figure 10, Appendix 2).

Comparison of models

The two series of year effects from observer data each describe a very similar pattern (Figure 18), but that is probably not surprising given the lack of contrast in the catch rate data (most catch rates are of a single fish per set). The lognormal series is flatter than the binomial and the error bars around each point are smaller. The first two points in each series are entirely the prediction of the models for years when very few striped marlin were observed caught.

The series modelled for the core fleet reporting on TLCERs agrees with the observer lognormal series in describing a relatively flat trajectory. There is an indication in all series of a slight step down since the late 1990s, but given the precision of the year effects, the trend in each series can generally be described as flat for the last decade at least (Figure 18, Table 12).

Reliability of commercial reporting of released striped marlin

Since 1996 there has been a requirement for commercial fishers to report striped marlin released or discarded on their catch and effort returns. Compliance with this appears to vary between skippers. An estimate of domestic longline discards in 1997–98 from observer records was 930 – more than twice the number reported on TLCERs (Francis et al. 2000). Many new entrants to the fishery in the late 1990s may have been unaware, or uninterested, in reporting released marlin. There were also anecdotal reports from some domestic surface longline skippers who did not report tagged marlin they caught. A comparison of striped marlin reported in observer records and TLCERs for the same set shows that reporting has improved since 2000 from about 50% to 88% over the last 6 years (Table 13). The skippers remaining in the surface longline fleet now appear to be recording data that match observer data well across a range of fields (time of set, start position, hooks set etc). This was not the case in the early 2000s.

3.2 Gear configuration and operational measures to reduce commercial longline catch of striped marlin

There are a number of operational measures in use by surface longliners that do reduce the catch of striped marlin. Fishing for southern bluefin tuna, bigeye tuna, and swordfish is not particularly productive in January and February when marlin are present in. Some vessels bottom fish or troll for albacore during this period. Generally there is not high surface longline effort in northern New Zealand over summer. Prohibiting marlin retention has removed the economic incentive to develop a summer longline fishery for striped marlin as has happened in the east Australian tuna and billfish fishery.

Most New Zealand vessels set their gear at night and some used weighted snoods to avoid seabird catch. When targeting tuna, fishers will set on the cool side of a temperature front, whereas striped marlin tend to prefer warmer water in New Zealand. Not all measures are directly attributable to avoiding marlin bycatch, but skippers have stated that striped marlin can tangle snoods and mainline which can result in gear loss and increased haul times.

The most significant factors influencing CPUE of striped marlin in New Zealand are month of capture and higher sea surface temperature which are correlated. One potential operational measure that would reduce the catch of marlin is time area closure to longline fishing in FMAs 1, 9, and 10 between January and May. This would reduce commercial catches of striped marlin by about 70% but potentially would have significant effects on the catch of target species such as bigeye and swordfish during that time. Between 30 and 33% of the catch of these species is caught during these months. Bigelow & Mourato (2010) recently investigated the potential of similar large-scale time/area closures in an evaluation of longline mitigation to reduce catches of North Pacific striped marlin. Similarly, the potential reduction of striped marlin catches through spatial closures would result in a reduction in catches of target species.

Generalised Linear Mixed Models reported by Bigelow & Mourato (2010) suggested that using large (18/0) circle hooks reduced CPUE of striped marlin by about 42% compared to standard tuna longline hooks. The combined effect of using 18/0 circle hooks with removal of shallow hooks (#1 and #2 adjacent to floats) was estimated to reduce striped marlin CPUE by about 70%. Ward et al. (2009) reported higher catches of istiophorid billfishes on (14/0) circle hooks compared to normal tuna hooks. The difference between Ward et al. (2009) and Bigelow & Mourato (2010) may be attributed to differences in hook sizes used in the trials. Bigelow & Mourato (2010) asserted that "larger minimum width relates to a smaller probability of ingestion and probably accounts for the reduced catchability of non-bigeye species."

A study by Francis et al. (2000) used discriminant function analysis of observer data to investigate a range of environmental and fishing variables to determine whether longline sets that caught striped marlin could be distinguished from those that did not. Longline sets catching striped marlin in New Zealand could be identified with a low error rate (14%) using a suite of variables, primarily when sea surface temperature exceeds 18 ^{o}C and fish was the main bait used. The effective fishing depth of longline gear also affects striped marlin catch rate, with the highest catches coming from the shallowest hooks.

The log normal model of observed sets (above) also shows striped marlin catch rates decreasing with buoy-line length and depth of set (see Figure 6, Appendix 2). This observation aligns well with biological information gathered from pop-off satellite tags in New Zealand, which demonstrate that striped marlin spend about 72% of their time in the top 5 m of the water column (Sippel et al. 2007). Depth of the set is influenced by the number of hooks between floats, length of float lines, and vessel speed during setting. Unlike large-scale spatial closures, controlling depth of longline gear may significantly reduce catch rates of striped marlin without decreasing catch of target species as much as a full closure. For example, Beverly et al. (2009) tested a modified longline basket design that sets the most shallow hook at over 100 m. Elimination of hooks in the top 100 m of the water column reduced catches of individual striped marlin by nearly 63% (Beverly et al. 2009). In the same trial, catches of swordfish were reduced by 28%, with a reduction of 25% in yellowfin tuna, and 19% in albacore tuna; bigeye tuna catches increased by 22%. Other investigators have also demonstrated significantly higher catch rates of striped marlin in shallow longline sets (Ward & Myers 2005).

The GLM applied to New Zealand observer longline data showed no difference in CPUE of striped marlin between day and night sets. This observation was likely due to the dominance of night-time sets and, therefore, lack of day-time sets recorded in the observer database. Ward and Myers (2005) reported that the relative catchability of striped marlin in the top 100 m of the water column was about 2.5 times greater during the day compared to night time sets. Examination of 87 day and 58 night sets in the Hawaii based longline fishery resulted in a CPUE (striped marlin/1000 hooks) of 13 striped marlin during the day and 3.76 at night (M. Musyl, University of Hawaii, unpublished) which closely matched the results presented by Ward (2009).

Some longline fishers have reported catching marlin on baited hooks that are towed to the boat while retrieving the line. These fish are far more active at the boat than fish hooked for a long time. Sets made at night are often hauled during the day and some secondary marlin catch may occur as fish attracted by offal and discards take moving baits. The time of set or depth of gear may not be a good predictor of secondary catch close to the boat during haul back.

3.3 Recreational fisheries

Overview

A sport fishery targeting marlin and sharks developed in New Zealand in the 1920s. The first sport fishing club in the Bay of Islands (BOI) was called the BOI Kingfish and Mako Club, eventually changing to the BOI Swordfish Club. Fishing clubs were established in ports close to fishing grounds and weighed and recorded fish. In the Bay of Plenty, the first club was the Mayor Island Game Fishing Club based on the island 20 nautical miles from Tauranga. Local boat captains would charter boats to individual anglers often for many weeks at a time. Striped marlin were targeted and occasional large black marlin or broadbill swordfish were caught. International tourists brought heavy tackle and new fishing methods that proved highly successful. The quality of the fishery was praised by bestselling author of the time, Zane Grey, in his book 'Tales of the Angler's Eldorado, New Zealand' (1926) and others.

Charter boats were responsible for most of the catch as they had the specialist tackle and experience. Competition between clubs for the highest catch tallies saw almost all marlin recorded, including those of non-members who used the club weigh station. Annual yearbooks were published with the season's highlights and details of each fish that crossed the weigh station or is tagged (Figure 19). There were periods during the early 1930s and in World War II where gamefishing largely stopped and no yearbooks were produced. The close association of fishers, charter skippers, and clubs has led to an almost complete record of recreational striped marlin catches from BOI and Whangaroa from the 1920s to the late 1970s. Since the late 1920s the mean weight of striped marlin caught in the New Zealand recreational fishery has declined by more the 20 kg (Kopf et al. 2005).

Although blue marlin and black marlin are also caught and at times targeted by sport fishers in New Zealand the BOISC records show that striped marlin is clearly the main species caught, making up about 96% of the recreational marlin catch (Holdsworth et al. 2003). Around the world there are fisheries with higher striped marlin catch rates, but none with a similar proportion of large fish.

The national organisation representing sport fishing clubs has been strong for 53 years. In 1957 the formation of a national organisation (the NZBGFC) was encouraged by the then Governor-General, Sir Willoughby Norrie (Later Lord Norrie). He was a skilled and widely experienced fisherman himself. Lord Norrie presented a magnificent gold cup – an exact replica of the Ascot Gold Cup – for annual competition between the New Zealand clubs. At that time there were five active game fishing clubs in existence and they decided that the cup should be awarded to the fisherman catching the heaviest striped marlin each season. The first time the Lord Norrie Gold Cup was awarded, it was shared by two Tauranga club members with identical fish weighing 177.35 kg. Remarkably in the second season it was also shared by two anglers, from Tauranga and Bay of Islands, with 188.24 kg fish. Since that time there has been a single winner every year. Virtually all of the current IGFA line-class world records for striped marlin are held in New Zealand (weights from 105 kg on 1 kg line to 224 kg), apart from some of the lighter line classes between 1 and 4 kg line and fish of 50 to 102 kg (IGFA2010). In 2010 the NZBGFC was renamed the New Zealand Sport Fishing Council (NZSFC), representing 57 affiliated fishing clubs.

Billfish management

Following protracted negotiations between the fishing clubs and the government, the Minister of Fisheries at the time, Colin Moyle, announced a seasonal moratorium on commercial fishing in 1987. The agreement, called the Billfish Moratorium, had the following elements:

- a three year trial closure of northern New Zealand waters applied to foreign licensed surface longline vessels from 1 October to 31 May;
- the number of licences for the fishery reduced from 64 to 45;
- commercial fishers on domestic vessels were not excluded, but were required to tag and release all billfish including swordfish;
- recreational fishers were asked to tag and release 50% of billfish caught, to collect information on the interaction between recreational and commercial fishing fleets;
- annual meetings between government officials and fishers (representatives of the domestic commercial and the recreational fishery) were introduced.

Few marlin had been tagged before this, so a change in attitude was required. Tagging was given a significant boost by the NZBGFC which passed a policy requiring member clubs to have a minimum size of 90 kg for marlin to qualify for points and trophies. Anglers were encouraged to tag and release all marlin less than 90 kg, which was based on the average weight of striped marlin from the Bay of Islands catch records. In practice, many anglers chose to tag marlin regardless of size. A major shift in attitude was achieved and the target of 50% of recreational catch tagged and released was almost reached in 1989–90. Since 1993–94 there have been more fish released than retained in the recreational fishery (Table 14).

The effect was dramatic, not only in the number of billfish tagged and released, but also in the numbers of billfish encountered by anglers in succeeding seasons. Catches in most clubs increased and many more clubs became affiliated to NZBGFC. The moratorium was eventually replaced by a national regulation prohibiting commercial fishers from landing marlin caught in New Zealand fisheries waters, but allowing swordfish to be taken as a bycatch.

While striped marlin is the primary target species for many sport fishers, other highly migratory species are also recorded. In the 1990s the Bay of Plenty was well known for a successful yellowfin fishery, and mako sharks were often caught as a bycatch or targeted during contests. There has been a significant decline in the availability of yellowfin and mako sharks to recreational fishers over the last 16 years (Figure 20). During this period striped marlin catch reported to sport fishing clubs and the gamefish tagging database has fluctuated between 1200 and 2400 fish per season but has not declined.

Fishing areas

Striped marlin are targeted around the North Island from Taranaki on the west coast to Poverty Bay on the east coast. However, the most concentrated effort is expended off Northland, including the banks north of the Three Kings Islands. One of the detailed data sources of location of recreational catch comes from release locations filled out on tag cards (Figure 21). The fishery in the Three Kings area developed in the mid 1980s, and has contributed over half of the national catch of striped marlin in some years. It is accessed by long-distance charter and private vessels operating out of east Northland ports. These ports are the historical base of the striped marlin fishery and east Northland continues to be a major fishing ground (Figure 21).

The west coast of Northland, from Ahipara to Kaipara Harbour and further south, has a fast-developing trailer boat fishery accessed from the west coast harbours or directly off the beach in suitable conditions. The west coast fishery is less consistent than the east coast fishery, and more subject to adverse weather conditions due to the prevailing westerly swell and wind. Access across harbour bars or from open beaches is often difficult or impossible. However, in years when the conditions allow, catch rates are superior to those on the east coast, and the mean size of striped marlin caught is larger. Nationally there are hundreds of private boats from 5 to 30 m in length participating in the fishery and there are about 80 charter boats that target striped marlin seasonally (Peter Saul, Blue Water Marine Research & charter skipper, pers. comm.).

Catch per unit effort

A postal survey of Northland gamefish charter skippers was started in 1977 and was repeated annually by the Ministry of Agriculture and Fisheries until 1996. With support from various organisations, including MFish and the New Zealand Marine Research Foundation, data collected was maintained for a further 11 years. However, annual average catch per vessel for the whole season was a relatively coarse measure of catch per unit effort (CPUE) which could not effectively be modelled against special and environmental variables. In 2006–07 a national billfish logbook scheme was introduced to collect daily CPUE and detailed location and environmental data as part of an MFish project STM2006/01 (Holdsworth & Saul 2008). Participation in the logbook scheme is voluntary and open to charter and private skippers. Since then about 60 skippers per year have participated. A subset of these fishers were the same Northland charter skippers who had been involved in the previous postal survey. Their catch on the east Northland coast could be used to add to the existing time series for the same area. A GLM was used to model log CPUE for core vessels that had provided at least 6 years catch and effort data (Figure 22). This 34 year time series has been useful when considering the implementation and effectiveness of the billfish moratorium and subsequent regulations. Current catch rates are about equivalent to the best seasons around 1980 and 1990 but are below the very best years in 1993–94, 1994–95 and 1998–99. Modern vessels, equipment, and fishing techniques do not appear to be more effective that those used by experienced charter fishers in the early 1980s in this area. They may, however, have made quite a difference to the catch rate and accessibility of marlin to private fishers. Some of the larger charter vessels also fish outside this area, attaining high catch rates over the King Bank and Middlesex Bank north of the Three Kings Islands. This area was seldom fished by recreational vessels before 1990.

Holdsworth et al. (2003) noted that surface longline CPUE in the SW Pacific (10^{o} S to 40^{o} S and 165^{o} E to 160^{o} W) had a strong correlation with recreational charter vessel CPUE (P = 0.001), but a poor correlation was found between commercial longline and recreational CPUE from the western Tasman Sea and Coral Sea (10^{o} S to 40^{o} S and 145^{o} E to 165^{o} E longitude). The total commercial catch of striped marlin in New Zealand was negatively correlated with recreational CPUE (P = 0.019), which indicates a possible interaction between these fisheries (Holdsworth et al. 2003).

3.4 General biology and ecology

Systematics

The striped marlin, *Kajikia audax* (Philippi, 1887), is one of at least 10 species of marlin, sailfish, and spearfish (Istiophoridae) and one species of swordfish (Xiphiidae) collectively known as the billfishes. Five species of billfish occur in the Pacific Ocean and all five of these occur in New Zealand waters where striped marlin is most common. Billfishes all posses a distinctive bony extension of the upper jaw and are large-bodied top-predators that inhabit subtropical or tropical surface waters of the open ocean (Nakamura 1985).

Collette et al. (2006) revised the generic classification for striped marlin and phylogeny of the billfishes (Table 15). The revised classification places white and striped marlin together in a single genus (*Kajikia*), which reflects the close evolutionary relationship between the two species (Graves & McDowell 2003). The generic name *Kajikia* has previously been used to describe striped marlin (Ueyanagi & Wares 1975). The former genus classification of striped marlin (*Tetrapturus*) is now applicable only to the spearfishes.

Distribution and movement patterns

Striped marlin are widely distributed and regularly occur in tropical, subtropical, and temperate latitudes of the Indian and Pacific Oceans (Figure 23, Table 16). New Zealand lies within the southern range of the distribution for striped marlin in the Pacific Ocean. Striped marlin migrate to New Zealand during the summer and are part of a larger semi-independent population (Langley et al. 2006, McDowell & Graves 2008) in the SWPO; 0°–45° S, 145° E–130° W. A seasonal north-south movement of striped marlin to high latitudes during the summer and low latitudes during the winter has been reported in the northwest and northeast Pacific Ocean (Ueyanagi & Wares 1975).

Warm equatorial waters act as a physiological barrier for adults except in the eastern Pacific Ocean (Figure 23) where extensive cold-water upwelling permits north-south movements across the equator (Squire & Suzuki 1990, Ortiz et al. 2003). Movement patterns of electronically tagged striped marlin in New Zealand reflect some degree of habitat selectivity for oceanographic features, such as oceanic ridges, and particularly SSTs between 20.1 and 24.0 °C (Sippel et al. 2007, Holdsworth et al. 2009). Vertical movements of striped marlin reflect a strong preference for depths less than 5 m, which varies slightly by season, latitude, and diurnally (Sippel et al. 2007).

Conventional and electronic tagging studies have revealed that adult striped marlin commonly undertake long distance movements in excess of 1000 km (Ortiz et al. 2003, Domeier 2006, Sippel et al. 2007, Holdsworth et al. 2009) but the species is clearly less migratory than blue or black marlin. The mean daily displacement of striped marlin tagged with satellite transmitters in New Zealand was 45 ± 27.6 km per day (Holdsworth et al. 2009). The southerly movement to subtropical and temperate areas during the summer correlates with the movement of warm (over 20 °C) water currents and convergence zones, which generate primary productivity and attract prey. Subtropical regions, such as northern New Zealand, and southern New South Wales, appear to be feeding grounds during the summer, as body condition increases throughout the season (Kopf et al. 2005).

Population structure

Previously proposed stock structures for the Pacific Ocean have included a one stock theory (Squire &Suzuki 1990), two stocks divided by the equator (Hinton & Bayliff 2002), and up to four semi-independent stocks (Graves & McDowell 1994, 2003). Population structure in the Indian Ocean has not been examined. The most recent genetic evidence from the Pacific Ocean suggests the presence of four independent populations (McDowell & Graves 2008). Population structuring in the southern hemisphere and eastern Pacific appears to be significant in genetic comparisons of samples from Australia, Ecuador, and Mexico (McDowell & Graves 2008) but the biological significance of these differences is unknown.

Length and weight

This species reaches a maximum length of over 3000 mm LJFL and 200 kg whole weight (Nakamura 1985). The heaviest striped marlin on record weighed 244 kg and was caught in the Bay of Islands. Less than 1% of the striped marlin sampled for age and growth studies have been over 150 kg or 2700 mm LJFL. Length-weight conversion equations are provided in Table 17 (Kopf et al. 2010). Striped marlin under 2000 mm LJFL are also extremely rare in the New Zealand recreational catch (see Figures 29c, 30c). However, the number of small and juvenile striped marlin tends to increase in unusually warm seasons, such as 1998–99 (Table 14). This suggests that summer water temperatures around New Zealand are not sufficiently warm for juvenile striped marlin to tolerate.

Individuals caught in New Zealand typically average 95–105 kg whole weight or 2300–2500 mm LJFL. Striped marlin caught in New Zealand are significantly heavier than those caught in most other areas of the Indian and Pacific Oceans (Squire & Suzuki 1990, Kopf et al. 2005).

Sexual dimorphism is present in striped marlin. Females are heavier on average than males (Kopf et al. 2005), but the difference is not as prominent as seen in blue or black marlin. The proportion of females increases significantly with length class in striped marlin caught in the southwest Pacific Ocean and most (99%) individuals approaching 3000 mm LJFL are female (Kopf 2010).

Age and growth

Unvalidated age estimates for striped marlin have ranged from 8 in New Zealand (Davie & Hall 1990) to 11 and 12 years in Mexico (Melo-Barrera et al. 2003) and Hawaii (Skillman & Yong 1976) respectively (see Figure 24, Table 19). Ages of striped marlin from New Zealand estimated by Kopf & Davie (2009) ranged from 2 to 8 years in fish ranging in length from 2000 mm to 2871 mm LJFL. The median age of striped marlin landed in the New Zealand recreational fishery was 4.4 years for females and 3.8 years for males.

A method of estimating the age of striped marlin using fin spine annuli and otolith micro-increments was indirectly validated for striped marlin collected throughout the southwest Pacific Ocean (Kopf & Davie 2009, Kopf 2010). This study represents the first quantitative evidence to support annual increment formation in the fin spines of striped marlin and supplements previous research highlighting the value of fin spines for estimating the age of billfishes (Speare 2003, Hoolihan 2006, DeMartini et al. 2007). Marginal increment ratios showed that annuli were formed on a yearly basis (Figure 25) but daily micro-increment counts confirmed that false increments were present in fin spines and were common during the first year of life (Figure 26).

Examination of otolith micro-increments (Figure 27) from young striped marlin facilitated the development of a daily growth model. The generalised von Bertalanffy growth curve (Figure 28) predicted that male and female striped marlin attained a length of 1289-1291 mm LJFL during the first 6 months of life and a length of 1603–1607 mm LJFL by age one. Young-of-the-year striped marlin exhibited rapid growth (up to 4.7 mm per day), and were caught mainly in tropical waters north of 23° S latitude. Growth rates during the first year of life were amongst the fastest of any teleost fish in terms of body length, but were less than daily growth estimates from juvenile blue marlin (Prince et al. 1991) and larval growth rates estimated for other open ocean fishes (Brothers et al. 1983). Although growth in body length was rapid, the relative increase in body mass with length was less than other large-pelagic scombrids and amounted to a mean weight of approximately 24 kg whole weight by age 1.

Overall ages ranged from 130 days to 8 years and length ranged from 990 mm (about 4 kg) to 2871 mm (about 168 kg) LJFL in this study. Females grew to a larger maximum length, weight, and age compared to males, but there were no significant differences in von Bertalanffy growth curve parameters (male L_∞=2494 mm LJFL; female L_∞=2609 mm LJFL) (Table 18). Length-at-age was estimated from von Bertalanffy growth curves and in the latest study is greater than previously estimated (Table 19).

Juveniles

Very little is known about the early life history of striped marlin, particularly in the SWPO where fish under 1600 mm LJFL are rarely reported in commercial or recreational fisheries (Squire & Suzuki

1990, Bromhead et al. 2004), although billfish less than 400,mm LJFL have occasionally been caught by recreational anglers in Australia (J. Pepperell, Pepperell Research & Consulting, pers. comm.).

Juveniles are vulnerable to longline fishing gear at less than 1000 mm LJFL (Bromhead et al. 2004, Kopf 2010) and fish between 1000 mm and 1600 mm LJFL are taken in large numbers by commercial longline fishing gear near Hawaii (Squire & Suzuki 1990). The rarity of striped marlin smaller than 1600 mm LJFL in the SWPO is therefore perplexing because spawning activity has been recorded in the southern Coral Sea (Hanamoto 1977, Kopf 2010). Recent collections of juvenile striped marlin near Fiji and French Polynesia (Kopf 2010) and the collection of larvae (Nishikawa et al. 1985) further support the presence of a juvenile component of the population in the southwest Pacific Ocean.

Maturity

Females spawning in the Coral Sea start to mature between 1709 mm LJFL (Hanamoto 1977) and 1900 mm LJFL (Kopf 2010). Previous estimates of minimum length-at-maturity from other regions of the Pacific and Indian Oceans range from 1676 mm LJFL to 1957 mm LJFL, or approximately 28 kg to 50 kg whole weight (Kume & Joseph 1969, Merrett 1971, Eldridge &Wares 1974).

Kopf & Davie (2009) provided maturity estimates based on histological examination of gonads from striped marlin caught in the southwest Pacific Ocean. In this study, females matured between the ages of 1.5 and 2.5 years old (L_{50}=2026 mm ± 72 mm SE; A_{50}=1.9 years), while males matured (L_{50}=1898 mm ± 19.8 mm SE LJFL; A_{50}=1.4 years) about six months earlier at a smaller length than females. The age-at-50% maturity estimated by Kopf & Davie (2009) suggest that 88% of females and 95% of males caught in the New Zealand recreational fishery are mature (Figure 29). Age- and size-at-50% maturity have not been estimated for other regions of the Pacific or Indian Oceans.

Biological information from the sample of aged fish was used to develop a model for converting length frequency information to sex-specific proportions at age (Figures 30 and 31). There was significant latitudinal partitioning of age-classes (Figure 32) with young-of the-year most common at tropical latitudes and the oldest (4–8 years) striped marlin most common at subtropical latitudes near New Zealand and the south coast of New South Wales.

Reproduction

Most striped marlin spawning activity takes place between the latitudes of 10° N/S and 30° N/S during late spring or early summer in the respective hemispheres (Kume & Joseph 1969, Eldrige & Wares 1975, Ueyanagi and Wares 1975, Hanamoto 1977, Nishikawa 1985, Gonzales-Armas et al. 1999, 2006, Hyde et al. 2006). Larvae or mature adults have been collected in the western and central Pacific (Ueyanagi 1974, Hyde et al. 2006), eastern Pacific (Kume & Joseph 1969, Gonzalez-Armas et al. 1999) and in the Indian Ocean (Merrett 1971).

Spawning adults in the southwest Pacific Ocean have been observed between 15° S and 30° S extending from the east coast of Australia to Fiji, with ripe females observed as far east as French Polynesia (144° W) (Hanamoto 1977, Kopf 2010). Spawning in this region occurs during the fourth quarter of the year and peaks during November and December (Figure 33). Females in the Coral Sea release multiple batches of up to 4.1 million hydrated oocytes per spawning event or about 29.7 ± 8 oocytes per gram of body weight (Kopf 2010). The combined presence of degraded post-ovulatory follicles and hydrated oocytes indicates that females are capable of spawning daily (Kopf 2010). Post-ovulatory follicle examination showed that most striped marlin caught in the New Zealand recreational fishery did not spawn in New Zealand (Kopf 2010).

The percentage of females observed in 100 mm LJFL classes increased significantly between 1900 mm to 2800 mm LJFL in all fisheries sampled (Figure 34). The spatial distribution of spawning striped marlin was significantly different from mature resting individuals and other reproductive stages. This strongly suggests that striped marlin have discrete spawning grounds, and feeding grounds are spatially segregated between warm tropical waters and more productive sub-tropical waters. After spawning in the Coral Sea during the fourth quarter of the year, females migrate south

Diet

The striped marlin is an opportunistic top predator (Abitia-Cardenas et al. 1997, 2002) feeding primarily on squid (*Nototodarus* spp.), saury (*Scomberesox saurus*), and mackerel (*Trachurus* and *Scomber spp.*) off the coasts of New Zealand and Australia (Morrow 1952, Baker 1966, Holdsworth & Kopf 2005).

3.5 Review of recent research

Satellite tagging

The first striped marlin to be tagged with electronic tags in the southern hemisphere were tagged in New Zealand waters. Two prototype tags were deployed in the mid 1990s at the King Bank but did not remain attached. In 2003 six electronic tags manufactured by Wildlife Computers (Redmond USA) were deployed on fish off northeastern New Zealand. This and subsequent projects were funded by the New Zealand Marine Research Foundation, NZSFC, gamefish clubs, Stanford University, and University of Auckland. Between 2003 and 2008 34 striped marlin were released with satellite tags. All fish were caught on lures using a rod and reel. Only fish in good condition were selected for tagging.

Two different kinds of tags have been deployed, Pop-up Archival Tags (PAT) and Smart Position or Temperature Tags (SPOT). PAT tags collect water temperature, diving depth, and sunlight intensity data several times each minute. PAT tags were tethered to a plastic anchor driven into the connective tissues underneath the dorsal fin. On a pre-programmed date the tag releases from the fish and transmits summaries of the data to satellites. An accurate pop-up location is reported and approximate daily positions using the light level and temperature data from the tag can be calculated. PAT tags are capable of detecting the death of the fish and transmitting their data before their pre-programmed date if needed. SPOT tags are attached to the upper lobe of the caudal fin. This tag transmits high quality location (and water temperature) data when the fish's tail is out of the water. The technique of SPOT tail attachment was developed and refined in New Zealand (Holdsworth et al. 2009). Twenty two of the fish carried both tag types giving highly accurate locations alongside the archived data in the pop-up tag.

The data retrieved from satellite tags clearly show that striped marlin are resilient, with almost all surviving tag and release. In most cases there was considerable extra handling required when compared to conventional tagging. Fish had to be transferred from the catching boat to the tagging boat and the tags required more time to attach. Eight of the fish tagged had capture times of 40 minutes or more and just one of these died. This fish was quite tired on release and 14 hours later, while still swimming, it was attacked and eaten by a shark. The tag was swallowed whole and recorded data from inside a warm bodied animal that spent a considerable period at 600 m deep as well as in the top 100 m, before the tag passed out of the shark 10 days later. The resulting data are consistent with the behaviour of a great white or mako shark which are able to maintain elevated body temperatures and are known to prey on marlin. A study of striped marlin caught on live bait using satellite tags of Mexico found high mortality (63%) of fish hooked deep and just 9% mortality of fish that were released in good condition (Domeier et al. 2003). Circle hooks without an offset where found to be far less likely to lodge in areas other than the mouth or to damage the fish.

Striped marlin spend about 70% of their time near the surface, but will regularly dive below the thermocline to 100 or 150 m during the day (Sippel et al. 2003). At times they make regular dives to this depth at night as well. In the tropics, where water is warmer and clearer, the dives tend to get deeper but normally are separated by periods close to the surface. The simple explanation is that these dives are associated with feeding as marlin are visual predators and most of this activity occurs during the day at depths with good light penetration .

Striped marlin prefer surface waters warmer than 19 ^{o}C and during the period tracked (January to July) spent 75% of their time in areas with surface temperatures between 20 and 24 ^{o}C. When diving, the fish seldom entered waters more that 5 degrees cooler than the surface temperature. The maximum temperature recorded was 29.2 ^{o}C for a fish that was east of Vanuatu in June. The maximum depth observed overall was 460 m, where the temperature was 10.8 °C, and surface temperature was 23.4 °C (Sippel et al. in press).

Tagged striped marlin cover large areas of ocean averaging about 20 to 45 km per day. Occasionally they will stay in a large area (70 km diameter) for a few days. Some fish will also move along a geographic feature such as the Colville Ridge or the Norfolk Ridge. By May' most tracked marlin were north of 30^{o} S. Fish reaching 20^{o} S in May to July stopped heading north and in some cases reversed direction (Figure 35).

By combining the accurate locations from the SPOT tags with the environmental data from the PAT tags much better models of the behavioural preferences of striped marlin can be developed. These can be used to detect different modes of behaviour, such as foraging in an area or a migratory mode where the fish tends to swim in straight lines about 80 km per day (Figure 36). A further 34 PAT tags were deployed on striped marlin by an American research team in 2004 and 2005 in the Three Kings area and 24 were deployed in southeastern Australia (Domeier 2006).

4. MANAGEMENT IMPLICATIONS

Validated age and growth data are expected to improve the accuracy of a stock assessment model for striped marlin in the SWPO. These data are cautiously encouraging and generally fall within the more productive range of values explored in the preliminary stock assessment model for striped marlin in the SWPO (Langley et al. 2006). Key differences in biological parameters between Kopf (2010) and the previous stock assessment (Langley et al. 2006) were related to mean length-at-age one, as well as the observation of sex-specific and spatial differences in age-structure within the SWPO. Kopf (2010) was not able to age the largest fish caught in New Zealand and the resulting maximum longevity remains uncertain and is likely to exceed 8 years. Despite this, the age and growth data presented by Kopf (2010) should be used for the 2012 assessments of the striped marlin stock in the SWPO.

Uncertainty in the population status of striped marlin led in part to the adoption by the WCPFC of a Conservation and Management Measure (CMM) in 2006. The CMM was aimed at preventing increases in fishing mortality until the population status of striped marlin could be estimated with greater certainty. The CMM represents an important first step to ensuring the long-term sustainability of striped marlin populations (WCPFC 2006), although in its current form it does not directly limit total fishing mortality on the stock; it restricts the number of fishing vessels targeting striped marlin. Very few vessels outside Australian waters and the Coral Sea target striped marlin so the effort limits in this measure have not had any practical effect on fisher behaviour.

The overlap between peak commercial longline catches of striped marlin in the Coral Sea and peak spawning activity warrants careful management consideration in order to ensure that spawning stock biomass is fished at a sustainable level. Size-based indicators are increasingly being used in fisheries management and could be a useful tool to monitor the population status of striped marlin between periods when formal stock assessments are conducted. Monitoring of length distribution and CPUE in longline fisheries during the primary spawning season (November and December) in the Coral Sea may provide some insight into the stability of the spawning population. Over the duration of the present investigation, there was no indication of a declining mean size of spawning striped marlin in the Coral Sea but longer-term trends were not investigated. Catch records from the New Zealand recreational fishery has shown a significant decline, of nearly 20 kg, in the mean weight over the past 75 years.

The geographic position and timing of spawning suggests that warm (over 24°C), less turbulent waters of the Coral Sea are critical to the survival and rapid growth of larvae. The distribution of juveniles and young-of-the-year (YOY) appears restricted to tropical latitudes, and while these areas contain significant longline fisheries, the total catch of striped marlin is currently and has always been low in the SWPO. The low proportion of immature and YOY fish captured in most fisheries of the SWPO and, therefore low total catch, suggests that that the risk of over-exploiting this portion of the population may be low. This is in stark contrast to longline fisheries based out of Hawaii, which are at a similar latitude to Fiji and New Caledonia but catch a much greater proportion of juvenile and young adult striped marlin (Bromhead et al. 2004). Fisheries data suggest targeted recreational and surface longline fisheries in the SWPO occur in areas or habitats (horizontal and vertical) where adult striped marlin occur and that these areas are not frequented by juveniles.

Juvenile striped marlin may migrate or drift away from the spawning ground during the first year of life. In the northern hemisphere such a process was described where young striped marlin move from the Japanese spawning ground eastward to the north-central Pacific Ocean (Squire & Suzuki 1990). Little is known of juvenile marlin behaviour. Possibly they are widely dispersed in subtropical open oceans, capable of foraging as individuals rather than forming large schools. As ocean nomads they seem not to aggregate around FADs and are seldom caught by tuna purse seine vessels.

Despite the relatively rapid growth rate, early maturity, and high fecundity of striped marlin, there is some uncertainty over the resilience of marlin stocks to withstand fishing pressure. A preliminary stock assessment of striped marlin in the North Pacific (Piner et al. 2007) has suggested that the stock may be overfished. Closely related species such as the Atlantic white marlin are overfished with estimated biomass at about 12% of that required to produce MSY (ICCAT 2002, 2003).

5. ACKNOWLEDGMENTS

Striped marlin age, growth, and reproductive biology research was funded by the Australian Fisheries Management Authority (AFMA) and Fisheries Research and Development Corporation (FRDC) grant 2006/816 and New South Wales Saltwater Recreational Fisheries Trust project number L33. Thanks to Peter Saul and Tim Sippel for contributions to research on striped marlin in New Zealand and to this report. Many thanks to Stephen Brouwer for his comments and recommendations on the draft report and Terese Kendrick for the CPUE analysis of observer and TLCER data. This report was funded by the Ministry of Fisheries project STM2009/02.

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Table 1: Commercial catch (t) of striped marlin by longline fishing vessels and other commercial fishing methods in the New Zealand Exclusive Economic Zone (NZ EEZ) during 2000–09. Note that all striped marlin caught by commercial vessels in the NZ EEZ are discarded (mostly alive). Annual catch weight was estimated by multiplying the recreational mean individual weight for each year by the number (N) reported in TLCER database.

	Longline forms (t) (TLCER)	General forms (t) (CELR)	High seas forms (t) (HCE)
2000	65.1	0.2	0
2001	49	0	0
2002	21.4	0	0
2003	22.7	0	0
2004	41.4	0	1.42
2005	30	0.71	0.2
2006	18.4	0.55	0.48
2007	15.6	1.27	0
2008	21.9	1.59	0
2009	23.9	0.236	0
Total	309.4	4.556	2.1
Average	30.9	0.4556	0.21

Table 2: Commercial catch (t) of striped marlin reported in the New Zealand Exclusive Economic Zone by domestic (NZ) and foreign commercial longline (AUS, Australia; JAP, Japan; PHI, Philippines) vessels between 2000 and 2009. Catch weight was estimated by multiplying the recreational mean individual weight for each year (Table 1) by the number (N) reported in the TLCER database.

Year	NZ		Unknown		AUS		JAP		PHI		Total	
	N	t	N	t	N	t	N	t	N	t	N	t
2000	703	63.5	16	1.4	0	0.0	2	0.2	0	0.0	721	65.1
2001	524	47.6	15	1.4	0	0.0	0	0.0	0	0.0	539	49.0
2002	182	18.5	28	2.9	0	0.0	0	0.0	0	0.0	210	21.4
2003	172	17.0	48	4.7	0	0.0	3	0.3	7	0.7	230	22.7
2004	418	41.3	0	0.0	0	0.0	1	0.1	0	0.0	419	41.4
2005	304	30.0	0	0.0	0	0.0	0	0.0	0	0.0	304	30.0
2006	193	18.4	0	0.0	0	0.0	0	0.0	0	0.0	193	18.4
2007	152	14.7	0	0.0	9	0.9	0	0.0	0	0.0	161	15.6
2008	220	21.8	0	0.0	0	0.0	1	0.1	0	0.0	221	21.9
2009	239	23.9	0	0.0	0	0.0	0	0.0	0	0.0	239	23.9
Total	3107	296.8	107	10.4	9	0.9	7	0.7	7	0.7	3237	309.4
Average	310.7	29.7	10.7	1.0	0.9	0.1	0.7	0.1	0.7	0.1	323.7	30.9

Table 3: Distribution of surface longline sets observed and striped marlin observed caught, by nationality and fishing year. AUS, Australia (charter); JAP, Japan (charter); NZ, New Zealand (domestic); PHL, Philippines (charter).

Fishing year	Number of records (sets)				Number of striped marlin observed			
	Nationality				Nationality			
	AUS	JAP	NZ	PHL	AUS	JAP	NZ	PHL
1989–90	0	74	0	0	-	10	-	-
1990–91	0	122	0	0	-	4	-	-
1991–92	0	84	16	0	-	0	0	-
1992–93	0	114	0	0	-	9	-	-
1993–94	0	27	0	0	-	10	-	-
1994–95	0	13	50	0	-	0	33	-
1995–96	0	0	63	0	-	-	52	-
1996–97	0	43	97	0	-	0	33	-
1997–98	0	93	43	0	-	15	21	-
1998–99	0	29	26	0	-	0	39	-
1999–00	0	22	16	0	-	2	8	-
2000–01	0	0	155	0	-	-	69	-
2001–02	0	4	94	0	-	0	11	-
2002–03	0	27	0	194	-	5	-	12
2003–04	0	16	40	0	-	0	4	-
2004–05	0	38	122	0	-	0	24	-
2005–06	8	17	24	0	1	1	0	-
2006–07	36	52	140	0	8	0	12	-
2007–08	0	0	118	0	-	-	5	-
2008–09	0	23	155	0	-	0	9	-

Table 4: Number of striped marlin observed on tuna longliners north of 38° S by month and fishing year. The data described by the cells inside the border (January to August) were included in the analysis dataset.

Fishing year	Month 10	11	12	1	2	3	4	5	6	7	8	9	Total STM
1989–90	-	-	-	-	-	-	-	-	0	1	9	-	10
1990–91	-	-	-	-	-	-	-	-	0	0	4	-	4
1991–92	-	-	-	-	-	-	-	0	0	0	-	-	0
1992–93	-	-	-	-	-	-	-	-	7	1	1	-	9
1993–94	-	-	-	-	-	-	-	-	10	-	-	-	10
1994–95	-	-	1	23	7	-	-	-	0	0	2	0	33
1995–96	-	-	8	24	15	-	-	2	3	0	-	-	52
1996–97	-	-	-	9	17	2	3	2	0	0	-	-	33
1997–98	-	-	-	-	15	5	0	-	12	3	1	-	36
1998–99	-	-	6	33	-	-	-	-	-	0	0	-	39
1999–00	-	-	0	6	2	-	-	-	0	2	-	-	10
2000–01	-	-	0	16	39	7	-	-	2	5	-	0	69
2001–02	0	0	0	4	5	2	0	-	0	-	0	0	11
2002–03	-	-	-	-	-	-	-	0	2	10	5	0	17
2003–04	-	-	-	-	-	0	3	0	1	0	0	-	4
2004–05	-	-	-	18	3	-	1	1	0	0	0	1	24
2005–06	0	0	-	-	-	-	-	-	0	1	-	1	2
2006–07	0	3	0	1	6	7	1	1	0	0	1	0	20
2007–08	-	-	-	1	0	2	0	1	0	0	1	-	5
2008–09	0	0	-	2	3	-	0	1	0	0	2	1	9

Table 5: Summary of the analysis dataset based on observer records for tuna longline sets north of 38° S in the months January to August, and fishing years 1992–93 to 2008–09. All data were included in the binomial standardisation and only positive sets were included in the lognormal standardisation.

Fishing year	Sets	Trips	Number of STM	Observed hooks('000's)	Zero catch(%)	Sets (+ve)	Trips (+ve)	Hooks ('000's)(+ve)
1992–93	114	5	9	298 615	94.7	6	2	15 486
1993–94	27	3	10	74 115	81.5	5	2	13 374
1994–95	50	4	32	72 345	56.0	22	2	26 600
1995–96	60	4	44	58 182	60.0	24	4	22 084
1996–97	140	9	33	193 208	80.0	28	4	22 864
1997–98	136	10	36	277 624	83.8	22	6	36 930
1998–99	40	5	33	93 371	72.5	11	2	10 042
1999–00	34	6	10	74 163	79.4	7	3	11 311
2000–01	136	11	69	202 759	66.9	45	10	64 252
2001–02	54	8	11	64 525	79.6	11	4	12 585
2002–03	219	8	17	693 783	93.6	14	5	45 559
2003–04	56	10	4	89 006	94.6	3	2	3 910
2004–05	156	13	23	234 775	95.5	7	3	7 087
2005–06	36	7	1	63 709	97.2	1	1	2 412
2006–07	186	16	17	294 575	94.1	11	5	10 067
2007–08	118	14	5	114 277	95.8	5	3	4 020
2008–09	132	13	8	166 176	95.5	6	4	6 264

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

Factor	Description	
Fishing year	Categorical	1992–93 to 2008–09
Month	Categorical	January - August
Day/Night set	Categorical	Time of set D, ; N,
Target species	Categorical	BIG, SWO, STN, ALB
Latitude	Continuous	3rd order polynomial
Longitude	Continuous	3rd order polynomial
Temperature	Continuous	3rd order polynomial
Buoy line length	Continuous	3rd order polynomial
HBF	Continuous	Hooks between baskets 3rd order polynomial
Log (Hooks)	Continuous	Number of observed hooks for the set 3rd order polynomial

Table 7: Summary of the final binomial 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,

Binomial Term	DF	Deviance	AIC	R2	Final
None	0	1 271	1 273	0.000	
fyear	17	1 104	1 138	0.131	*
poly(temp, 3)	20	848	888	0.333	*
poly(lat, 3)	23	833	879	**0.345**	*
poly(log(hooks), 3)	26	823	875	0.353	
poly(buoy_length, 3)	29	815	873	0.359	
DayNight	30	813	873	0.361	

Table 8: Summary of final lognormal model for the fishery. 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	R2	Final
None	0	54.2	321	0.000	
fyear	17	45.3	313	0.164	*
poly(temp, 3)	20	42.2	303	0.221	*
poly(lon, 3)	23	40.7	301	0.250	*
poly(buoy_length, 3)	26	39.1	299	**0.278**	*

Table 9: Summary of dataset of TLCER positive striped marlin records for core vessel fleet defined as having completed 3 trips per year in at least two years.

Fishing year	Sets (+ve)	Vessels	Trips	Catch (# fish)	Hooks ('000's)
1999/00	126	12	67	280	146 140
2000/01	224	21	119	395	272 520
2001/02	98	13	48	167	138 840
2002/03	95	20	58	132	126 096
2003/04	155	16	72	329	192 730
2004/05	141	11	46	249	169 266
2005/06	74	9	39	120	82 415
2006/07	78	8	43	137	96 190
2007/08	108	8	54	208	112 420
2008/09	114	9	56	185	123 690

Table 10: Description of potential explanatory variables offered to the models of TLCER data.

Factor	Description	
Fishing year	Categorical	1992–93 to 2008–09
Month	Categorical	January - August
Vessel	Categorical	27 vessel keys
Target species	Categorical	BIG, SWO, STN, ALB
Fleet	Categorical	Whether domestic or charter
Latitude	Continuous	3^{rd} order polynomial
Longitude	Continuous	3^{rd} order polynomial
Log (Length)	Continuous	Length of longline (km)
HBF	Continuous	Hooks between baskets 3^{rd} order polynomial
LBH	Continuous	Lightsticks per 1000 hooks
Log (Hooks)	Continuous	Number of hooks set 3^{rd} order polynomial
Month:Latitude	Interaction	

Table 11: 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.

Term	DF	Deviance	AIC	R2	Final
None	0	360	1 965	0.0000	
fyear	10	352	1 956	0.0219	*
month	21	327	1 889	0.0916	*
vessel	47	296	1 823	0.1767	*
poly(lat, 3)	50	292	1 811	0.1891	*

Table 12: Year effects ±2 s.e. from the binomial and lognormal models of observed tuna longlines north of 38° S and from the lognormal model of positive catches of striped marlin reported on TLCERS for 2000–01 to 2008–09.

Fishing year	Observer binomial year effects	Observer lognormal year effects	TLCER lognormal year effects
1992–93	0.045	1.733 (1.045-2.874)	
1993–94	0.050 (0.011-0.201)	1.698 (1.101-2.619)	
1994–95	0.038 (0.010-0.137)	0.931 (0.739-1.172)	
1995–96	0.016 (0.004-0.065)	1.199 (0.891-1.613)	
1996–97	0.015 (0.004-0.052)	0.871 (0.699-1.084)	
1997–98	0.010 (0.003-0.034)	1.040 (0.819-1.321)	
1998–99	0.025 (0.006-0.099)	1.399 (1.036-1.890)	
1999–00	0.012 (0.003-0.052)	0.996 (0.707-1.402)	1.237 (1.102-1.388)
2000–01	0.012 (0.003-0.041)	0.906 (0.759-1.083)	1.057 (0.969-1.153)
2001–02	0.005 (0.001-0.019)	0.666 (0.486-0.912)	0.887 (0.798-0.987)
2002–03	0.002 (0.000-0.009)	1.211 (0.815-1.799)	0.910 (0.816-1.015)
2003–04	0.003 (0.001-0.016)	0.772 (0.446-1.336)	1.094 (1.003-1.193)
2004–05	0.003 (0.001-0.015)	0.814 (0.460-1.442)	0.976 (0.891-1.068)
2005–06	0.013 (0.001-0.124)	1.064 (0.451-2.508)	0.966 (0.854-1.092)
2006–07	0.004 (0.001-0.015)	0.852 (0.624-1.164)	0.971 (0.867-1.087)
2007–08	0.001 (0.000-0.007)	0.572 (0.354-0.925)	1.009 (0.910-1.118)
2008–09	0.005 (0.001-0.022)	1.013 (0.653-1.570)	0.937 (0.850-1.033)

Table 13: The number of striped marlin found in match reports from the Observer and TLCER databases by fishing year and the proportion of observed fish not reported on TLCERs for that set.

	Total STM report by observers	No. STM Observed and in TLCER	Number of observed STM not reported on matching TLCERs	Proportion not matching
1999–00	10	5	5	0.50
2000–01	69	37	31	0.45
2001–02	11	4	7	0.64
2002–03	17	9	8	0.47
2003–04	4	4		0.00
2004–05	23	23		0.00
2005–06	2		2	1.00
2006–07	17	13	4	0.24
2007–08	5	5		0.00
2008–09	8	7	1	0.13
Total	166	107	51	0.31

Table 14: The number of striped marlin landed by NZSFC clubs and recorded in the gamefish tagging database in New Zealand by season. Average weights from individual catch records from four large clubs.

	No. of striped marlin		Average weight (kg)		Total weight (tonnes)	
Season	Landed	Tagged	Landed	Tagged	Landed	Tagged
1989–90	463	365	95.17	90.42	44.1	33.0
1990–91	532	229	97.70	87.96	52.0	20.1
1991–92	519	239	111.57	92.98	57.9	22.2
1992–93	608	385	102.97	95.10	62.6	36.6
1993–94	663	928	99.94	87.97	66.3	81.6
1994–95	910	1 202	102.73	88.57	93.5	106.5
1995–96	705	1 102	98.48	91.10	69.4	100.4
1996–97	619	1 301	105.78	98.13	65.5	127.7
1997–98	543	895	102.75	89.12	55.8	79.8
1998–99	823	1 541	88.58	85.03	72.9	131.0
1999–00	398	787	100.19	88.87	39.9	69.9
2000–01	422	851	102.75	89.44	43.4	76.1
2001–02	430	771	106.34	101.95	45.7	78.6
2002–03	495	671	110.01	97.31	54.5	65.3
2003–04	592	1 051	102.70	98.23	60.8	103.2
2004–05	834	1 348	103.84	97.43	86.6	131.3
2005–06	630	923	96.48	92.98	60.8	85.8
2006–07	688	964	98.14	96.86	67.5	93.4
2007–08	485	806	100.31	98.89	48.6	79.7
2008–09	731	1 058	100.82	98.63	73.7	104.4
2009–10	597	808	103.93	98.29	58.7	79.4

Table 15: Taxonomy of billfishes (Xiphioidei) showing revised genus classifications proposed by Collette et al. (2006). The revised name for striped marlin, *Kajika audax* is used in this report.

Suborder	Family	Revised genus classification	Previous Genus and species [1]
Xiphioidei			
	Istiophoridae	Istiophorus	Sailfish *Istiophorus platypterus (albicans[2])*
		Makaira	Blue marlin *Makaira nigricans (mazara[2])*
		Istiompax	Black marlin *Makaira indica*
		Kajikia	White marlin *Tetrapturus albidus*
			Striped marlin *Tetrapturus audax*
		Tetrapturus	Shortbill spearfish *Tetrapturus angustirostris*
			Longbill spearfish *Tetrapturus pfleugeri*
			Mediterranean spearfish *Tetrapturus belone*
			Roundscale spearfish *Tetrapturus georgei*
			Hatchet marlin[3] *Tetrapturus sp.*
	Xiphiidae	Xiphias	Swordfish *Xiphias gladius*

1. Classification system used by Nakamura (1985)
2. Former Atlantic species no longer recognized (Collette et al. 2006)
3. Species recognition uncertain

Table 16: Synopsis of biological and fisheries information pertaining to striped marlin.

Scientific name [1]	*Kajikia audax* (Philippi, 1887): Formerly *Tetrapturus audax*
Common names [2,3]	Striped marlin (world-wide); A'u (Hawaii); makajiki (Japan); marlin rayado (Mexico); takeketonga (New Zealand- Maori); stripey (Australia)
Distribution [4]	Indian and Pacific Oceans between 40° N and 40° S. Low densities in warm pool equatorial waters of the Pacific Ocean
Fisheries [2,3]	Commercial longline fisheries throughout the Indian (minimum 2000 t year) and Pacific (minimum 6000 t per year) Oceans mainly service Japanese sushi and sashimi markets. Primary target of recreational fleets in Mexico, New South Wales Australia, New Zealand, and southern California
Biology and ecology [2,3]	Highly migratory, top predator in epipelagic and oceanic subtropical and tropical waters, between 20-25°C sea surface temperature. Maximum estimated age 12 years, maximum size 250kg or 3000mm LJFL, diecious, sexual dimorphism minimal, high fecundity pelagic spawning
Population status	Indian Ocean - No stock assessment north Pacific Ocean[5] – Stock assessment underway eastern Pacific Ocean [6] - Stable southwest Pacific Ocean [7] - Stock assessment uncertain

1. Collette et al. (2006)
2. Bromhead et al. (2004)
3. Ueyanagi & Wares (1975)
4. Squire & Suzuki (1990)
5. WCPFC (2008)
6. Hinton & Bayliff (2002)
7. Langley et al. (2006)

Table 17: Conversion equations and parameters used to standardize length and weight information for striped marlin in the southwest Pacific Ocean (Kopf 2010). Regression equations were developed to convert: Eye – Fork Length (mm, EFL); Upper Jaw – Fork Length (mm, UJFL) and whole weight (kg, Wt) to Lower Jaw – Fork Length (mm, LJFL) and to convert Trunk (head, gills, and organs removed) weight (kg, Twt) to whole weight (kg).

Regression equation	Sex	R^2	N	*a*	*b*	X_0	Y_0
EFL = a x LJFL + b	Both sexes	0.95	301	0.834	36.61	-	-
	Female	0.96	136	0.838	23.75	-	-
	Male	0.94	159	0.827	49.83	-	-
UJFL = a x LJFL + b	Both sexes	0.87	299	1.060	211.31	-	-
	Female	0.92	81	1.067	192.85	-	-
	Male	0.88	51	1.021	319.35	-	-
$Wt = a \times LJFL^{b}$	Both sexes	0.93	214	1.012×10^{-10}	3.55	-	-
	Female	0.95	120	4.171×10^{-11}	3.67	-	-
	Male	0.89	89	1.902×10^{-9}	3.16	-	-
[1] $Wt = a \times Twt^{b}$	Both sexes	-	254	1.179	0.99	-	-
% Fem. = $Y_0 + a / 1 + e^{-(LJFL\mathit{class} - Xo) / b))}$	-	0.95	257	0.889	132.58	2322	0.15

1. Regression equation was sourced from Langley et al. (2006).

Table 18: von Bertalanffy growth parameters estimated in age and growth studies for striped marlin.

Location	Method	N	Range LJFL (mm)	Sex	L∞ (mm)	K	to	Max age	Natural mortality M[6]
Southwest Pacific[1]	Otoliths and fin spines	425	990-2872	M,F	2636	0.44	-1.07	8	-
Southwest Pacific[1]	"	206	990-2872	F	2634	0.45	-1.02	8	-
Southwest Pacific[1]	"	211	1120-2540	M	2525	0.51	-0.92	8	-
New Zealand[2]	Fin spines	94	1890-2830	M,F	3010	0.22	-0.04	8	-
Mexico[3]	Fin spines	399	1560-2630	M,F	2210	0.23	-1.6	11	-
North central Pacific[4]	Length frequency	13,532	1331-2135	F	2518	0.71	0.14	11	1.33
North central Pacific[4]	"	16,898	1331-2087	M	3144	0.32	-0.52	12	0.79
Western north Pacific[5]	Length frequency	-	1476-2854	M,F	2750	0.26	-	6	0.49

1.Kopf & Davie (2009)
2. Kopf et al. (2005)
3. Melo-Barrera et al. (2003)
4. Skillman & Yong (1976)
5. Koto (1963)
6. Boggs (1990)

Table 19: Length (LJLF, mm) at age estimated by von Bertalanffy growth curves for striped marlin.

	Southwest Pacific [1]			New Zealand[2]	Mexico[3]	North central Pacific[4]	
Age	Both Sexes	Female	Male	Both sexes	Both sexes	Female	Male
1	1576	1573	1577	616	995	1153	1197
2	1953	1957	1955	1088	1244	1846	1723
3	2196	2203	2183	1468	1443	2187	2107
4	2353	2359	2320	1772	1600	2355	2387
5	2454	2459	2402	2017	1726	2438	2592
6	2519	2522	2451	2213	1825	2479	2741
7	2560	2563	2481	2370	1904	2499	2850
8	2587	2589	2498	2497	1967	2508	2929
9	-	-	-	-	2017	2513	2987
10	-	-	-	-	2057	2516	3030
11	-	-	-	-	2088	2517	3061
12	-	-	-	-	-	-	3083

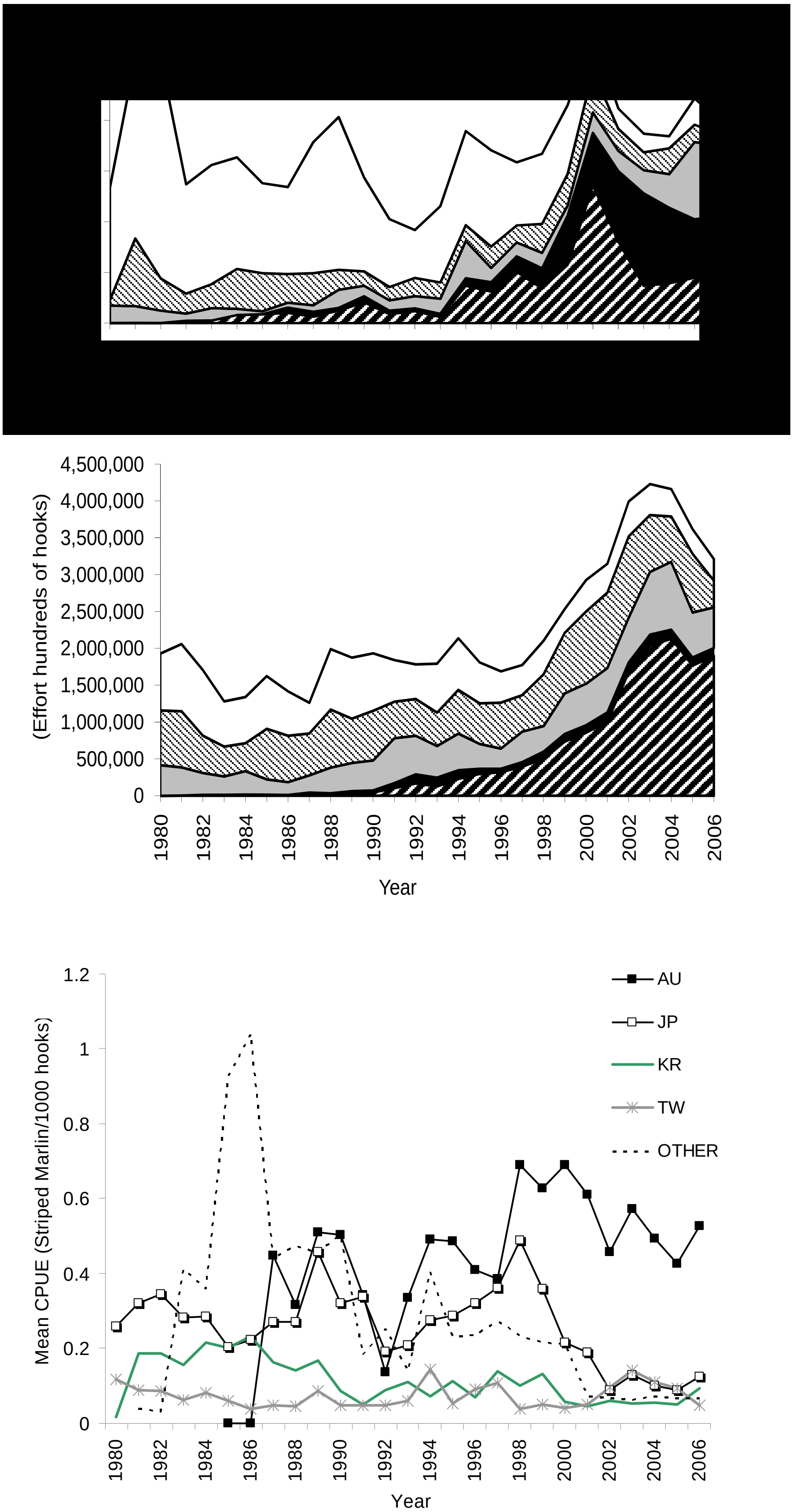
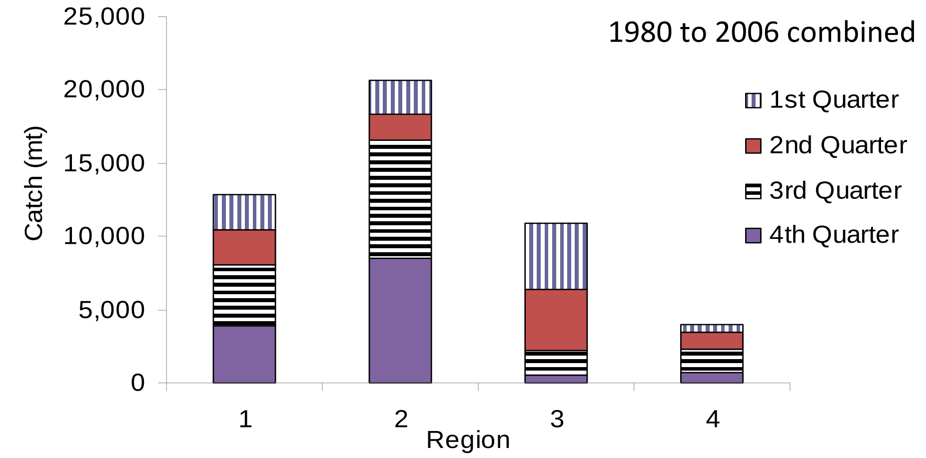


Figure 1: Annual commercial longline catch (t) of striped marlin (top), total effort and mean CPUE in the SWPO by fleet from 1980 to 2006. Japan ; Korea ; Taiwan ; Australia ; Others includes: New Zealand, China, Indonesia, Philippines, Pacific Island States, Territories, and the United States. Mean catch rate by fleet (bottom). Data sourced from the Secretariat of the Pacific Community.



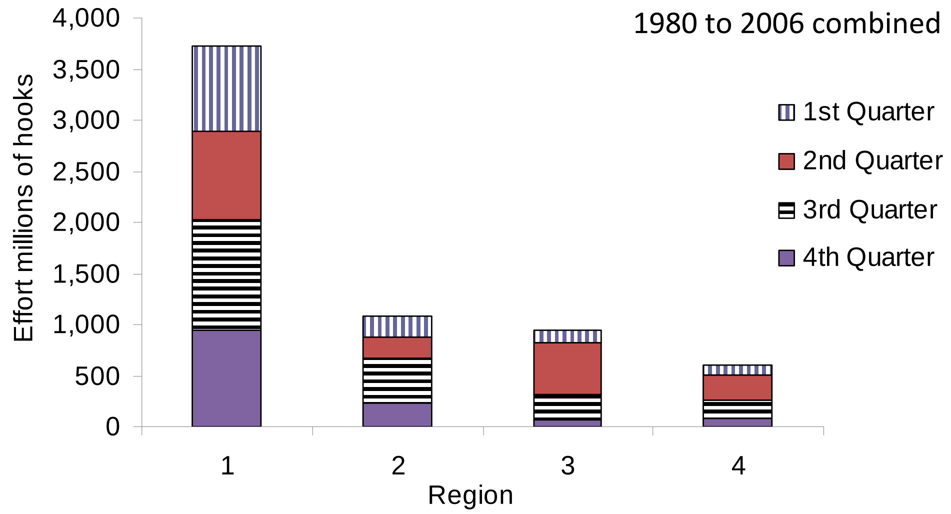


Figure 2: Regions of the southwest Pacific Ocean modelled in most recent stock assessment for striped marlin (Langley et al. 2006) and respective total longline catch and effort between 1980 and 2006. Data sourced from the Secretariat of the Pacific Community.

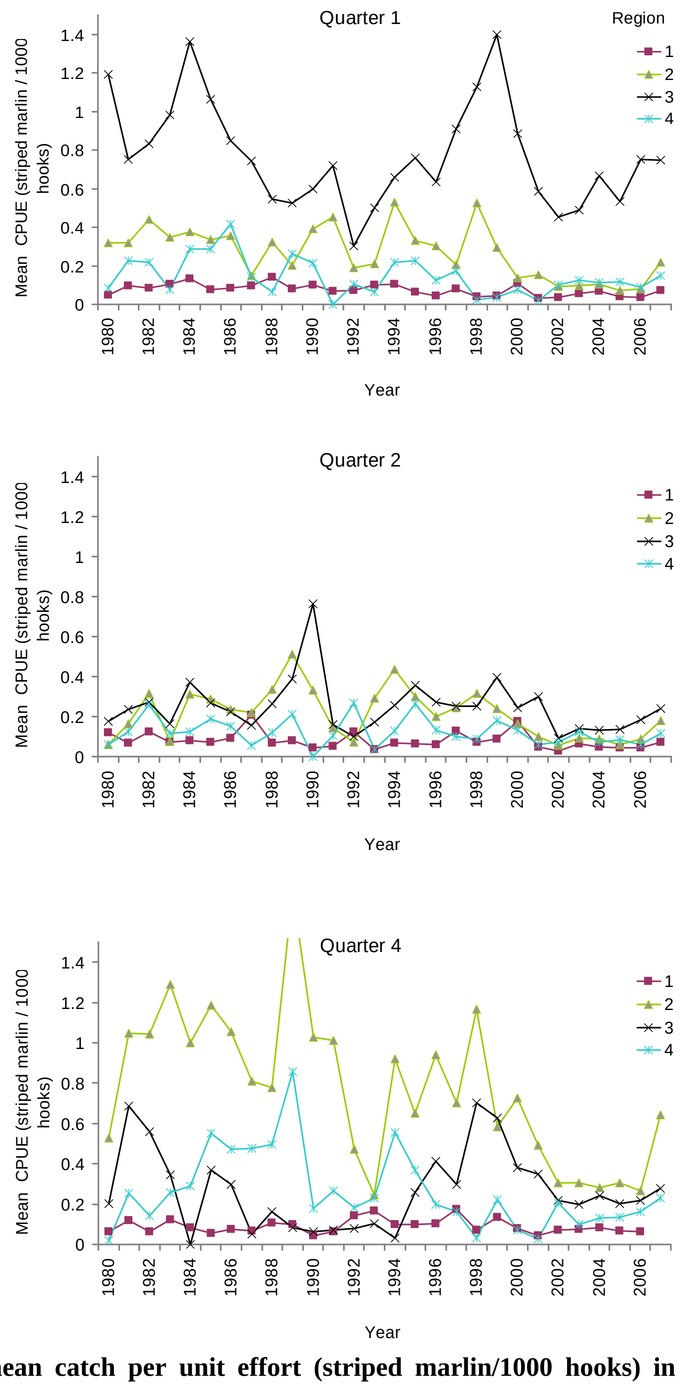


Figure 3: Annual mean catch per unit effort (striped marlin/1000 hooks) in the four regions of the southwest Pacific Ocean separated by quarter of the year. All fleets combined. Data sourced from the Secretariat of the Pacific Community.

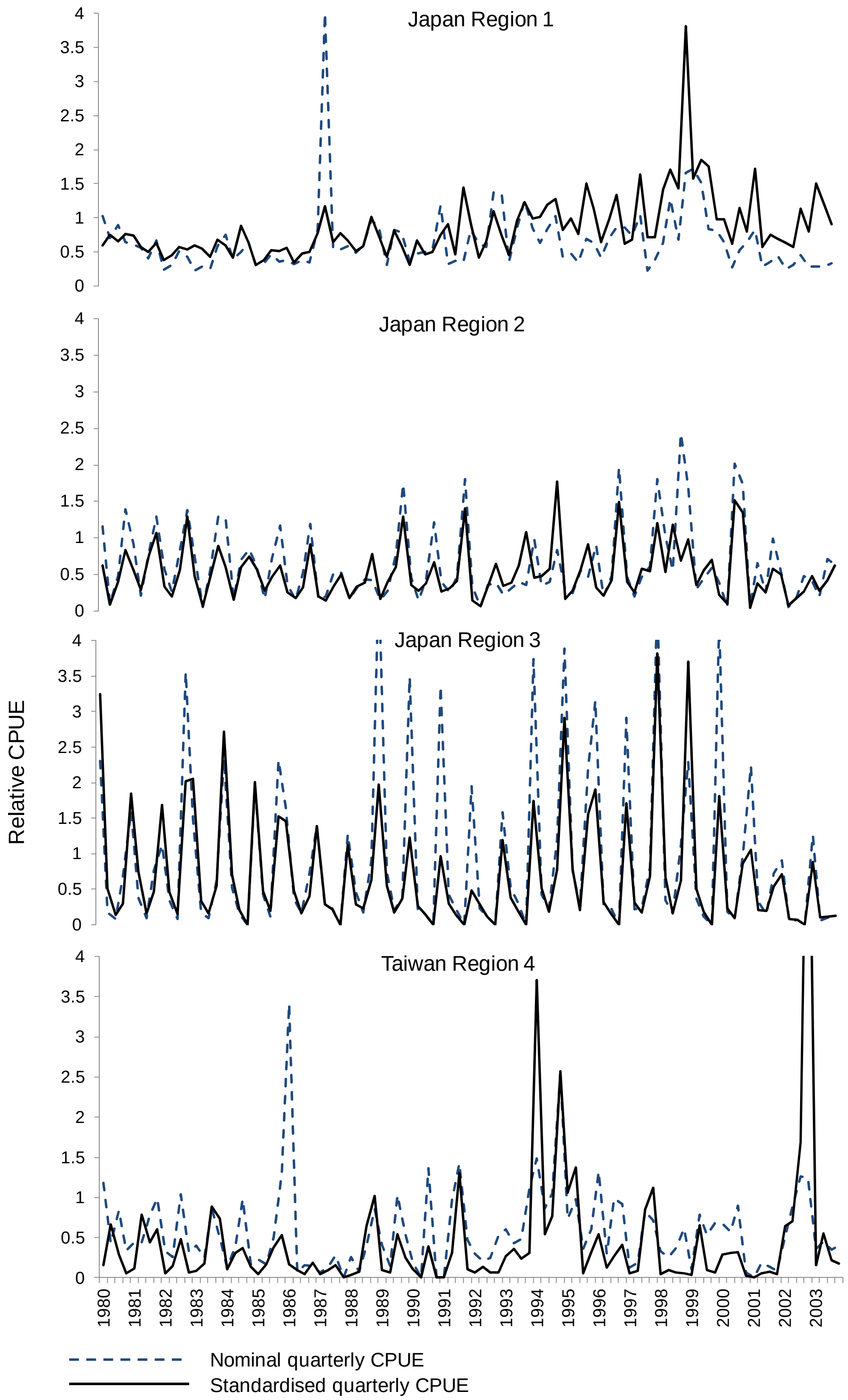


Figure 4: Nominal and standardised catch per unit effort (striped marlin/1000 hooks) of striped marlin by region reported by commercial longline fishing vessels in the southwest Pacific Ocean between 1980 and 2004. Regions 1–3 modelled from Japanese longline data and Region 4 from Taiwanese data. CPUE standardisation courtesy of the Secretariat of the Pacific Community (Langley et al. 2006).

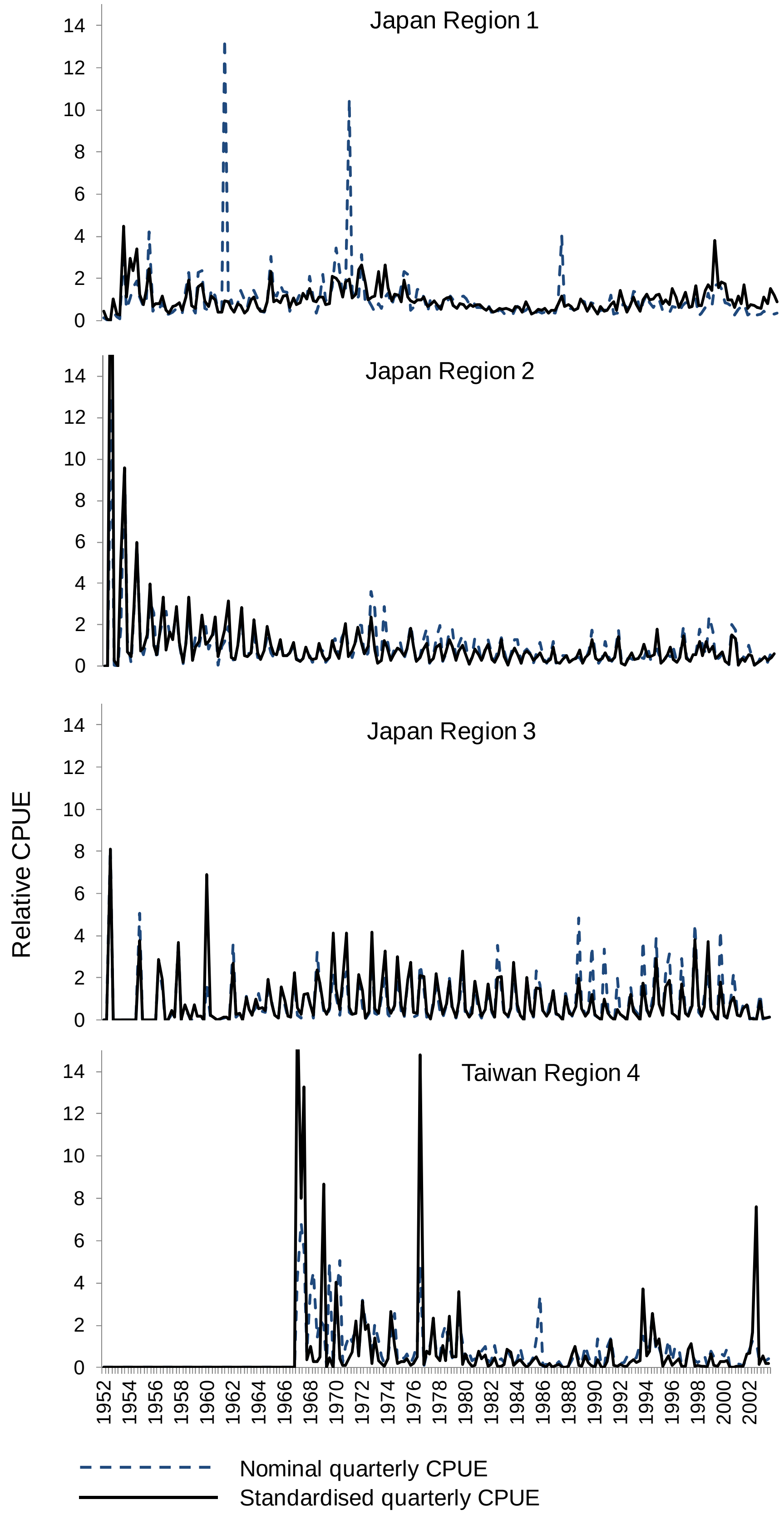


Figure 5: Nominal and standardised catch per unit effort (striped marlin/1000 hooks) of striped marlin by region reported by commercial longline fishing vessels in the southwest Pacific Ocean between 1952 and 2004. Regions 1-3 modelled from Japanese longline data and region 4 from Taiwanese data. CPUE standardisation courtesy of the Secretariat of the Pacific Community (Langley et al. 2006).

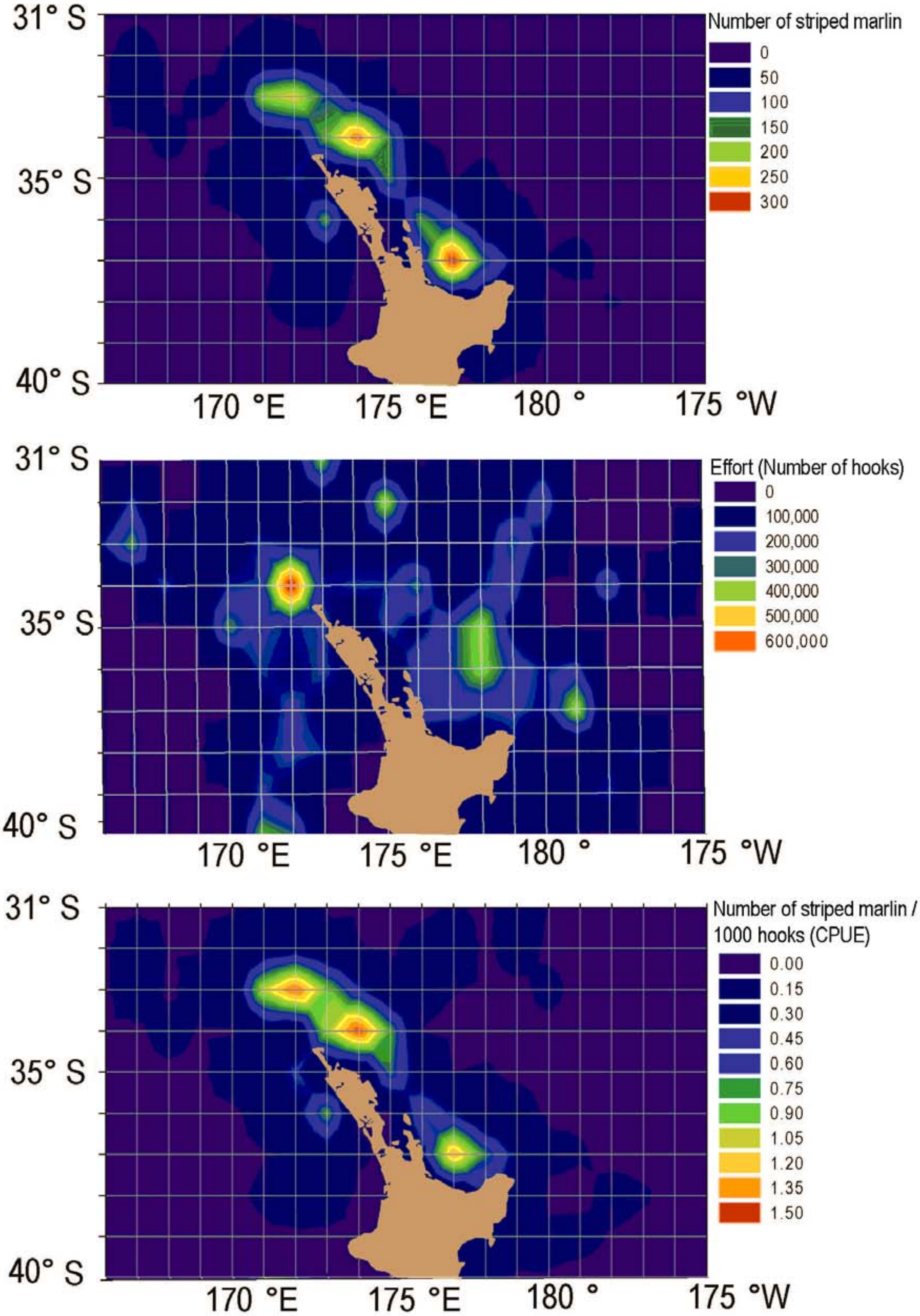


Figure 6: Catch, effort, and catch per unit effort (striped marlin / 1000 hooks) in commercial longline during the peak season (January-May) between 2000 and 2009. Data sourced from the TLCER database.

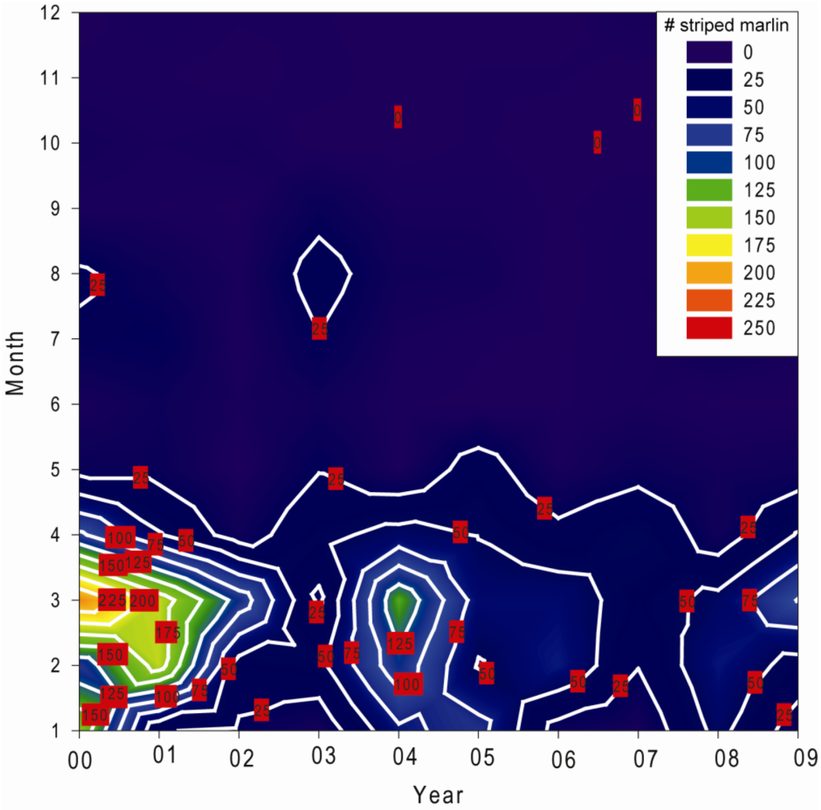


Figure 7: Number of striped marlin reported by commercial longline vessels in New Zealand by month and year between 2000 and 2009. Data sourced from the TLCER database.

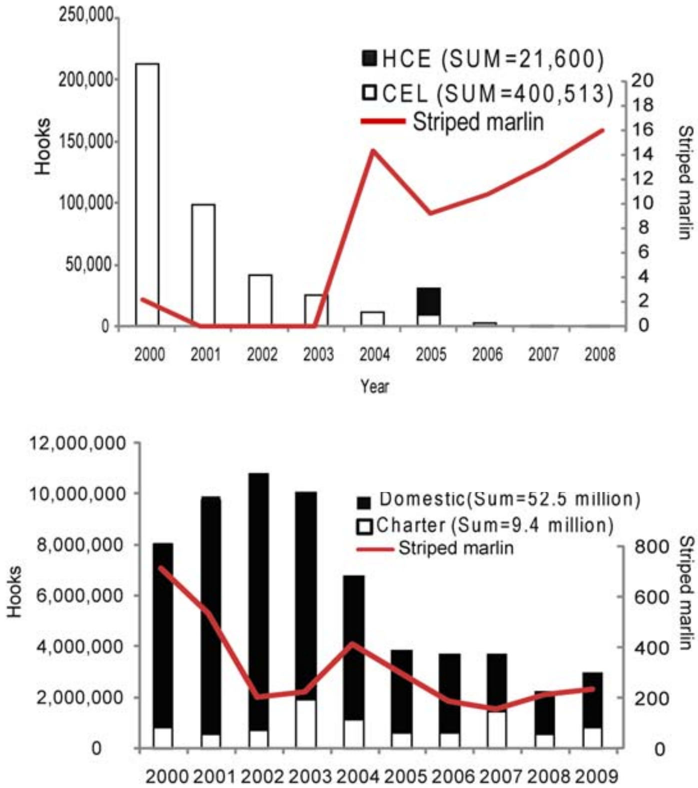


Figure 8: Number of hooks and striped marlin reported by (top) High Seas (HCE) commercial longline fishing vessels and other commercial fishing methods (CELR) and (bottom) commercial tuna longline fishing vessels (TLCER) in New Zealand between 2000 and 2009.

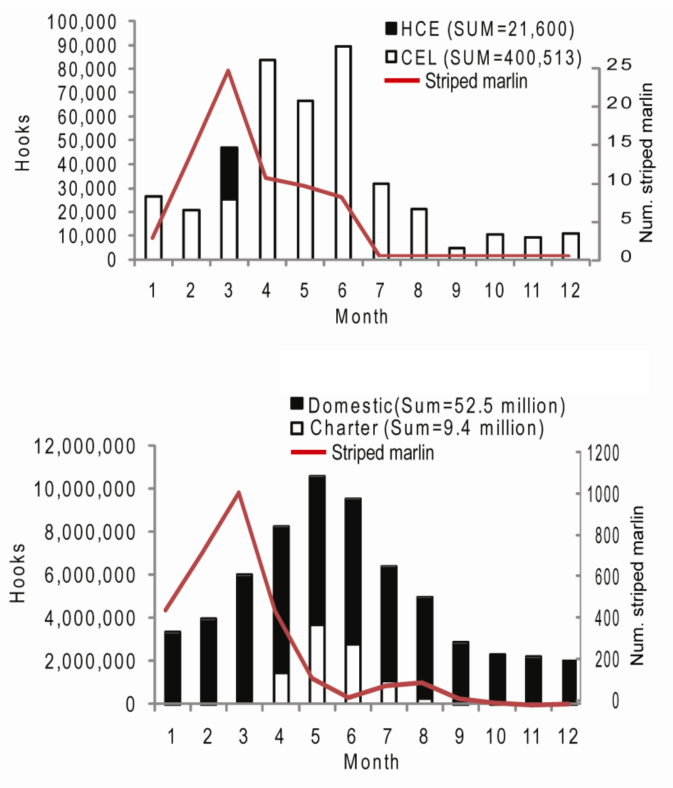


Figure 9: Number of hooks and striped marlin reported by month (top) High Seas (HCE) commercial longline fishing vessels and other commercial fishing methods (CEL) and (bottom) commercial tuna longline fishing vessels (TLCER) New Zealand between 2000 and 2009.

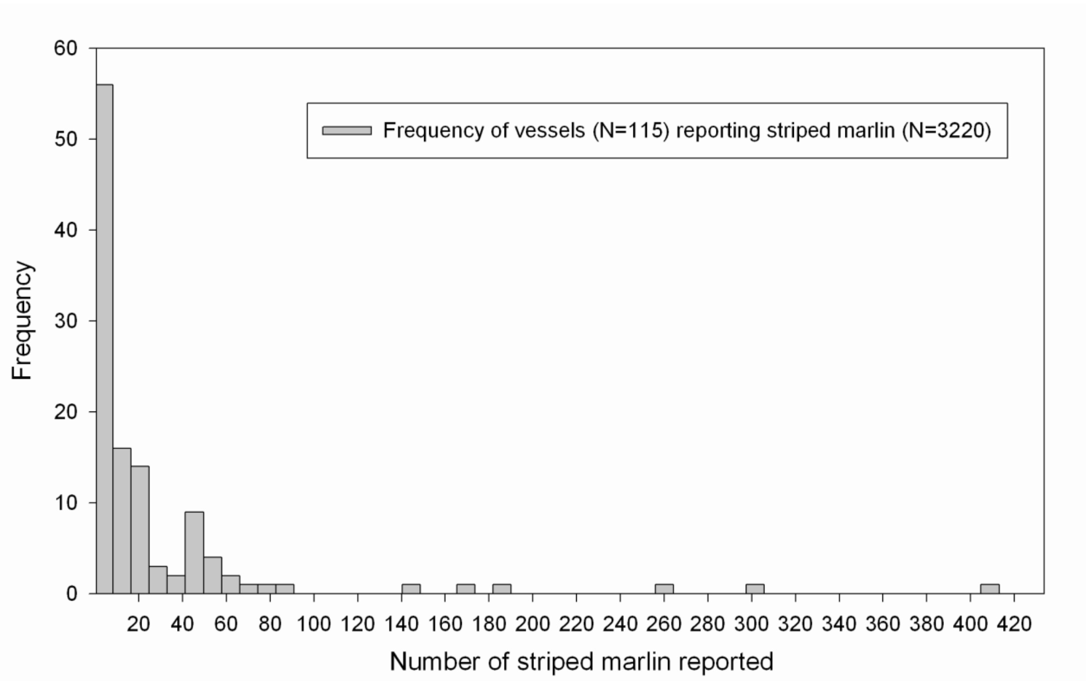


Figure 10: Frequency distribution of commercial longline fishing vessels (N=115) and total number of striped marlin (N=3220) in TLCER forms between 2000 and 2009.

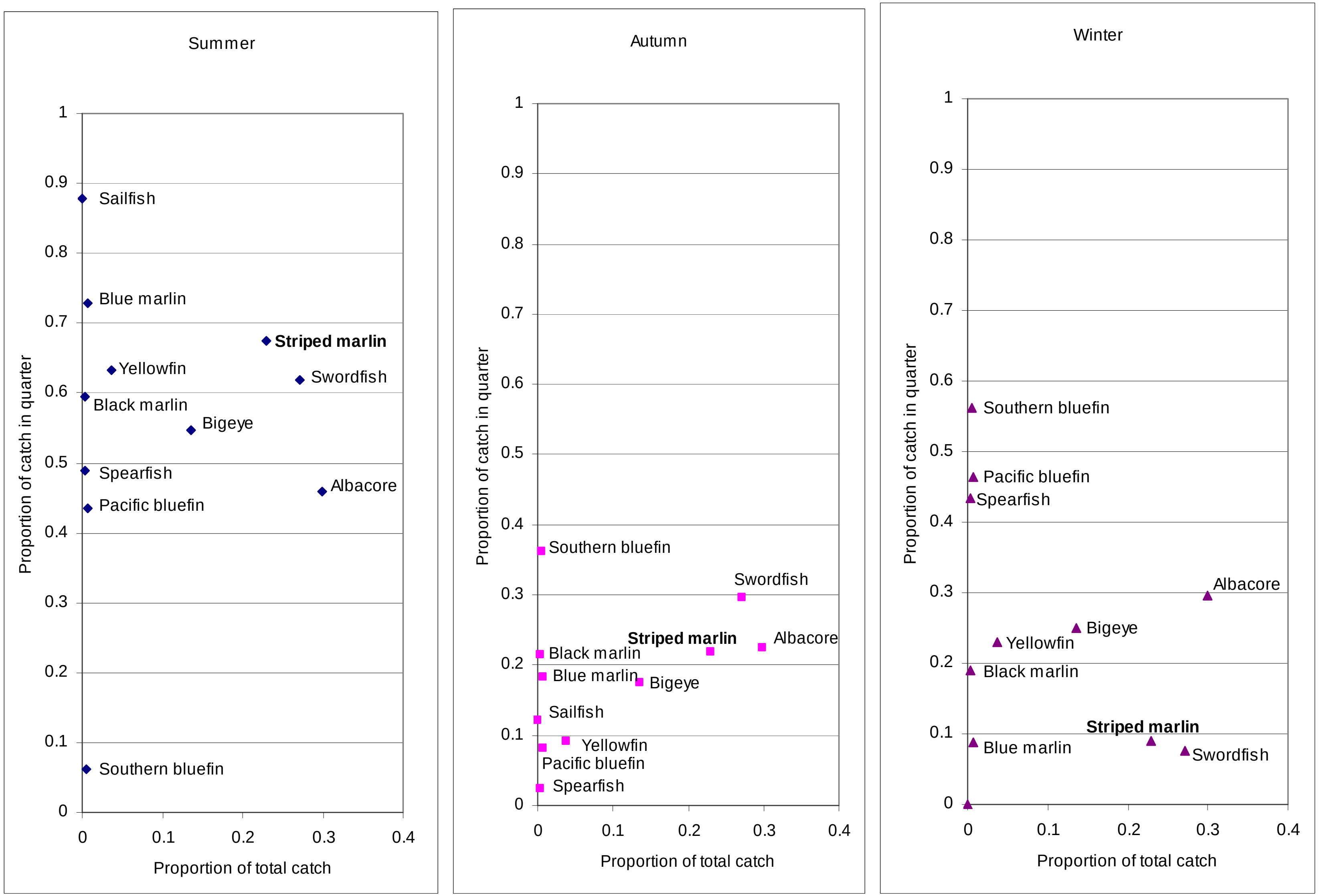


Figure 11: Proportion of catch by weight for species and quarter reported in TLCER forms between 2000 and 2009 where marlin was present in catch.

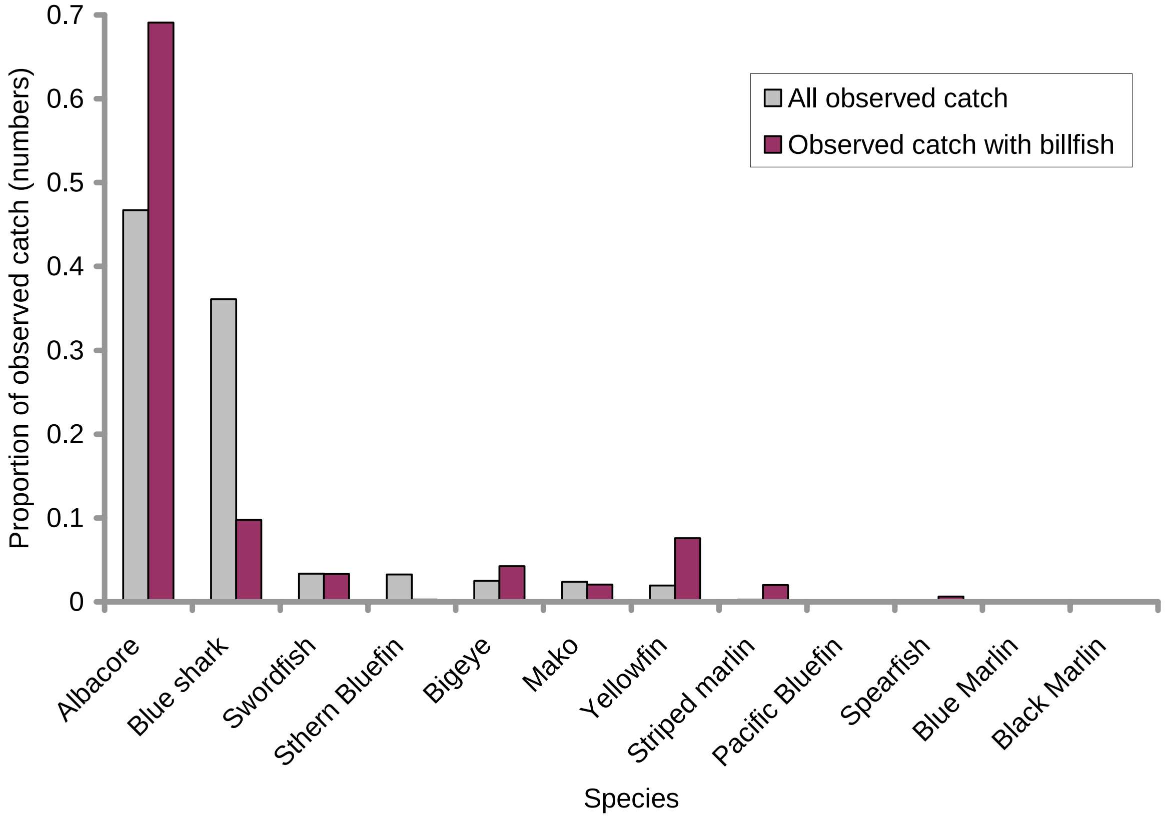


Figure 12: Proportion of observed catch by species (numbers of fish) north of 38° S for all sets and for sets where billfish were caught.

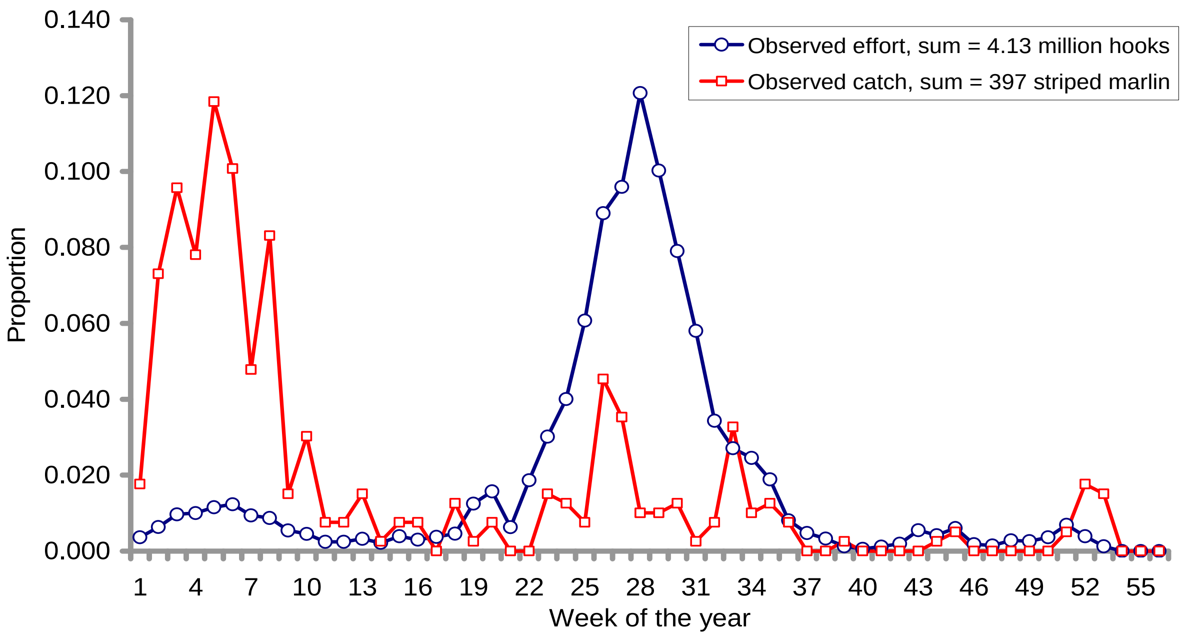


Figure 13: Proportion of observed striped marlin catch and proportion of observed longline effort by week for the area north of 38° S 1990 to 2009.

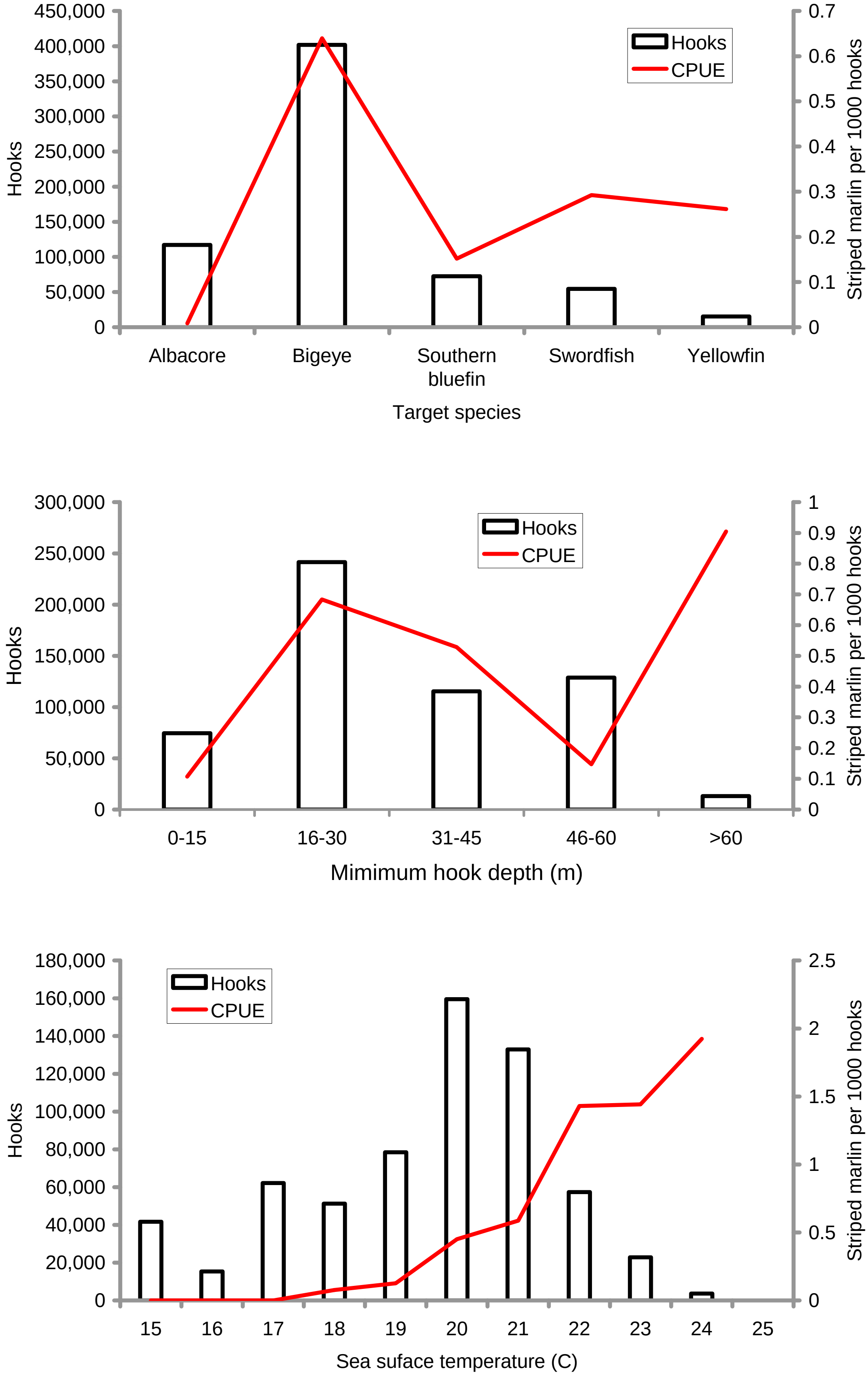


Figure 14: Striped marlin CPUE by target species, minimum hook depth and sea surface temperature from of observed longline catch 1990 to 2009 north of 38° S. Observed hooks in columns.

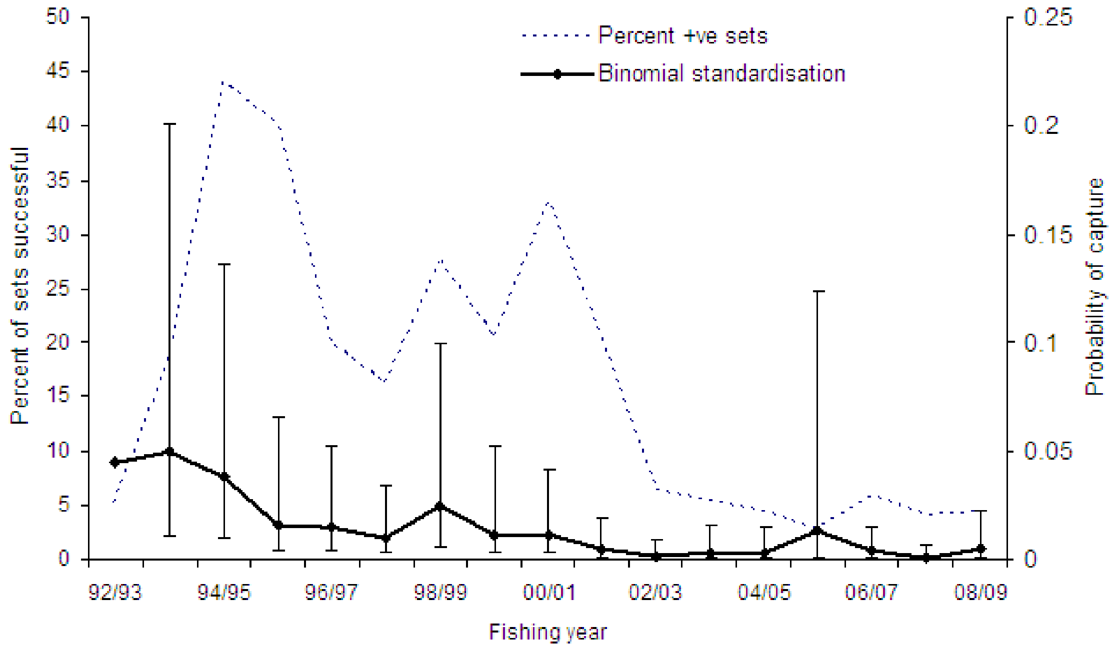


Figure 15: The percentage of observed sets north of 38° S that were successful (dotted line, left vertical axis) and the year effects (solid line) from the binomial model of the probability of capture (±2 s.e.).

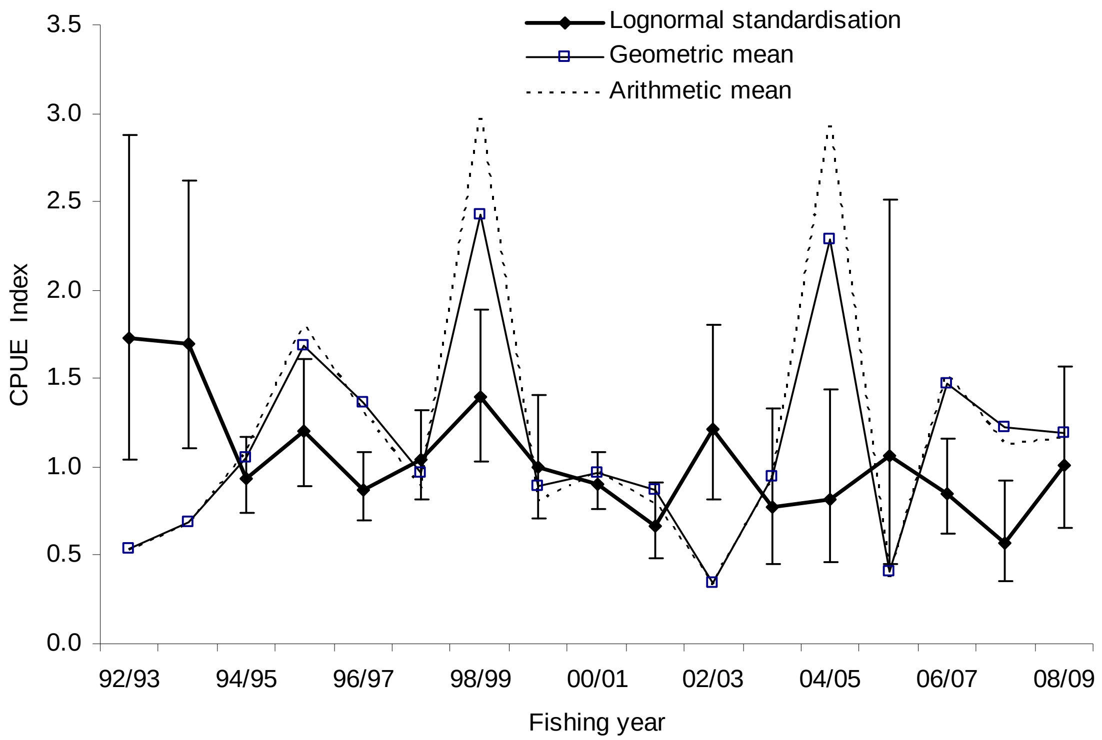


Figure 16: Unstandardised CPUE (arithmetic and geometric mean numbers of striped marlin per set) and the year effects from the lognormal model of observed catch rates in successful sets (± 2 s.e.).

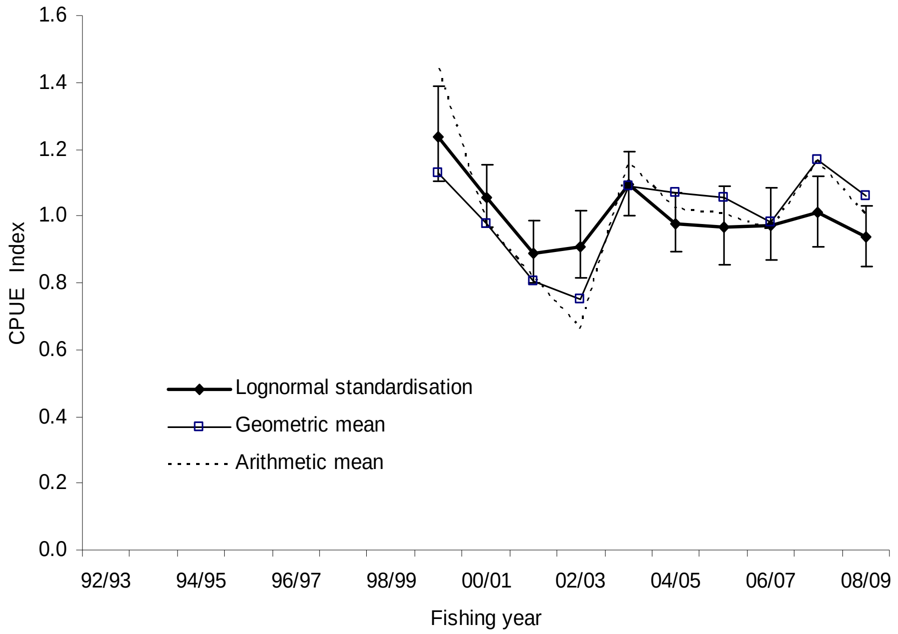


Figure 17: Unstandardised CPUE (arithmetic and geometric mean numbers of striped marlin per set) and the year effects from the lognormal model of catch rates in successful sets reported on TLCERs (± 2 s.e.).

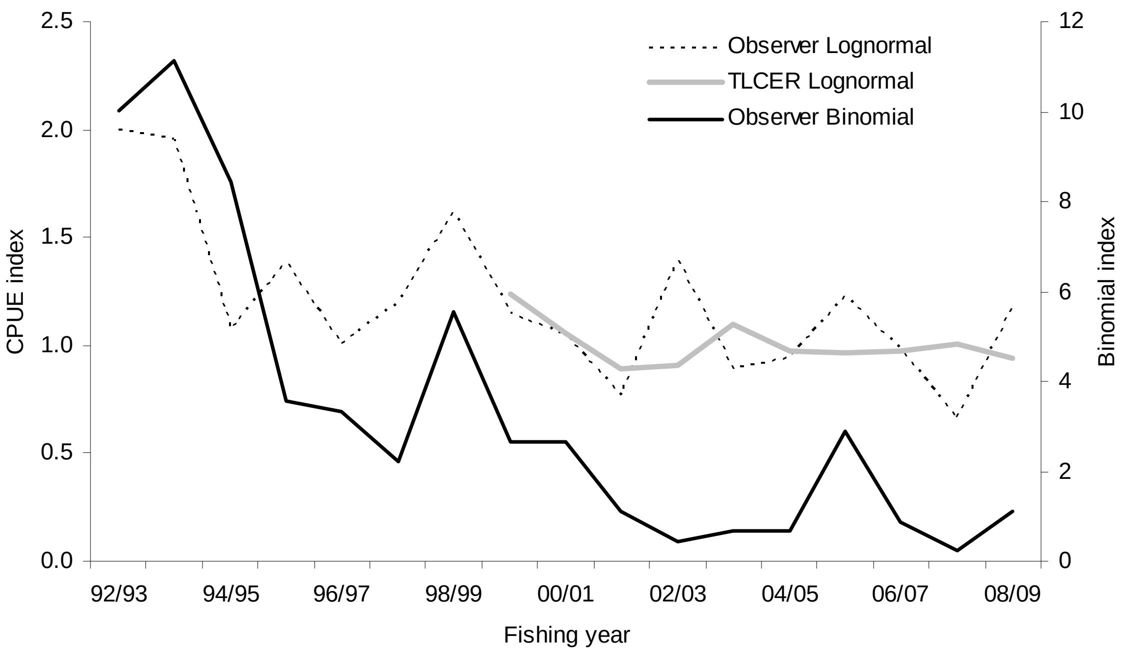


Figure 18: As above but with the observer binomial and lognormal series plotted for comparison. The observer series have been rescaled relative to the years in common (1999–00 to 2008–09).

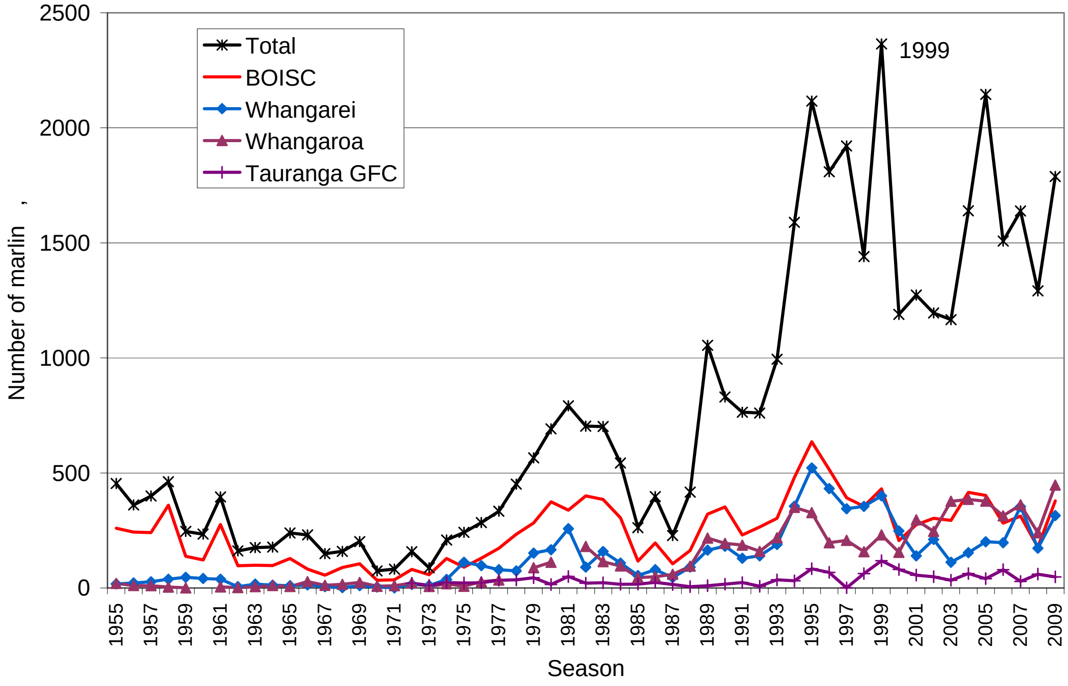


Figure 19: Recreational striped marlin catch (landed and tagged) for all New Zealand (NZSFC club tallies, Total) and for four large clubs with long term record of catch.

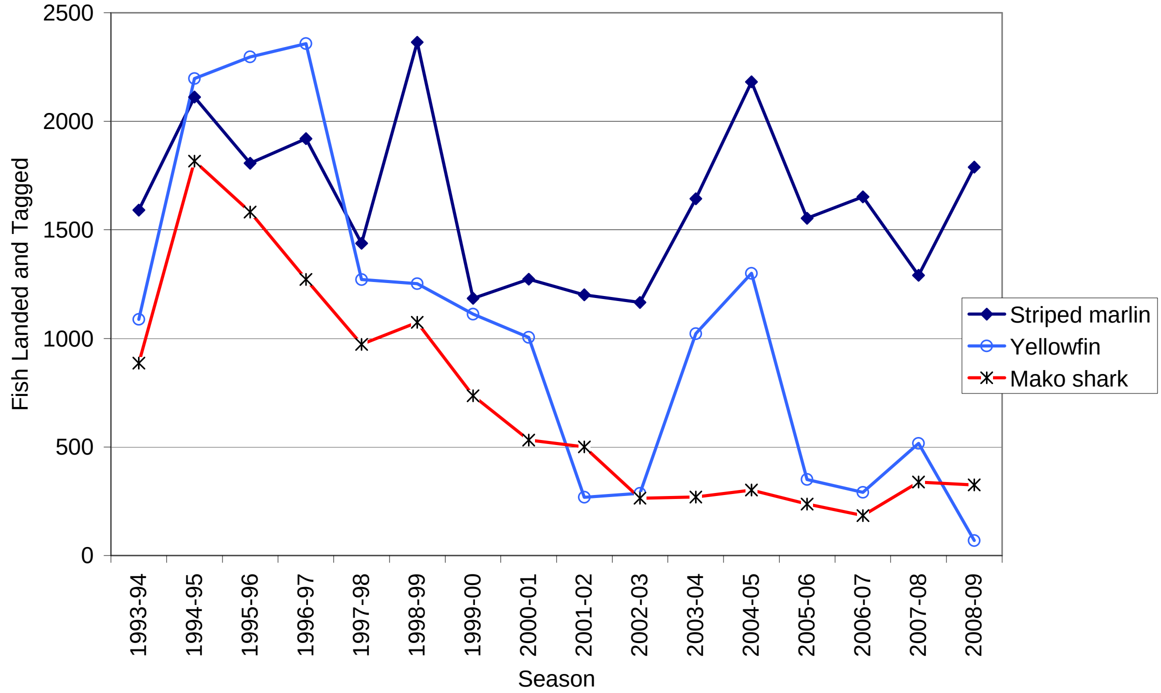


Figure 20: Combined landed and tagged recreational catch of the main highly migratory gamefish species in New Zealand by season.

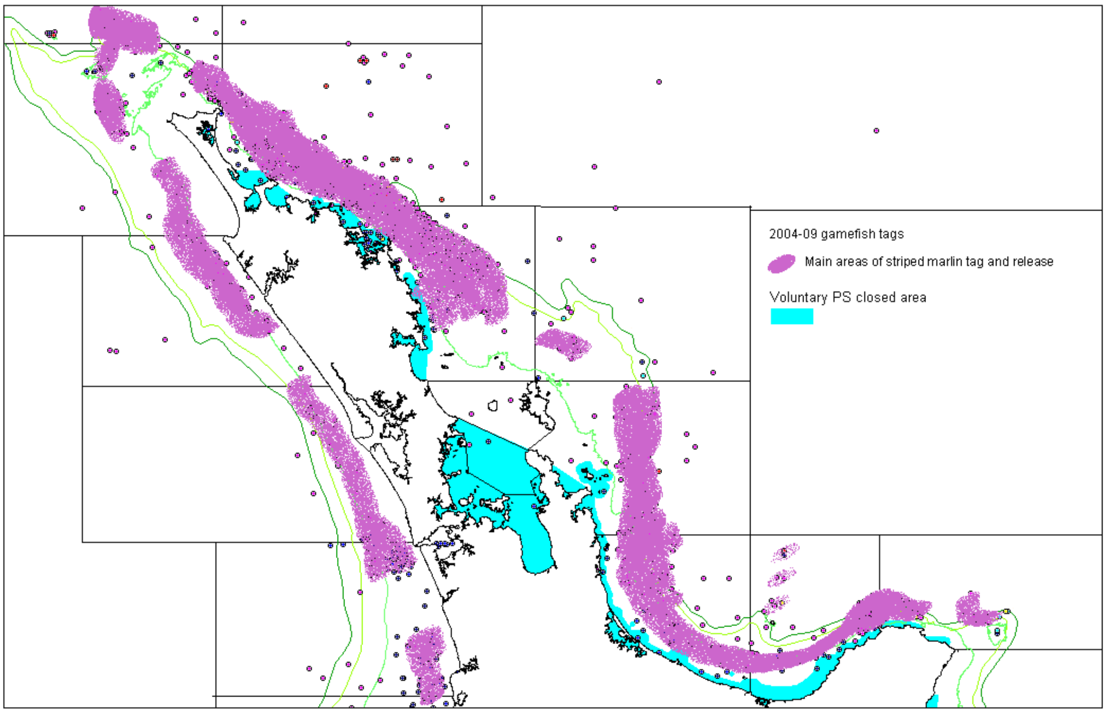


Figure 21: Release areas of tagged striped marlin from the New Zealand gamefish tagging programme and areas closed to purse seine vessels. The three Kings area is at the top left. (Plot adapted from Graeme McGregor, MFish).

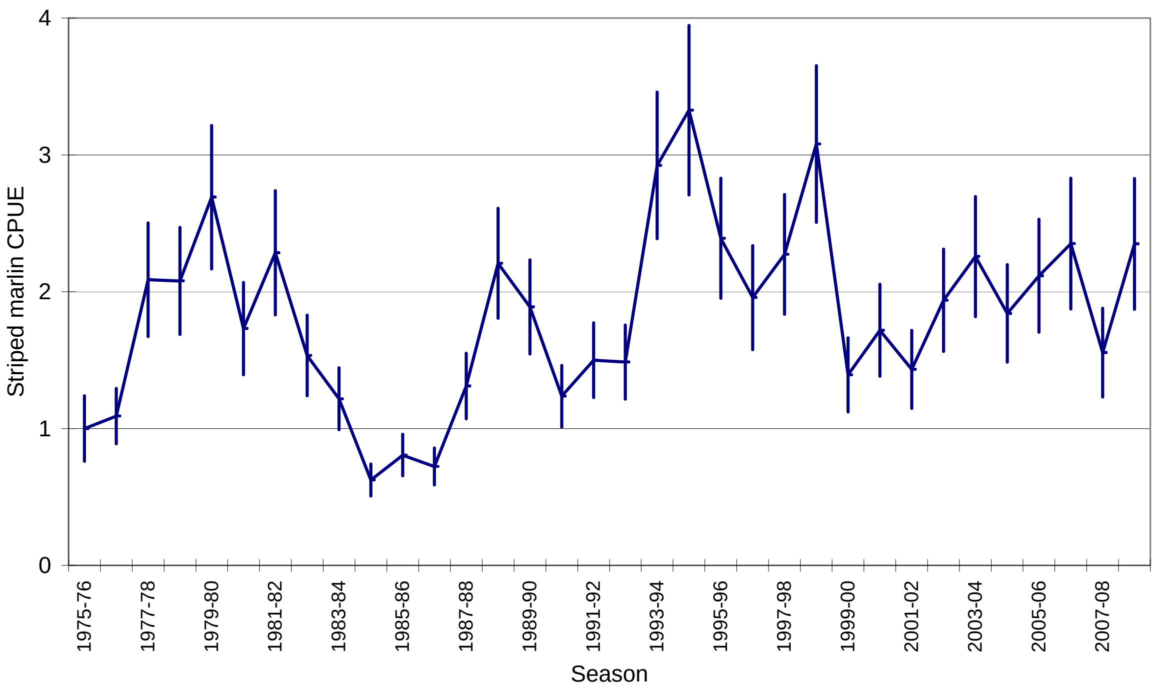


Figure 22: Index recreational striped marlin CPUE for east Northland charter boats only from the general linear model using year, vessel and port.

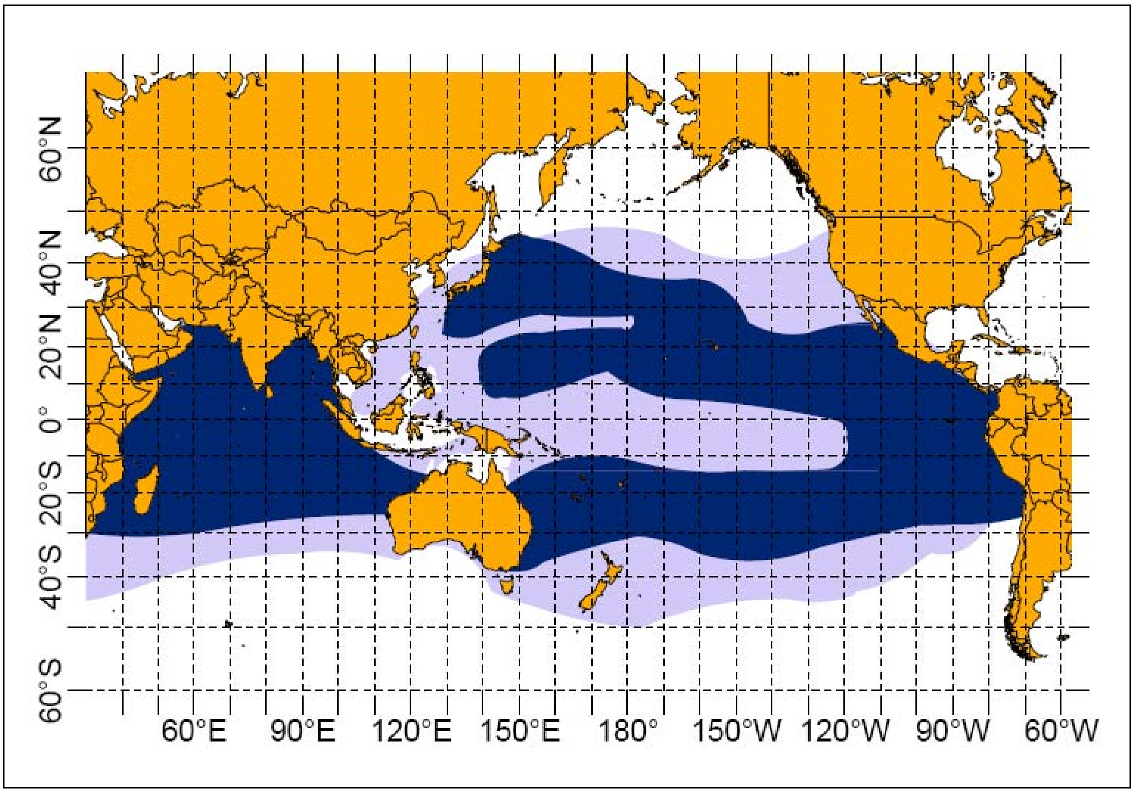


Figure 23: Occurrence [light purple box], and primary distribution [dark blue box], of striped marlin inferred from commercial longline catch rates in the Pacific and Indian Oceans. Adapted from Squire & Suzuki (1990) and Nakamura (1985).

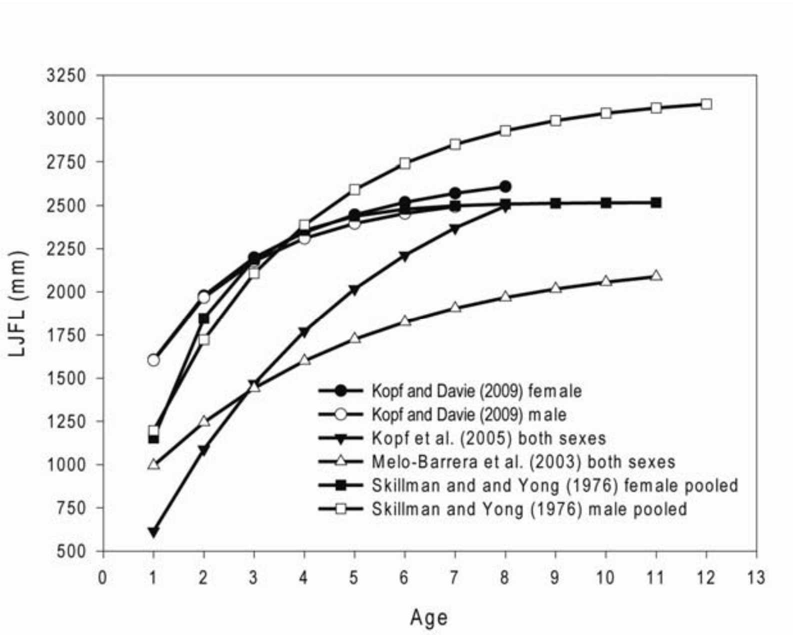


Figure 24: Comparison of von Bertalanffy growth curves for striped marlin calculated for the southwest Pacific Ocean (Kopf 2010); New Zealand (Kopf et al. 2005); Mexico (Melo-Barrera et al. 2003); and Hawaii (Skillman & Yong 1976).

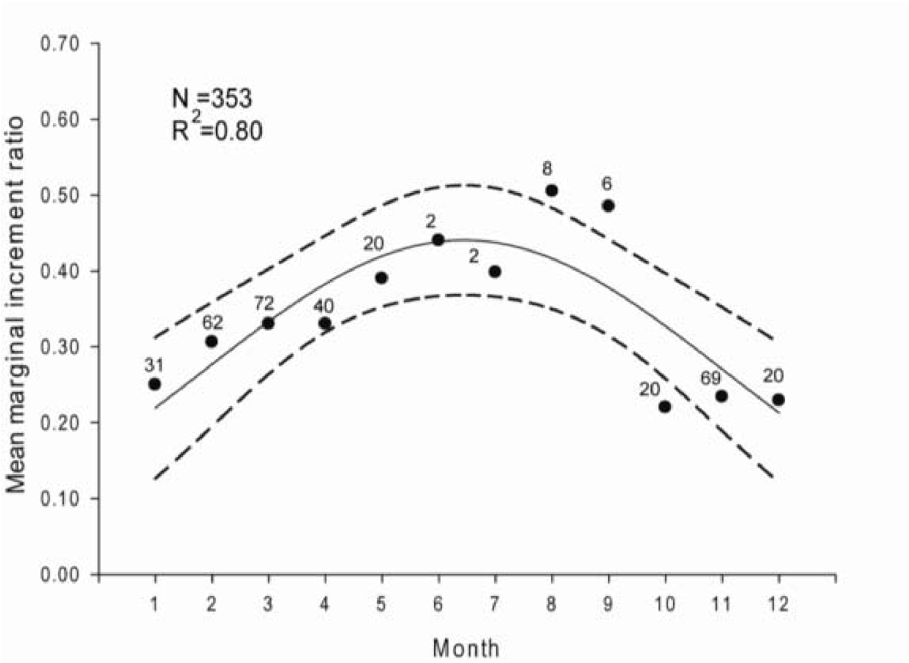


Figure 25: Mean marginal increment ratio by month and year from fin spine sections of striped marlin. Mean values were fitted to a Gaussian Peak regression (solid line) which displayed a 12 month sinusoidal cycle of annuli formation and predicted peak marginal increment values to occur over the austral winter (months 6-8). Dashed lines are 95% confidence intervals and numbers indicate the sample size (N) for month.

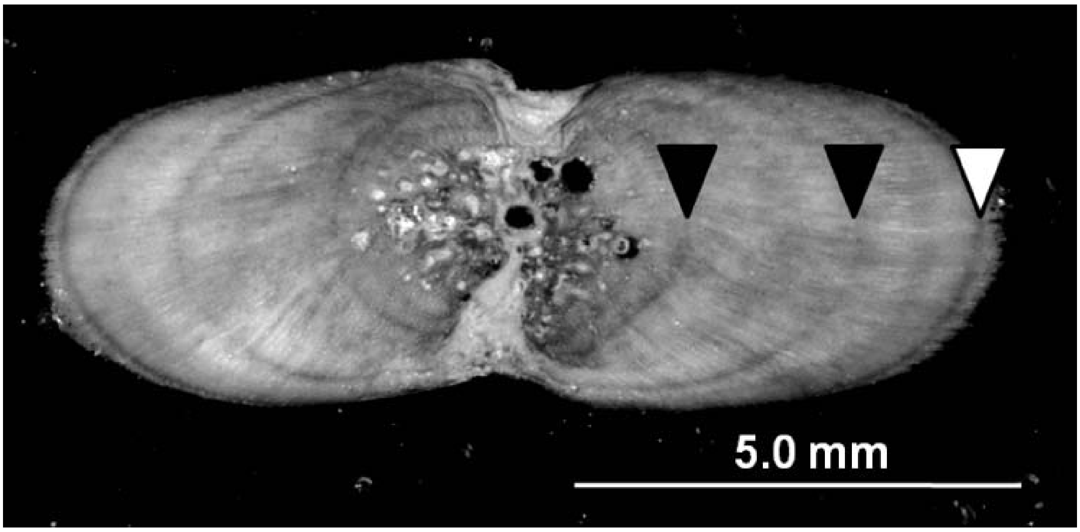


Figure 26: Transverse section of first dorsal fin spine four, ¼ condyle width (CW), from a 1490 mm Lower jaw – fork length striped marlin that was estimated to be 383 days old. The two black arrows indicate presumed false annuli that formed prior to the first yearly annulus indicated by the white arrow. The radius of the first yearly annulus closely matches the predicted spine radius at 365 days (6.34mm). Note that the fish was caught in November and the first yearly annulus is close to the edge of the section, which suggests that the annulus was recently formed.

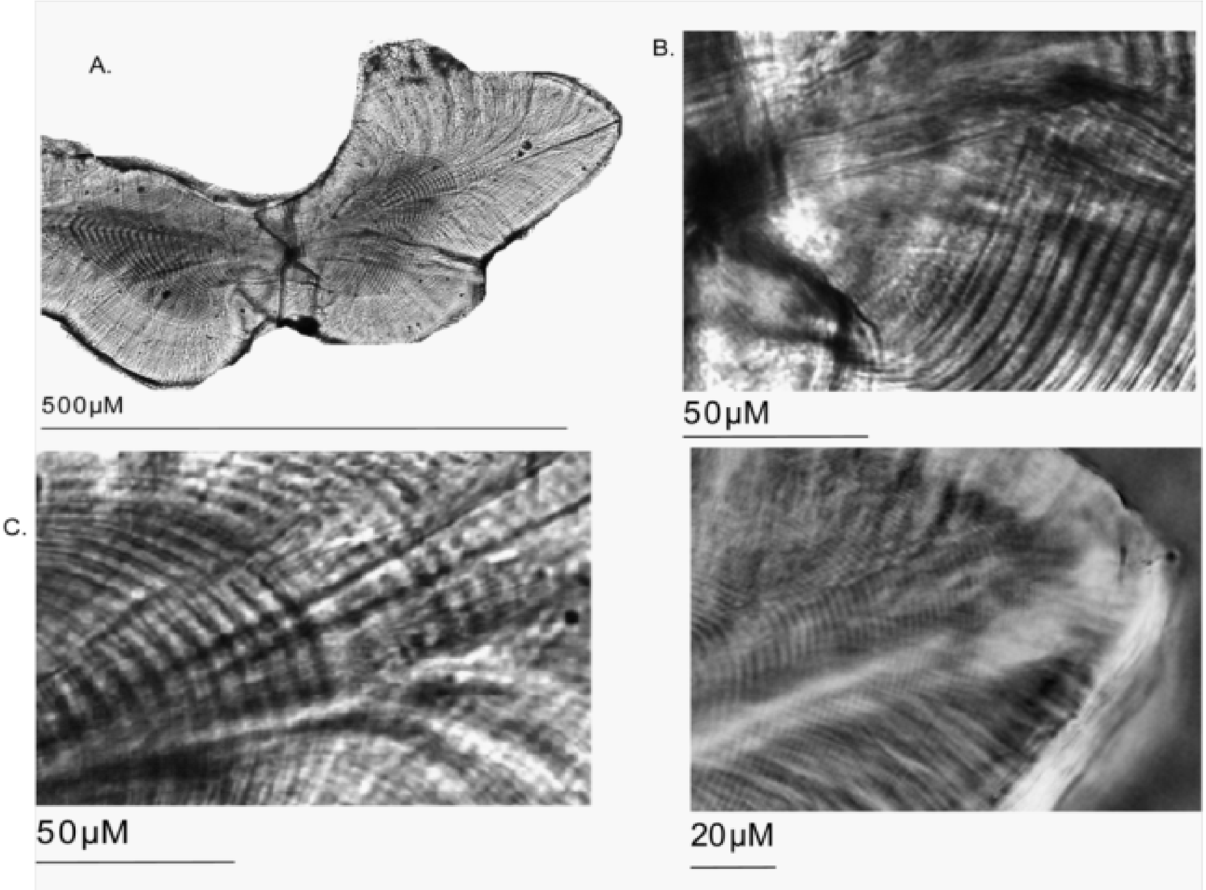


Figure 27: Images of presumed daily micro-increments from a 1120 mm Lower jaw-fork length striped marlin sagittal otolith that was aged 130 days. Images display the ventral lobe which was used as the counting path (A), the primordium (B), transition zone in the middle of the counting path (C), and closely spaced micro-increments near the edge (D).

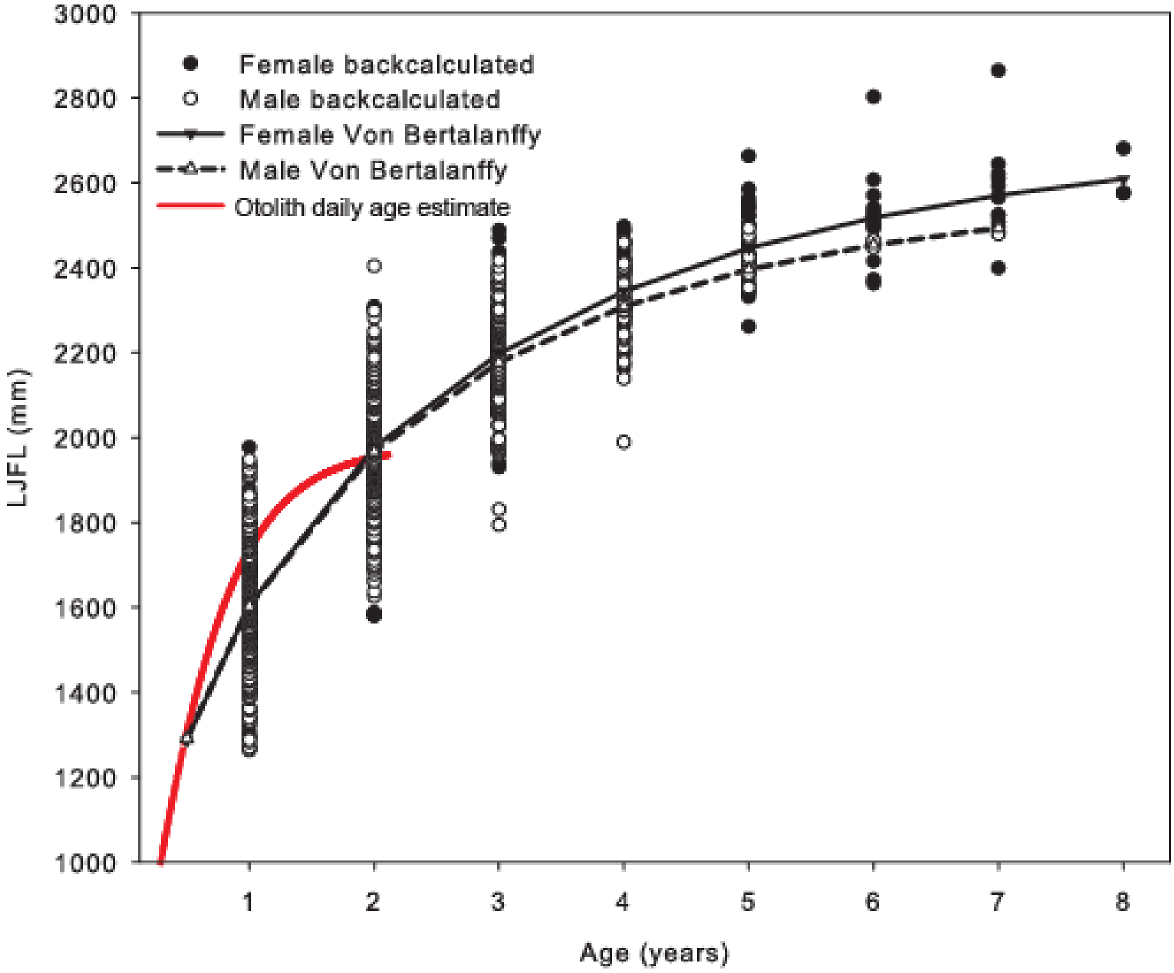


Figure 28: Generalised von Bertalanffy growth curves for female (N=179) and male (N=189) striped marlin from the southwest Pacific Ocean between 2006 and 2008. The red line represents growth curve estimated using daily otolith micro-increments.

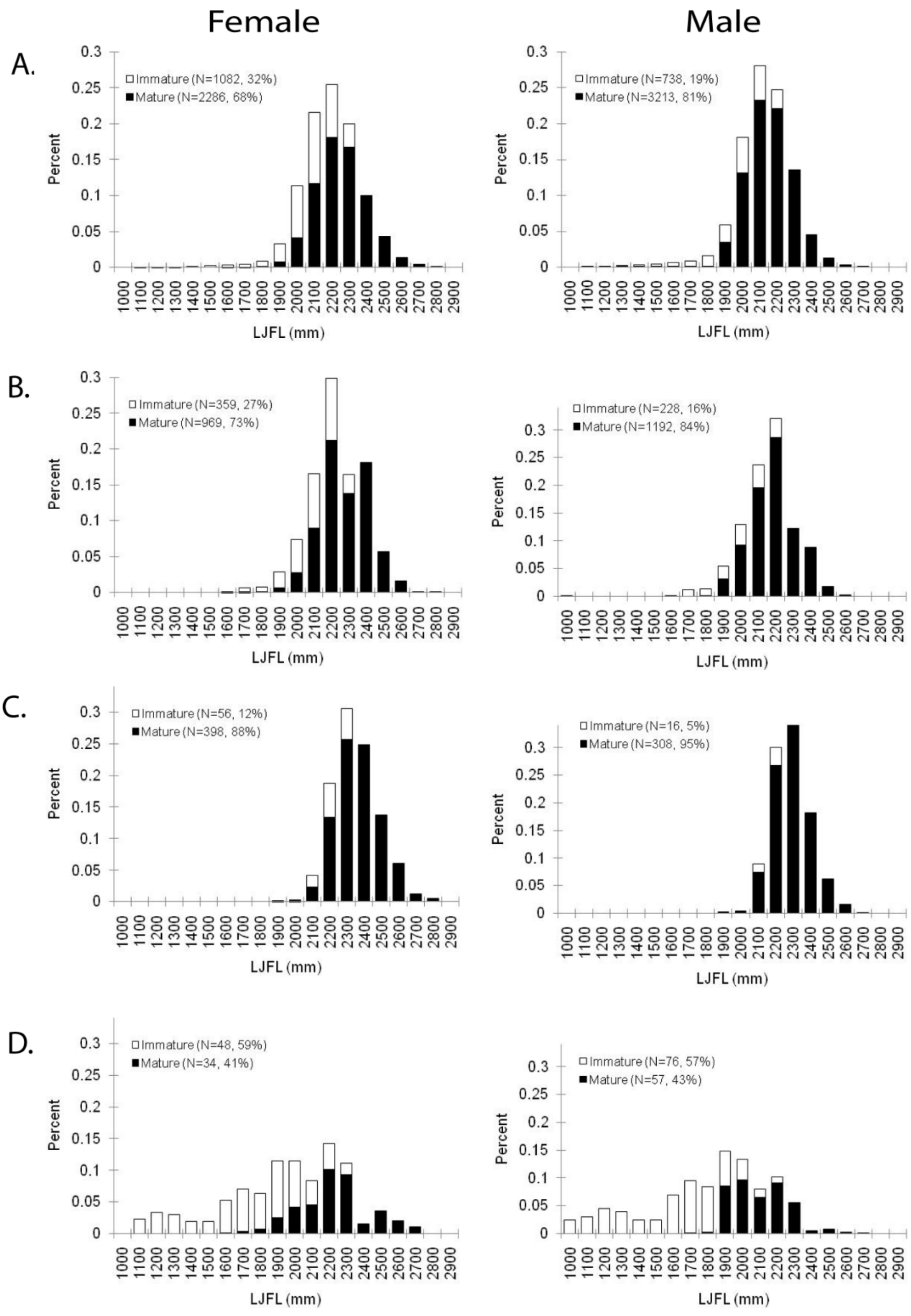


Figure 29: Proportion of female and male striped marlin immature and mature by length (LJFL,mm) class caught in fisheries in the southwest Pacific Ocean between 2006 and 2008 including the Australian commercial longline fishery (A.), Australian recreational (B.), New Zealand recreational (C.), and commercial longline fisheries from Pacific Island countries and territories (D).

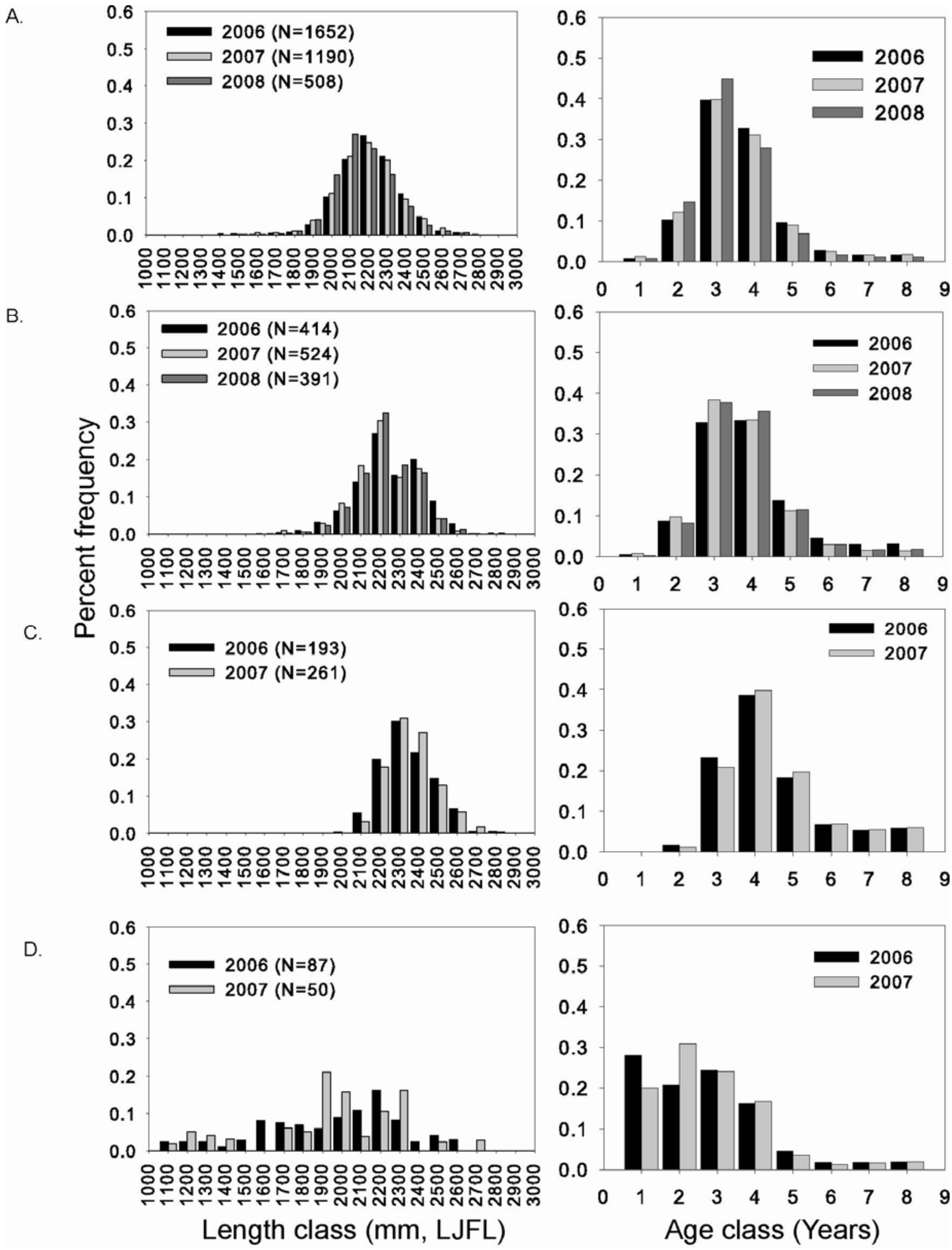


Figure 30: Length (LJFL) and age-structure of female striped marlin from 2006 - 2008 caught in (A.) the Australian commercial longline; (B.) Australian recreational; (C.) New Zealand recreational; and (D.) commercial longline fisheries of Pacific Island countries and territories including Fiji, New Caledonia, Tonga, and Papua New Guinea.

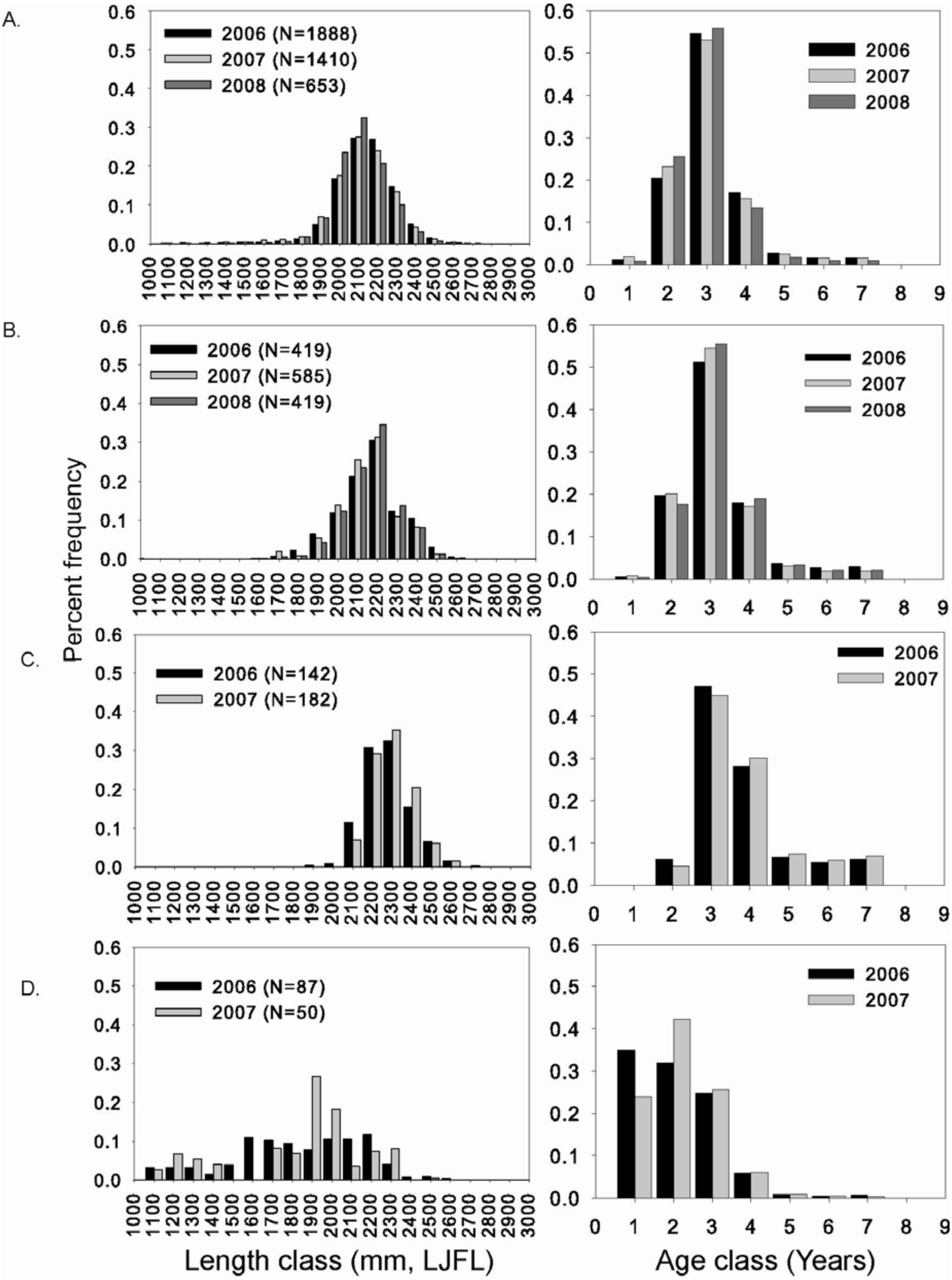


Figure 31: Length (LJFL) and age-structure of male striped marlin from 2006 - 2008 caught in (A.) the Australian commercial longline; (B.) Australian recreational; (C.) New Zealand recreational; and (D.) commercial longline fisheries of Pacific Island countries and territories including Fiji, New Caledonia, Tonga, and Papua New Guinea.

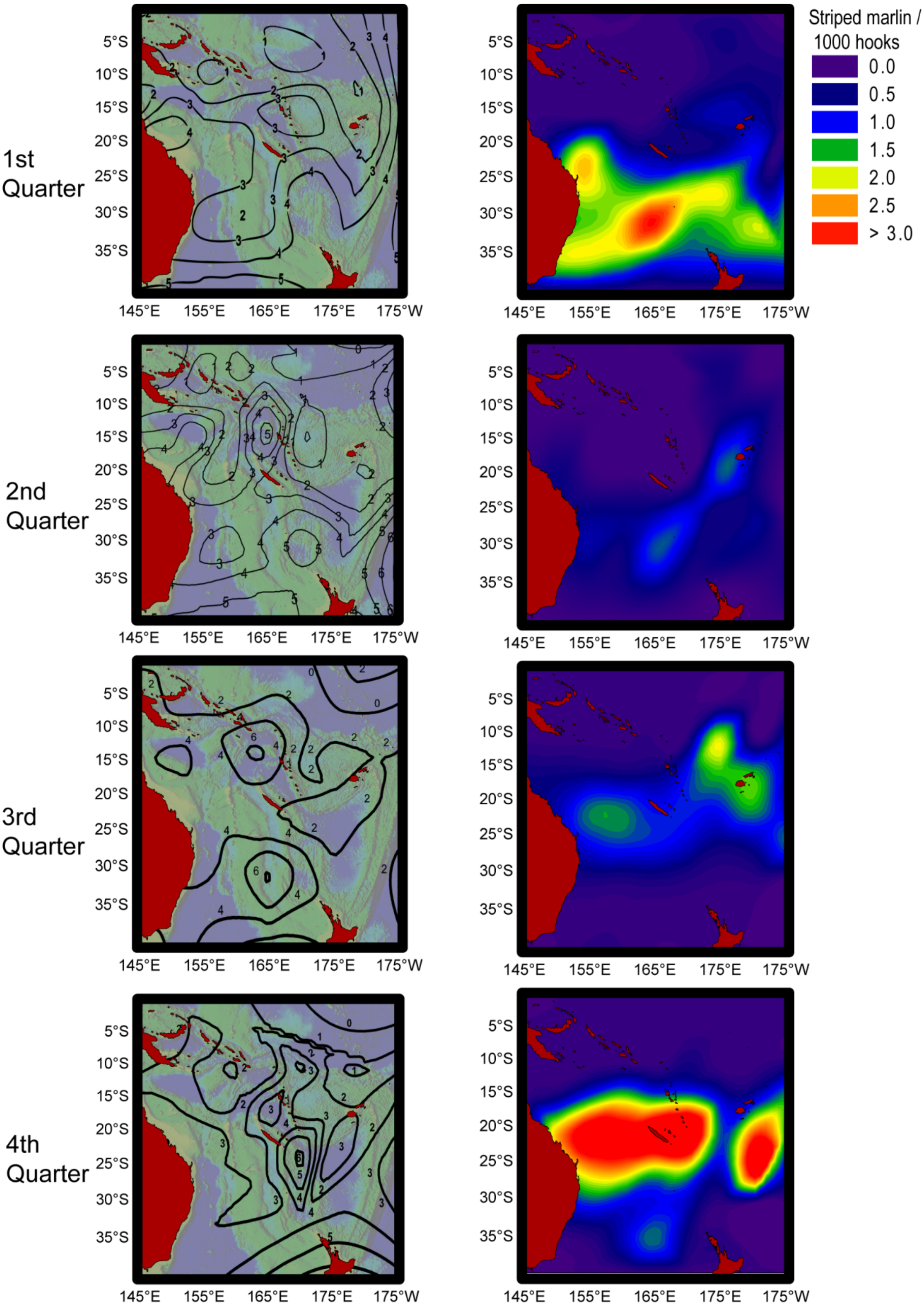


Figure 32: Spatial patterns in age-structure (left column) and catch per unit effort (CPUE; right column) of striped marlin in the southwest Pacific Ocean during quarters 1-4 of the year. Age contour plots were developed from pooled length measurements (N =16,685) from commercial longline and recreational fisheries between 1998-2008. CPUE was calculated by the number of striped marlin (N=91,981) caught per 1000 hooks by Japanese longline fishing vessels between 1970 and 1998.

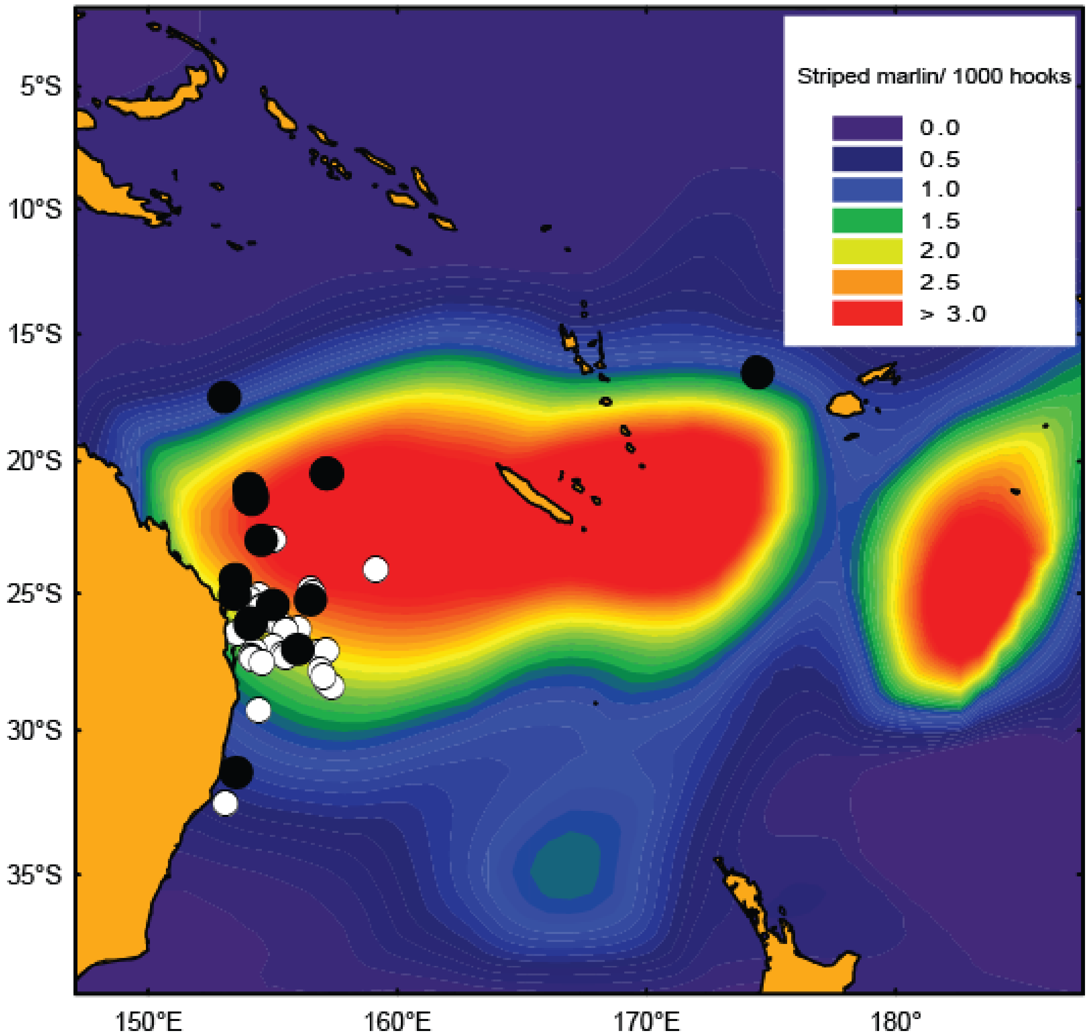


Figure 33: Spatial distribution of ripening (white dots) and spawning (black dots) female striped marlin, *Kajikia audax* in the Coral Sea between 2006 and 2008 in relation to nominal catch per unit effort (CPUE) of Japanese longline fishing vessels during the fourth quarter of the year between 1970 and 1999.

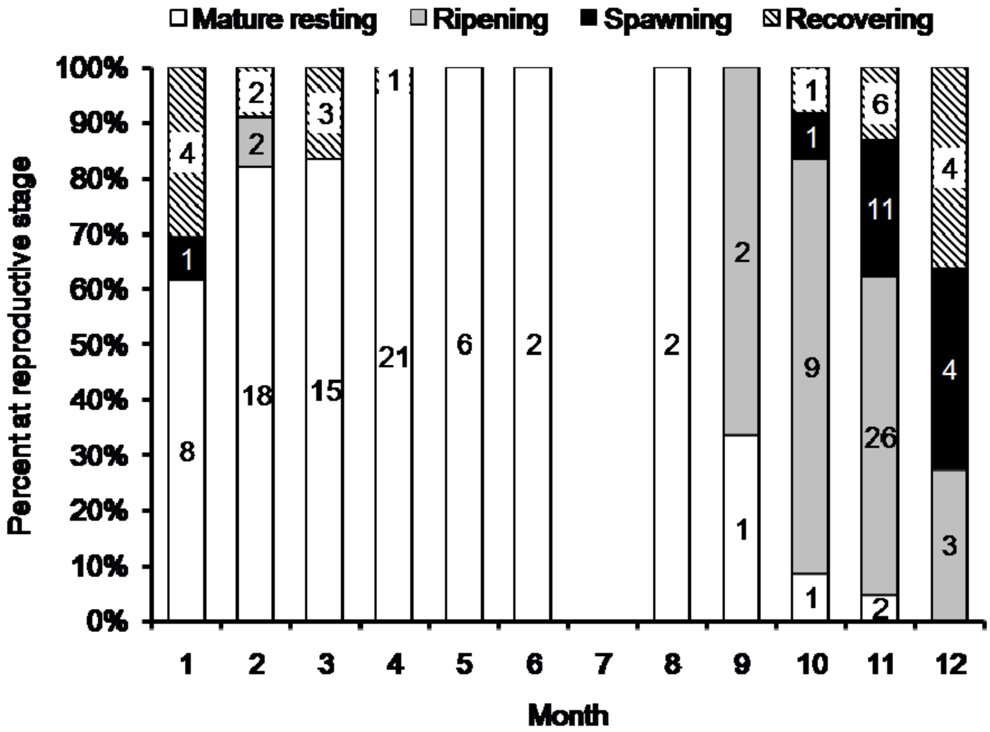


Figure 34: Proportion of female striped marlin, *Kajikia audax* at different reproductive stages sampled by month in the southwest Pacific Ocean.

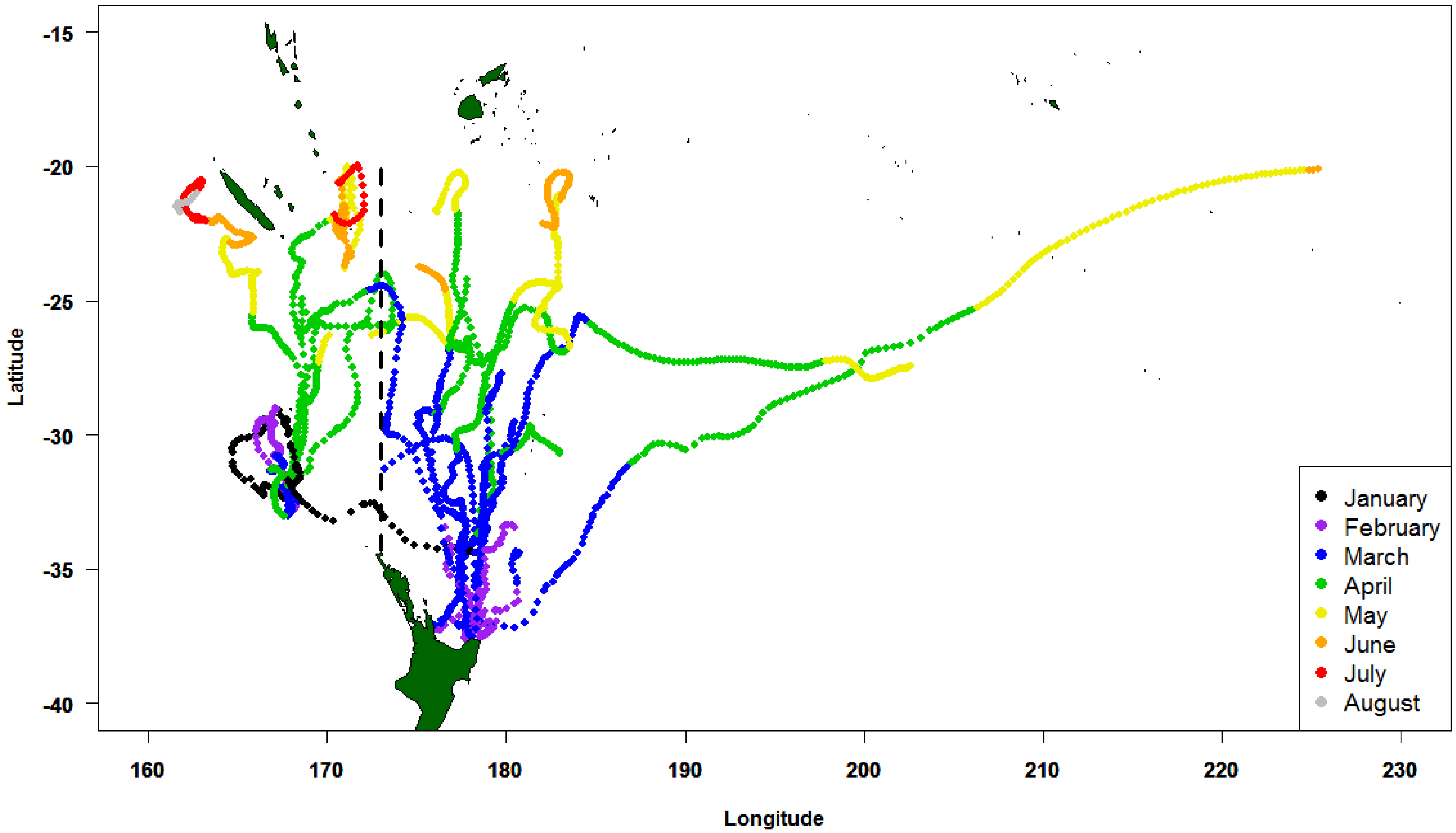


Figure 35: Two to 5 month striped marlin tracks interpolated from satellite tag data into 12 hour intervals coloured by month of the year (see figure legend).

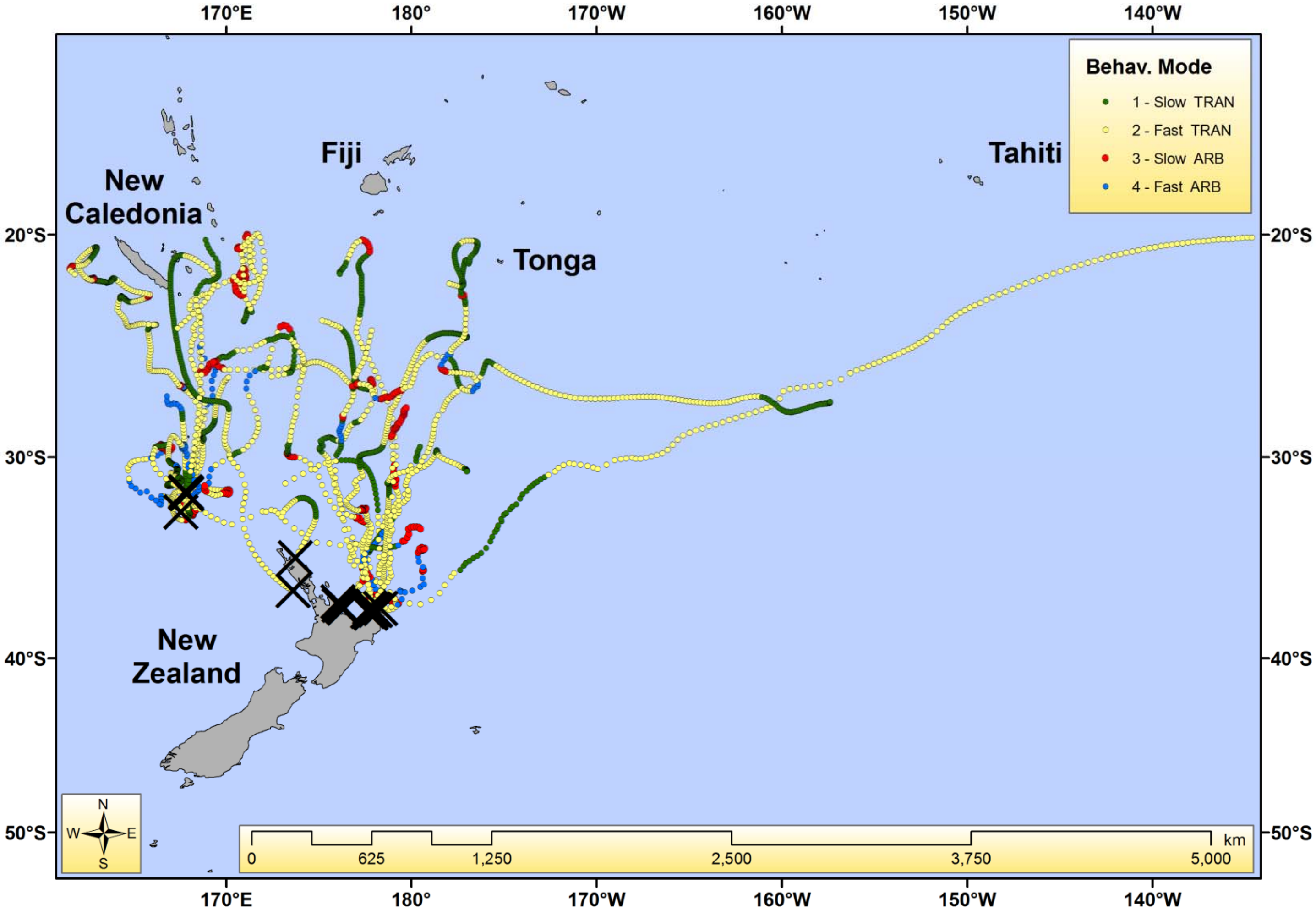


Figure 36: Striped marlin tracks showing behavioural modes divided in straight segments (called 'Transiting') and turning segments (called 'ARB'), and divided by periods when they are travelling faster or slower than the median speed for each animal.

Appendix 1: Catch (t) of striped marlin in the southwest Pacific Ocean reported by Langley et al. (2006) and the present study. Data sourced from the Secretariat of the Pacific Community.

Year	Australia		Japan		Korea		Taiwan		Others		Total catch	
	Langley et al. (2006)	Present	Langley et al. (2006)	Present	Langley et al. (2006)	Present	Langley et al. (2006)	Present	Langley et al. (2006)	Present	Langley et al. (2006)	Present
1952			5								5	
1953			2004								2004	
1954			12197								12197	
1955			5074								5074	
1956			4005								4005	
1957			3435								3435	
1958			5682								5682	
1959			4254								4254	
1960			4538								4538	
1961			7097								7097	
1962			8569		0						8569	
1963			6695		0						6695	
1964			4011		0		0				4011	
1965			3964		0		0				3964	
1966			4310		0		0				4310	
1967			2216		0		165				2381	
1968			1821		0		121				1942	
1969			1877		0		84				1961	
1970			4251		0		226				4478	
1971			4763		0		159				4922	
1972			3567		0		280				3847	
1973			3531		0		181				3712	
1974			2992		0		180				3172	
1975			1783		26		169				1978	
1976			1928		318		140				2385	
1977			817		131		196				1144	
1978			1392		948		213				2553	
1979			2130		312		216				2658	
1980			1977	1109	59	53	173	172			2208	1335
1981			3424	1783	925	667	166	166	1	1	4517	2617
1982			4216	2174	409	318	122	122	1	1	4748	2615
1983			2025	1079	271	196	70	70	23	23	2389	1369
1984			2121	1176	287	237	122	122	24	25	2554	1560
1985			2075	1101	569	393	62	62	78	79	2785	1635
1986			1614	888	600	376	29	29	86	86	2329	1380
1987	51	51	1554	858	398	282	50	49	100	100	2153	1342
1988	48	48	2142	1293	402	316	64	64	63	63	2719	1785
1989	26	26	2759	1507	216	197	178	178	124	124	3303	2032
1990	60	60	1666	925	176	142	99	104	204	204	2205	1435
1991	34	34	1195	670	249	132	102	102	87	88	1668	1025
1992	27	27	767	473	225	179	112	121	118	118	1248	918
1993	32	32	1269	753	195	161	148	149	59	60	1702	1154
1994	74	74	1537	929	197	156	368	368	353	368	2529	1894
1995	93	93	1709	950	272	210	141	141	272	310	2487	1704
1996	152	152	1121	623	227	168	138	138	322	506	1961	1586
1997	209	199	1175	693	351	285	153	153	297	341	2185	1671
1998	481	483	1233	679	381	311	101	100	506	573	2702	2147
1999	518	520	544	364	543	407	197	202	686	1356	2488	2849
2000	680	697	320	200	289	217	195	200	555	803	2038	2117
2001	836	914	314	184	234	176	228	228	348	367	1960	1868
2002	667	746	171	120	286	254	331	331	341	392	1797	1843
2003	499	576	440	259	200	171	577	762	421	448	2136	2216
2004	337	395	125	132	87	117	477	689	386	662	1412	1995
2005		488		87		139		390		532		1636
2006		543		135		187		242		500		1607

Appendix 2: Model outputs for the binomial and logistic models from scientific observer collected striped marlin catch 1992–93 to 2008–09 north of 38° S.

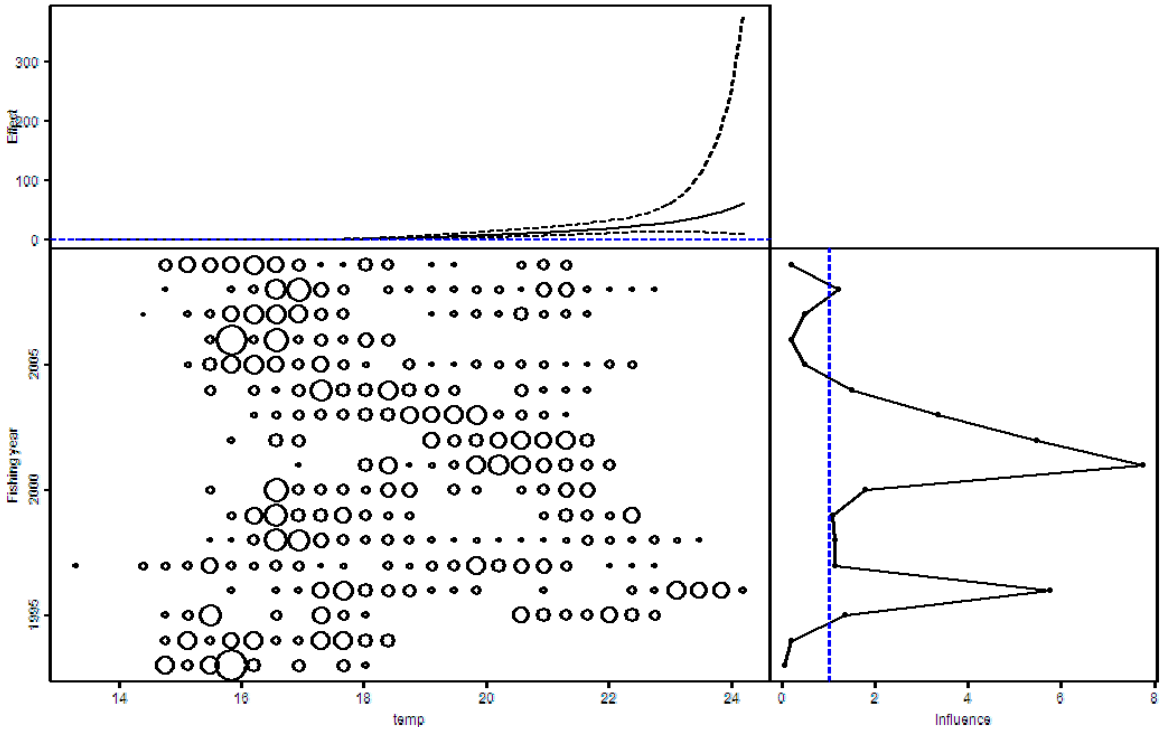


Figure A1: Effect of *Sea Surface Temperature* **in the binomial model of success rate in observed tuna longline sets 1992–93 to 2008–09 north of 38° S. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.**

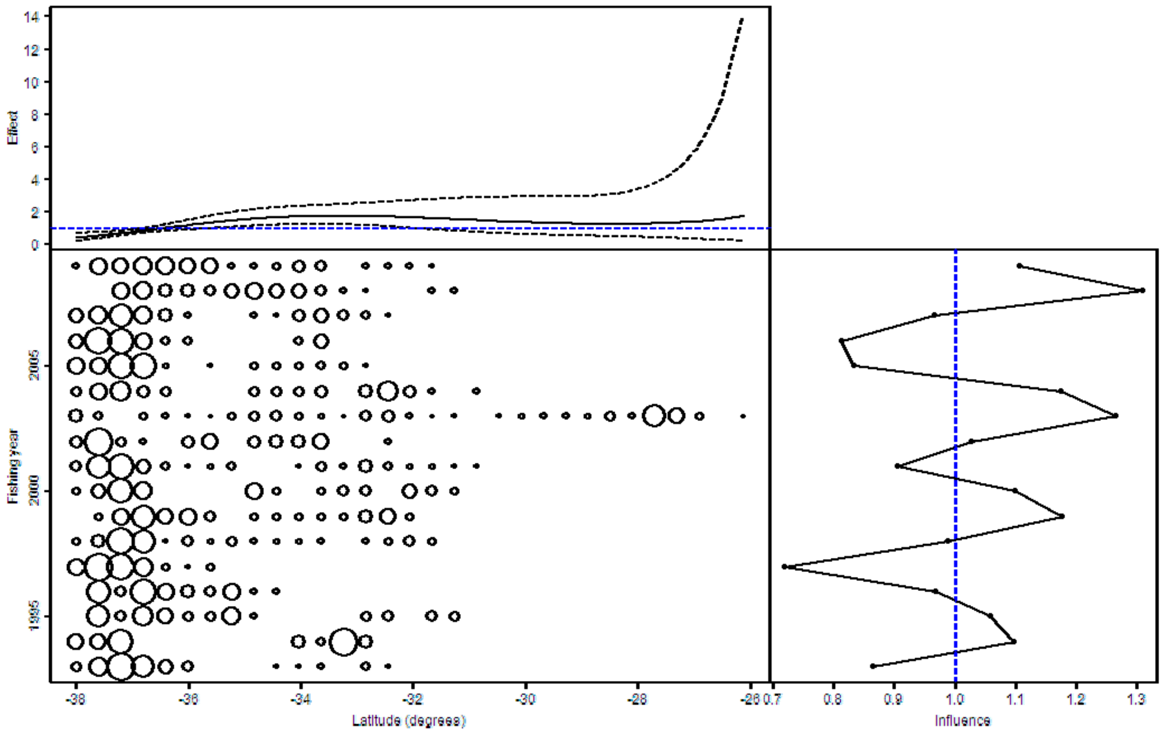


Figure A2: Effect of *Latitude* **in the binomial model of success rate in observed tuna longline sets 1992–93 to 2008–09 north of 38° S. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.**

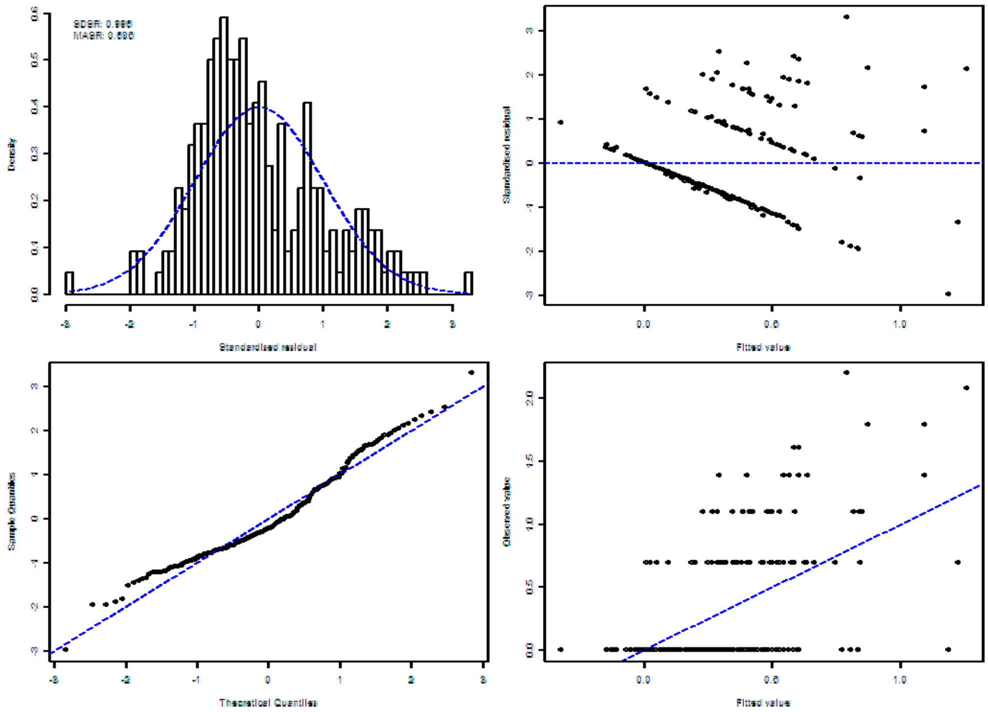


Figure A3: Plots of the fit of the standardised CPUE model to successful catches of striped marlin in the observed longline sets. [Upper left] histogram of the standardised residuals compared to a lognormal distribution (SDSR: standard deviation of standardised residuals. MASR: median of absolute standardised residuals). [Upper right]; Standardised residuals plotted against the predicted model catch per trip [Lower left] Q-Q plot of the standardised residuals; [Lower right] Observed catch per record plotted against the predicted catch per record.

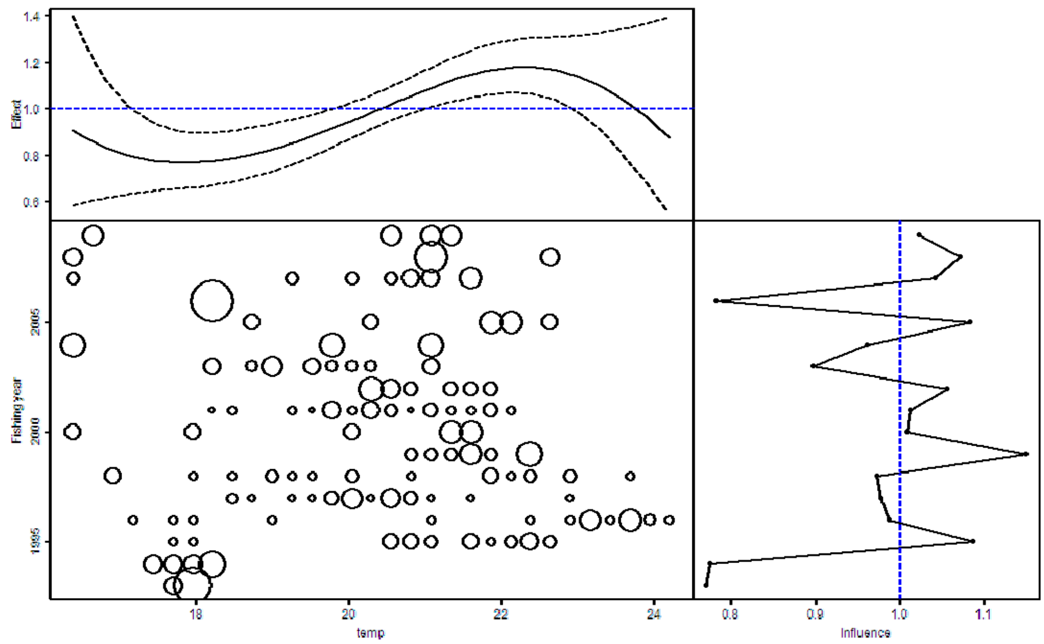


Figure A4: Effect of ***Sea surface temperature*** **in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.**

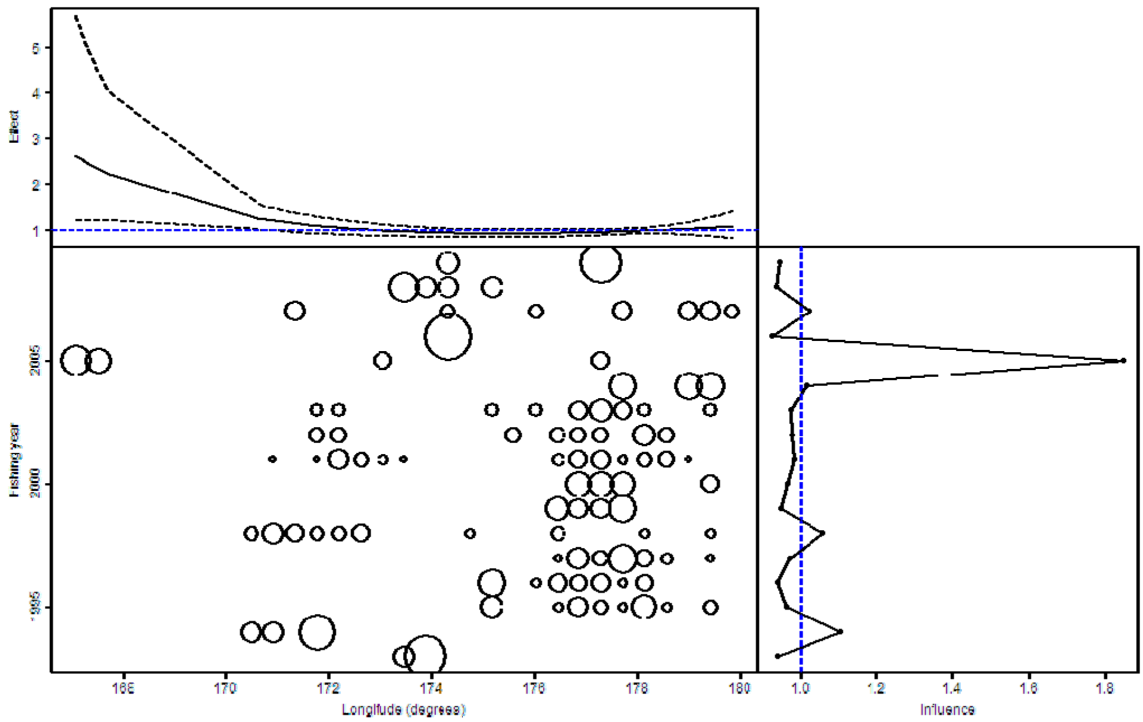


Figure A5: Effect of *Longitude* in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

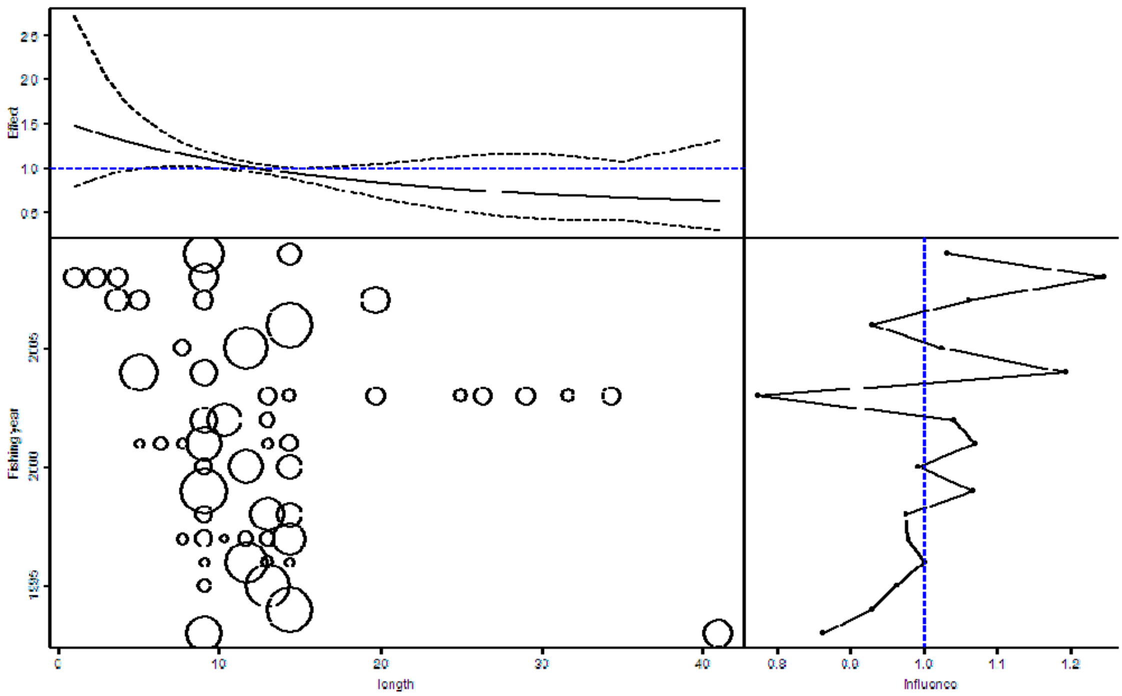


Figure A6: Effect of *buoy-line length* in the lognormal model of catch rates in observed tuna longline sets. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

Model outputs for the logistic model of TLCER recorded striped marlin discards 1999–00 to 2008–09.

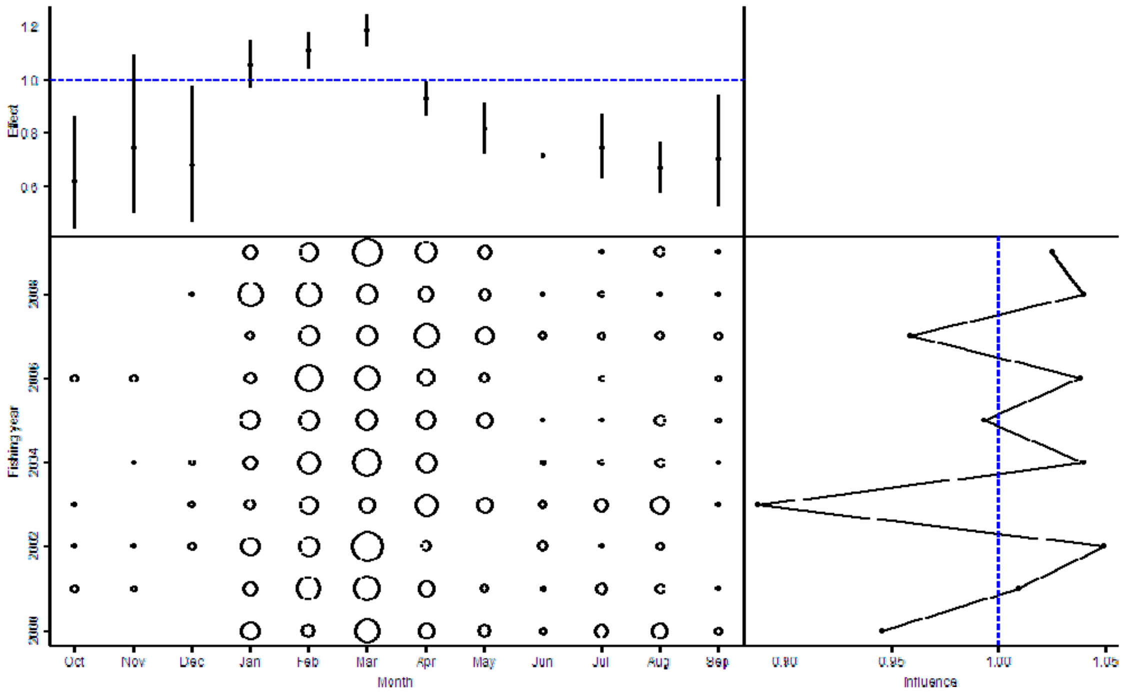


Figure A7: Effect of *month* in the lognormal model of TLCER catch rates for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

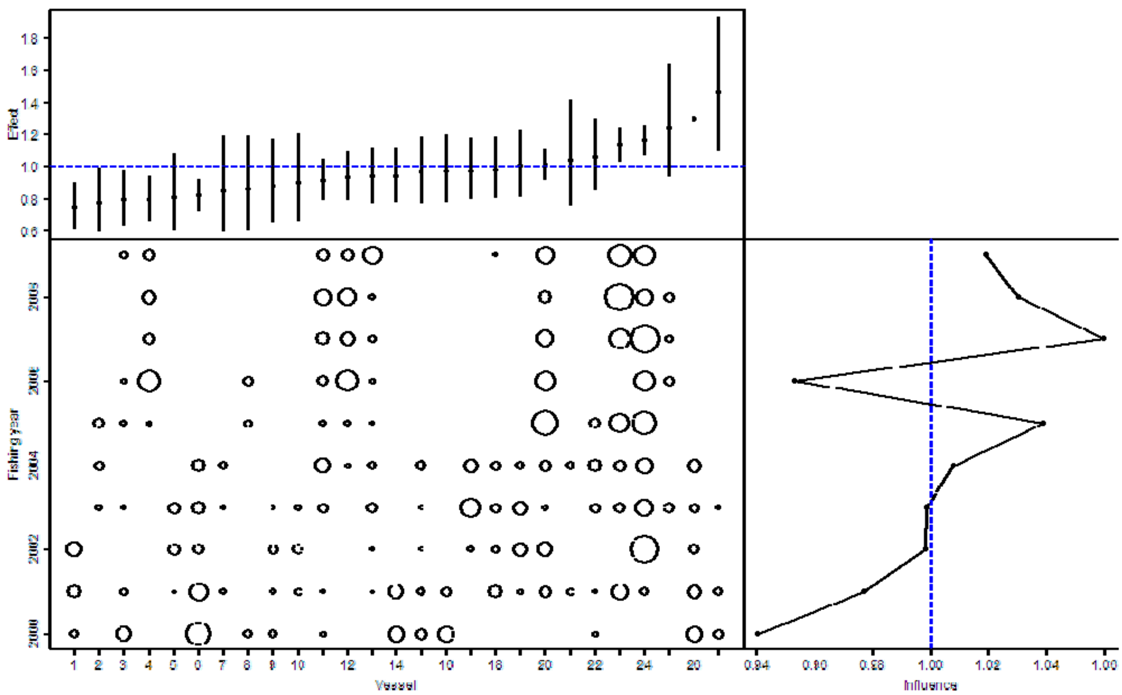


Figure A8: Effect of *vessel* in the lognormal model of TLCER catch rates for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

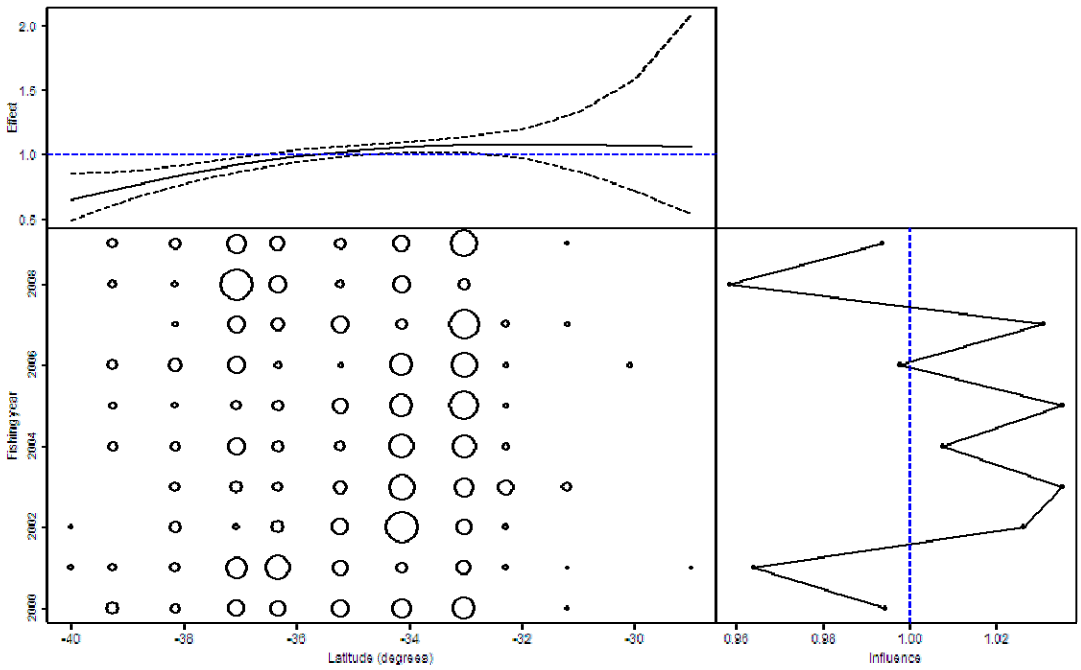


Figure A9: Effect of *latitude* in the lognormal model of TLCER catch rates for a core fleet of tuna longline vessels. Top: effect by level of variable. Bottom-left: distribution of variable by fishing year. Bottom-right: cumulative effect of variable by fishing year.

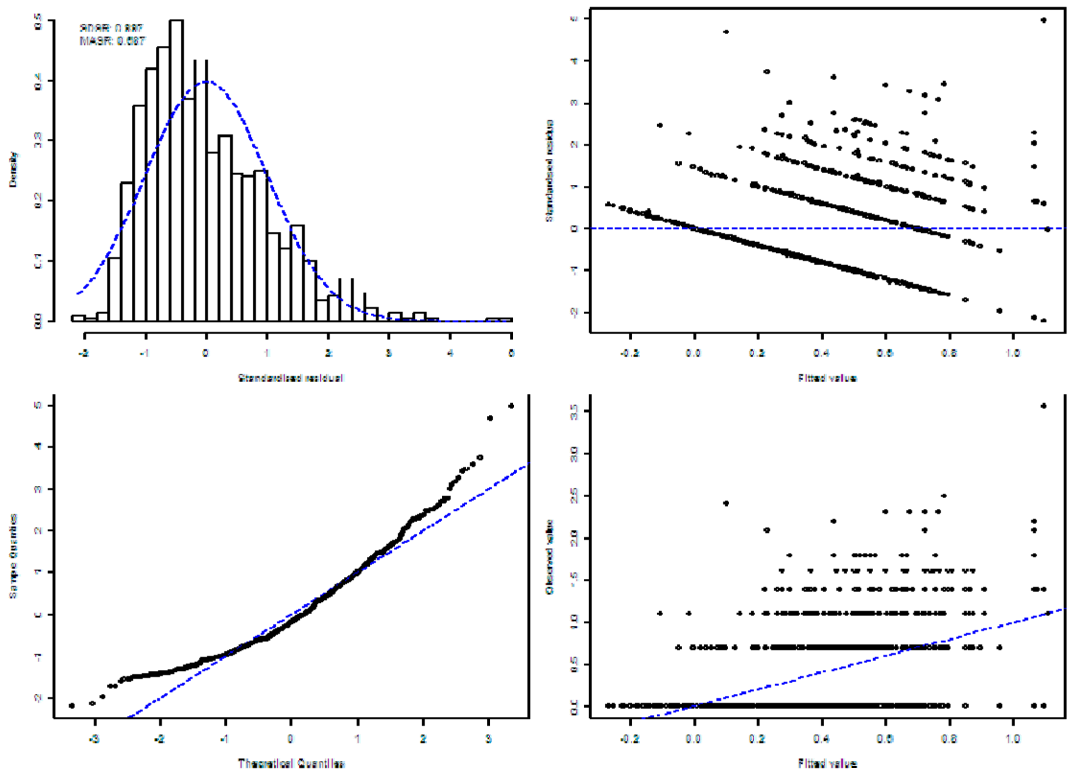


Figure A10: Plots of the fit of the standardised CPUE model to successful catches of striped marlin in longline sets reported on TLCERs. [Upper left] histogram of the standardised residuals compared to a lognormal distribution (SDSR: standard deviation of standardised residuals. MASR: median of absolute standardised residuals); [Upper right] Standardised residuals plotted against the predicted model catch per trip; [Lower left] Q-Q plot of the standardised residuals; [Lower right] Observed catch per record plotted against the predicted catch per record.