Analysis of interactions between longline and recreational gamefish fisheries taking or tagging striped marlin off NSW

Final Report to the Fisheries Research Resource Fund

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Summary

Conflict between commercial longliners and recreational gamefishers over striped marlin

Striped marlin are a highly migratory species that inhabit the open ocean throughout the tropical and temperate Indo-Pacific. They are prized by recreational anglers, who fish from private or charter boats in many areas, including waters off eastern Australia. They are also taken by pelagic longliners in the Indo-Pacific region, as a target species or, more commonly, as a bycatch of tuna longlining. We assess the level of interaction between the Australian longline and recreational sectors off eastern Australian to inform the development of resource-sharing arrangements in the Eastern Tuna and Billfish Fishery (ETBF).

Large, highly mobile predators that grow quickly

Striped marlin grow quickly and can achieve large sizes (up to 250 kg). Age at maturity is believed to be two or three years. They may live for ten years or longer. Striped marlin are highly fecund, with mature females able to produce 11–29 million eggs per spawning season. They are distributed throughout the Indian Ocean north of 40ºS, and the Pacific Ocean (40ºS–40ºN), but showing a region of low abundance in the equatorial western and central Pacific. Stock structure is uncertain, but tag-recapture data and genetic research suggest a largely independent southwest Pacific stock. Striped marlin inhabit the surface layer to depths of around 150 m, making them particularly susceptible to shallow-set longline gear.

Long history of fishing

The first records of striped marlin being caught by rod-and-reel off eastern Australia are from Port Stephens and dated between 1910 and 1920. They were regularly caught off Bermagui in the 1930s and regular gamefishing tournaments have been held off eastern Australia since 1938. Longliners have taken striped marlin in the region since the late 1950s. In this area, and in the wider Pacific Ocean, distant-water Japanese longliners accounted for almost all of the striped marlin catch until the 1970s. Japan’s catches then declined, partly due to increased targeting of bigeye tuna with deeper longlines and the exclusion of distant-water longliners from national 200 nautical mile exclusive economic zones (they have not been permitted to fish in Australian waters since 1997). The decline in Japan’s catches has been partly offset by increased striped marlin catches by other distant-water longline fleets (e.g., Korea and Taiwan) broadly across the Pacific and by fleets based in South Pacific nations, such as Australia and Fiji. The annual catch of striped marlin has remained at about 5000 t whole weight in the western and central Pacific Ocean in recent years.

Fivefold increase in catches

There was a fivefold increase in striped marlin catches by the recreational and domestic longline sectors off eastern Australia during the 1990s, followed by declines in both sectors since 2000/2001. ETBF longline landings of striped marlin in 2003 (638 t whole weight or 7658 fish retained) were valued at $3.345 million, compared to over 884 striped marlin tagged and released by anglers in that year. The number tagged significantly

underestimates the total recreational catch because many anglers are not involved in the tagging program and may not report fish that are released or retained. Involving several thousand anglers, gamefishing for striped marlin also has substantial social and economic benefits. Gamefishers now release more than 94% of the striped marlin that they catch during tournaments, whereas ETBF longliners release or discard about 5% of their striped marlin catch.

Anglers and longliners harvest the same striped marlin stock

Several lines of evidence indicate that the two sectors harvest a common stock. First, ETBF longliners reported 54% of the recaptures of striped marlin that were tagged and released by recreational anglers. Second, data from both sectors indicate that they are fishing the same sizes of striped marlin. Third, there is considerable spatial and temporal overlap in the distributions of commercial and recreational fishing activities.

Intense interactions in central and southern NSW waters

The catch of striped marlin by recreational anglers is greatest on the continental shelf and slope off southern and central NSW so this is the region where interaction has the greatest probability of occurring. Within this region, waters off Bermagui have the highest levels of interaction, with the largest striped marlin catches reported there in January–April each year.

No trend in average size in the north

…but, decline in southern waters

There has been no significant change in the mean size of striped marlin landed by longliners north of Sydney since 1998 and, more broadly, the mean estimated size of striped marlin tagged by anglers since 1990. However, there has been a decline in the mean size landed by longliners south of Sydney since 1998. Estimates of the size of striped marlin tagged by anglers show a small, but significant decline in size during 2000–05. The difference in size trends in several regions and fisheries may reflect complex, size-dependent movement patterns and variations in availability to fishing gear. The relatively low mean estimated sizes of tagged striped marlin in NSW central and northern waters in 1997, for example, might indicate a recruitment pulse of smaller striped marlin in those regions.

Highest catch rates off NSW

ETBF longliners range over a wide area, generally from the shelf break to several hundred kilometres offshore, from far North Queensland to eastern Tasmania. Important ports include Mooloolaba, Coffs Harbour, Cairns and Ulladulla. The highest striped marlin catch rates are reported by longliners that target yellowfin tuna off NSW during summer by deploying relatively shallow longlines (25–200 m depth range) with live bait during the day. Our analyses of longline logbook data confirmed previous analyses showing that the use of live bait had a significant positive effect on striped marlin catch rates. Relatively low catch rates of striped marlin are reported by longliners off North Queensland and by those that deploy their longlines at night to catch broadbill swordfish. However, the swordfish fishery accounts for a significant proportion of the total striped marlin catch because of the relatively large amount of fishing effort in this component in recent years.

Highly variable recreational catch rates

Compared to longlining, tournament fishing has a limited geographical and temporal range; it usually involves day trips within 75 km of ports such as Port Stephens, Sydney, Bermagui, Ulladulla and Coffs Harbour. Almost 90% of recreational tag-releases are reported from areas where the depth is less than 1000 m. By contrast, less than 25% of the longline catch of striped marlin is taken in sets starting in waters shallower than 2000 m. Tournament fishing occurs on pre-designated date(s), regardless of prevailing conditions. Consequently, there is considerably more variation in tournament catch rates than in longline catch rates.

Remarkably similar trends in tournament and longline catch rates

We used a statistical technique known as Generalised Additive Models to standardise striped marlin catches for the effects of various factors such as the location and season. Separate models were fitted to striped marlin encounters and catch rates in NSW gamefishing tournaments and those in longline fishing operations. For tournaments, standardised catch rates show a steady increase until the late 1990s followed by a decline. That pattern is almost identical to the trends in standardised longline catch rates as well as in charter boat catch rates from a previous study. These trends are likely to indicate broad-scale changes in striped marlin availability or abundance because they occurred in several independent fisheries and at a range of geographical scales.

Catch rate increase possibly due to recruitment, availability or broad-scale movement

Plausible explanations of the increasing trend in standardised catch rates during the 1990s include: a recruitment pulse of striped marlin off eastern Australia; migration of striped marlin into the area associated with broad-scale oceanographic conditions; increased availability due to decreased activities of Japanese longliners in the south-western Pacific; increased targeting of striped marlin that our models could not account for; or increased targeting by fishers due to increased availability. Without additional information, it is difficult to draw firm conclusions on the cause of the increases in standardised catch rates.

Decline possibly due to emigration, local depletion or stock reduction

Plausible explanations of the decreasing trend in standardised catch rates since 1999 include the movement of striped marlin away from eastern Australia associated with El Ninõ conditions or depletion of striped marlin by fishing. A recent stock assessment indicates significant reductions in striped marlin biomass in the south-western Pacific, where longline catches were particularly high in the 1950s. The full results from this assessment will be available by June 2006.

Tournament catch rates decline when longliners take large catches nearby

Striped marlin are vulnerable to fishing gear from a relatively young age, and movement data indicate they are not as migratory as once thought, suggesting increased potential for localised depletion and interactions between sectors. We explored the effect of longlining on tournament catch rates by including a range of spatial and temporal scales of longline catches as explanatory variables in the tournament model. At the finest scale, longline catches had a statistically significant effect on standardised tournament catch rates – tournament catch rates fell by about 10% when longline catches in the same area and at the same time as the tournament increased from 8 to 25 striped marlin. Beyond those catch levels we could not draw firm conclusions on the effects of longlining on tournaments because of the low number of observations. The effect of longline catches on tournament catch rates in slightly larger time-area strata (the same tournament period and area and waters 1° north, east and south of the tournament area) were not statistically significant at the 95% level, but were significant at the 90% level. Similarly, longline catches in tournament areas one month prior to tournaments had a significant effect on tournament catch rates at the 90% level. Longline catches may affect tournament catch rates at larger spatial and temporal scales, but we did not find a statistically significant effect because of the large amount of variability or "noise" in the system. Tournament catch rates also declined as the number of gamefishing boats in the area increased from about 45 to 85 boats, so it is unclear whether the decline in tournament catch rates is solely due to longlining or competition among gamefishing boats.

Time-area closures are a management option

Measures that have been used to manage commercial-recreational interactions over striped marlin and other billfish species in other parts of the world include bans on retention or sale, limited entry, non-targeting policies, time-area closures and gear restrictions. Time-area closures have been particularly effective in reducing interaction rates because relatively small time-area strata are often responsible for large proportions of commercial and recreational marlin catches. Time-area closures also ease conflict and perceptions of interaction by physically separating recreational and commercial fishers. Note, however, that a simple separation along a depth contour may not be sufficient where the continental shelf is narrow, such as along the southern NSW coast.

Contents

1. Introduction

1.1 Background and need

Introduction

The rapid growth of the domestic longline fishery and an increase in recreational gamefishing tag-releases of striped marlin off eastern Australia (Figure 1) over the past decade has been accompanied by a perception of increased spatial and temporal interactions between the two sectors and concerns over the sustainability of catches of certain species and their impact on future resource access. The availability of historic time-series of striped marlin catches and fishing effort recorded by each of these fishing sectors presents some opportunity to examine the relationship between commercial and recreational catches of striped marlin.

An analysis of striped marlin fishery interactions was first undertaken by Bromhead et al. (2004). Based on data available at the time, that report stated that:

> *Both sectors are catching similar sized marlin from the same stock, often in similar locations and at similar times of year, but no conclusive evidence that charter catch rates are negatively impacted by longline catches was identified. However, analyses were limited by data quality, and the main interaction regions should continue to be monitored closely and further analyses of interactions undertaken as more data becomes available from the charter boat sector.*

The Australian Government is currently facilitating a process by which resource sharing arrangements pertaining to striped marlin and other species might be agreed upon by all stakeholders. The current report was commissioned to provide data bases and analytical support to this process, and represents an update of key information, as well as the presentation of new data and analyses.

Basic biology and status

The striped marlin, *Tetrapturus audax*, is a migratory pelagic billfish species caught by both recreational and commercial (predominantly longline) fisheries off the east and west coasts of Australia. Evidence suggests a largely-independent south-west Pacific stock, but its status is currently unknown. A model-based stock assessment will be completed by the Bureau of Rural Sciences (BRS) and the Secretariat of the Pacific Community (SPC) in May 2006.

Importance to Australian fisheries

A recreational fishery for striped marlin has existed off eastern Australia since the 1930s. Between 1995 and 2000 there was a rapid increase in charter catch rates (catch per unit of fishing effort or “cpue”) and in the reported number of striped marlin tagged and released off south-eastern Australia (>1500 in some years). It has become an extremely important species in tournament gamefishing and an economically important species for numerous charter boats (Ernst and Young, 2004). In addition, striped marlin has become an increasingly important catch species for longliners operating off eastern Australia in recent years, with total annual catches increasing from 194 mt (processed weight) in 1997 to a peak of 527 mt in 2001 (Bromhead et al., 2004).

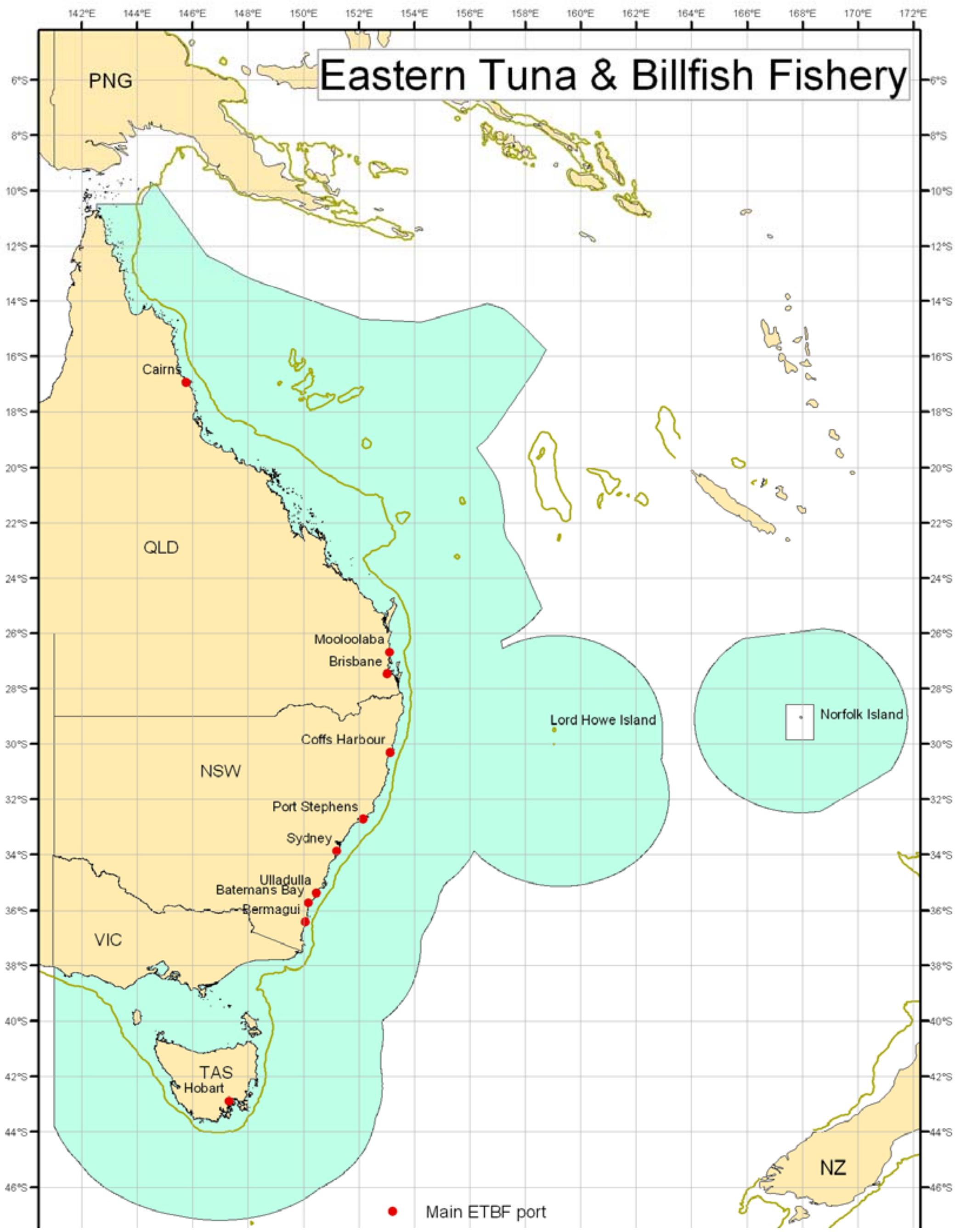


Figure 1. Map of eastern Australia and the south-western Pacific showing the Australian fishing zone (AFZ), key fishing ports and the 200-metre isobath.

Concerns over access, allocation and sustainability

The increased commercial catches of striped marlin in recent years have raised concerns in the recreational sector over sustainability of the catches and consequently, their immediate and long term impacts on gamefishers' access to the resource. Furthermore, there has been a perception that commercial vessels have increasingly impinged upon "traditional" recreational fishing grounds. As a result, there has been increased friction over perceived rights to exploit the striped marlin resource.

Resource allocation issues need to be resolved using best available data

As part of the Commonwealth Fisheries Policy Review, '*Looking to the Future*' (2003), the Australian Government made a commitment to develop and implement an agreed framework for developing resource sharing arrangements in Commonwealth managed fisheries. The Eastern Tuna and Billfish Fishery (ETBF) has been identified as a key fishery in need of resource sharing arrangements and where the resource sharing framework would be first implemented. Striped marlin is currently the species of highest importance in this process.

The Department of Agriculture, Fisheries and Forestry (DAFF) has engaged an independent facilitator to work with stakeholders to identify options for resource sharing arrangements off eastern Australia. In order to improve the baseline data and analyses to support the independent facilitator and provide all parties with the best available data and information to inform the process, the Fisheries and Aquaculture Branch of the Department have asked the Bureau of Rural Sciences, in collaboration with the NSW Department of Primary Industries Cronulla Fisheries Research Centre (NSW DPI), to prepare the current analyses of interactions between sectors.

A previous analysis of interactions between the commercial and recreational sectors taking or tagging striped marlin off NSW was unable to use key tournament and charter boat logbook data due to confidentiality issues (Bromhead et al., 2004). That study determined from tag-recapture data that both sectors are catching overlapping size classes of marlin from the same stock, with 54% of recaptured marlin taken by longline gear and 46% by recreational gear. Spatial and temporal mapping of catch and tag-release data indicates the region of most intense interaction to be in southeast coastal waters between Port Stephens and Merimbula. However, due to spatial and temporal gaps in the data, little could be concluded with regard to the impact of one sector on the other's access to the resource. Data confidentiality issues have subsequently been resolved, significantly more data has been collected, and NSW DPI have agreed to a collaborative study that would include these key data sets.

Using these data, the current proposal aims to characterize fine-scale spatial and temporal interactions between both sectors operating off the NSW coast, examine historical trends in distribution of effort by both sectors, and undertake analyses to determine if there is any evidence for a negative impact of either sector on the other's access to the resource.

1.2 Need

Given the Australian Government's commitment to developing effective resource sharing arrangements in Commonwealth fisheries, it is important that the impasse reached in the Western Tuna and Billfish Fishery (WTBF) is not repeated in other Commonwealth fisheries. This impasse occurred in part due to a lack of verified data by which to assess arguments put forward by the different parties involved. For appropriate and informed decisions to be made, the current process requires access to the best available information and data from both sectors that will be relevant to the issue. Key to this process is an understanding of whether a quantifiable impact is being made by either sector on the other's access to the resource. Previous analyses of interactions between these sectors were significantly limited by a lack of detailed catch and effort data from the recreational and charter sectors. Therefore there is a clear need for up to date analyses based on the most comprehensive and recent data available.

1.3 Objectives

The project was divided into two stages, to allow termination of the project at the end of stage 1 if data were considered unsuitable for stage 2 analyses. Objectives 1-5 and 7 relate to stage 1. Objective 6 relates to stage 2.

1. To collate catch, effort, size and other fishery-specific data for both recreational charter, gamefishing and longline sectors taking or tagging striped marlin, to improve the baseline data and analyses to support the development of options for resource allocation off eastern Australia.

2. Provide updated analyses of total catch, tagging and size data by sector over time, as pertains to striped marlin.

3. To develop detailed fine-scale maps and animations of charter and longline catch and effort off the NSW coast, to demonstrate regions and times of spatial interaction between sectors.

4. To characterize trends in distribution of longline and recreational fishing effort over the past 5-10 years, and to assess both charter and longline vessel behavior in the vicinity of key recreational gamefishing time-areas.

5. To assess available charter and tournament monitoring raw data to determine whether it has appropriate coverage to include in an interactions model.

6. To determine whether there are any signals in the charter boat and tournament catch and effort data suggesting a negative impact on gamefishing catch rates by commercial longline catches of striped marlin.

7. To discuss findings and potential implications under different scenarios for current and future management of the commercial and recreational sectors.

1.4 Structure of report

This report is structured in three main parts. Firstly, an update of key data summaries of commercial and recreational fishing catch and effort. Secondly, standardisations of catch rates for both sectors, and finally, an analysis of interactions between the two sectors, which builds upon information and analyses presented in the first two sections. Managing fishery interactions requires a comprehensive understanding of the spatial and temporal patterns in fishery catch and effort for both sectors. Figure 2 describes how analyses and data will be spatially grouped in the report so as to facilitate our understanding of the interactions between the two sectors, and the various factors that influence those interactions. In brief, data summaries are provided at the whole fishery level, and then by regions and subregions within the fishery, concentrating on those subregions where fishery interactions are highest, as identified in Bromhead et al. (2004). Catch rate indicators are also presented at the whole fishery and regional level, while the fishery interactions analyses focus on the subregion scale.

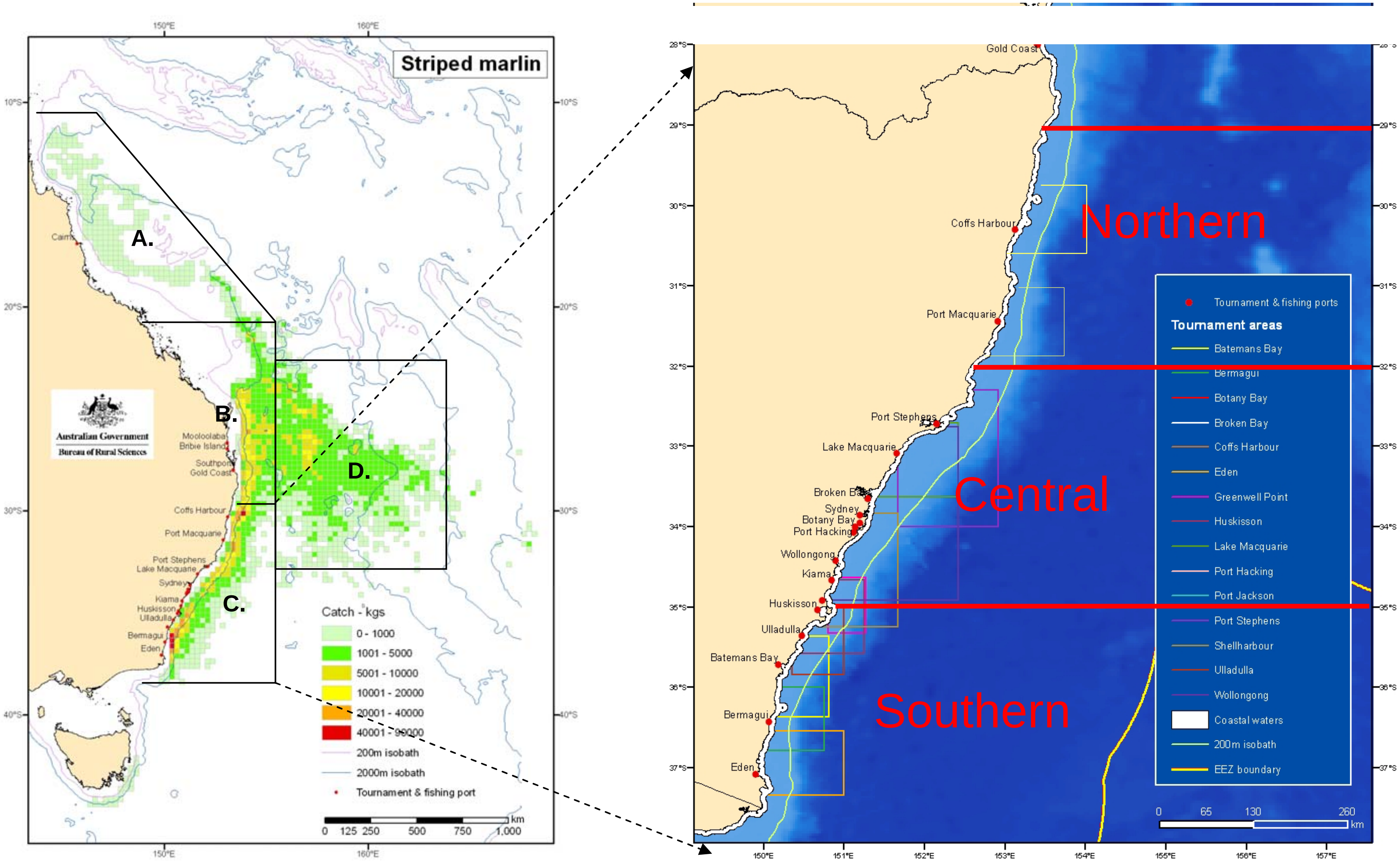


Figure 2. Regions by which data will predominantly be grouped and analysed within this report. A. Major fishery regions are denoted regions A,B,C, and D, showing ETBF longline catches during 1998–2004. Within region C where both commercial and recreational sectors fish in close proximity, there are further spatial groupings used, being northern, central and southern subregions (Data Sources: NMFS, NSW DPI, NIWA, TBF, 2005).

2. Review of commercial and recreational catch and effort data

2.1 Introduction

This chapter presents a concurrent review of both commercial, recreational and charter-based catch, effort and size data. It represents an update on the review of Bromhead et al. (2004).

2.2 Data – types, sources and reliability

Longline catch and effort data

Domestic longline catch and effort data was provided by the Australian Fisheries Management Authority (AFMA). Bromhead et al. (in prep) undertook a comparative analysis of observer and logbook data from the domestic longline fishery in an attempt to verify the logbook data. Because of the relatively "patchy" spatial and temporal nature of observer coverage off eastern Australia to date, it was felt that the most appropriate way to compare observed and unobserved catch and discard data in the fishery was to focus comparisons within four discrete times and areas where observed coverage and unobserved effort were both well represented (See Figure 3). These time-areas were used as indicators of reporting reliability within the fishery. Mean catch rates and mean discard rates for each region and each species were assessed to determine if significant differences occurred between the means of the observed and unobserved samples.

Commercial size data was obtained from the East Coast Size Monitoring database held by the AFMA.

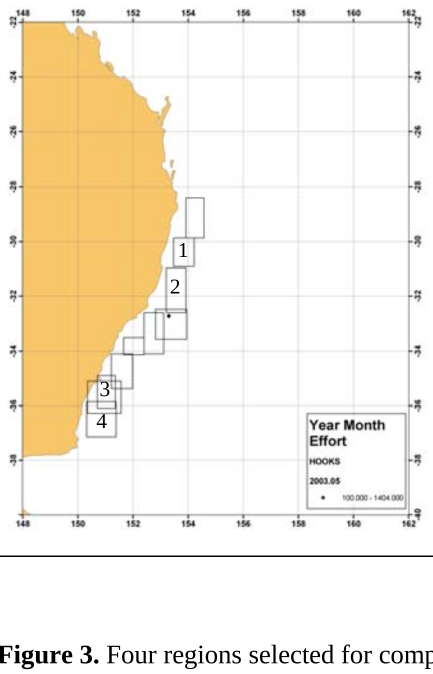


Table 1. Observed and unobserved effort and percentage observer coverage* for each of the four regions selected for comparative analyses of catch and discard rates.

Zone	Reporting System	Effort	Operations	%Coverage
1	LOGBOOK	209202	219	
1	OBSERVER	49292	57	19.07
2	LOGBOOK	474696	535	
2	OBSERVER	52166	57	9.90
3	LOGBOOK	98600	117	
3	OBSERVER	23980	29	19.56
4	LOGBOOK	216990	227	
4	OBSERVER	50182	55	18.78

*Overall observer coverage for the ETBF was much lower (~4%).

Figure 3. Four regions selected for comparative analyses of observed and logbook reported catch rates and discards rates. Only data pertaining to months in which there was equal to or greater than ~10% observer coverage was used for each regional analysis. Regions 3 and 4 overlapped in area but not in the time periods for which data was selected. Also shown are other regions considered but subsequently rejected based on observer coverage levels being too low for the months in which observers were present.

Recreational catch and effort data

Recreational tag-release, recapture and estimated size at release data were provided by NSW DPI, the Billfish Foundation (TBF), the US National Marine Fisheries Service (NMFS), and the New Zealand Gamefish Tagging Program.

NSW DPI also provided Gamefish Tournament Monitoring Program catch and effort data (collected since 1993), as well as charter boat logbook data (collected since 2001). The tournament database comprises detailed information pertaining to catch and effort taken during east coast gamefish tournaments. The program also collects data pertaining to locations of fishing, environmental conditions, fishing methods used and species being targeted. However, it is worth noting that coverage is not 100% (Figure 4) and the number of tournaments monitored each year varies. For each tournament that is monitored, the level of reporting of catch and effort is thought to be near 100%. The NSW charter logbook system was phased in during the late 1990s, with reliable data on positions available since 1999.

In addition, historic catch and effort data from the charter boat sector had been previously sourced from the personal daily fishing diaries of operators and deckhands of 11 charter boats operating in a 6º latitudinal band stretching between Port Stephens and Merimbula, off the central and south-eastern coast of Australia between 1990-2002 (see Bromhead et al., 2004). In total, the dataset covered 1375 fishing days (with early years having fewer records due to fewer boats contributing data), with most of this data recorded in the main fishing season between January and May. It should also be noted that while it is believed that within a given season a 'standard' charter boat day is relatively consistent in length, quantification of the duration of each day's fishing was not possible, introducing some uncertainty into the quantification and interpretation of catch rate data. In addition, low efficiency fishing methods (e.g. fly fishing) were excluded from analyses of recreational data where possible. Where detailed catch and effort data was not available, charter captains were contacted and asked to determine from their records how many days they fished in each season. Using tags reported per season from the NSW Tag database, a catch rate (mean striped marlin per day per season) was calculated from this information and compared to the detailed catch and effort data trends.

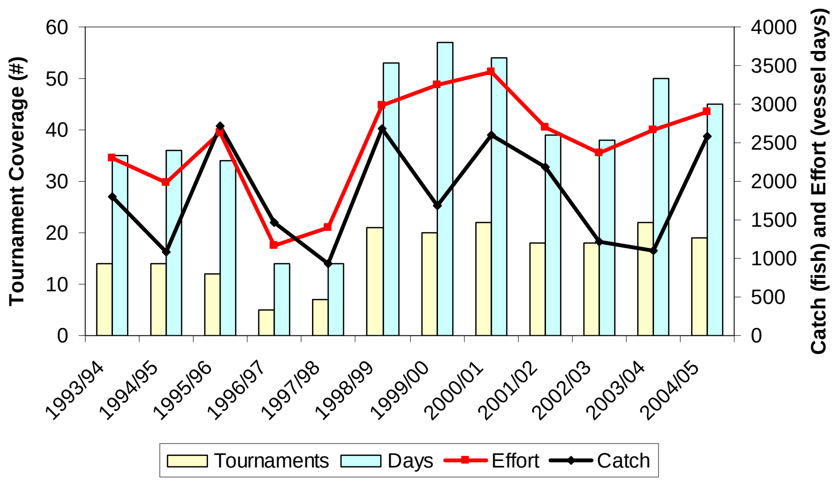


Figure 4. NSW DPI Gamefish Tournament Monitoring Program monitoring coverage per annum. Coverage given as number of tournaments (yellow bars), number of tournament days (blue bars), amount of fishing effort as vessel days (red line) and resultant catch data collected as number of fish (black line).

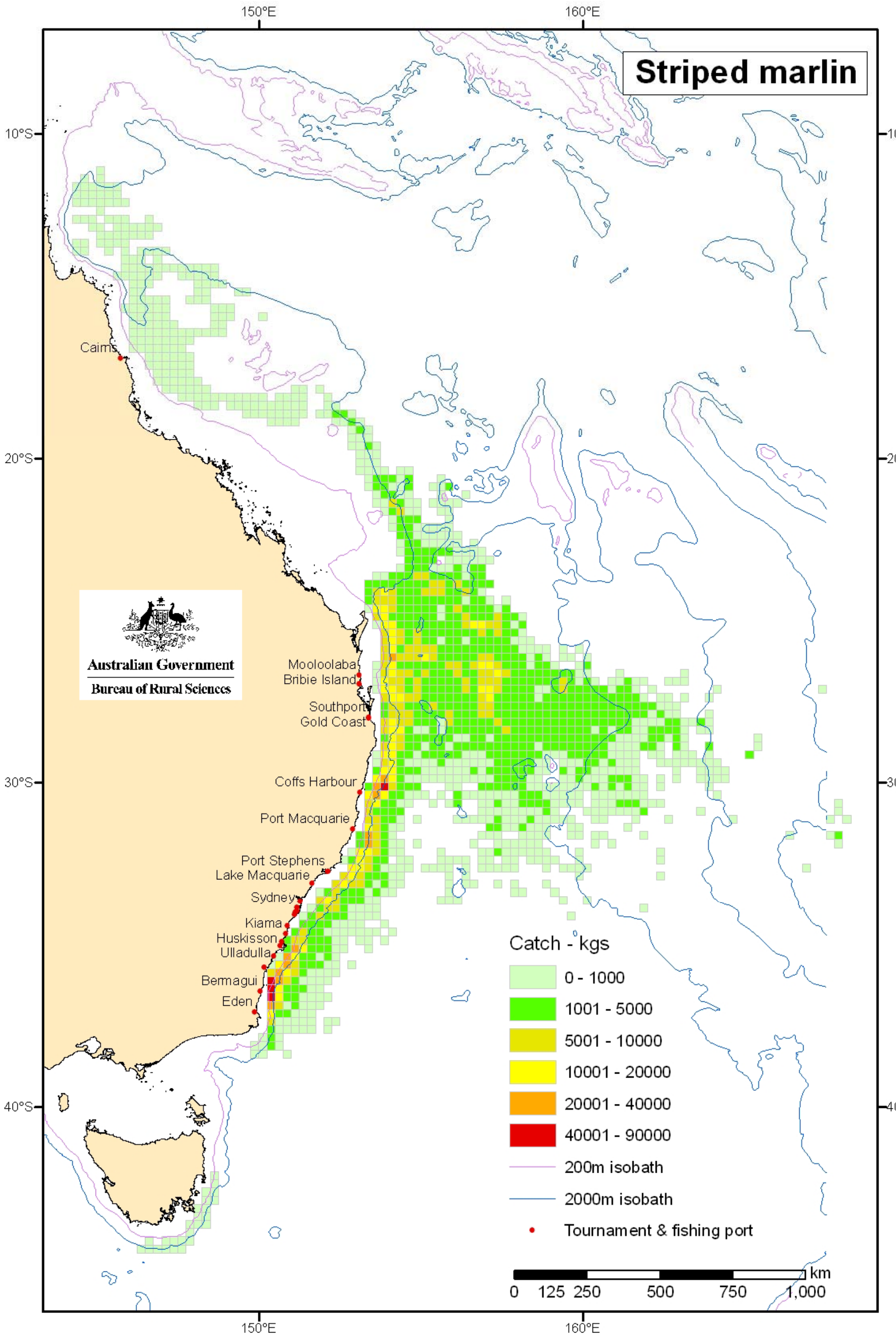


Figure 5. Catch (in kilograms) of striped marlin taken by ETBF longliners (1998–2004), showing key longline and recreational fishing ports. The location of the 200 m and 2000 m isobaths are also shown.

2.3 Fishing effort

Gamefishing effort

Accurately quantifying recreational gamefishing effort, either in total or as applied to targeting of striped marlin, is not possible at the current time. However there is some effort data available with respect to some components of the gamefishing sector.

Recreational gamefishing can be split into three categories: that occurring in club or association-based tournaments (including club point scores etc), that occurring via chartered vessels and that occurring privately outside organised events (the latter two categories would include both club and non-club anglers). NSW DPI monitors fishing effort at many, but not all gamefishing tournaments in NSW. NSW DPI also conducts a Charter Fishing Logbook Program to which many (but not all) charter boats have reported. It is difficult and costly to routinely quantify or estimate gamefishing effort that occurs privately outside of club-based tournaments or point scores, and using private (non-charter) vessels. The latter represents an unknown level of fishing effort and consequent catch (NSW Maritime Authority had 2407 registered fishing boats over 8m in 2005). Only one estimate of this non club-based effort targeting billfish and tuna has been attempted. Pepperell (1994) surveyed a cross-section of gamefish anglers using exit interviews at fishing tackle shops from Cairns to Melbourne and found that about one third of gamefish anglers belong to a fishing club. The fishing effort of some of the non-club anglers would be picked up through charter boat records, but not through tournament or club-based records.

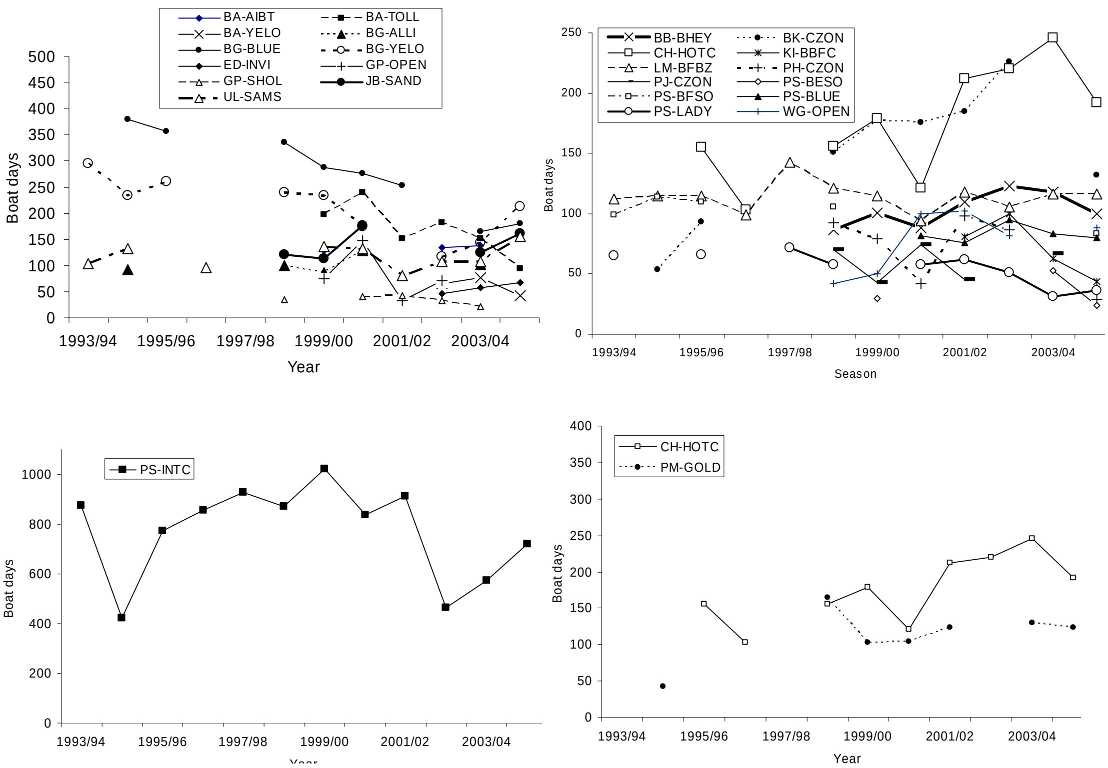


Figure 6. Total recreational fishing effort by tournament (in boat days) since 1993, for those tournaments for which data has been collected. Note that many tournaments have not been consistently monitored across all years. The top left graph is for southern zone, top right for central (excluding the interclub tournament), bottom left is interclub only and bottom right is for the northern zone. Note that these graphs represent total effort, not just effort directed towards striped marlin.

Figure 6 represents recreational gamefishing effort (boat days), in this instance as relates only to major gamefish tournaments by boats targeting tuna and billfish (trolling), and only those with consistent recorded time series. It indicates that participation at many of the major tournaments varies significantly between years. The Port Stephens Interclub tournament represents by far the largest tournament in terms of effort directed at tuna and billfish, with effort peaking in 1999/2000 at over 1000 boat days, before dropping more than 50% by 2002/03 (due to half the fishing days being cancelled due to bad weather, for the first time in the 40 year history of the tournament), and increasing over the two subsequent seasons. Overall, effort in the past three seasons has been lower than in the late 1990s at that tournament. However, it is important to note that representing effort in this way does not necessarily indicate tournament participation as such, factors such as poor weather conditions can significantly affect fishing effort at any given tournament regardless of how many people register and turn up to fish. Similar problems exist with using the number of hooks deployed as a measure of longline fishing effort, where variations in fishing power are ignored.

When tournaments are grouped and considered by zone, a number of trends are apparent. In the southern zone, the larger tournaments in Batemans Bay and Bermagui in particular have shown a drop in effort (boat days fished) since the early 1990s. In the central zone, the larger tournaments have shown overall higher effort in the past few seasons than in the 1990s. In the northern zone, Coffs Harbour effort has been higher in recent seasons, while Port Macquarie has been steady after reporting over 150 boat days in the 1998/1999 tournament. However, due to gaps in tournament monitoring and the fact that some tournaments are generally not monitored, overall tournament effort cannot be calculated.

Longline effort

ETBF longliners report fishing effort levels via the compulsory logbook program enforced by the AFMA. Observers report the number of hooks deployed in each longline operation. ETBF longline effort increased through the 1990s from 1.6 million hooks in 1993 to 12.6 million hooks in 2003, before dropping to 9.9 million hooks in 2004. Longline effort off continental NSW in the main interactions zone has approximated 40-50% of the total ETBF effort since the mid 1990s when the fishery expanded to northern and offshore waters (Figure 7). Of the three NSW zones (see Figure 2), effort tends to have been highest in the northern NSW zone, having peaked in 2002 (2.74 million hooks), before declining in 2003 to 2.1 million hooks. Recent declines have been due to lower effort in autumn, winter and spring. Fishing effort in summer has typically been lower, but has not declined. In general, fishing effort in the central zone during the autumn, winter and spring period has increased at least since the mid-1990s such that total effort in 2004 was just over 1.5 million hooks. However, summer fishing effort has declined by 50% since 2000. In direct contrast, the southern zone has seen effort fall sharply in the autumn, winter and spring period since 1998 (when total effort peaked at 1.7 million hooks) such that in 2003 only 0.57 million hooks were fished. This decline in effort may be linked to seasonal restrictions on fishing associated with southern bluefin tuna related management measures. However, summer fishing effort over the same period has increased.

Table 2. Tournament codes, names and hosting port used in this report.

Tournament_ID	**Tournament**	**Tournament_Port**
BA-AIBT	Australian International Billfish Tournament	Batemans Bay
BA-SZON	Southern Zone Interclub	Batemans Bay
BA-TOLL	Tollgate Islands Classic	Batemans Bay
BA-YELO	Batemans Bay Yellowfin	Batemans Bay
BB-ANNI	Botany Bay Anniversary	Botany Bay
BB-BHEY	Bill Heywood Memorial	Botany Bay
BB-CLUB	Club Pointscore	Botany Bay
BB-CZON	Central Zone	Botany Bay
BB-OLYM	Botany Bay Olympic	Botany Bay
BG-ALLI	Alliance Tag & Release	Bermagui
BG-ANNI	Bermagui Anniversary	Bermagui
BG-BLUE	Bluewater Classic	Bermagui
BG-BLUEL&J	Bluewater Classic Ladies & Juniors	Bermagui
BG-JINK	Jinkai Classic - Latrobe Valley	Bermagui
BG-SEIG	S.E.I.G.T	Bermagui
BG-YELO	Canberra Yellowfin Tournament	Bermagui
BK-CZON	Broken Bay Invitational	Broken Bay
BK-SIGT	Sydney International Game Fishing Tournament	Broken Bay
CH-AIBT	Australian International Billfish Tournament	Coffs Harbour
CH-HOTC	Hot Current	Coffs Harbour
ED-INVI	Eden Open Invitational	Eden
GP-OPEN	Shoalhaven Open Tournament	Greenwell Point
GP-SHOL	Shoalhaven Light Tackle	Greenwell Point
JB-SAND	White Sands Tournament	Huskisson
KI-BBFC	Kiama Blowhole Big Fish Classic	Kiama
KI-SZON	Southern Zone Interclub	Kiama
LM-BFBZ	Big Fish Bonanza	Lake Macquarie
LM-SHRK	Shark Tournament	Lake Macquarie

Tournament_ID	Tournament	Tournament_Port
ME-BROA	Merimbula Broadbill	Merimbula
ME-OPEN	Merimbula Open	Merimbula
PH-AIBT	Australian International Billfish Tournament	Port Hacking
PH-ANIV	Anniversary Tournament	Port Hacking
PH-CZON	Central Zone	Port Hacking
PH-HUND	Port Hacking 100	Port Hacking
PJ-CZON	Central Zone	Port Jackson
PJ-MAKO	Monster Mako Tournament	Port Jackson
PJ-SIGT	Sydney Invitational	Port Jackson
PM-GOLD	Golden Lure	Port Macquarie
PM-GOLDL&J	Golden Lure Ladies & Juniors	Port Macquarie
PM-SHOO	Shootout	Port Macquarie
PS-AIBT	Australian International Billfish Tournament	Port Stephens
PS-ANIV	Port Stephens Anniversary	Port Stephens
PS-BESO	George Bessoff Memorial	Port Stephens
PS-BFSO	Billfish Shootout	Port Stephens
PS-BLUE	Port Stephens BlueWater Classic Tournament	Port Stephens
PS-INTC	NSW Interclub	Port Stephens
PS-LADY	Ladies Day	Port Stephens
PS-SPOR	Sportivo	Port Stephens
SL-OPEN	Shellharbour Open Tournament	Shellharbour
UL-JSLT	Jess Sams Light Tackle	Ulladulla
UL-SAMS	Jess Sams Ulladulla Open	Ulladulla
UL-SZON	Southern Zone Interclub	Ulladulla
WG-CZON	Central Zone	Wollongong
WG-OPEN	Wollongong Open Tournament	Wollongong

A)

B)

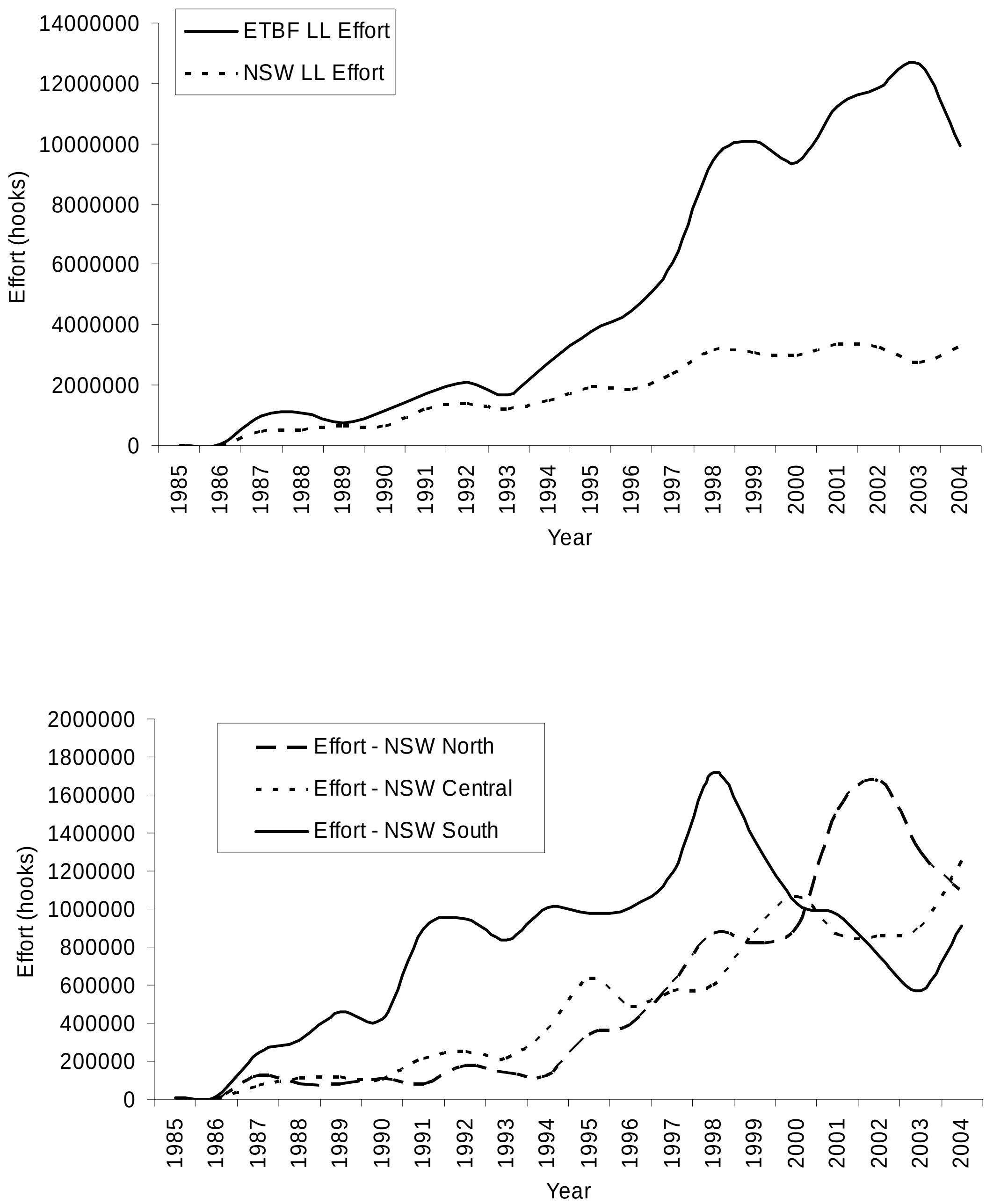


Figure 7. A) Total ETBF longline effort off NSW; and B) in subregions off NSW.

2.4 Catch

The practice of tag-and-release has been widely adopted in the gamefishing sector over the past 15 years, to the point that the tag-database held by NSW DPI is believed to represent a reasonable estimate of the “catches” of striped marlin off eastern Australia. However, it is recognised that it will still represent an underestimate as it will not include fish that are retained and weighed (a small percentage of the club-based catch, but an unknown percentage of the substantial non-club fishery) or which are simply not reported as caught. This report uses the NSW DPI tag-release data to indicate trends in taggings at different spatial and temporal scales. No attempt was made to acquire club capture records (although this was done in Bromhead et al., 2004). Commercial longline catch data is obtained from the logbook database maintained by AFMA, and there is little evidence to suggest the data is not reflective of total catch.

Whole fishery

Total reported *longline* catch of striped marlin by ETBF longliners peaked at 9750 fish in 2001 but subsequently declined to 5170 fish in 2004. Longline catches off continental NSW peaked in 1999 at 4708 and numbered 2955 fish in 2004.

The total reported *recreational* taggings of striped marlin by gamefishers is significantly lower than catches by longline, with total annual taggings reported off eastern Australia rising from 451 in 1995 to peak at 1832 in 2000. However, similar to the drop in longline catches, reported taggings fell by 48% between 2001 and 2004 (to 880 fish). Nearly all of the tags reported off eastern Australia are from NSW waters (Figure 8).

Catches by zone and season

Northern zone: Longline catch in the northern NSW zone has been the highest of all three zones in recent years, having increased throughout the 1990s (with some annual variation) to peak at 1900 fish in 2003 before dropping by nearly 50% in 2004 to just over 1000 fish. Significant catches are taken in each season, but in general the highest catches have been taken in spring and winter, and the lowest in autumn. In contrast, the northern zone represents the region with lowest reported recreational tagging, ranging between 12-95 fish annually over the last 15 years.

Central zone: Longline catch in the central NSW zone rose to a peak of 998 fish in 2000 before dropping to 500 fish in 2003 and then increasing to 845 in 2004. Annual catches in this zone have typically been lower than in the northern and southern zones. The largest seasonal catches have been reported in autumn and spring although seasonal patterns have varied over the years. Recreational taggings in the central zone were highest in 1997 (763 fish) and have fluctuated between 300-630 fish per year since.

Southern zone: Longline catch in the southern NSW zone rose to a peak of 1697 fish in 1999 before showing a general declining pattern (with the exception of 2002), dropping by 66% to 563 fish in 2004. The majority of the annual catch is taken in autumn, with significant catches also taken in summer months. These seasons also represent the periods of highest recreational tagging of striped marlin. Between 1998 and 2002, the southern zone represented the region of highest recreational taggings, with the total for 2000 (1179 fish) the most for any region in any year. However, reported taggings in this zone fell by 74% by 2004 (when only 305 fish were tagged), thus showing a similar trend to the decline in longline catches over the same period. It is worth noting that both sectors had increased catches in both 2000 and 2002.

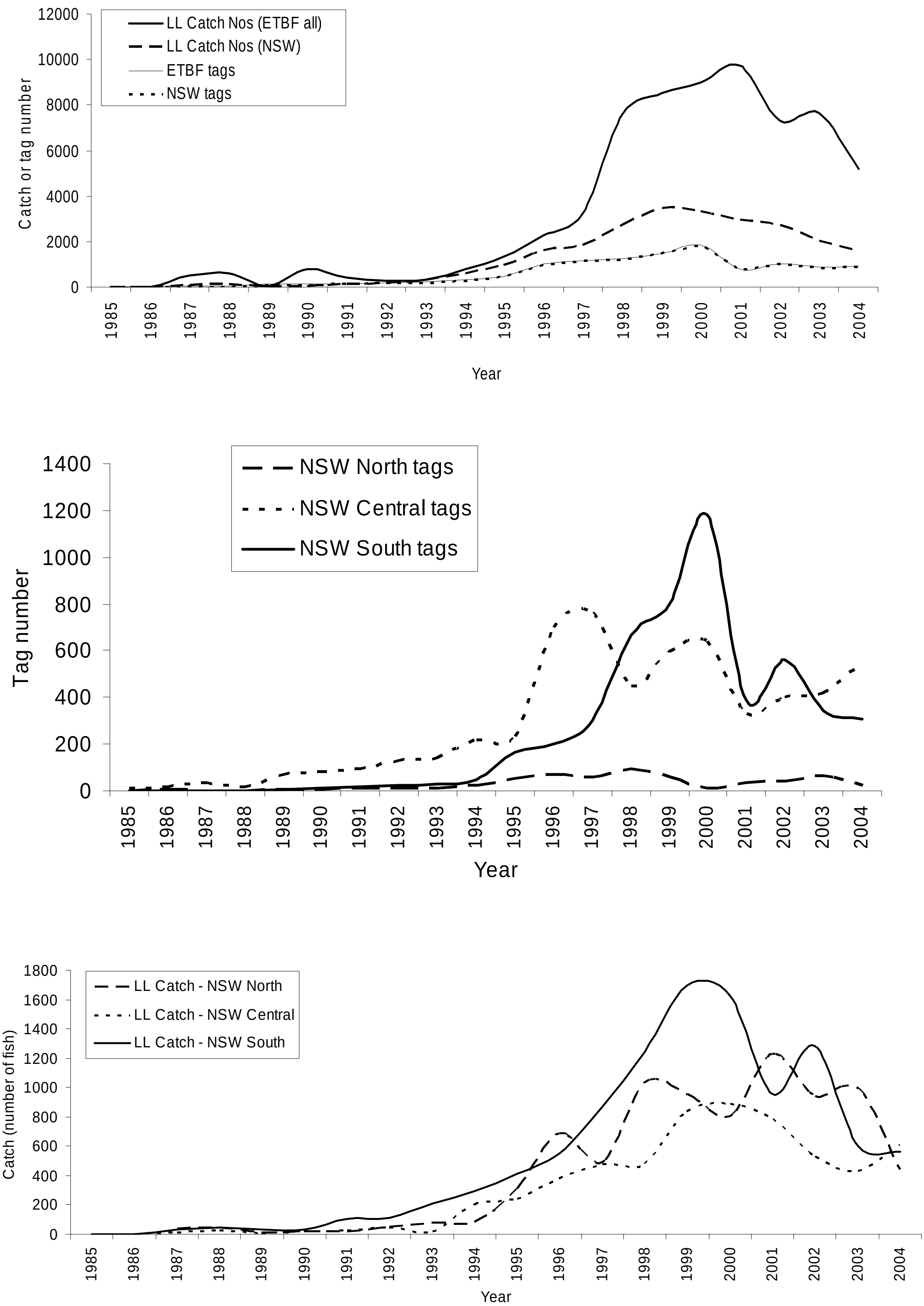


Figure 8. A) Total longline catch and recreational taggings off NSW; B) Total annual number of striped marlin reported to be tagged and released in three regions off NSW; C) Total annual catch (including discards – generally 2-4%) of striped marlin in three regions off NSW.

2.5 Catch rates

Whole fishery

Annual longline catch rates of striped marlin off NSW show a similar pattern to those for the entire eastern AFZ , excepting the first few years when fishing effort was low. Catch rates increased from around 0.2 fish/1000 hooks in the early-mid 1990s off NSW to a peak in 1999 of about 1.0 fish/1000 hooks. Catch rates have steadily declined by almost 50% since to 0.53 fish/1000 hooks in 2004. The key question raised by this pattern is what is driving the changes in longline catch rates, and in particular, why have they steadily declined over the past 6 years? This question will be looked at in more detail in Chapter 3. Significant temporal gaps in data collection for various areas within the recreational fishery mean that recreational catch rates are best assessed at a finer spatial scale. Consequently, fishery-wide recreational catch rates will not be discussed in relation to commercial fishery catch rates here.

Catch rates by zone and season

Northern zone: Longline catch rates in the northern NSW zone peaked at almost 1.80/1000 hooks in 1996, and while it has varied somewhat since, has shown a declining trend to 0.39/1000 hooks in 2004 (a decline of 78%). In the peak catch years (1998-2002) the highest catch rates were recorded in spring and summer, although the highest seasonal catch rate on record was winter 1996. More recently, the differences in catch rates between seasons have not been so pronounced. Similar to the pattern observed in longline catch rates, recreational tournament catch rates in the northern zone have shown a strong declining trend since 1998 (data collection was sparse before that year), with a decline of 91% between 1998-2005. Catch rate data derived from the NSW DPI Charter Logbook Program exists only from 2001 onwards, and indicates an increase in catch rates in 2003, before dropping in 2004. Similar spikes are observed in the longline and tournament data series in 2003. This data also suggests (like the longline and tournament data series) that catch rates are generally lower in the northern region than in the southern (at least in later years).

Central zone: Longline catch rates of striped marlin in the central NSW zone peaked at almost 0.97 fish/1000 hooks in 1999, and has shown a declining trend since, reaching 0.48/1000 hooks in 2004 (a decline of 51%). Catch rates are typically lowest in winter (<0.5 fish/1000 hooks) and in recent years have been highest in autumn. However, prior to 2001, summer and spring catch rates were high (~1.0) but catch rates in these seasons have declined by more than 60% since 1999. Recreational tournament catch rates were highest in the central zone in the mid 1990s and, after 6 years of lower catch rates, jumped in 2003 and 2004 to similar levels. The longline and tournament temporal patterns in the central zone are almost opposite, being high and low in opposite periods. Charter logbook catch rates are relatively steady since commencing in 2001. The historic charter catch rate data shows a very similar temporal trend to the longline data series, increasing through the 1990s to peak in 2001 before declining substantially (>50%) in 2002. Note there is significant difference in the historic and logbook charter catch rates for 2001.

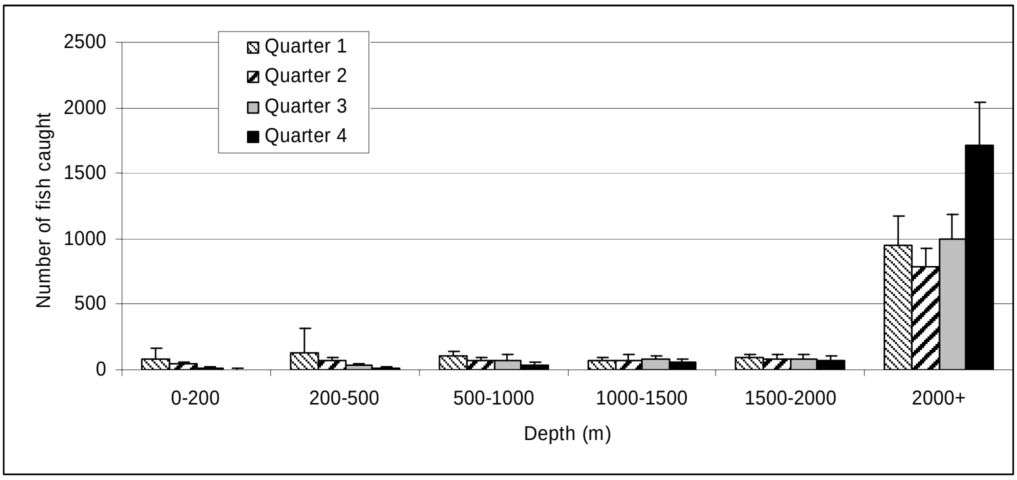
Southern zone: Longline catch rates in the southern NSW zone rose steadily from 0.07 fish/1000 hooks in 1990 to 1.58 fish/1000 hooks in 2000, dropping to 0.97 in 2001, before reaching its peak value of 1.70 fish/1000 hooks in 2002. Catch rates have since declined by 64% to 0.67/1000 (in 2004). Catch rates are much higher in summer (~0.8-2.0/1000) and autumn (~1.0-4.0/1000) than in winter and spring (both <0.5/1000). The highest seasonal catch rate on record, autumn 2002, is associated with a targeting event by a number of fishers in the region (Bromhead et al., 2004). Recreational tournament catch rates from this zone also show a strong spike in 2000 before dropping in 2001. However the 2002 spike evident in longline data is absent from the tournament data. There is some evidence of slightly increased catch rates in 2002 from the charter logbook data but not from the charter historic data series which overlaps it. It should be noted that the historic charter data typically cover many days in the southern fishing season, as opposed to the tournament data, which cover a limited number of days where tournaments are monitored. However, for the southern zone in 2002, a number of charter boats known to target striped marlin did not supply data to the historic charter data set, potentially explaining the reduced catch rates (See Bromhead et al., 2004 for further discussion of this). Bromhead et al. (2004) showed that the highest catch rate seasons in the southern zone are summer and autumn, similar to the longline sector. This seasonality is linked to the seasonal movements and availability of marlin in the region.

2.6 Catch by depth zone

One of the management options that might be considered by decision makers in order to resolve resource sharing issues is that of spatio-temporal management. The previous section has highlighted north to south "horizontal" or regional spatial variations in catch and catch rates for striped marlin caught by both recreational and commercial fishers off NSW. However, given that striped marlin live in a three dimensional habitat, it is important to explore whether vertical (water depth) related variations in fishing patterns and catches might also offer potential in the development of management options.

Considering then the mean annual catches of striped marlin taken in each of the six depth zones (0-200 m, 200-500 m, 500-1000 m, 1000-1500 m, 1500-2000 m, >2000 m) by both longline and recreational sectors, over the period 2001-2004, there is a clear separation in the depths at which the majority of catch is taken by both sectors (Figure 9).

A.



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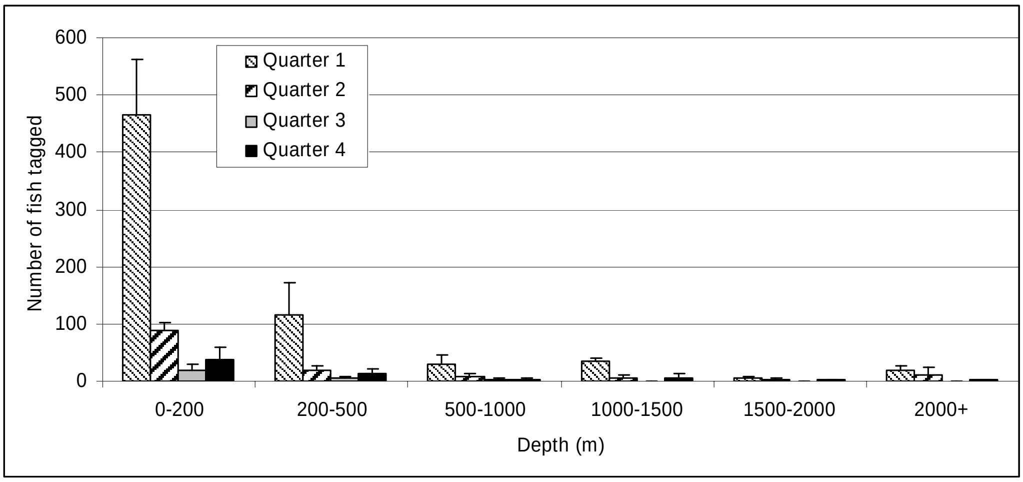


Figure 9. Mean annual catch of striped marlin by depth strata for both commercial A) and recreational sectors B), operating off eastern Australia. Error bars represent 2 standard errors.

Less than 23% of the total longline catch of striped marlin is taken in longline fishing operations that start in waters shallower than 2000 m, with the majority taken in longline operations over greater depths. In contrast, almost 90% of recreational tag-releases are reported as occurring in depths less than 1000 m. Effectively, most longline catch of striped marlin is taken by operations starting on or past the shelf edge, while most recreational catch occurs over the continental shelf.

However, some caution should be applied in interpreting these data. Firstly, note that catches in the “2000+” depth category, pertain to all catches taken east of the 2000 m bathymetry line that runs around the continental shelf. It will include shallow water catches taken far offshore but beyond the range of the recreational fishery. The data is summarised based on the starting position of longline operations, but it should be recognised that longlines span about 30–60 km and could cross over a number of depth ranges. It is extremely important to understand that where shelf-associated depth contours run relatively close to one another (steep slopes, such as off south-eastern Australia), such catch summaries will have less meaning due to the length of longline and uncertainty over where the majority of the catch was taken on the longline for any shot in that region. The data also do not take into account longline drift. A far more detailed analysis of catch by depth, which would account for longline setting direction and drift, may be warranted in future if it was determined that depth-based spatial management options were to be seriously considered.

2.7 Size trends

Size is one of the key indicators of recreational fishing success. Large fish are sought by recreational fishers due to the greater challenge, prestige and in some tournaments, prizes given for landing the largest fish or record-size fish. Subsequently, when considering fishery interactions, it is important to look at trends in sizes of fish caught over time in association with trends in fishing effort and catch rates. Declines in fish sizes over time can also be an indicator of overexploitation of a stock.

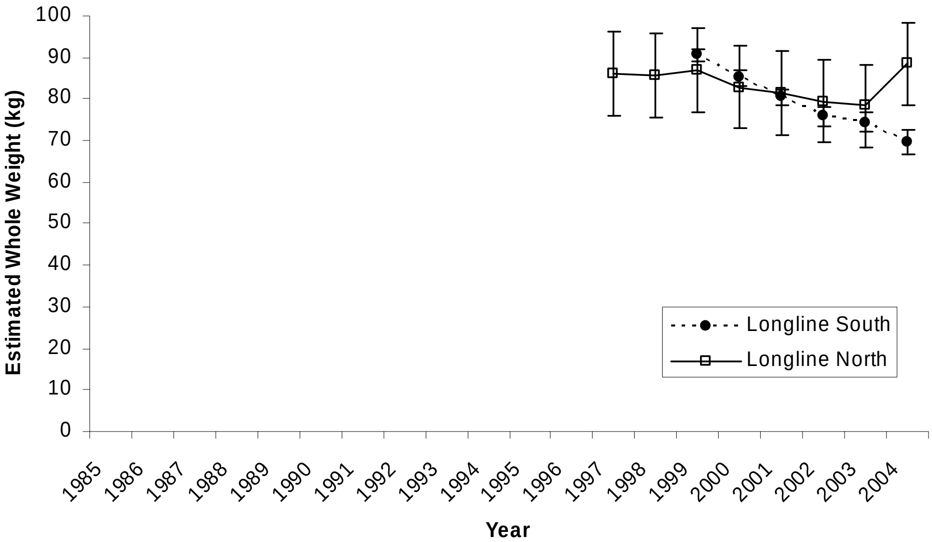
Size data are available from both sectors. Commercial size data is available from 1998 and is grouped (due to location of contributing processors) into data from processors north of Sydney (including Queensland) and those in and south of Sydney. Size data are presented in Figure 10. There is no significant change in mean annual size of fish processed north of Sydney since 1998, however there is a significant decline in the mean size of fish processed in and south of Sydney over that period.

Overall, there was a statistically significant ($p < 0.001$) decline in the estimated size of tagged and released striped marlin during 2000–05, but the reduction amounted to only 1–2 kg per year. They showed no significant decline in any of the interaction zones over the same period and if anything, mean size of fish may be higher in the last 5 years than it was in the late 1980s and early 1990s. It is interesting to note that there was a significant drop in mean size in the central and northern zones in 1997 (Figure 10), potentially indicating a recruitment of smaller fish into these regions.

Bromhead et al. (2004) presented analyses to show that, while mean size caught by each sector can differ significantly, the size range and distribution of marlin caught by each sector off eastern Australia is very similar.

It is uncertain why a similar trend in declining sizes in the southern zone (as seen in longline data) is not apparent in the recreational size data, if both data sets reflected the size of fish available to capture. Declining size may be one indicator of overfishing, although it should not be used alone without other indicators or quantitative assessments to judge stock status. The recreational tag release data set indicates an increase in mean size over the past 15 years, particularly in the more southern coastal area. Whether this reflects an actual increase in mean size of marlin off eastern Australia, changes in targeting or is related to changes in size regulations or a reduction in landings of bigger fish (which normally might appear in the club capture data rather than the tagging database) is unknown. It is also noteworthy that anglers usually estimate the size of released fish while they are alongside the boat, and this may introduce uncertainty or bias in those data.

A.



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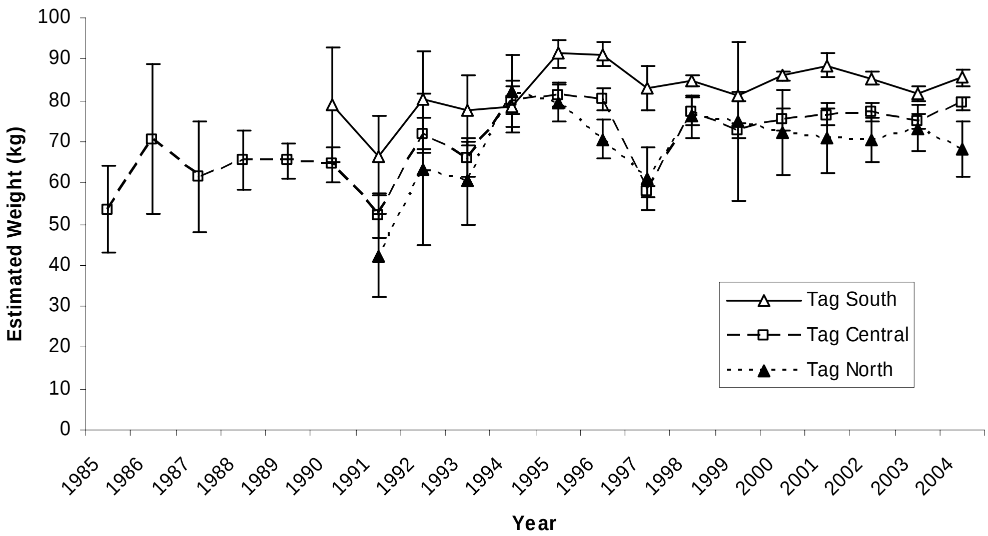

Figure 10. A comparison of trends in mean sizes of striped marlin caught by both the commercial (A) and recreational (B) fisheries off eastern Australia. Error bars represent 2 standard errors. (Sources: NSW DPI Gamefish Tagging Database, 2002; East Coast Size Monitoring Project, 2002)

2.8 Other relevant data

Any measures considered to reduce catches of striped marlin may also impact on catches of target species. Figure 11 shows the relative proportions of different target species, including striped marlin, in the commercial catch off Australia, at the scale of 5 degrees. Table 3 shows the proportion of sets taking at least one striped marlin off north-eastern Australia – off central and northern Queensland, central – off southern QLD and northern NSW and southern – off south-eastern Australia, for both day and night sets. Note that these regions differ in area to those used in this current report, but use a similar terminology. Care should be taken not to confuse them. This provides an indicator of the relative frequency of capture of striped marlin in different areas against frequency of captures of the other target species in those same areas.

Striped marlin occur in 8-13% of northern longline shots and 31-43% of central longline shots, with higher occurrence in day time shots in these two regions (Table 3A). Albacore tuna and mahi mahi both co-occur in more than 25% of sets taking striped marlin across all regions (day and night sets) (Table 3B), with albacore co-occurrence tending to be higher in night sets (52-65% depending on region), and mahi mahi co-occurrence being higher in the north (>60% in the north-eastern region versus <31% in the south-eastern region). Rudderfish co-occur with striped marlin in >25% of sets taking marlin in the central region (night sets) and southern region. Shortfin mako co-occur in 38% of southern night sets. Five species (blue shark, bronze whaler, oceanic whitetip shark, wahoo and black marlin) all co-occur in 31-40% of sets taking striped marlin in northern day shots only.

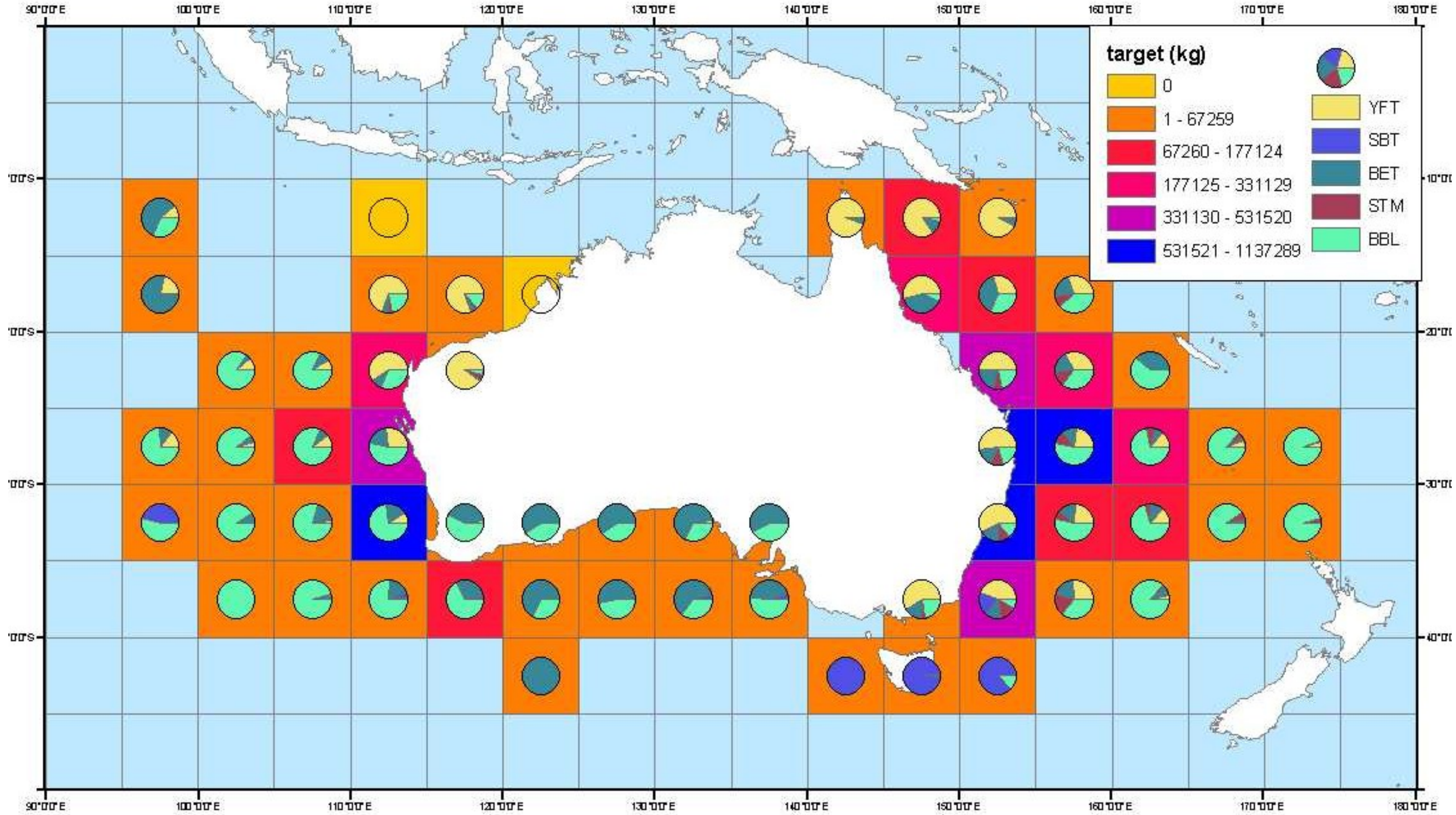

Figure 11. Relative proportion and amounts of target catch by species taken in Australian longline fisheries on a 5º scale (Data: AFMA 2003), where YFT = yellowfin tuna; SBT = southern bluefin tuna; BET = Bigeye tuna; STM = striped marlin; BBL = swordfish

Table 3. A) Percentage of shots for each region (ETBF1 = north; ETBF2 = central; ETBF3 = southern region of the fishery) and time combination containing at least one record of the target species; B) Percentage co-occurrence in only those shots containing the target species striped marlin ('STM'), for each region, by time (AL05 data). Only those byproduct species co-occurring in greater than 25 % of these shots are shown.

A)

Target Species	ETBF1		ETBF2		ETBF3	
	Day (n = 4075)	Night (n = 3354)	Day (n = 7742)	Night (n = 20759)	Day (n = 4301)	Night (n = 2764)
YFT	89.30	84.53	87.55	79.93	83.79	79.23
BET	41.47	66.49	42.15	65.25	38.39	64.54
STM	8.20	13.48	43.27	40.63	37.34	31.04
BBL	13.45	56.56	38.38	80.85	24.27	64.18

B)

Target Species	Co-occur Species	Region					
		ETBF1		ETBF2		ETBF3	
		Day (n = 334)	Night (n = 452)	Day (n = 3350)	Night (n = 8435)	Day (n = 1606)	Night (n = 858)
STM	YFT	95.21	92.04	89.04	80.45	86.49	80.77
	BET	36.53	71.24	39.28	61.01	37.67	63.05
	ALT	44.91	65.49	47.28	52.09	44.02	56.53
	BBL	.	82.96	40.03	84.18	.	69.81
	DOL	67.37	61.73	46.12	44.22	29.89	30.89
	RUD	.	.	.	33.40	37.24	51.40
	SFM	.	.	.	.	.	38.69
	BLS	35.03	.	.	.	.	.
	BWH	32.34	.	.	.	.	.
	OWS	33.23	.	.	.	.	.
	WAH	40.42	.	.	.	.	.
	BLM	31.14	.	.	.	.	.

2.9 Summary and discussion

The preceding chapter has characterised trends in catch, effort, size and catch rates for striped marlin caught in both the recreational and commercial fisheries operating off eastern Australia, focussing on waters off NSW. The key trends to note from this chapter are:

1. Overall longline fishing effort off NSW is highest in the northern zone, but this region is the area of lowest spatial-temporal interaction between sectors (Bromhead et al., 2004). However, 2004 saw increased longline effort in both the southern and central zones, effectively offsetting the decline in effort to the north. The central and southern zones are regions of very high spatial-temporal interaction between the recreational and commercial sectors. Southern zone longline effort has concentrated into the summer period in recent years. This is a peak gamefishing period in that region. Understanding the seasonal and long-term variability in commercial and recreational fishing effort is important when considering long-term and seasonal management measures to deal with fishery interactions.

2. The northern zone represents the region of lowest recreational taggings, but in recent years, the highest regional catches taken by longline. Catches and taggings in the central zone peaked 5-8 years ago but are still at a significant level for both sectors, although varying significantly between years. Large declines in catches (66% decline) and taggings (74% decline) have occurred in the southern zone since the peak years of 1999/2000, raising the key question of what has caused these declines for a species important to both sectors? The key catch and tagging seasons switch from winter-spring in the north to summer-autumn in the south, probably due to seasonal movements and availability of striped marlin.

3. While catches of striped marlin along with longline fishing effort have increased in the northern zone over the past 10-15 years, nominal catch rates have shown a very substantial decline for both longline and tournament sectors in that region. The decline in nominal catch rates is partly attributed to increased fishing effort directed at swordfish (Section 3 of this report describes statistical models that we used to remove the effects of swordfish targeting and other variables on catch rates). The possibility of localised depletion occurring in this area should also be considered. Another possibility is that improved surveillance and scrutiny by observers has resulted in improved species identification; in the past, blue and black marlin may have sometimes been reported in logbooks as striped marlin.

4. Temporal and regional correlations in catch rates derived between all three independently collected catch and effort data series support the idea that they are likely to be reflective of the availability of striped marlin in the different regions over time. This can be further investigated by catch rate standardisation (See Chapter 3). The one clear point of deviation between data series is in 2002 in the southern zone, when concentrated targeting of striped marlin is believed to have occurred in the longline sector. Hence longline catch rates may have spiked significantly due to changed fishing practices.

5. It is important to explore whether vertical (water depth) related variations in fishing patterns and catches might also offer potential in the development of management options. Less than 23% of the total longline catch of striped marlin is taken in longline fishing operations that started in waters shallower than 2000 m, with the majority taken in longline operations over greater depths. In contrast, almost 90% of recreational tag-releases are reported as occurring in depths less than 1000 m. Effectively, most longline catch is taken by operations starting on or past the shelf edge, while most recreational catch occurs over the continental shelf. Some caution is required in interpreting longline

data, with uncertainty over movement of line during operations and the direction of line setting with respect to continental shelf (although preliminary analyses indicate most lines are set parallel to the shelf edge). A far more detailed analysis of catch by depth, which would account for longline setting direction and drift, could be undertaken in future if it was determined that depth based spatial management options were to be seriously considered.

6. Size data: Size estimates of tagged striped marlin show a sudden upwards shift in the early 1990s. This was a period when overall tag numbers increased and there was a shift in tag versus capture rates for striped marlin (Park and Austin, in prep.) Since then, the sizes have been mostly stable, with the southern zone having the largest striped marlin. This stability is interspersed with occasional years, e.g. 1997 when a pulse of striped marlin clearly entered into the fishery. Longline mean weight estimates per year differ from the recreational data. In particular, mean sizes in the south have steadily declined from 1998 to 2004.

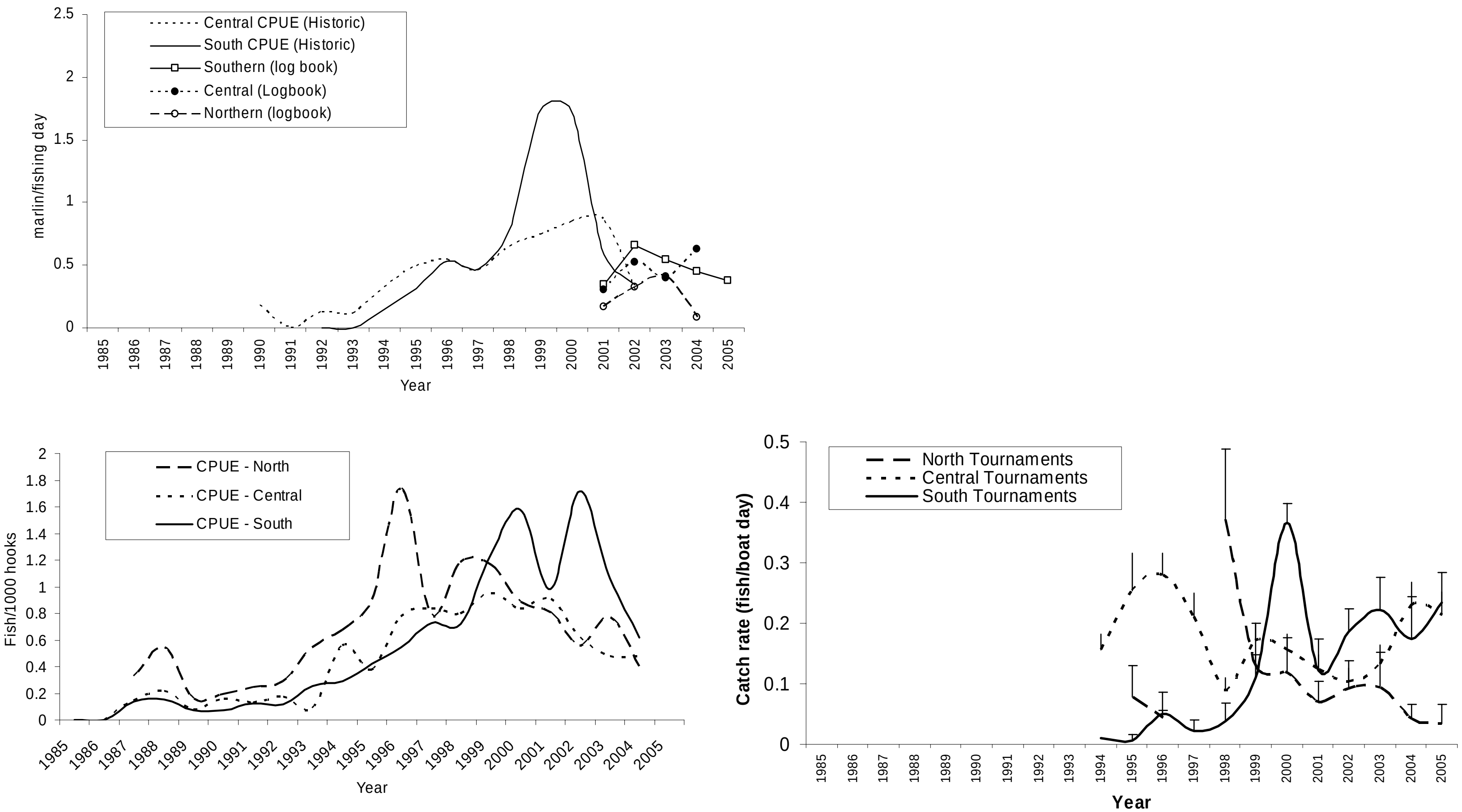

Figure 12. Annual catch per unit effort for both the domestic longline fishery (A and B); from charter boat logbooks and diaries (C) and for tournament based gamefishing grouped by region off NSW (D)(Data Sources: NMFS, NSW DPI, NIWA, TBF, AFMA, 2005).

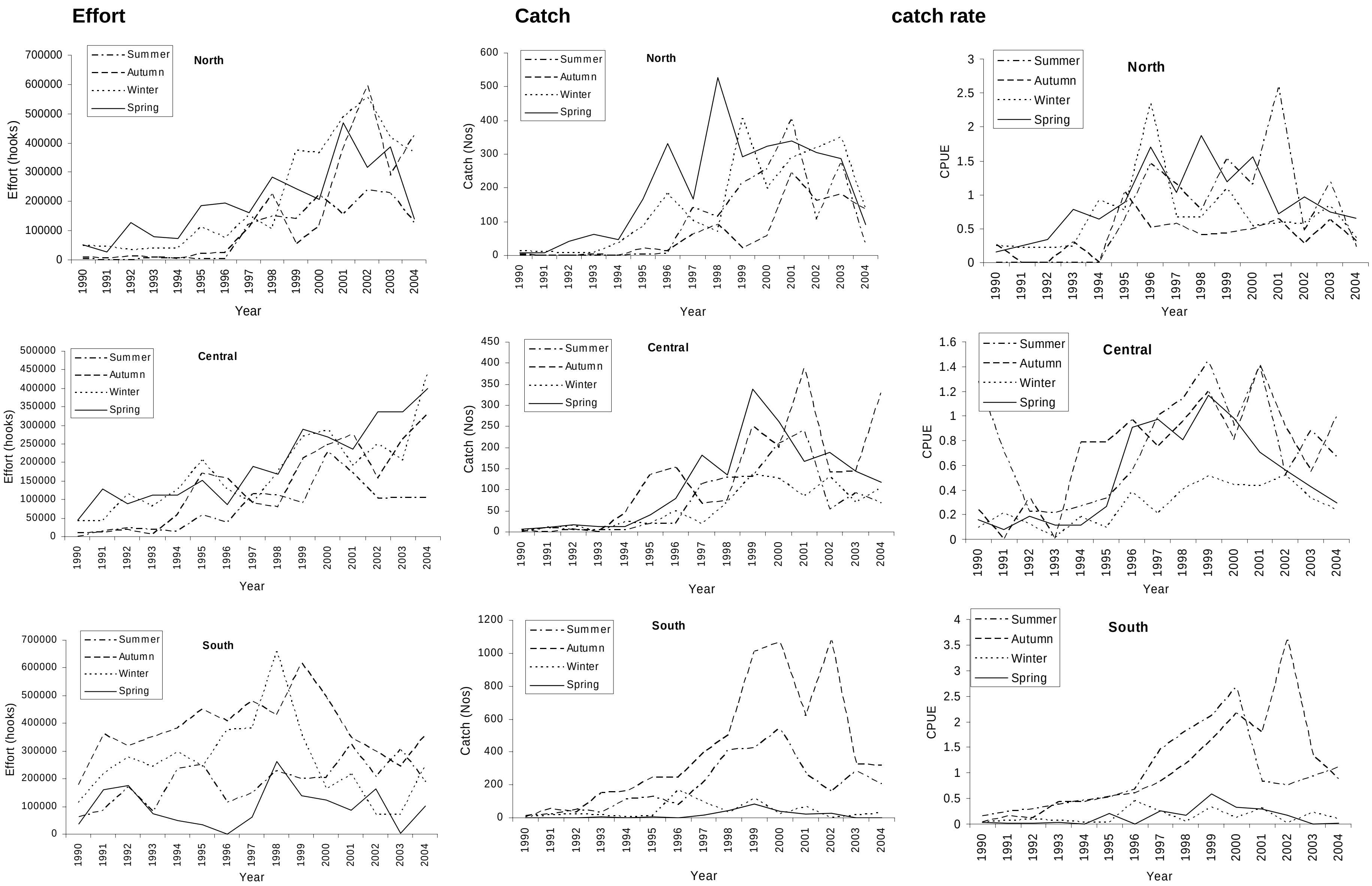

Figure 13. Longline effort (hooks), catch of striped marlin and catch rates for striped marlin by region, season and year.

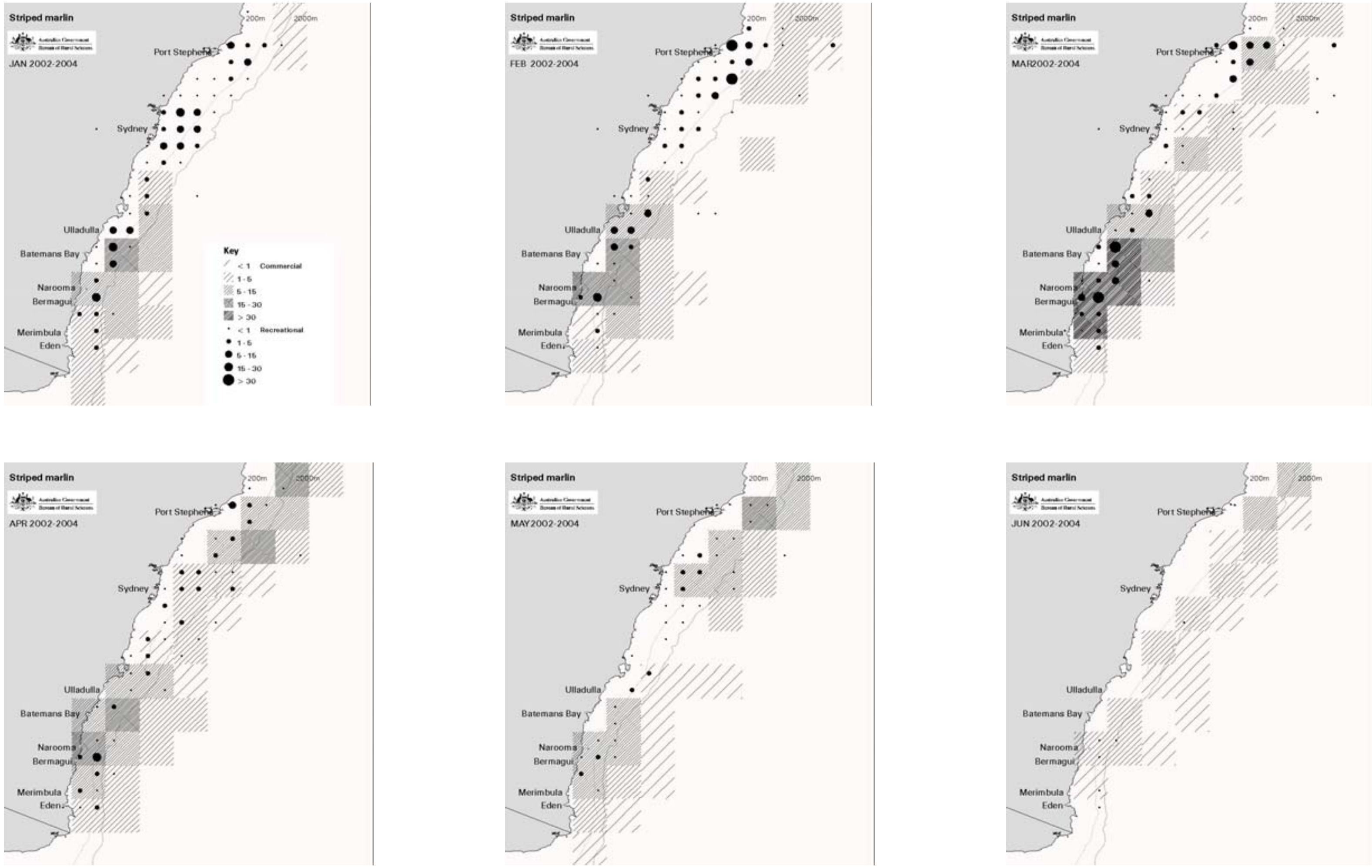

Figure 14. Mean monthly catch (longline) and taggings (gamefishing) by 0.25º area, for the main interaction region between 32-38ºS.

Figure 15. Mean monthly catch (longline) and taggings (gamefishing) by 0.25º area, for the main interaction region between 32-38ºS.

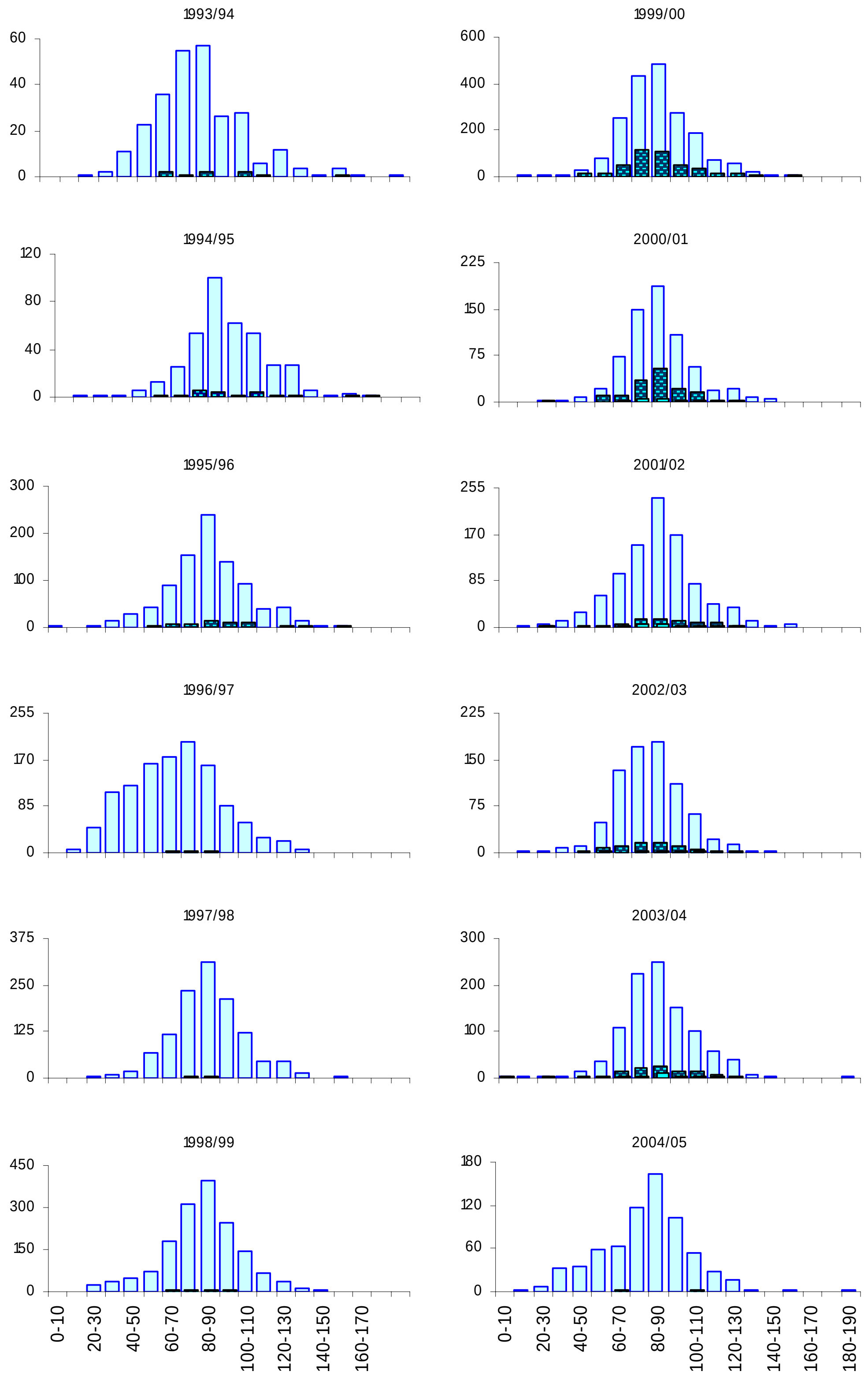

Figure 16. Number of striped marlin reported by 10kg size category by fishing seasons by three recreational sources, number tagged (pale blue), number reported at monitored tournaments (dark, mottled) and number from dockside interviews (aqua). Most weights are estimated.

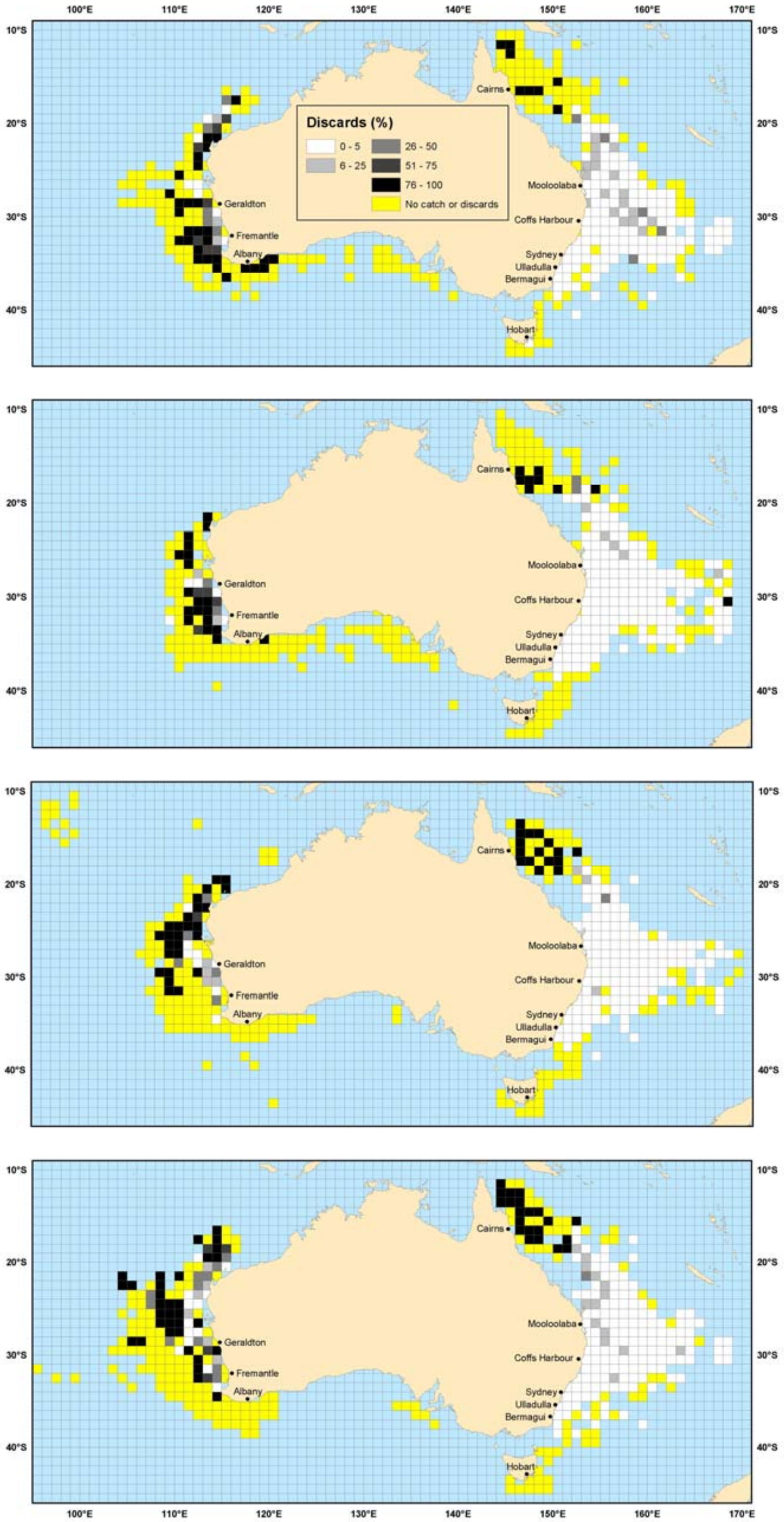

Figure 17. Mean annual discarding (percentage of total catch and discards) of striped marlin taken by domestic longliners, for the period 1998-2002.

3. Multi-sector based analyses of striped marlin abundance off eastern Australia: 1990-2004

3.1 Introduction

This chapter presents a number of temporally parallel indices of abundance or availability of striped marlin that are based on standardisations of catch per unit effort (catch rate) for striped marlin using data collected from both domestic commercial longline, recreational gamefishing and charter gamefishing sectors operating within the Eastern Tuna and Billfish Fishery off the east coast of Australia. More specifically, indices of abundance (or availability) have been developed using:

1. Domestic commercial longline logbook data (collected and held by AFMA);

2. Gamefish Tournament Monitoring data (collected and held by NSW DPI).

The analyses update and improve upon those conducted by Bromhead et al. (2004) which were limited through utilising longline and personal charter logbook data sets, and did not include an estimate of uncertainty around the end combined abundances indices.

Catch rates are commonly used as a surrogate of abundance. This follows the classic fisheries assumption that catch divided by effort is proportional to the population size. The relationship is expressed in the form

$$\text{cpue} = \frac{C}{E} = qN$$

where cpue is the catch rate or catch per unit effort, C is the catch, E is the effort, N is the population size and q is the catchability coefficient (Hilborn and Walters 1990). This assumption allows the use of catch rate as an index of abundance. However, caution is necessary as the relationship is variable and the catchability coefficient may change due to changes in fishing technology and may also vary unpredictably with time.

The main reason for standardising catch rates is to attempt to remove from the data any variation due to effects other than fish abundance. This can be done using a range of regression techniques with catch rate as the dependent variable explained by a number of independent explanatory variables, including year (Gavaris 1980; Kimura 1981; Olsen and Laevastu 1983). Other explanatory variables include area, fishing vessel, gear characteristics, and factors that might indicate targeting, such as hooks per basket and live bait usage. The aim is to select the explanatory variables that account for as much of the variation in catch rates as possible other than variation in abundance and random ‘noise’ (*i.e.* catchability can then be assumed constant over time), the year effect estimates the trajectory of abundance over time. In addition, environmental variables such as sea surface temperature and Southern Oscillation Index may also be used as explanatory variables, although there is a danger that broader-scale environmental variables may affect abundance rather than catchability.

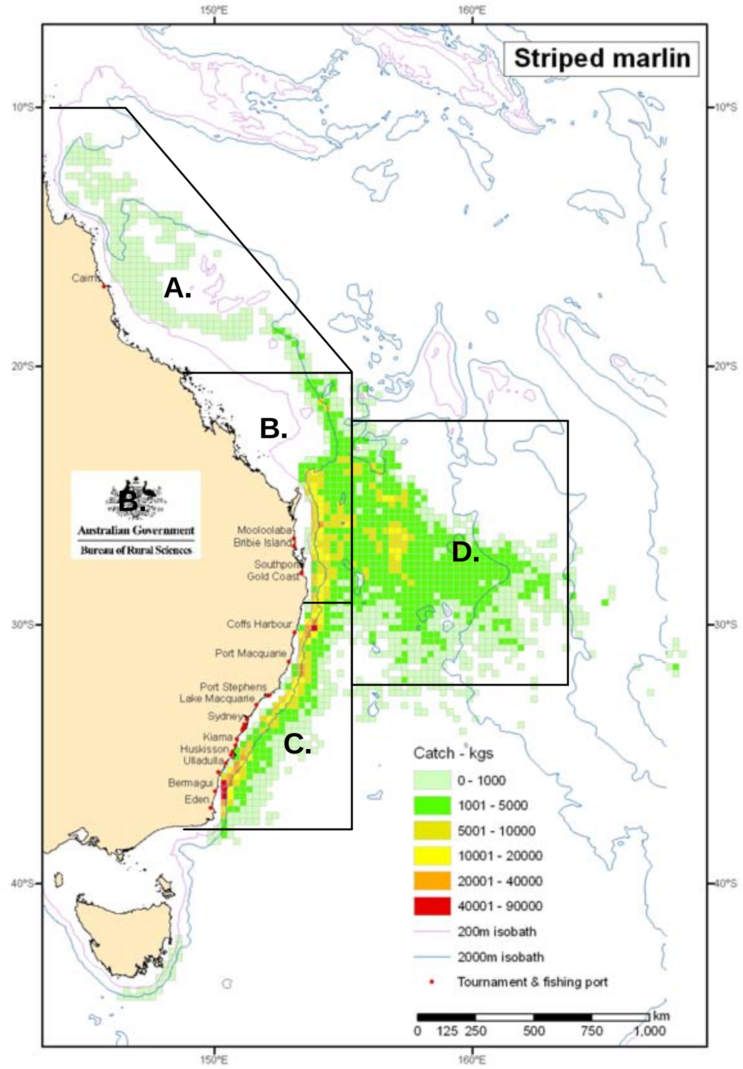

Figure 18. Regions by which data were grouped and analysed in this report. Major fishery regions are denoted regions A, B, C and D. Within region C where both commercial and recreational sectors fish in close proximity, there are further spatial groupings used, being north, central and southern regions (Data Sources: AFMA, 2005)**.**

Maunder and Punt (2004) reviewed recent approaches to catch rate standardisation. Generalised linear models (GLMs; McCullagh and Nelder 1989) are the most common method used. However the use of generalised additive models (GAMs; Hastie and Tibshirani 1990) has increased significantly over the last decade (Venables and Dichmont 2004). GAMs are extensions of GLMs that allow explanatory variables to be modelled non-parametrically, i.e. explanatory variables can be fitted as smooth terms. In GLMs, a function of the mean of the response variable is assumed to be linearly related to the explanatory variables. In GAMs this relationship is not forced to be linear, allowing non-linear relationships. GAMs allow continuous explanatory variables to have nonlinear effects on the response variable as determined by a smoothing algorithm (Cleveland 1979).

A distinctive feature of catch and effort data is that it is often “zero inflated”. That is, the data contain more zeros (*i.e*. in this case, longline operations or charter fishing days for which no marlin were caught) than might be predicted from standard error models used with GLMs (Ridout et al., 1998). If this feature of the data is ignored, and a standard Poisson error model is applied, problems with inference may occur as the Poisson assumption may not be an adequate approximation to the distribution of the catch data (McCullagh and Nelder 1989). In an attempt to overcome this problem, some studies have applied a small arbitrary constant either to zero catches or to all records when using log-transformed data. However this method may introduce a significant bias if there are reasonable numbers of catches with varying effort (Caputi 1996). Other studies have ignored the zero catches altogether, however this method runs the risk of overlooking important trends in abundance indicators. For example, it is possible that non-zero catch rate may remain constant over time suggesting that the stock is fished sustainably, while in reality, the number of zero catches is increasing over the time period indicating that the stock is in decline (Stefansson 1996). Constant catch rates and increasing zero-catches can occur if the stock contracts to prime habitats, with density in those habitats remaining high, but with total biomass falling.

An appropriate solution is to use the delta approach (Maunder and Punt 2004, Barry and Welsh 2002), that is to model the probability of obtaining a non-zero catch (in this case, the probability of catching at least one striped marlin), and the catch rate for non-zero catches, separately. This methodology was used here to model the data in these two steps. Firstly we modelled striped marlin “encounters” – the presence or absence of striped marlin in the catch – in terms of the explanatory variables to obtain the probability of a non-zero catch. Secondly, we modelled the relationship between catch rate and the explanatory variables, conditional on the species being present in catch. A combined abundance index was then calculated from these analyses, taking into account trends from both these data series.

The GAM models were used in an effort to gain information pertaining to the following questions:

1. What do catch rate data derived from longline and recreational data sets indicate about trends in abundance of striped marlin off the east coast of Australia, and is there any evidence for localised depletions?

2. Do trends in the indices of abundance differ depending on the data source from which they are derived and if so, what might be driving these differences?

3. What environmental, gear related and regional factors affect the variability in catch rates for striped marlin by the different sectors? What do these relationships imply about the biology and catchability of the species?

The results of these analyses are then discussed in light of potential implications for both fisheries management and resource sharing processes in the ETBF.

3.2 Methods

3.2.1 Data collection

Eastern Tuna and Billfish longline fishery data:

Longline data from this fishery was sourced from AFMA catch and effort logbooks. Logbook data is filled out by longline fishing captains after each fishing operation, and submitted to the AFMA for entry onto their electronic database. It should be noted that domestic longline data drawn from logbook records can suffer from errors in reporting, and from inconsistent or incomplete format of reporting (most detail catches by species, but others only record total catch per set etc). Other errors such as species misidentification can also introduce an unknown, but probably small degree of error into the database. That noted, a comparative analysis of observed and logbook based catch data conducted by Bromhead et al. (2004) found no significant difference between observed and logbook recorded catch rates or discard rates for striped marlin taken by longline in the ETBF in any of the four small time area strata examined.

For the ETBF longline fishery, catch and effort data is recorded in logbooks on an operation by operation basis. Nominal catch rates are calculated as the number of fish caught per 1000 hooks, for each fishing operation. Other ETBF longline data considered in the modelling process included:

Vessel ID

Year

Quarter

Start time of set

Latitude

Longitude

Hooks per basket

Use of lightsticks

Bait life-status

Region

Region*Quarter

Other gear specific variables recorded in logbooks were not considered due to a lack of data. Some factors were excluded (e.g., Vessel ID) where they represented too many separate categories for the model to easily handle. We used calendar year to represent the quantity of interest: long-term trends in striped marlin catch rates. Gamefishing tournaments are held during a fishing season that extends from about October to May. We restricted analyses to January–May because this is when most of the tournament catches of striped marlin are reported. Longlining is also seasonal, depending on the geographical location and species targeted. However, coding the data by calendar year or fishing season would not make any difference to the long-term trends that we see in standardised catch rates. It might show the time of peaks (or troughs) several months earlier or later than they actually occurred. However, this would be difficult to discern along an axis that consists of ten or more years (>120 months). Furthermore, the standardised catch rates and encounters presented in this report are smoothed. Seasonal variations in striped marlin encounters or catch rates are covered by the three month quarter variable in each model.

Tournament monitoring data:

Gamefishing tournaments have been monitored on the east coast through a program originally initiated by Pepperell Research through the Eastern Tuna Management Advisory Committee, and subsequently taken over by NSW DPI. The Gamefish Tournament Monitoring Program (GTMP) is designed to collect information on recreational catch, effort, sizes and spatial distribution of catches. The program has monitored tournaments from 15 east coast ports (Mooloolaba to Bermagui) throughout each game fishing season from 1993 to 2005 (since 1996, it has been limited to Coffs Harbour – Bermagui). Catch rates are recorded for over 30 species (Murphy et al., 2002; Pepperell and Henry, 1998). The fishing season constitutes a 10-month period from September to June. Data are collected via radio reports from participating boats at 2-3 hour intervals during each fishing day of a tournament. The location of each vessel is reported on each radio schedule. Catch data is collected in the form of number of strikes, hook-ups and actual captures (for weigh ins). Effort data is collected in the form of “directed effort”, whereby boats report on the method being used such as ‘trolling’ or ‘drifting’ (which indicates species groups being targeted) at the same time they report on catch and effort data. Catch rates for species are calculated only for boats which actually targeted these species groups. It should be noted however that this method does not allow separation of effort by individual species. Details of the methods used to monitor these tournaments are described in Pepperell and Henry (1998), Murphy et. al. (2002) and Lowry and Murphy (2003) and Park and Austin (in prep.).

Tournaments are scheduled according to the expected general movement patterns of billfishes, tunas and sharks for various localities along the coast (Murphy et al., 2002). Availability and abundance of many of these species is related to the seasonal changes in the Eastern Australian current.

For the tournament based “fishery”, catch (number of fish tagged or retained) and effort (hours fished) data is recorded in via radio schedules. Nominal catch rates are calculated as the number of fish caught per hour, for each fishing day. Other tournament data considered in the modelling process included:

Year

Month

Port

Latitude

Longitude

Number of other species caught

Three different subsets of data were extracted from the tournament monitoring database to assess their use as indices of abundance or availability over time. These subsets were:

1. Trolling data subset – all catch and effort data for radio reports where the fishing methods were specified as trolling were extracted to this data subset. This dataset excludes “drifting” methods of fishing which are primarily targeted at shark species and typically do not catch marlin.

2. Marlin subset – extracted from the “Trolling” dataset.

Both tournament and tag-release databases were used to identify boats that met the following criteria:

1. Marlin made up greater than 50% of their total tag-release record

2. Vessels had fished for at least 5 years

3. Vessels had fished at least 5 tournament days in each year

These criteria aim to exclude much of the fishing effort attributable to infrequent, inexperienced gamefishers whose fishing methods are likely to vary widely in success. This subset of fishers may swamp the more targeted effort in many of the tournaments and at different times of year, making catch rates extremely difficult to standardise in a way that will provide a meaningful relationship with the availability of the fish or their abundance in an area over time.

Striped marlin subset – extracted from the “Marlin” dataset. This dataset comprises data from vessels meeting the following criteria:

4. Striped marlin make up greater than 50% of the total tag-release or capture record
5. At least 20 striped marlin had been caught by the vessel over its recorded fishing history
6. Vessels had fished for at least 5 years
7. Vessels had fished at least 5 tournament days in each year

In addition, fishing effort occurring in water depths of less than 80 metres were also excluded, on the basis that vessels targeting small black marlin tend to fish inshore in shallower waters where striped marlin rarely occur. These criteria aim to further refine the catch and effort dataset to those vessels and fishing effort that are more likely to be consistent in how and where they fish over time and are more likely to fish for striped marlin.

Subsequent analyses determined that only the “Troll” data subset had sufficient data for a model based analysis. The “Marlin”, “Striped Marlin” and “less than 80 metre” subsets might be considered in future.

Initial characterisation and screening of the “Troll” tournament monitoring database resulted in some data being excluded from further analyses, generally based on reasonable evidence to suggest the data were incorrectly recorded, or were not relevant to the analyses being undertaken. These exclusions included fishing records lacking dates, latitudes or longitudes.

Environmental data: The environmental data sets used as independent explanatory variables were obtained from various sources (AFMA logbook data; Bureau of Meteorology; US Naval Observatory; Commonwealth Scientific and Industrial Research Organisation; BRS) and included the following:

Variable	Longline	Tournament	Source
Wind speed	x	x	AFMA
Southern Oscillation Index	x	x	BM
Moon phase	x	x	USNO
Bathymetry	x	x	CSIRO/BRS
Sea surface temperature	x	x	CSIRO
Chlorophyll a concentrations	x	x	CSIRO
Magnetic anomaly	x	x	CSIRO

These were added into the longline and tournament databases using the dates, latitudes and longitudes to attribute variables to fishing operations. In the Eastern Tuna and Billfish Longline Fishery, sea surface temperature (SST) values were assigned to each set contained within each one-degree grid. For tournament data where boats moved during the day, the "mean" latitude and longitude was used to assign environmental variables.

3.2.2 Models

Catch rate standardisations were obtained using the delta approach (Maunder and Punt 2004). The probability of obtaining a non-zero catch was modelled using a GAM with binomial response. The catch rate, given that the catch rate was non-zero, was modelled using a GAM with a lognormal model. The two models were fitted and predictions were obtained for each observation for each year for both models. These predictions were multiplied together to obtain an expected catch rate index for each observation for each year. The average index was calculated for each year to give the standardized catch rate for that year.

Models were fitted in R (R Development Core Team 2004) using the *gam* function in the *gam* package described in Hastie (1990). Continuous variables were fitted as smooth terms through the use of a smoothing spline. For example, if *var* is a continuous variable, s(*var*) will fit *var* as a smooth term.

Models were selected using the stepwise procedure implemented in the *step.gam* function (Hastie 2004) in R (R Development Core Team 2004). This function fits GAMs in a stepwise fashion selecting the model with the smallest AIC statistic. For each continuous variable considered in the model, a list of candidate forms for the term is supplied. In this case the term could either appear not at all, linearly or as a smooth function estimated non-parametrically.

The uncertainty around the index was calculated using a parametric bootstrap with two levels. For each bootstrap sample, a presence-absence random variable was generated from a Bernoulli distribution with probability equal to the bootstrap predicted probability for each observation for each year. A random variable was generated from a lognormal distribution with mean equal to the bootstrap predicted mean for each catch rate observation for each year and variance equal to the residual variance of the bootstrap model. The two sets of simulated predictions were multiplied together for each bootstrap sample to give the predicted catch rate indices for each observation for each year. The average abundance index was calculated for each year for each of the 500 bootstrap iterations. A 95% confidence interval was then calculated for each year by taking the 0.025% and the 0.975% percentiles from the bootstrap distribution for each year.

3.3 Results and discussion

Eastern Tuna and Billfish longline fishery data

For practical reasons the variables used in the stepwise model selection process were chosen to contain no missing data or small amounts of missing data. These variables were weekly sea surface temperature (SST), region, quarter, hooks per basket, start time, magnetic anomaly, moon phase, bait type and year. These were chosen because of their hypothesised relationship with catch rate.

The final model used for the probability of obtaining a non-zero catch was

pa ~ s(weeklysst) + region1 * quart.f + s(hpb) + s(sttime.r) + s(moon) + baitlife + s(year)

where pa is the presence-absence of striped marlin. Each variable in the final model had a statistically significant effect (95% level) on the probability of one or more striped marlin being caught in a longline set. Figure 19 contains plots of the components in this model. These indicate that the probability of catching at least one striped marlin is highest when SST is between about 22-26°C, during the 1st and 4th quarters of the year, for early morning and daytime sets, with live baits, around the full moon, and is much lower in region A (north) than in the central and southern regions, and declines as the number of hooks per basket is increased. The probability of catching at least one striped marlin increased through the 1990s to peak in 2000 and declined thereafter.

The final model used for the catch rate, given that the catch rate was non-zero was

log(cpue) ~ s(weeklysst) + region1 * quart.f + s(hpb) + s(sttime.r) + s(maganom) + s(moon) + baitlife + s(year)

where cpue is the number of striped marlin caught per 1000 hooks. Each variable in the final model had a statistically significant effect (95% level) on striped marlin catch rates. Figure 20 shows plots of the components in this model. These indicate that for operations taking at least one striped marlin, catch rates are highest above 20ºC, during the 1st and 4th quarters of the year, for early morning and daytime sets, and declines as the number of hooks per basket is increased. In contrast to the first model for probability of catching at least one marlin, the catch rate model indicated that region A (north) had higher catch rates than any of the other regions. In other words, striped marlin was rarely encountered in the northern region, but when they were encountered, longliners reported high catch rates. This might reflect regional differences in behaviour. Striped marlin in the northern region, for example, might form feeding aggregations, resulting in high catch rates when they are occasionally encountered by longliners.

Significant effects were also noted for moon phase and magnetic anomaly although these were relatively minor. Catch rates increased through the 1990s to peak around 1998 and declined thereafter.

Predictions from the two models were combined and averaged to give the standard catch rate for each year. Figure 21 contains plots of the standardised catch rate for each year and the yearly mean of the raw catch rate for the longline data. The uncertainty around the abundance index was calculated using the parametric bootstrap with two levels described above. Figure 22 shows the average standardised catch rate for each year with 95% confidence intervals, showing a clear peak in 1999 followed by a steady decline to 2004. Comparison of raw and standardised catch rate shows that standardisation did not greatly affect the long-term trend in annual longline catch rate, other than smoothing out some of the variation during 1995–2003.

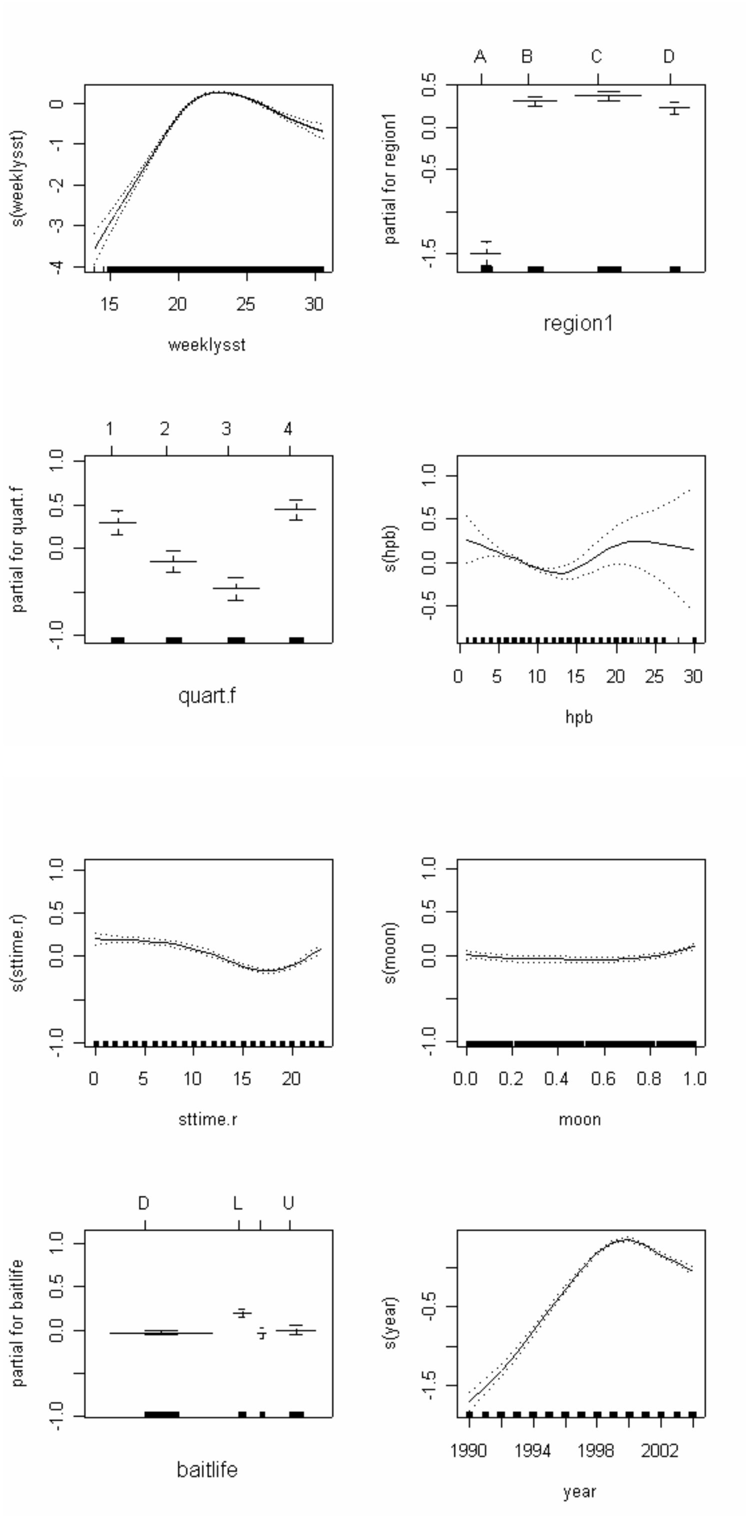

Figure 19. Effect of each explanatory variable that had a statistically significant effect on the probability of one or more striped marlin being caught in a longline set. Note that y-axis scales are not the same for all variables. For continuous variables, the dashed lines indicate plus and minus two point-wise standard errors.

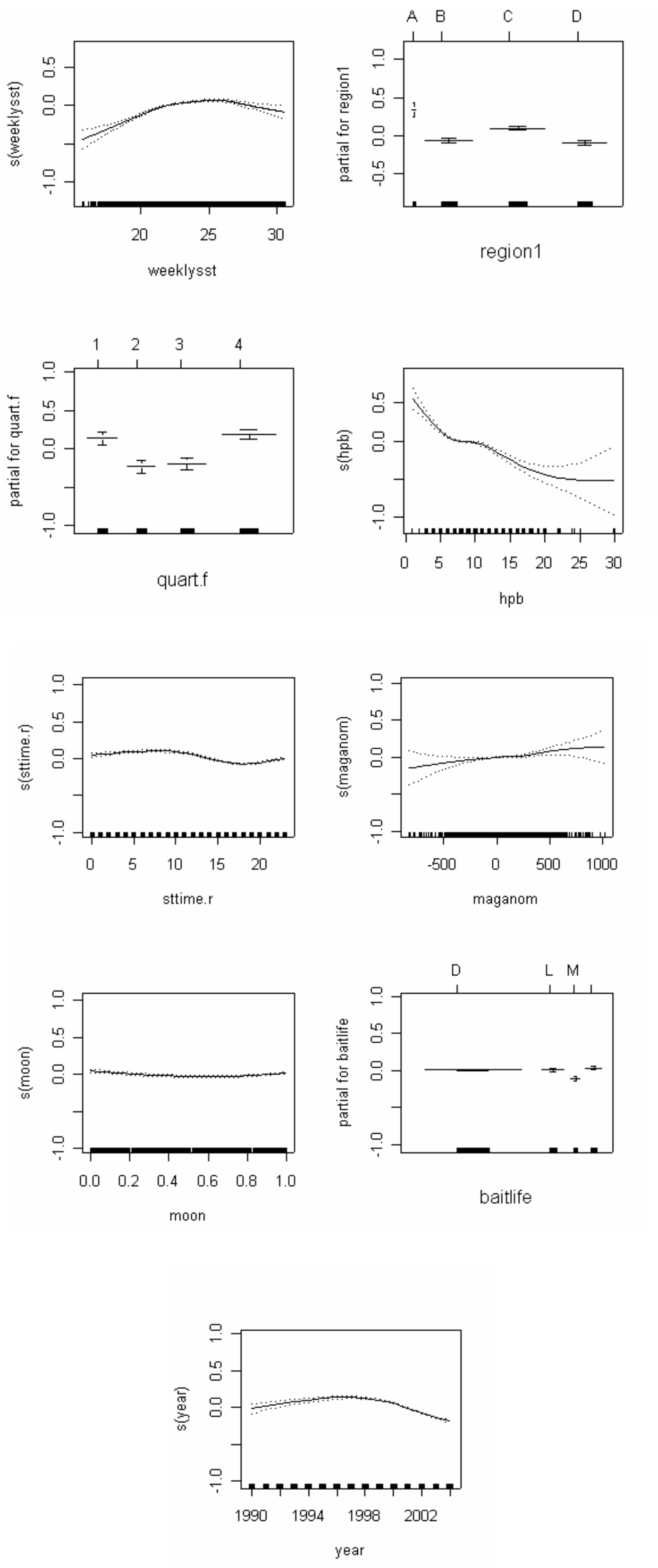

Figure 20. Effect of each explanatory variable on the catch rate for each longline set where striped marlin were caught.

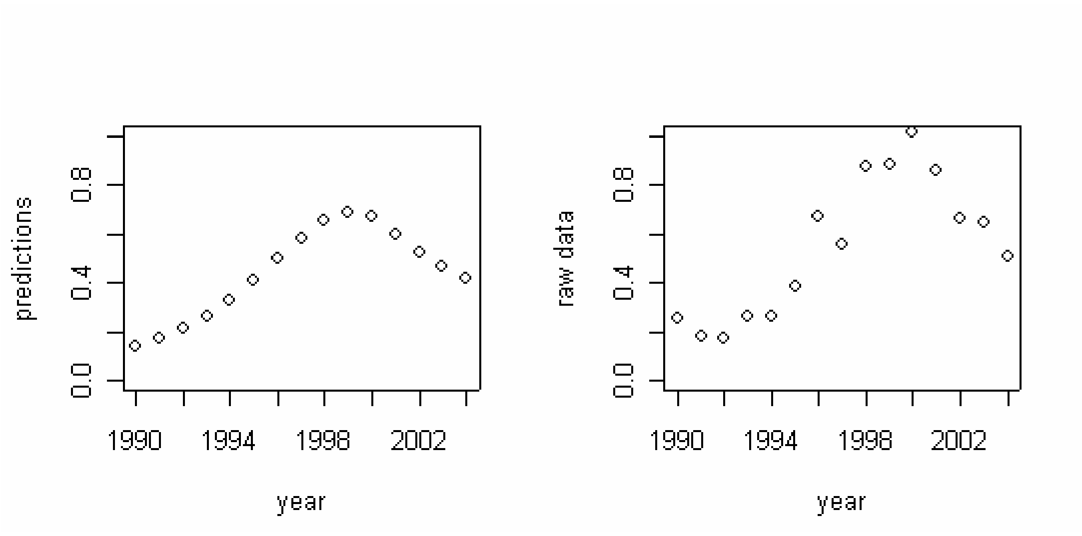

Figure 21. Plots of the standardised catch rate ("predictions") for each year and the yearly mean of the raw catch rate for the longline data.

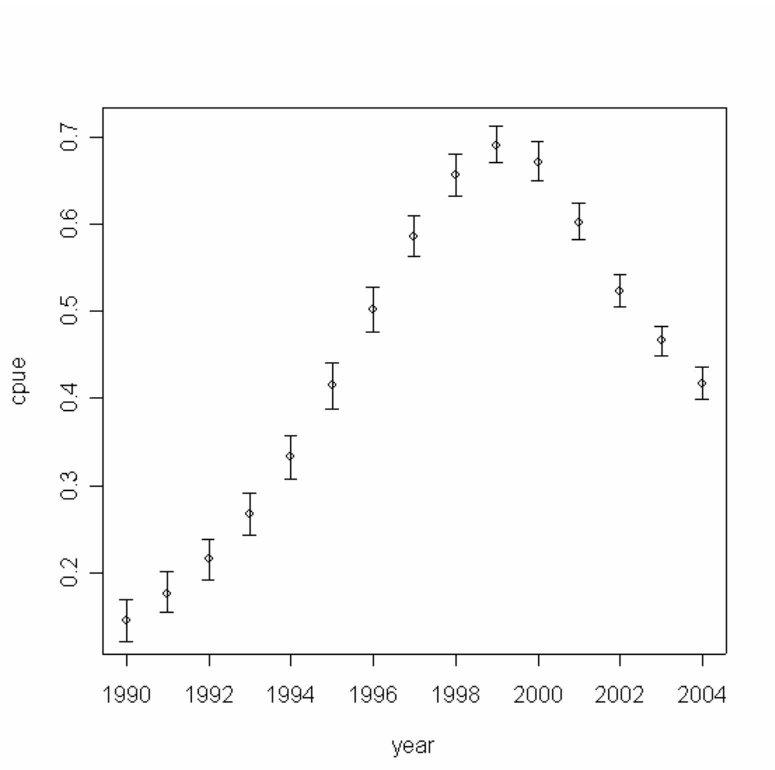

Figure 22. The average, annual standardised catch rate of longliners (open circles; vertical lines are 95% confidence intervals).

Tournament monitoring data

For practical reasons the variables used in the stepwise model selection process were chosen to contain no missing data or small amounts of missing data. These variables were weekly SST, region, month, average SOI, latitude, longitude, magnetic anomaly, moon phase and year. These were chosen because of their hypothesised relationship with catch rate. We did not have enough data to fit Tournament ID and a region by month interaction once weekly

SST, region, month, soirav, latitude, longitude, magnetic anomaly, moon phase and year have been fitted.

The final model used for the probability of obtaining a non-zero catch was

pa ~ s(weeklysst) + region2 + month.f + s(soirav) + s(lat) + s(long) + s(maganom) + s(moon) + s(year)

Each variable in the final model had a statistically significant effect (95% level) on the probability of one or more striped marlin being caught in a tournament. Figure 23 contains plots of the components in this model. These indicate that the probability of catching at least one striped marlin is highest when SST is between about 20-23°C, during the first three months of the year (1st quarter), during La Ninã periods (high SOI), and at more southerly latitudes and higher longitudes, and around the full moon. The probability of catching at least one striped marlin increased between 1994 and 1998 before declining to 2002 and then showing signs of increase again the following year.

The final model used for the catch rate, given that the catch rate was non-zero was

log(cpue) ~ weeklysst + region2 + month.f + s(soirav) + long + s(maganom) + s(moon) + s(year)

where cpue is the number of striped marlin caught per day. Each variable in the final model had a statistically significant effect (95% level) on tournament catch rate. Figure 24 shows plots of the components in this model. These indicate that catch rates for striped marlin are highest during the first three months of the year (1st quarter), and at more southerly latitudes and higher longitudes. Catch rates do not show the strong temporal (yearly) trend evident from the presence-absence model above.

Predictions from the two models were combined and averaged to give the standardised catch rate for each year. Figure 25 shows plots of the standardised catch rate for each year and the yearly mean of the raw catch rate for the longline data. Standardisation had a substantial effect on tournament catch rate. This is probably related to the limited temporal and spatial extent of tournament fishing. Tournaments nearly always involve day trips over a limited geographical area – most anglers do not venture more than 75 km from port during a tournament. Tournament anglers have a limited ability to follow the fish or operate in relatively rough weather (in fact, fishing is normally cancelled if a gale warning is current). Furthermore, tournament dates are set well in advance; fishing occurs in the designated location regardless of prevailing conditions. Consequently, there is considerably more variability in tournament catch rate than in the catch rate of longliners, which may follow target species over tens or hundreds of kilometres for days or weeks. Figure 26 shows the average standardised catch rate for each year with 95% confidence intervals, showing a pattern of steady increase until the late 1990s, then decline until 2002. Overlapping confidence intervals hamper conclusions about trends in the subsequent two years.

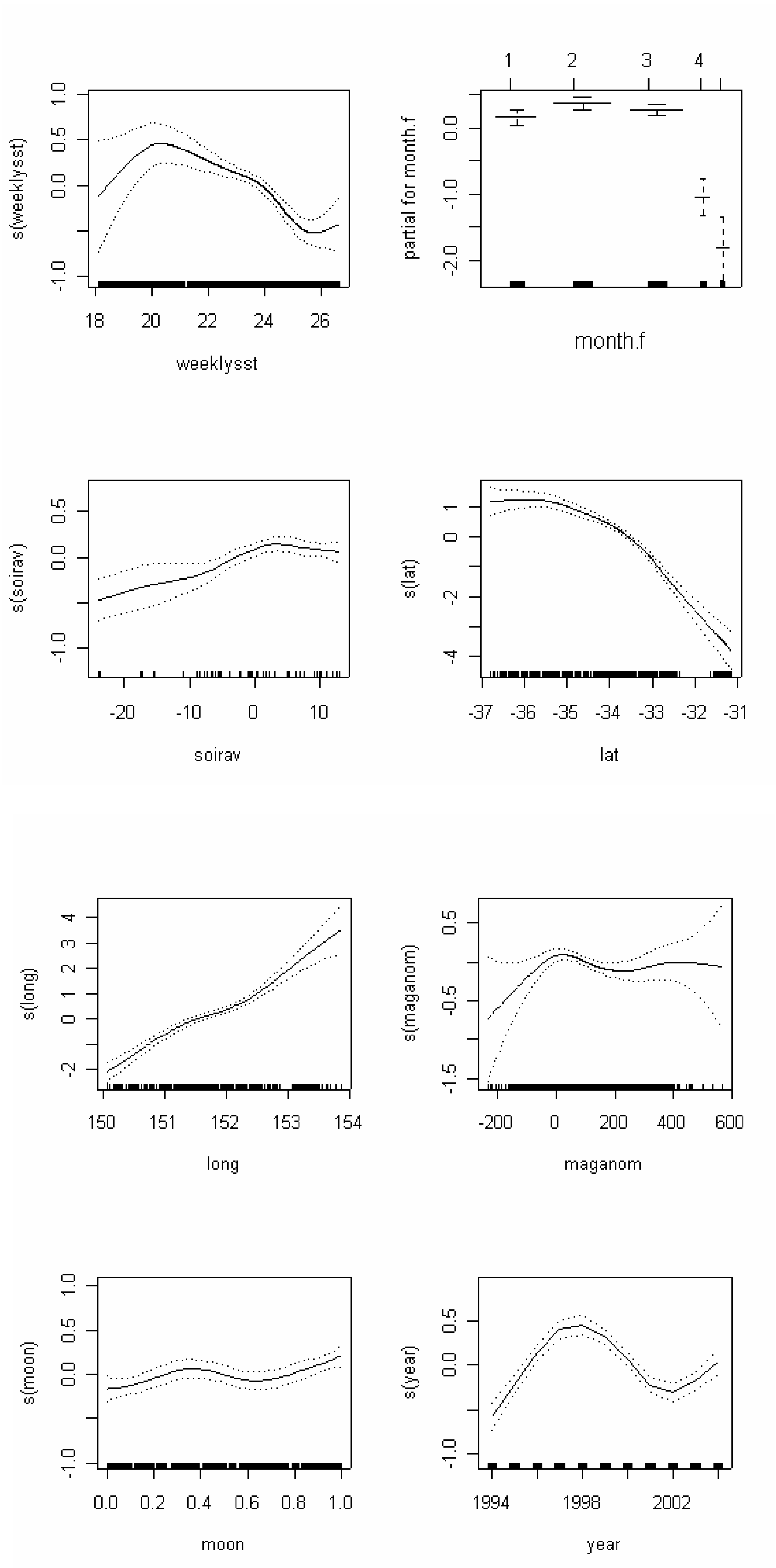

Figure 23. Effect of each explanatory variable that had a statistically significant effect on the probability of one or more striped marlin being caught by a gamefishing boat in one day of tournament fishing.

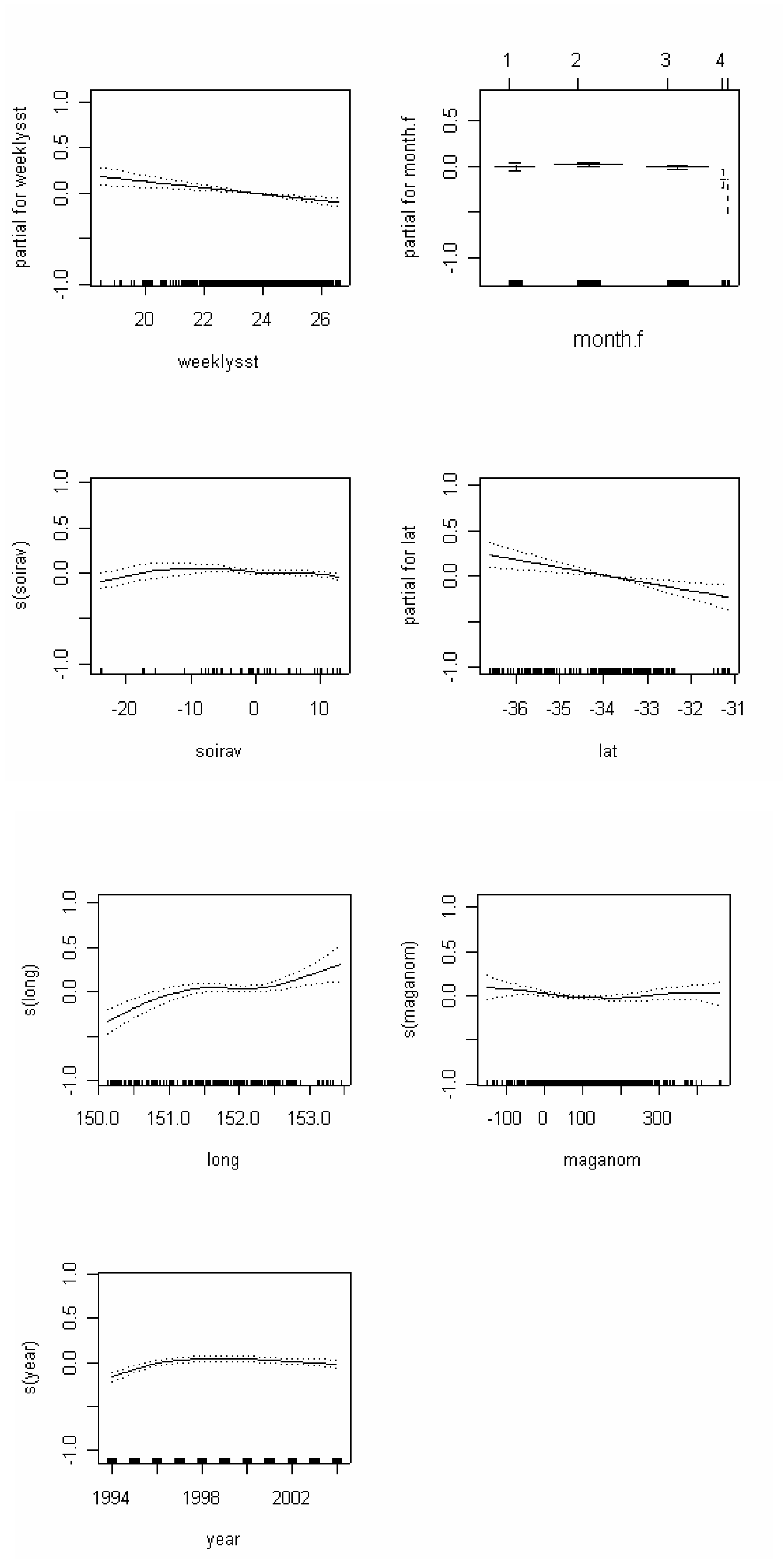

Figure 24. Effect of each explanatory variable that had a statistically significant effect on the catch rate of a gamefishing boat in one day of tournament fishing where striped marlin were caught.

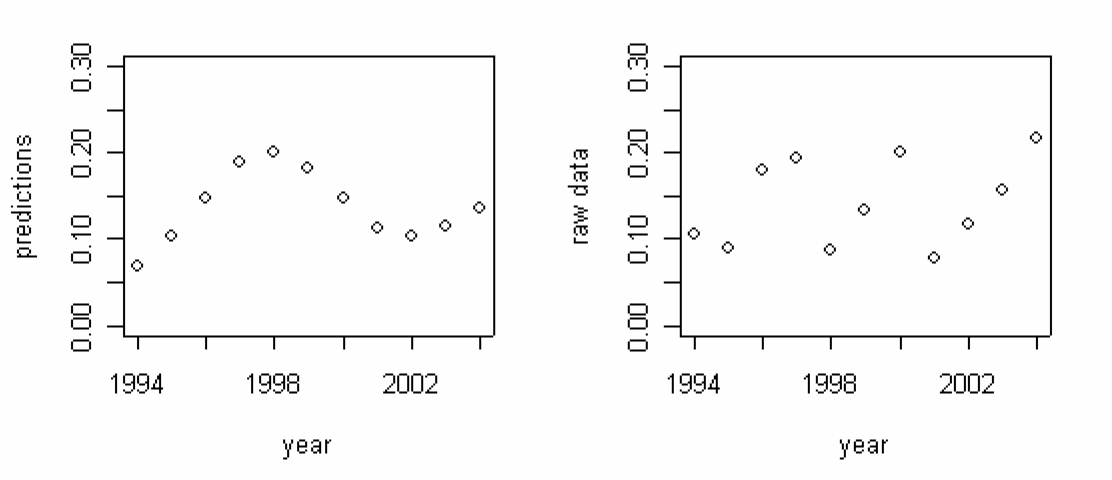

Figure 25. Plots of the standardised catch rate ("predictions") for each year and the yearly mean of the raw catch rate for the tournament data.

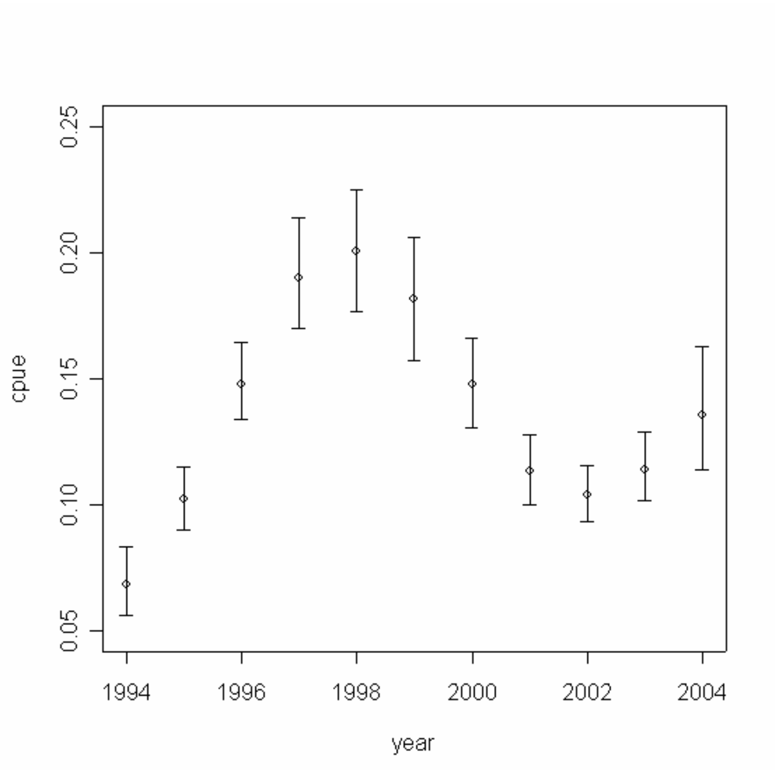

Figure 26. The average, annual standardised catch rate in tournaments (open circles; vertical lines are 95% confidence intervals).

Discussion

Striped marlin encounters (i.e., presence-absence) and catch rate in tournaments were low at elevated sea surface temperatures (>22ºC) and at high latitudes. By contrast, longline encounters and catch rate peaked at sea surface temperatures of 23–25°C. There was no clear pattern with latitude in the longline data, other than Region C (coastal NSW) producing frequent encounters and high catch rate, whereas encounters were relatively rare but catch rates were high in Region A (North Queensland).

Encounters and catch rates were high during summer and in shallow longline sets. Encounters – but not catch rates – were high in sets that used live bait. This apparent contradiction is explained by the lack of data on the life-status of bait. The longline models included 77 715 sets where bait life-status was known and 24 149 sets where bait life-status was unknown (most of these are from the 1990s when logbooks did not include a field for recording bait life-status). Live bait had a significant, positive effect on catch rates when the analyses were restricted to sets where life-status was known. We decided to include sets where life-status was unknown because life-status affected striped marlin catches and because omitting sets with unknown bait status would greatly reduce the total number of sets available for analysis.

For brevity, we refer to the combined catch rate – presence-absence GAM predictions for each sector as "standardised catch rate". Comparison of raw and standardised catch rates shows that standardisation did not greatly affect the long-term trend in annual longline catch rate, other than smoothing out some of the variation during 1995–2003 (Figure 21).

Standardization seems to have accounted for the variability in tournament catches, showing a pattern of steady increase until the late 1990s, then a decline until 2002 (Figure 26). Overlapping confidence intervals hamper conclusions about trends in subsequent years. The pattern of standardized tournament catch rates is remarkably similar to the pattern in standardized longline catch rates (although shifted temporally) (Figure 22). The tighter confidence intervals of the standardized longline catch rates show a clear peak in 1999 followed by a steady decline to 2004.

There are various interpretations of the annual trends in standardised catch rate. Hypotheses to explain the increasing trend in standardised catch rates during the 1990s include:

1. A strong recruitment pulse of striped marlin off eastern Australia during the early 1990s.

2. Striped marlin migrating to eastern Australia during the late 1990s.

3. Decreased activity by distant-water longliners in the south-western Pacific resulted in increased availability of striped marlin.

4. Longline and tournament fishers increased targeting of striped marlin or became progressively better at catching the species.

Hypotheses to explain the decreasing trend in standardised catch rates in subsequent years include:

1. Striped marlin migrated away from eastern Australia after 1999

2. Fishing depleted striped marlin off eastern Australia after 1999.

To be plausible, a hypothesis needs to be consistent with the trends in both sectors. For hypothesis #4, for example, improvements in targeting are unlikely to peak in exactly the same year for both sectors. On the other hand, depletion would result in the same pattern of declining catch rates in both sectors. This is a common pattern in commercial fisheries (e.g., swordfish) where catches and catch rates rapidly increase until fishing effort overshoots the sustainable level and catches and catch rates then decline. Evidence in both the NSW tagging database and Japanese longline data for the southwest Pacific indicates that a large pulse of smaller marlin entered the fishery in 1996–97, supports hypothesis #1 (recruitment pulse). Shifts in the geographical distribution of striped marlin associated with broad-scale oceanographic events (hypothesis #2) are also difficult to discount. High striped marlin catch rates are often associated with La Ninã periods, not just off eastern Australia, but in other parts of the Pacific Ocean. There were three consecutive La Ninã years in the mid to late 1990s.

Our models did not include variables that represent improvements in fishing gear and increased experience and skills among gamefishers and longliners targeting striped marlin that can be expected to have occurred over the years. Such improvements would have contributed to the increased catch rates witnessed during the 1990s. The absence of those effects in the model may have resulted in the post-1999 decline in abundance or availability being greater than indicated by our estimates of standardised catch rates.

The development of the Australian fishery immediately after the Japanese withdrawal makes it very difficult to analyse interactions over time. If Australia's fishery had developed a few years later, then it would have been easier to measure the effects of reduced longline fishing on the high catch rates experienced by the recreational fishery. However, such was the increased availability in the late 1990s that even if an impact was occurring, both sectors had higher catch rates than in the past, which would effectively mask the temporal effect.

Without further information, it is not possible to distinguish between these and other plausible hypotheses. In particular, we need to understand what standardised catch rates represent – the species' abundance, its availability or vulnerability to the fishing gear, or a combination of these. Regardless, of those explanations, we can conclude that the long-term trends in standardised catch rates are not due to the variables included in the models.

Localised depletion

To investigate whether there was evidence of localised depletion we modelled a restricted portion of the longline data, Region C (coastal NSW), where interactions between longliners and recreational anglers are most intense and striped marlin catch rates are highest. The Region C models had the same variables as the models for all four regions combined (termed the "All Regions"), except that they did not include the region variable. The distribution of variables was very similar for the Region C and All Regions, and the standardised catch rates showed the same pattern of steady increase until the late 1990s, followed by a declining trend. This suggests that the changes in standardised catch rates occurred across all regions and were not restricted to local areas.

4. Analyses of fishery interactions

4.1 Introduction

Past research: Analyses of fishery interactions presented by Bromhead et al. (2004) have been improved upon in the current chapter. The previous analyses looked for evidence of variation in nominal recreational catch rates and catches that might be linearly associated with changes in commercial fishing catches and catch rates. A positive relationship was found between commercial and recreational catch rates off southern NSW, but little could be concluded due to a lack of fine-scale recreational data. Furthermore, recreational catch rates need to be standardised to ensure that variation over time is not simply due to environmental or other factors not considered in the original analyses.

Model based approach: The following analyses use the models developed to standardise gamefish tournament catch rates over a 15 year period (see previous chapter) and test whether terms describing longline catches at the same times and in the same areas might explain a significant amount of additional variation in the tournament catch rates. One can then look at whether the relationship between longline catches and tournament catch rates is a positive or negative relationship. In other words, are high tournament catch rates associated with low longline catch, and are low tournament catch rates associated with high longline catches (a negative relationship), or do both fluctuate in a similar manner (a positive relationship). The former could be interpreted as evidence for a negative impact of longline catches on the recreational fishery targeting striped marlin while the latter might indicate little effect of one fishery on the other.

Selecting appropriate scales: Fishery interactions can potentially operate at a number of different scales. Vessels from one sector operating in the same times and areas as those from a second sector will be competing for the same local resource. Alternatively (or additionally) the interaction might also operate at broader spatial and temporal scales. For example, where a species is migratory (such as marlin), the catches of a sector operating in an adjacent area (and possibly adjacent seasons) from which the fish might migrate, could impact on abundance due to reduced immigration or reduction of the population as a whole. A range of interaction scenarios have been considered in the current analyses. Determining the scales at which longline catches might impact on the recreational fishery, requires consideration of the spatial and temporal variation in distribution of both sectors’ fishing effort (and catches) as well as aspects of the biology of striped marlin, in particular, their movements across seasons.

The previous chapter has shown that the recreational fishery is coastal, with most catches of striped marlin south of the NSW-Queensland border and highest off southern NSW. The commercial fishery also operates in the same area most of the year, as well as in northern offshore or high seas areas beyond the reach of recreational boats. A long history of commercial catch data suggests that 15-30°S constitutes the area of highest biomass of striped marlin in the southwest Pacific. Off eastern Australia, the highest catches in that latitudinal band are taken in the 3rd and 4th quarters, while the highest catches in coastal NSW waters, particularly south of Port Stephens, occur in the 1st and 2nd quarters. Tagging data (Figure 28) indicate that there is a seasonal migration at least between southern and northern latitudes. Hence, while current recreational concerns focus on longliners operating in the same times and areas as the recreational sector, it is also possible that the considerable level of commercial effort (not just domestic but foreign also) in the northern high seas waters (3rd and 4th quarters) could also affect the numbers of striped marlin migrating into southern coastal waters in the 1st and 2nd quarters where the recreational sector is operating. Conversely, there is little evidence of significant migration of marlin south of 38°S, so it might not be relevant to include commercial catch terms from areas at or beyond the edge of the striped marlin's usual range.

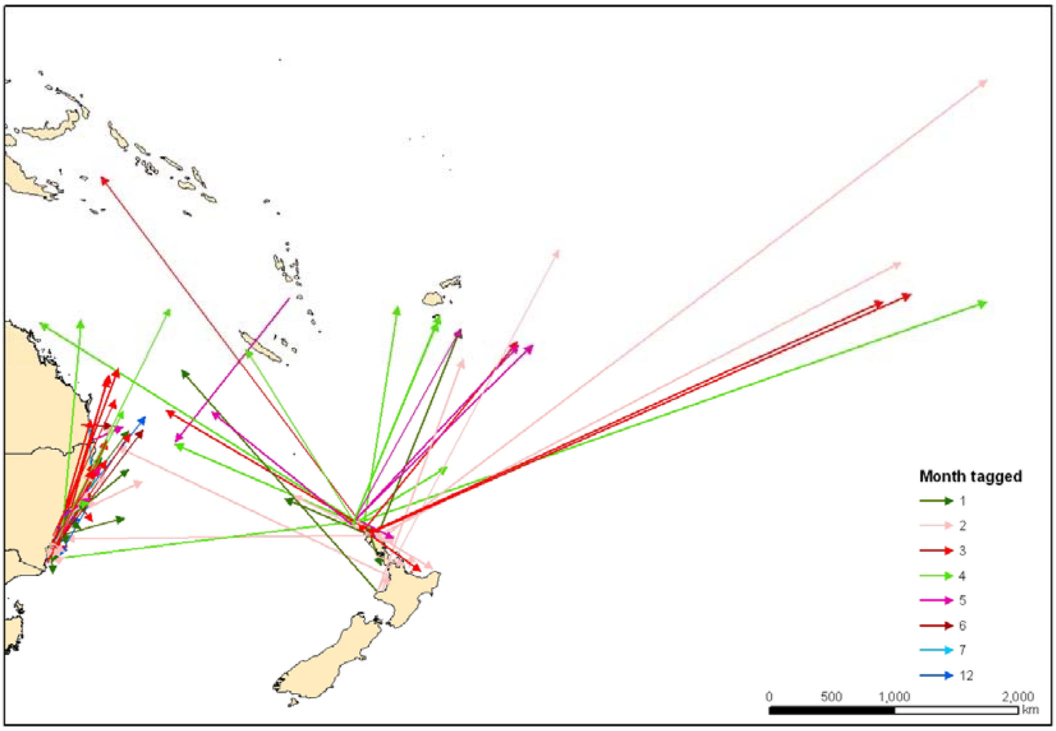

Figure 27. The positions of striped marlin tagged and recaptured in the Southwest Pacific Ocean (Data Sources: NMFS, NSW DPI, NIWA, TBF, 2005).

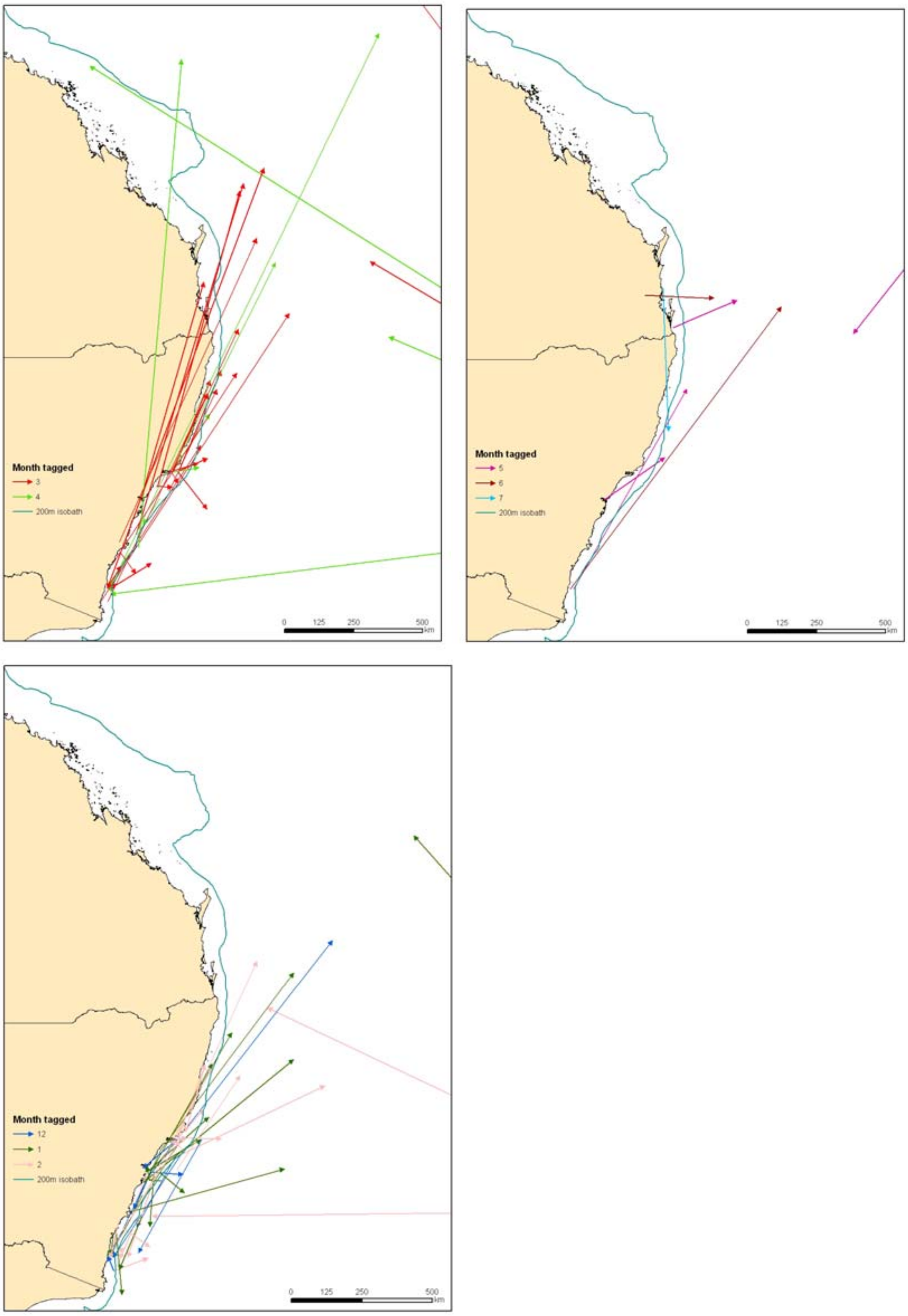

Figure 28. The positions of striped marlin tagged and recaptured off Eastern Australia since 1990. Movements of marlin from the east of these panels were tagged off northern New Zealand, with the exception of the single fish shown in the top right panel which was tagged off Vanuatu (Data Sources: NMFS, NSW DPI, NIWA).

Terms representing six different spatial and temporal aggregations of longline catches were tested within the catch rate model to determine if any of these explained additional variation in tournament catch rates. The levels of aggregation were:

1. Longline catch in the same tournament period and area (defined as a box covering the outer limits of the tournament grids reported during the tournament under examination).

2. Longline catch in the same tournament period and area, but including waters one degree north, east and south of the tournament area (the western boundary is land).

3. Longline catch in the month prior to and including the tournament period and in the tournament area.

4. Longline catch in the month prior to and including the tournament period, and including waters one degree to the north, east and south of the tournament area.

5. For tournaments in the southern NSW zone, longline catch in that zone, and to the north of the zone up to 15°S, for the tournament month and including the previous nine months (i.e. including the northern high catch commercial seasons), for the domestic fleet only. For tournaments in the central and northern zones, the same limits, but including the southern zone catches.

6. Longline catch and catch rates derived for all fleets operating in the western south-west Pacific Ocean, during and nine months prior to any particular tournament boat day

Table 4. Summary of spatial and temporal aggregations of longline catches that were tested to determine whether they explained any additional variation in tournament catch rates

Variable no.	Time	Area
1	tournament	tournament
2	tournament	tournament + 1° N, E and S
3	tournament – 1 month	tournament
4	tournament – 1 month	tournament + 1° N, E and S
5	tournament – 9 months	tournament + eastern Australia
6	tournament – 9 months	tournament + SW Pacific

4.2 Methods

The aim was to assess whether the longline catch variables explain a significant amount of variation in the tournament catch rates after having accounted for tournament and environmental variables. The model for tournament catch rates (given that the catch rate was non-zero) as presented in the previous chapter was fitted:

log(cpue)~weeklysst+region+month+s(soirav)+long+s(maganom)
+s(moon)+s(year)

We fitted the tournament catch rate model holding the coefficients of the tournament and environmental variables fixed by fitting the predictions of the above model as an offset. Each aggregated longline catch variable (‘catch’) was individually fitted in this model to assess whether it explained additional variation in tournament catch rates:

log(catch rate)~offset(log(standardised catch rate))+s(longline catch)

An offset is a commonly used device in GLMs and GAMs It is a component of the linear predictor that is known and requires no coefficient. An offset allows us to evaluate the contribution of additional terms while holding fixed those already fitted.

The rationale behind this approach was to provide a fixed basis for assessing the effect of the longline catch variables. While the flexibility of GAMs is a major advantage, it can also lead to unstable behaviour as new correlated variables are added. The approach chosen seeks to minimise this instability of structure allowing the effect of the terms to be assessed more easily.

The effect of the terms was tested in a number of ways. First, the significance of the nonparametric component (s(longline catch)) was assessed using the approximate ANOVA test obtained as part of the summary of the fitted model in the R package. If the nonparametric component was not significant, the presence of a linear relationship was then tested using ANOVA. The robustness of these conclusions was tested by two different approaches. First, the same models were fitted to a restricted set of data and the results verified. This was done to check that extreme values were not skewing the relationship. Second, GLMs were used to check the significance of the variable when added as a linear term. This was done because the inference from the GLM is more readily accepted. However if a significant non-linear relationship is identified from a GAM, it is possible that the relationship will be found to be non-significant when a GLM is fitted to the same data. This is because the effect may truly be non-linear and forcing a linear relationship in a GLM is not appropriate.

4.3 Results

Figure 29 shows plots of the relationships between the tournament catch rate and the aggregated longline catch variables (once the fishing and environmental variables have been accounted for). The relationship with the first longline catch variable, viz longline catch in the same tournament period and area was significant at the 95% level. The second and third longline catch variables (longline catch in the same tournament period and area, but including waters one degree north, east and south of the tournament area, and longline catch in the month prior to and including the tournament period and in the tournament area) were significant at the 90% level.

Note that the tic marks along the x-axis of Figure 29 (and other graphs in this chapter) indicate the density of observation. Trends are not statistically significant at extreme ranges of the data where few observations were available, as indicated by the wide confidence intervals. For variable #1, for example, the apparent increase in tournament catch rates when more than

40 striped marlin are taken by longline in the tournament area during the tournament is not statistically significant because this is based on only one observation.

The models were fitted to restricted sets of data excluding the extreme longline catches to make sure that the extreme values were not driving the relationship for the variables #1–4, which contained extreme values. Figure 30 shows plots of the relationships between the tournament catch rates and the first four aggregated longline catch variables for reduced data sets where the extreme longline catches were excluded. Again, the relationship between the first longline catch variable (longline catch in the same tournament period and area) and tournament catch rates was significant at the 95% level. Once the extreme longline catches (in the same tournament period and area, but including waters one degree north, east and south of the tournament area) were excluded, the relationship between the tournament catch rates and the longline catch in the same tournament period and broader area (longline catch variable 2) was significant at the 95% level. The relationship between the tournament catch rates and longline catch in the month prior to and including the tournament period and in the tournament area (longline catch variable 3) was significant at the 90% level once the large catches were removed. These results show that the extreme values are not driving the relationship.

The results show that high longline catches in the same tournament period and area are associated with reductions in standardised tournament catch rates. There is a significant decrease in the tournament catch rates for longline catches of 0 to 8 fish and 25 to 26 fish. The drop in the effect of the first and second longline catch variables on the log catch rate is about 0.1. This relates to a 10% drop in tournament catch rate.

The model used to assess the effect of the longline catch on tournament catch rates is:

$$\begin{aligned}
\log(\text{catch rate}) &= \log(\text{standardised catch rate}) + s(\text{longline catch}) \\
\text{catch rate} &= e^{\left(\log(\text{standardised catch rate}) + s(\text{longline catch})\right)} \\
&= e^{\log(\text{standardised catch rate})} e^{s(\text{longline catch})} \\
&= \text{standardised catch rate} \times e^{s(\text{longline catch})}
\end{aligned}$$

where s(longline catch) is a smooth function of the longline catch.

For the first longline catch variable (Figure 29), we see a drop of 0.1 in the effect of the longline catch on the log of the catch rate. The vertical axis represents the value of the smooth function at each value of the longline catch. The value of the smooth function drops from 0 to 0.1. The change in catch rate is then:

$$\begin{aligned}
&\text{catch rate}_1 - \text{catch rate}_2 \\
&= \text{standardised catch rate} \times e^{s\left(\text{longline catch}_1\right)} - \text{standardised catch rate} \times e^{s\left(\text{longline catch}_2\right)} \\
&= \text{standardised catch rate} \times e^{0} - \text{standardised catch rate} \times e^{-0.1} \\
&= \text{standardised catch rate - standardised catch rate} \times 0.9 \\
&= 0.1 \times \text{standardised catch rate}
\end{aligned}$$

This corresponds to approximately a 10% drop in catch rate. The same drop in catch rate is seen in the plot for the second and third longline catch variable (note however that these relationships were not significant at the 95% level but were significant at the 90% level).

Looking at the plots in Figure 29 of the relationships between tournament catch rate and the longline catch variables, the relationships for first and second longline catch variables are convincingly non-linear, whereas the relationship for the third variable could possible be simplified to a non-linear relationship. There does not appear to be a relationship with tournament catch rate for the fourth, fifth and sixth longline catch variables. Generalized linear models were fitted to check the significance of each longline catch variable when fitted as a linear term. As expected, the third longline catch variable (longline catch in the month prior to and including the tournament period and in the tournament area) was the only significant variable. This suggests that a linear relationship is adequate.

Each aggregated longline catch was also individually fitted in the presence-absence model, to assess whether it explained additional variation in the probability of at least one striped marlin being caught by a gamefishing boat on one day of tournament fishing.

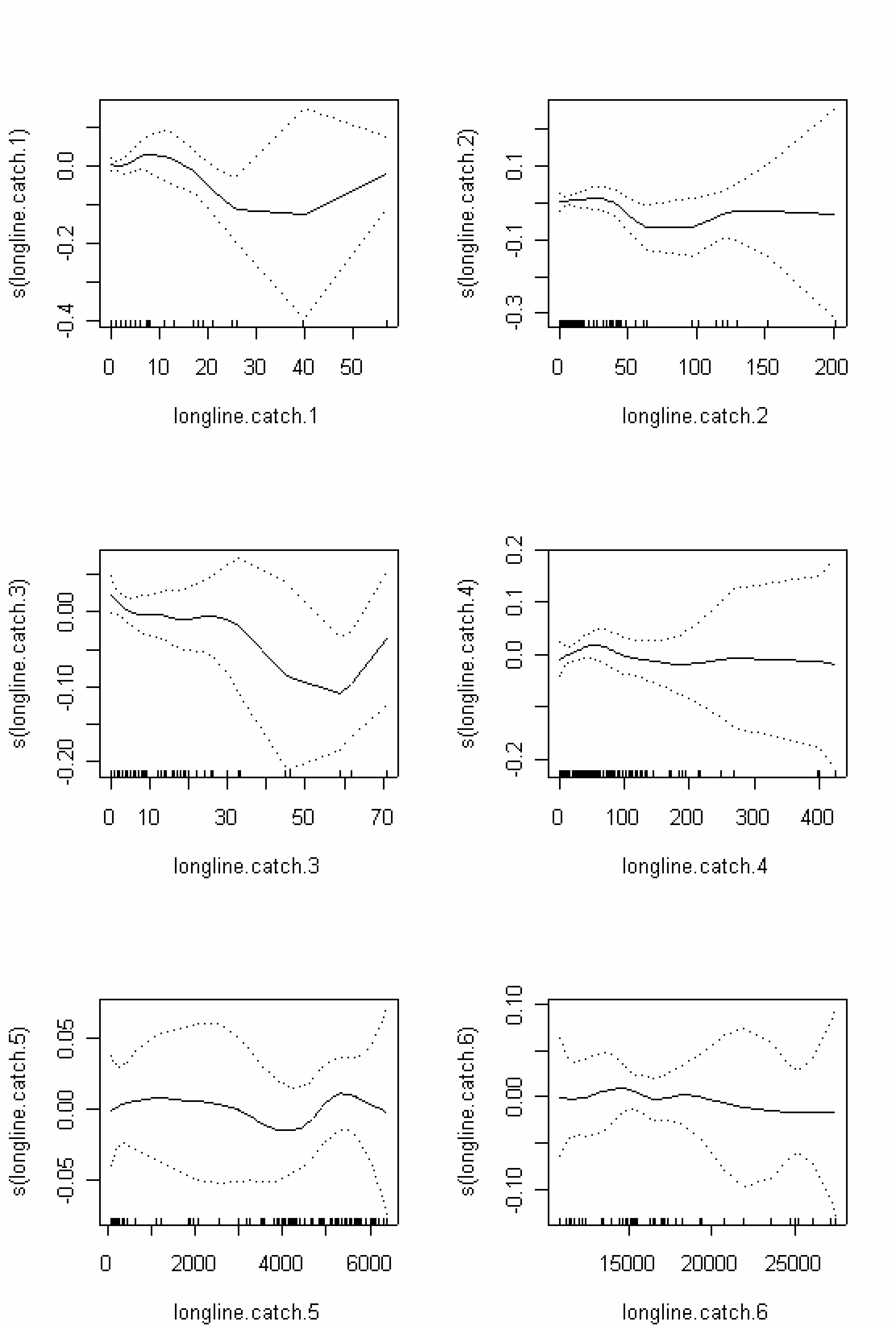

Figure 29. Effect of each longline catch variable on the catch rate (when the catch rate was non-zero) of a gamefishing boat in one day of tournament fishing.

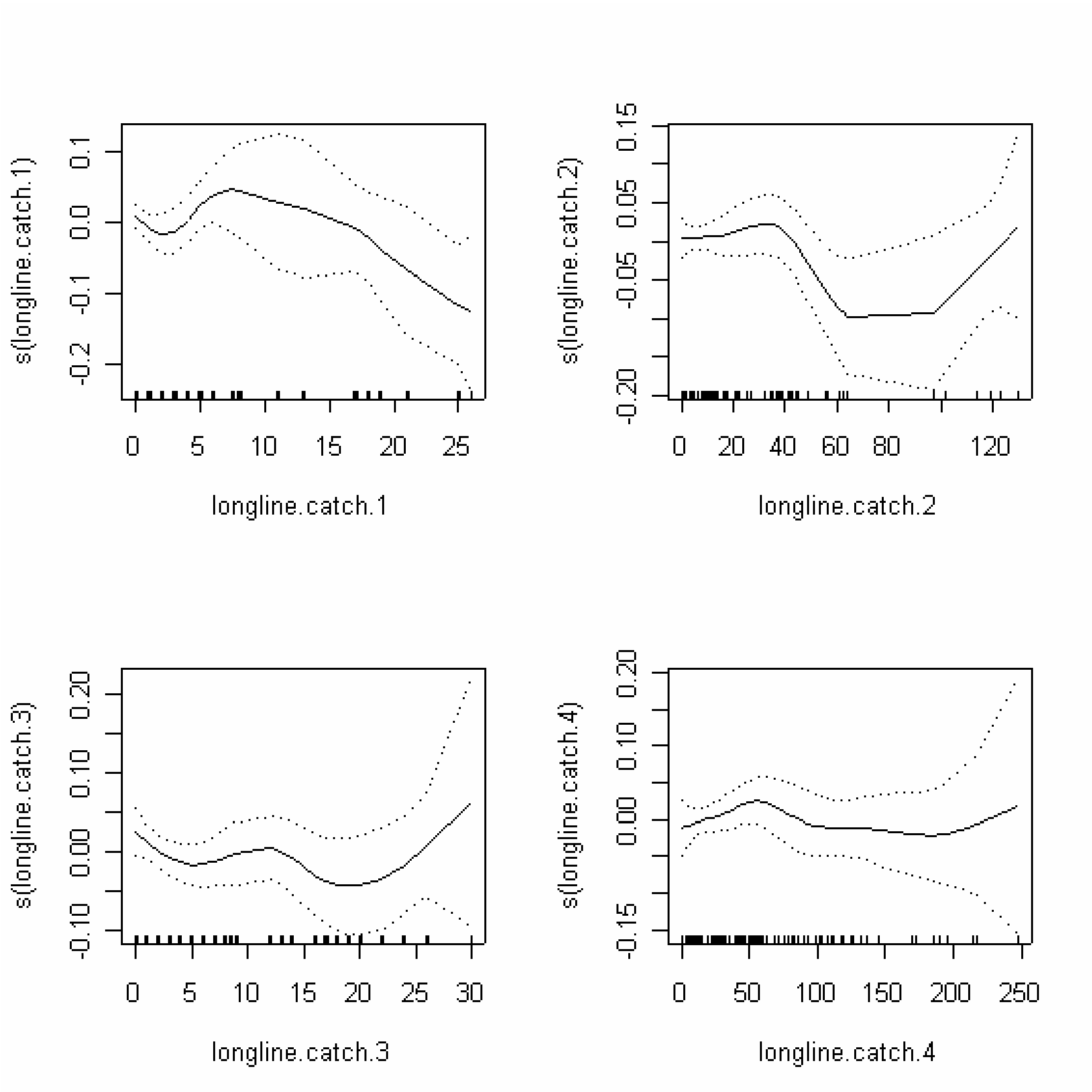

Figure 30. Effect of longline catch variables #1-4 on the catch rate of a game fishing boat in one day of tournament fishing for reduced data sets that exclude extremely large longline catches.

Figure 31 presents plots of the relationships between the probability of a non-zero tournament catch and the aggregated longline catches (once the fishing and environmental variables have been accounted for). There were significant non-linear effects for all of the six aggregated longline catches. Figure 32 presents plots of the relationships between the probability of a non-zero tournament catch and the first four aggregated longline catches for reduced data sets where the extreme longline catches were excluded. Again all of the non-linear relationships were significant at the 95% level demonstrating that the extreme values are not driving the relationship. It is difficult to interpret the effects of longline catch on the probability of encountering one or more striped marlin because situations where large numbers of striped marlin are caught are not distinguished from situations where only one striped marlin was caught.

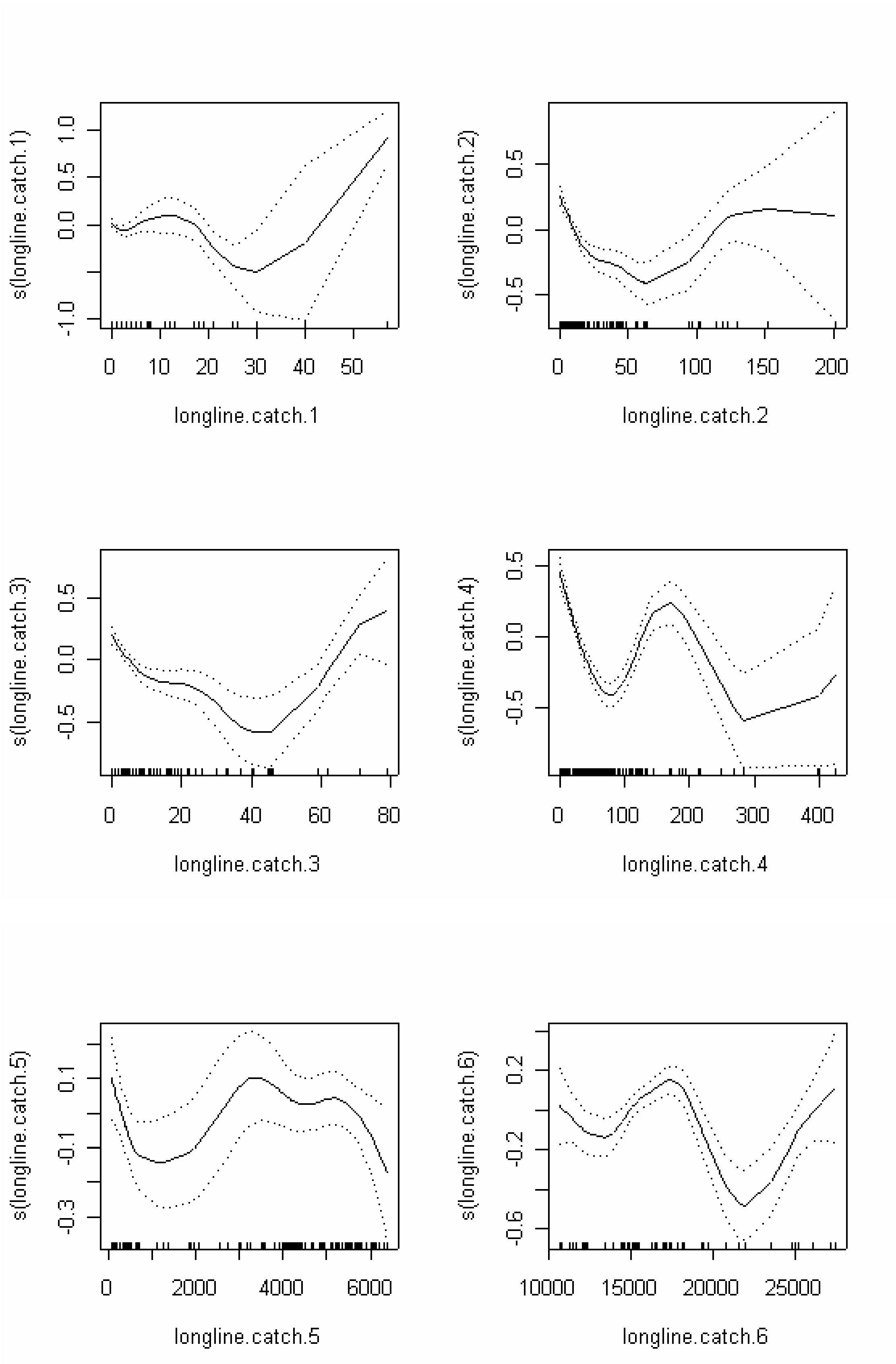

Figure 31. Effect of each longline catch variable on the probability of a gamefishing boat catching at least one striped marlin in one day of tournament fishing.

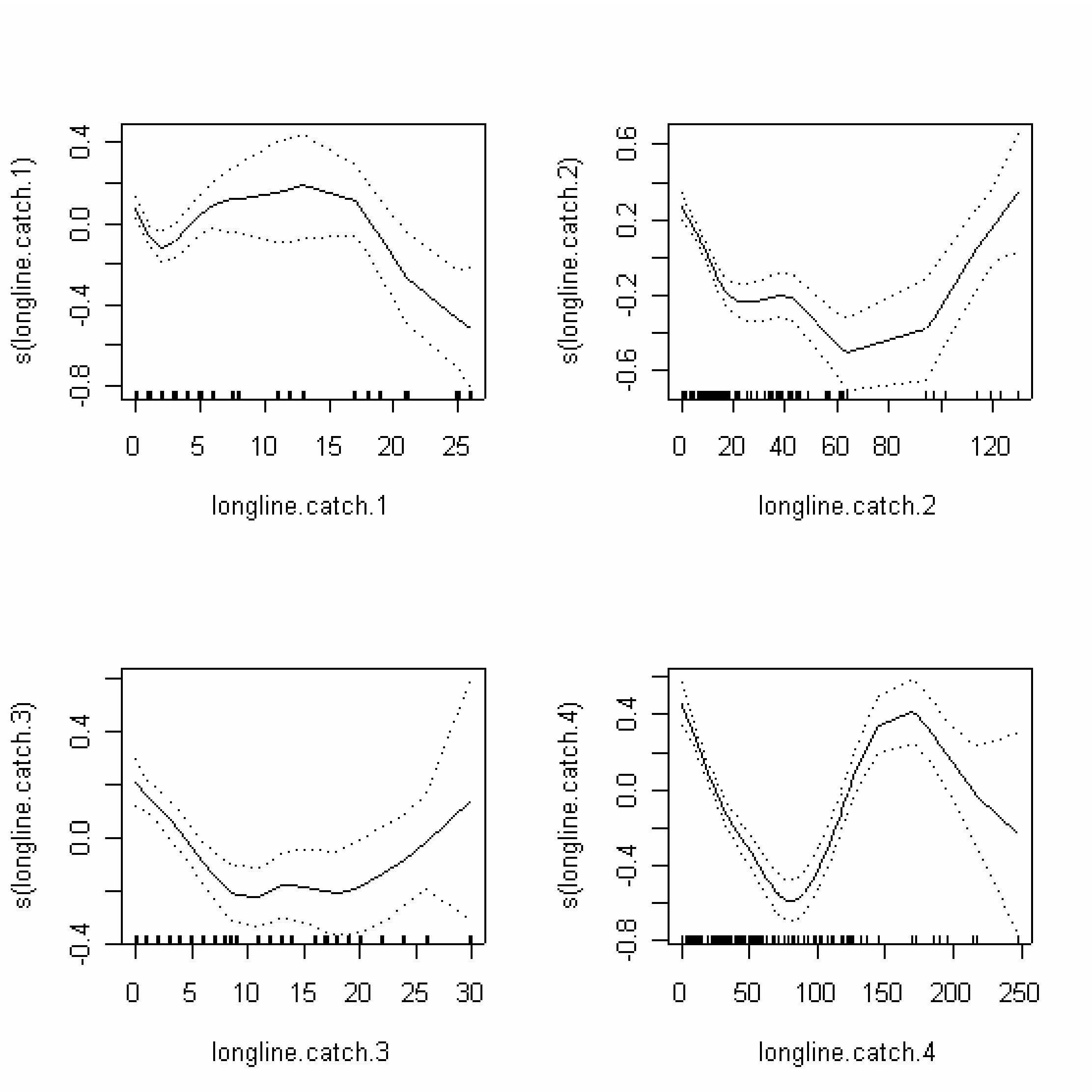

Figure 32. Effect of the first four longline catch variables on the probability of a gamefishing boat catching at least one striped marlin in one day of tournament fishing for reduced data sets that exclude extremely large longline catches.

We also attempted to assess the effect of competition among gamefishing boats on tournament catch rates by fitting the average number of boats fishing per tournament day in the tournament catch rate model:

$$\log(\text{catch rate}) \sim \text{offset}(\log(\text{standardised catch rate})) + s(\text{boat days})$$

The non-linear relationship between tournament catch rates and the average number of boats fishing per tournament day was not significant at the 95% level, but was significant at the 90% level (Figure 33). Tournament catch rates decline by about 10% when the number of gamefishing boats increased from 30–45 to 85–90 boats in the tournament. There was also a significant decrease in tournament catch rates from 30–45 to 170–180 boats. The trend for an average of 90–150 gamefishing boats per tournament is uncertain due to the absence of data in this interval. Competition among boats is intrinsic to tournaments. Since most of the striped marlin that are caught in tournaments are released, our results also imply that at least some of the striped marlin go “off the bite” after they are released; they are not immediately available again to the fishery.

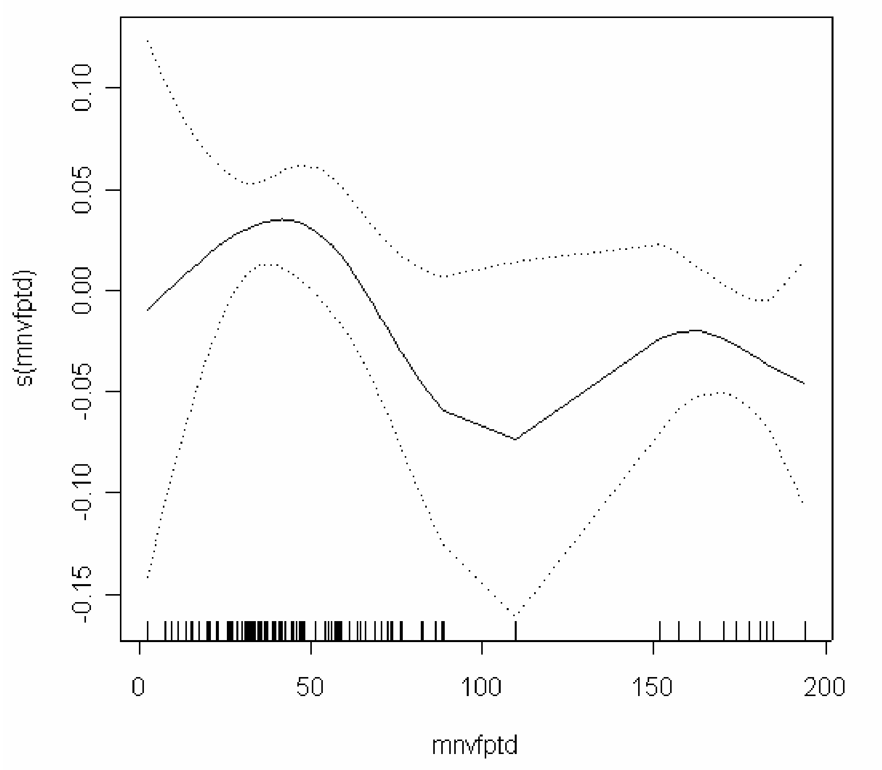

Figure 33. The effect of the number of boat days fished in each tournament on the catch rate of a gamefishing boat in one day of tournament.

4.4 Discussion

A significant decline of about 10% in tournament catch rates accompanied longline catches from 8 to 25 striped marlin in the same area, at the same time as tournaments. A similar correlation was found with the amount of gamefishing effort, so it is difficult to conclude whether the catch rate decline was due to the effects of longlining or competition among gamefishing boats or a combination of both those factors. It does not matter whether longliners catch the striped marlin or gamefishing boats catch them; the result is that competition from whatever source appears to reduce tournament catch rates. Longline catches may have a similar effect on tournament catch rates at broader levels of aggregation. However, those broader effects are difficult to measure because of confounding among variables and variation or "noise" in the system, such as time lags overlaid on the movements of fleets and variations in the distribution, abundance and availability of striped marlin.

In addition to high catch rates or "strike rates", the availability of large, record-size fish is a key performance measure for some gamefishers. This is especially the case for blue marlin, but is not quite as important for gamefishing activities that target striped marlin. A common effect of fishing is a rapid reduction in the abundance of large predators that have accumulated over many generations. A long-term moratorium on longline catches of striped marlin in the broader southwest Pacific would be required to rebuild the stock to earlier levels that featured abundant large striped marlin. Time-area closures at the scale of the jurisdictions of the state and federal management bodies will not improve the rate at which gamefishers encounter large striped marlin. Rebuilding of the striped marlin stock – if it is in an overfished state – will provide improvements in recreational catch rates that are comparable to the benefits of time-area closures.

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