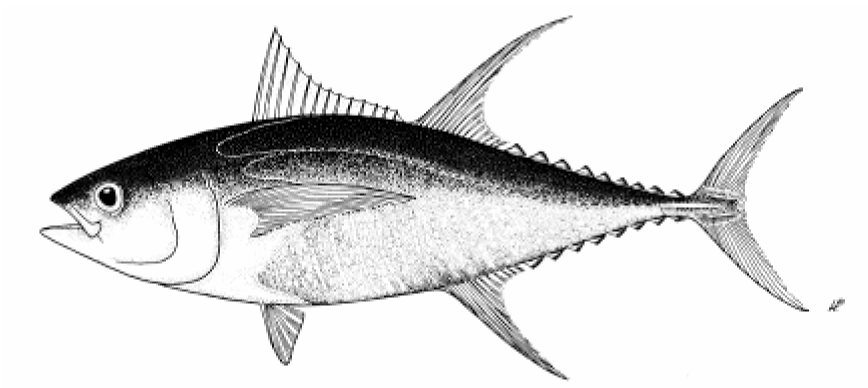
WCPFC–SC1 **EB WP–2**

Western and Central Pacific Fisheries Commission

1st Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission
WCPFC–SC1
Noumea, New Caledonia
8–19 August 2005

Summary of the biology, ecology and stock status of billfishes in the WCPFC, with a review of major variables influencing longline fishery performance



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August 2005

Executive summary

Six species of billfishes reside in the Pacific Ocean. All species have been reported over wide geographical areas of the Pacific Ocean. While some species such as black marlin and blue marlin are thought to comprise single stocks in the Pacific Ocean, other species are likely to be composed of several independent stocks or sub-stocks. However, details of biology and ecology of all species are limited.

The growth rates of all species are relatively rapid, with most species exceeding 100 cm in length with the first year of life. Maturity is obtained within 2–5 years in most species, with females generally attaining larger sizes than males. Most species of billfishes are capable of spawning year-round in some areas of the Pacific Ocean. However, spawning areas of black, blue and striped marlins have only been identified in the western Pacific Ocean. This infers that spawning of these three species in the WCPFC supports Pacific-wide stocks and fisheries.

Tagging studies have demonstrated the ability of all species to cover great distances, although clear migration pathways have yet to be identified. Tagging has also revealed that most billfish species spend much of their time in the upper 100 m of the water column, making them vulnerable to all commercial method fisheries. Swordfish are the exception and tend to spend daylight hours at depths greater than 200 m, entering surface waters at night, likely in response to prey availability. Other billfishes also shown diurnal patterns of movements.

Catches of billfishes by the longline method fisheries of the WCPFC were dominated by blue marlin and swordfish, with lesser amounts of striped marlin. Other species were captured in much lower amounts. Recently, fisheries specifically targeting swordfish and striped marlin have developed in several countries within the WCPFC area. Sportfisheries also rely heavily on most billfish species.

Catches of billfishes were influenced by a range of variables. Variations in CPUEs were noted among flags, likely a result of gear configurations and geographical distributions of fleets within the WCPFC region. For example, some billfish species displayed temperate patterns of distribution (e.g. striped marlin) while other species were more tropical (e.g. black and blue marlins). Thus the areas of operations of longline fleets influenced billfish CPUEs.

The configuration of longline gears (i.e. the number of hooks between floats (HBF)) greatly influenced CPUEs. Highest CPUEs for most species were reported from sets with less than seven HBF. However, CPUEs for individual species varied between day and night sets using similar HBFs. The CPUEs of most species were much lower at night.

Billfishes have contributed a small but important component of the longline catches of the WCPFC area. However, stock assessments of billfishes from the Pacific Ocean are rare. A MULTIFAN-CL assessment of the Pacific wide blue marlin stock indicated that the stock was not overfished but was likely to be approaching full exploitation. Assessments of swordfish stocks in the eastern Pacific indicated that the stocks are experiencing effort levels well below full exploitation. While assessments for western Pacific swordfish and northern and south-western Pacific striped marlin are underway, assessments for other species are not currently planned. The assessment of other species of billfish and the re-evaluation of the blue marlin assessments should be considered by the Commission.

Assessments are limited by relatively low amounts of data and uncertainties in basic biological parameters. For example, age, growth rates, movements and habitat preferences of many species are poorly known. The structure of the stocks in the WCPFC area and Pacific Ocean are also poorly understood. Efforts to redress these uncertainties would greatly benefit future assessments of billfish species.

1. Introduction

Billfishes are among the most easily recognisable groups of fishes. Twelve species of billfishes from two families (Families Istiophoridae and Xiphiidae) have been identified worldwide (Nakamura 1985). However, recent genetic work has suggested reducing the number of species to far fewer.

Six species of billfishes have been identified from the Pacific Ocean (Nakamura 1985, Skillman 1990, Okamoto and Bayliff 2003);

- Indo-Pacific sailfish, *Istiophorus platypterus* (Family: Istiophoridae)
- Black marlin, *Makaira indica* (Family: Istiophoridae)
- Blue marlin, *Makaira mazara* (Family: Istiophoridae)
- Striped marlin, *Tetrapturus audax* (Family: Istiophoridae)
- Short-bill spearfish, *Tetrapturus angustirostris* (Family: Istiophoridae)
- Broadbill swordfish, *Xiphias gladius* (Family: Xiphiidae).

These six species have been frequently reported on logsheets and observer datasheets from longline and purse-seine fleets in the WCPO and the new Commission area. In the longline method fisheries, billfishes are often retained and have accounted for a significant proportion of the overall catches of the industrialised longline fisheries in the WCPO (Figure 1). Fewer billfishes are captured or reported from the purse-seine method fisheries in the region. Billfishes are rarely reported from other method fisheries in the WCPO (e.g. pole-and-line and troll fisheries). However, billfishes are the focus of sport-fisheries throughout the region (Whitelaw 2001), which are commercially important fisheries in their own right.

This paper briefly summarises the biology and ecology of billfish species in the WCPFC area. While all major method fisheries in the WCPFC area have reported catches of billfish, only the longline method fisheries report significant quantities of billfish as part of their retained catches. Thus, this report will focus on the longline fisheries.

Fishery information on billfish catch and effort were summarised for the longline method fisheries in the WCPO, with an examination of the major variables that were likely to have influenced billfish catches. A summary of stock assessments and current status of billfish stocks of the WCPFC are also presented. Finally, areas of further research into billfish stocks and fisheries in the WCPFC area are presented. The overall aim is to provide the Commission with background information on the availability of billfish data at SPC, current status and uncertainties of exploited billfish stocks in the WCPO and to identify major gaps in knowledge and data in order to consider areas for research in the future.

2. Biology and ecology of exploited billfishes in the WCPFC area

2.1 Biology and ecology of Indo-Pacific sailfish in the WCPFC area

Indo-Pacific sailfish are found in tropical and sub-tropical waters of the Indian and Pacific Oceans. Since 1950, Indo-Pacific sailfish in the Pacific Ocean have been recorded from longline sets between 40°N to 30°S in the western Pacific Ocean and 30°N to 25°S in the eastern Pacific Ocean (Figure 2). Highest catches were generally made in the extreme eastern and western areas of the equatorial Pacific Ocean, especially immediately north of the equator (Figure 2a). Within their range, Indo-Pacific sailfish are most common around coasts, islands and reefs (Nakamura 1983) and are typically found year-round in many locations (www.aims.gov.au). Catch per unit effort (CPUE, numbers per hundred hooks) were very low throughout the WCPFC area, with highest CPUEs reported from the EPO between 0º–15ºN (Figure 2b).

Indo-Pacific sailfish have an estimated longevity of up to 15 years (www.aims.gov.au) although fish of 10 years and older have rarely been recorded, at least within the EPO. Between three and five length modes were identified from annual length-frequency data from the WCPO (Figure 3), suggesting that most fish captured by longline within the WCPO were less than 6 years old. However, a single tagged Indo-Pacific sailfish was recaptured after more than 10 years at liberty and has increased the estimated longevity of Indo-Pacific sailfish to more than 15 years (Prince et al. 1986).

Estimates of absolute ages of Indo-Pacific sailfish are generally achieved through the counting of increments in cross sections of dorsal spines. However, accurate ageing is complicated due to reabsorption of the core area of dorsal spines and subsequent loss of early increments. Age has also been estimated from recaptured Indo-Pacific sailfish, although the recapture rates of tagged fish are very low. As a result age and growth rate estimates vary greatly.

Like other billfishes, Indo-Pacific sailfish display rapid growth rates with estimates of fish exceeding 100 cm eye-fork length (EFL) within 4 months (Nakamura 1985). Typical growth rates using von Bertalanffy growth functions (VBGF) have estimated annual K-values of between 0.4–0.8 (www.fishbase.org), although the very rapid growth rate of young fish (less than 1–2 years of age) is often underestimated due to the lack of samples. Indo-Pacific sailfish may reach up to 100 kg but most individuals captured in the WCPO are between 20–40 kg (www.aims.gov.au). There is some evidence that Indo-Pacific sailfish in the EPO attain larger sizes than those in the WCPO (Nakamura 1985), although the age structures of fish from both areas has not been assessed at this stage. Both sexes display similar growth rates, although females tend to be larger than males.

Females are larger and older than males at first reproduction (Table 1). Spawning is suspected to occur year-round in the tropics and be more seasonal in temperate latitude. Fecundity estimates are rare but larger females tend to produce more eggs. As larger females are found in the EPO it is likely that females in this area are more fecund than females in the WCPO.

Indo-Pacific sailfish are top predators and consume a wide range of fish and cephalopod prey. Adult Indo-Pacific sailfish are likely to have few natural predators.

Indo-Pacific sailfish are reported year-round in longline catches from tropical areas of the Pacific and appear more seasonal at higher latitudes. Indo-Pacific sailfish are generally captured at depths of less than 30 m, thus making them available to most method fisheries, including sportfisheries.

2.2 Biology and ecology of black marlin in the WCPO

Black marlin are the most widely distributed billfishes and have been recorded from almost all waters of the Pacific Ocean between 40°N and 40°S (Figure 4), although their latitudinal range in the EPO is reduced to between 30°N and 30°S (Nakamura 1985). Much higher catches of black marlin have been recorded from the WCPO then the EPO since 1990 (Figure 4a). Higher CPUEs have also been reported from the WCPO (Figure 4b). Black marlin are captured from a range of depths, although they are generally reported close to islands and coasts, more so than blue or striped marlin (Kailola et al 1993), making them highly vulnerable to sportfisheries (Whitelaw 2001).

Black marlin are among the fastest growing fishes, exceeding 100 cm and 10 kg within their first year (Table 1). Growth declines after the first four years of age, likely a result of the onset of sexual maturity. While males and female grow at similar rates during the first four years of life, females tend to reach much larger sizes than males. Males have rarely been reported greater than 200 kg from the WCPO, while females have been recorded up to 465 cm TL and 750 kg (www.fishbase.org). The estimated longevity of black marlin is approximately 18 years (www.aims.gov.au). Most black marlin captured by longline method fisheries in the WCPO were above 150 cm LJFL (Figure 5), with strong modes at approximately 175 cm LJFL and above 200 cm LJFL in most years.

Suspected spawning areas for black marlin in the Pacific Ocean have been identified from the south China Sea (May-June), near Taiwan (August-September) and in the north-western Coral Sea (October-December) (Nakamura 1983). The water temperatures in these areas are 27–28°C at the indicated months, suggesting a requirement of high surface water temperatures for spawning. Although large black marlin (up to 350 kg) have been captured in the EPO, all fish examined to date do not possess mature gonads and thus there is no evidence of black marlin spawning in the EPO (www.aims.gov.au). Thus, all spawning of black marlin in the Pacific Ocean appears to occur in the western Pacific Ocean.

Black marlin are a highly mobile species that show rapid and extensive movements. The movements of five black marlin in a tagging study by Gunn et al. (2003) revealed movements between 200 km and 1,200 km, although no consistent direction was shown. Black marlin are generally accepted to display seasonal movements but clear migration routes have not been demonstrated to exist (Pepperell 1990, in Kailola et al. 1993). While other tagging studies have revealed large movements (up to 7,200 km in 359 days) they have also revealed that many recaptures are made at similar locations to the sites of tagging after a period of one or more years, suggesting that individual fish may return to the same site each year (www.aims.gov.au). It has also been suggested that movements and migrations vary among ages and sexes (Pepperell 1990, in Kailola et al. 1993).

Based on catch rates by longline fleets, black marlin are more abundant near the edges of continental slopes and in strong oceanographic systems (e.g. East Australian Current, Kailola et al. 1993). This may be due to bathymetric structures and oceanographic systems concentrating suitable prey species in high densities. A recent study on black marlin using pop-up satellite tags revealed that black marlin spent most of their time in the upper water column (less than 120 m) where water temperatures are generally above 24°C (Gunn et al. 2003).

Similar to other billfishes, black marlin are top order predators, mainly consuming small tunas, cephalopods and other fishes. Adult black marlin have very few natural predators.

2.3 Biology and ecology of blue marlin in the WCPO

Blue marlin (*Makaira mazara*) are the most commonly reported billfish species of the tropical Pacific (Yuen and Miyake 1980, Whitelaw 2001) and have the most tropical distribution of all billfishes. They are found principally in tropical and sub–tropical waters of the Pacific Ocean between 45°N–35°S in the western Pacific Ocean and 35°N–35°S in the eastern Pacific (Nakamura 1985) (Figure 6). Highest catches and catch rates of blue marlin since 1990 have been reported from the northern equatorial western Pacific (Figure 6). The range of blue marlin is consistent with the 24°C isotherm of the Pacific Ocean (Nakamura 1985) although blue marlin have been captured in surface waters with temperatures as low as 21°C (Kailola et al 1993). Blue marlin are rarely found in coastal waters or near islands and prefer surface waters over deep, oceanic areas. Longline catches have indicated that the abundance of blue marlin increases with distance offshore (P. Williams unpublished data.) with higher CPUEs reported within the range of 20ºN–20ºS. Despite preferring being over deep waters, blue marlin are a surface species with most fish remaining within top 40 m of the water column (www.fishbase.org).

Like most billfish, blue marlin display rapid growth rates and most fish exceed 150 cm lower-jaw to fork length (LJFL) and 40 kg within 4–5 years. Blue marlin are relatively long-lived (Kleiber et al. 2003) with a longevity of up to 28 years (www.fishbase.org). Blue marlin display sexual dimorphism in growth after the onset of maturity (approximately 5 years of age) with females attaining greater sizes and ages than males. Males rarely exceed 200 cm LJFL and 170 kg while females have been reported up to 450 cm LJFL and over 900 kg (Collette and Nauen 1983), although most females captured in the WCPO are much smaller. Most blue marlin captured by longline fisheries in the WCPFC area were greater than 150 cm LJFL between 1993 and 1999 (Figure 7), although smaller fish were also captured. Since 2000, a higher proportion of smaller blue marlin have been captured by longline fisheries of the WCPFC, with large modes identified at sizes below 100 cm LJFL reported (Figure 7).

Blue marlin are highly fecund and spawn year-round in tropical waters (10°S–10°N). Blue marlin larvae have been reported from the Coral Sea and other areas of the WCPO but there are no records of blue marlin larvae from the EPO. This suggests that blue marlin captured within the EPO have recruited from the WCPO and thus a single stock of blue marlin exists in the Pacific Ocean (see Kleiber et al. 2003).

Similar to other billfishes, blue marlin are top order predators, mainly consuming small tunas, cephalopods and other fishes. Large blue marlin have very few natural predators.

Blue marlin show the greatest movements of any billfish species in the WCPO, with many recorded movements exceeding 1,000 nmi. A single record of over 5,500 nmi exists for a single blue marlin which was tagged off south-eastern Australia (Pacific Ocean) and recaptured near Sri Lanka (Indian Ocean). Low recapture rates make the defining of migration paths and regular movements difficult. However, there is some evidence of regular movements of fishes back to the sites of tagging, suggesting some level of site fidelity and seasonal movements.

2.4 Biology and ecology of striped marlin in the WCPO

The biology and ecology of striped marlin has been recently reviewed by Bromhead and Pepperell (2004).

The distribution of striped marlin has been implied by total catches and CPUEs (numbers per hhooks (Bromhead and Pepperell 2004). The highest catches of striped marlin have been reported from southern and northern western temperate Pacific, along broadly diagonal bands to the central EPO (Figure 8a). The standardised catch rate for striped marlin indicated a ‘horseshoe-shaped’ distribution, with higher catch rates reported from 10–40° north and south of the equator, and in the eastern equatorial Pacific adjacent to the west coast of Mexico (Figure 8b). Low catch rates are reported from equatorial waters of the WCPO.

Similar to other species of marlin, striped marlin display very high growth rates, although empirical studies are rare. Bromhead and Pepperell (2004) indicated that striped marlin live for at least 10 years and reach a size of at least 290 cm (LJFL), while the record for striped marlin is 420 cm total length (TL) and 440 kg (www.fishbase.org). The results of all studies suggested that striped marlin grow rapidly until at least the onset of maturity between 2 and 4 years of age. Growth rates become reduced in older fish. No sexual differences in growth rates have been reported. Several strong modes are usually reported in annual length-frequency analyses of WCPO longline captured striped marlin, with modes at approximately 125 cm, 160 cm and 210 cm LJFL (Figure 9).

The size of first maturity for striped marlin is between 140 cm and 180 cm LJFL (Nakamura 1983) and 27–40 kg (www.aims.gov.au) at an age of 2–4 years (Kailola et al. 1993, Bromhead and Pepperell 2004). Unlike other species of marlin, striped marlin show little sexual dimorphism (Bromhead and Pepperell 2004) although females tend to be larger than males.

Based on the presence of larvae, spawning of striped marlin occurs between May and June in the north-western Pacific (10–30°N), June to November near the Gulf of California and between November and December in the south-western Pacific (Nakamura 1983. Armas et al. 1999, 2001 in Bromhead and Pepperell 2004). These periods coincided with the onset of summer in both hemispheres (Bromhead and Pepperell 2004). The higher occurrence of mature and/or larval striped marlin implies that most breeding of striped marlin in the Pacific Ocean occurs in the western Pacific Ocean, similar to black and blue marlin.

Striped marlin are almost always reported from the upper 100 m of the water column (epipelagic zone) (Brill et al. 1993, Domeier et al. 2003, Bromhead and Pepperell 2004), making them available to longline, purse-seine and sportfishing method fisheries. Holts and Bedford (1990, in Bromhead et al. 2004) followed 11 tagged striped marlin for 5 hours near California and recorded that all fish spent a majority of their time within 10 m of the surface, with occasional dives to 40–100m. Individual striped marlin tended to stay closer to the surface during daylight hours (less than 10–20 m) with movement to deeper water (20–40 m) during the night. Dives to depths greater than 40 m occurred more often at night than during the day. Archival tagging data from striped marlin within the New Zealand EEZ has been recently collected and will be available soon.

Striped marlin have a broader diet than other billfishes, consuming a wide range of fishes, cephalopods and crustaceans.

2.5 Biology and ecology of short-billed spearfish in the WCPO

Shortbill spearfish are a relatively small and slender species of billfish that rarely obtain sizes greater than 200 cm LJFL and 50 kg (Nakamura 1985). Catches and CPUEs of shortbill spearfish from the Pacific Ocean are much lower than for most other billfishes(Figure 10), suggesting a much lower stock size (Nakamura 1985). However, Indo-Pacific sailfish and shortbill spearfish were reported together by the FAO and on logsheets of distant water fleets (Skillman, 1989) until 1994 (Okamoto and Bayliff 2003). Consequently, very little biological, ecological and catch information is currently available for this species.

Shortbill spearfish are found the tropical and subtropical areas of the Pacific and Indian Oceans between approximately 35ºN and 35ºS. Shortbill spearfish are rarely recorded in coastal waters (Nakamura 1985) and prefer oceanic areas. Highest catches of shortbill spearfish in the Pacific Ocean since 1990 have been reported near Hawaii, in an area between 5º–15ºS to the east of French Polynesia and between 10º–40ºS in the WCPO (Figure 10a). The highest CPUEs were reported within similar areas (Figure 10b). Thus shortbill spearfish are a temperate species with very low catches and CPUEs reported from equatorial areas.

No ageing information is currently available for this species. The average size of shortbill spearfish captured by longline is approximately 135 cm EFL in the central south Pacific and 150 cm EFL in the EPO. The average weight of longline captured shortbill spearfish is approximately 18 kg (Nakamura 1985).

Shortbill spearfish from the EPO have a size of first maturity of approximately 115 cm EFL with nearly all fish greater than 125 cm EFL being mature (Okamoto and Bayliff 2003). Peak spawning in the northern hemisphere occurs during the winter months, commencing in November near Taiwan. In the central Pacific Ocean, spawning commences in March and has been reported between 25ºN and 25ºS, based on the presence of larvae and mature females. Spawning is generally associated with surface water temperatures of approximately 25ºC

(Nakamura 1985). Okamoto and Bayliff (2003) suggested that spawning of shortbill spearfish in the EPO is likely to occur year-round in the area of 150º–125ºW and 35ºN to 15ºS.

Recruitment to the longline fishery occurs below a size of 135 cm EFL in the WCPO. In the EPO, the smallest fish captured by longline were approximately 80 cm EFL. However, full recruitment occurred between 130–150 cm EFL based on size frequencies in longline catches during 1994–1997 (Okamoto and Bayliff 2003).

Shortbill spearfish are usually captured in surface waters as indicated by the declining CPUEs with increasing numbers of hooks between floats (Nakano et al. 1997). However, the highest catch rates were reported from surface waters in areas where the water depths exceed 900 m (Nakamura 1985).

While classified as highly migratory, movement data for shortbill spearfish are rare. Seasonal movements appear to occur in response to changes in surface water temperatures, especially the 28ºC isotherm. Most movements are likely to be related to reproduction.

The diets of juvenile and adult shortbill spearfish are composed mainly of fish and cephalopods, although the species that dominate the diet vary from area to area (Nakamura 1985). The size of shortbill spearfish prey items are smaller than for other billfish species (Nakamura 1985). Details of predators of adult shortbill spearfish are rare.

Limited information is known about the stock structure or size of shortbill spearfish stocks in the WCPO. However, Skillman (1989) suggested that two stocks of shortbill spearfish are likely to exist in the Pacific Ocean, separated by the equator. This was supported by differences in CPUE trends from reference areas in the north and south Pacific Ocean, with CPUE from the north Pacific generally being at least two-times greater than in the south Pacific (Skillman 1990). An analysis of the Japanese data in the EPO indicated that shortbill spearfish catches (and therefore abundances) were much greater than those for Indo-Pacific sailfish. However, as the data for Indo-Pacific sailfish and shortbill spearfish have only been recorded separately since 1994, only four years of reliable data were analysed (Okamoto and Bayliff 2003).

Nearly all shortbill spearfish captured in the WCPO are reported by the longline method fisheries, with little or no catches by the purse-seine fisheries. However, as total catches and CPUEs are very low, the importance of shortbill spearfish to the longline fisheries in the WCPO is also relatively low. Shortbill spearfish are also captured in very low numbers in troll fisheries (Nakamura 1985). Due to the offshore distribution and low abundances, the importance of shortbill spearfish to sport and recreational fisheries is likely to be very low.

2.6 Biology and ecology of broadbill swordfish in the WCPO

The swordfish, *Xiphias gladius*, is the only member of the family Xiphidae. Swordfish display a cosmopolitan distribution being recorded from all oceans and seas between approximately 45ºN and 45ºS. In the Pacific Ocean, swordfish have been captured by longline method fisheries between 50ºN–50ºS in the western Pacific and 45ºN–40ºS in the eastern Pacific (Figure 11a). Highest CPUEs were reported latitudes higher than 20º in both hemispheres (Figure 11b), from areas where surface temperatures were between 18º and 22ºC (Nakamura 1985). Thus, swordfish are a sub-tropical species.

Swordfish are a rapid growing species and have been estimated to attain 74 cm within 6 months (Megalofonou et al. 1995) and 90 cm LJFL by the end of their first year (Sun et al. 2002). Growth rates decline after the first year (Ehrhardt 1992). Growth rates for males and females are linear after the first year of life, with females growing faster than males (Sun et al. 2002). Females tend to be slightly larger than males of the same age (Table 1), attaining much larger sizes than males. In a recent study on north-west Pacific swordfish, Sun et al. (2002) concluded that males obtained at least 191 cm LJFL and 10 years of age, while females exceeded 226 cm LJFL and 12 years of age (Table 1). Most swordfish captured by longline method fisheries in the WCPO were greater than 110 cm LJFL in most years since 1996 (Figure 12). However, smaller fish (less than 90 cm LJFL) have been reported since 2002, likely a result of newly developed swordfish fisheries in the WCPO capturing smaller fish.

A wide range of sizes and ages at first maturity for swordfish have been reported. In the EPO, swordfish reached maturity at about 5–6 years of age, and 150–170 cm LJFL (IATTC 2004). In the western Pacific however, males started to become sexually mature at approximately 90 cm LJFL with females maturing at approximately 150 cm LJFL (Young et al. 2003). This corresponds to estimated ages of one year and four years for males and females, respectively (Table 1) (Sun et al. 2002). In the north-eastern Pacific near Hawaii, males (102 ± 2.5 cm EFL) are also much smaller than females (144 ± 2.8 cm EFL) at sizes when 50% of the population reach first maturity (DeMartini et al. 2000). Differences in size at first maturity suggest that swordfish in the EPO and WCPO are discrete stocks (Sun et al. 2002, Young et al. 2003).

Based on histological examination, females in the WCPO tend to spawn between September and March in waters off eastern Australia, with a peak during December and February. Mature males were identified between October and May in waters off eastern Australia. Females were more reproductively active in water temperatures above 24ºC and relatively low chlorophyll a concentrations (Young et al. 2003). However, no reproductive activity was recorded in swordfish captured further east within the New Zealand EEZ (Young et al. 2003). Swordfish have a relatively high fecundity with an average of 1.66 million eggs per female in the range 173–232 cm LJFL (Young et al. 2003). Due to the presence of oocytes of various stages of maturity within a single ovary, swordfish are likely to be batch spawners with multiple reproductive events per season (Young et al. 2003).

Swordfish display a very distinct diurnal pattern of movements. A single archival-tagged swordfish spent most time at depths greater than 200 m during daylight hours, within water with temperatures of 3–6ºC (Takahashi et al. 2003). The greatest recorded depth was approximately 900 m. At night, the swordfish was recorded in surface waters with temperatures of 12–27 ºC (Takahashi et al. 2003). Several swordfish have recently been tagged by SPC, although data are currently unavailable (B. Leroy, per. comm.). While empirical data detailing diurnal movements are limited, longline fisheries targeting swordfish generally set shallow hooks at night, exploiting the reported pattern of movements.

2.7 Summary of the biology and ecology of billfishes in the WCPO

All six species of billfishes in the WCPO have wide-ranging distributions that encompass large portions of the Pacific Ocean (Nakamura 1985). All species are capable of long-distance movements and/or migrations within the Pacific Ocean, although localised stocks and sub-stocks for some species have been suggested (e.g. Bromhead et al. 2004). Limited tagging and recapture records exist for most billfishes species. However, recapture information has demonstrated the ability of most billfish species to move vast distances, including between ocean basins and there is evidence of some fish returning to the sites of capture, suggesting long-term site fidelity. Thus, most species of billfishes are truly highly migratory species (HMS) and are listed within Annex 1 of UNCLOS. However, clear migration pathways are yet to be identified.

As a result of the records of movements of many species of billfishes in the WCPO, at least some species of billfishes in the Pacific Ocean are thought to be comprised of a single stock (e.g. *Makaira mazara*, Kleiber et al. 2003). In contrast, other species show some evidence of the existence of sub-stocks in the WCPO (e.g. *Tetrapturus audax*, Bromhead and Pepperell

2004). As a consequence, any management of billfish species needs to account for differences in stock structures of individual species.

All species of billfishes in the WCPFC area display rapid growth rates compared to other species of teleost. Maturity is generally reached between 2 and 6 years of age, although females tend to be larger than males in most species. Longevity varies greatly among all species, although all species display longevities of more than 10 years (Table 1).

Fecundity is relatively high for most species (compared to other species of teleosts). Of interest is that several species have only been reported to spawn in the western, equatorial Pacific Ocean, with little or no reproduction reported from the EPO. Thus stocks of some billfish species in the WCPO support fisheries throughout the Pacific Ocean.

Most billfishes are captured by the longline fisheries of the WCPO, with very low catches estimated for the purse-seine fishery. However, all species of billfish, except swordfish, are important sportfishing species. Thus interactions between sportfisheries and longline fisheries may be an area of future research needed in order to manage billfish resources in the future.

3. Summaries of currently held fishery data on billfish in the WCPO at SPC

3.1 Data sources

Extensive records of billfish exist in the logsheet and observer databases at SPC (Tables 2 and 3). Comprehensives logsheet data for the longline and purse-seine method fisheries held at SPC consisted of more than 1.6 million individual longline sets and 400,000 purse-seine sets (Appendix 1). While logsheet coverage rates for the purse-seine method fisheries were relatively high, longline coverage rates vary greatly among flags, between less than 1% and 100% coverage for different flag, fleet and year combinations (Lawson 2004). Further, the reporting of billfish by species varies among flags, although reporting of species has been more reliable in recent years. (see Okamoto and Bayliff 2003).

Billfishes make up a small but significant proportion of the total longline catches in the WCPO (Figure 13), representing approximately 10% of total catches in weight in recent years (Figure 1). In contrast, the purse-seine method fishery of the WCPO reported relatively minor catches of billfishes (Figure 13). Due to the relatively low catches of billfish by the purse-seine method fishery, the longline fishery was the focus of this report.

Observer data for the longline method fisheries of the WCPO were not as extensive and observer data existed for approximately 22,000 longline sets. Observer data were more detailed than logsheet data, and all taxa captured are generally recorded. Similar to logsheet data, coverage rates of different fleets, flag and areas very within the observer data.

Both logsheet and observer data were used to summarise the relevant catch and effort information on billfish catches in the WCPFC. Logsheet and observer data held at SPC for areas north of approximately 15ºN were limited. Thus distribution of individual species and fishery information for this region of the WCPFC presented within this report are incomplete.

3.2 Species compositions in longline catches

Longline logsheet records (in numbers of fishes captured) of billfish were dominated by blue marlin, striped marlin and swordfish (Table 2). From logsheet records, similar proportions of blue marlin and swordfish were captured by the longline fisheries during 1990–2004, each contributing between 30–40% of annual billfish catches in numbers (Figure 14). Striped and black marlin each contributed a lower proportion to overall catches, between 10–20% each per year. Indo-Pacific sailfish contributed a relatively low but stable proportion of the catch at approximately 5% to total billfish catches per year. Prior to 1996, shortbill spearfish were rarely reported within the longline fisheries but have contributed an increasing proportion of the billfish catches in recent years. The lack of shortbill spearfish in the early data may be due to the combining of shortbill spearfish with Indo-Pacific sailfish in logsheet records prior to the mid 1990s, as occurred in the eastern Pacific Ocean (EPO) (Okamoto and Bayliff 2003). Very few billfishes were reported as unidentified on logsheets.

The proportions of billfish species reported by observers between 1990–2004 varied greatly from the proportions recorded on logsheets (Table 3, Figures 14 and 15). While similar proportions of swordfish were reported overall by observers and on logsheets (Figure 15), a much lower proportion of blue marlin were reported between 1990 and 2004. The proportion of all other species reported by observers were much higher than recorded on logsheets.

The proportions of each species within the overall annual longline catches reported by observers also contrasted from logsheet records (Figure 14). Swordfish dominated observer records between 1990–2000, contributing more than 70% of total billfish catches in 1990. The proportion of swordfish in the catch reported by observers rapidly reduced to 20–30% in recent years. The proportions of blue marlin, black marlin and Indo-Pacific sailfish recorded by observers have increased since 1990. Striped marlin and shortbill spearfish proportions remained relatively stable between 1990 and 2004.

Some of the differences between the logsheet and observer proportions of billfishes maybe due to under-reporting of billfish on logsheets. Typically, only retained catches are reported in logsheets. Thus differences in reporting may be due to differential retention of individual species of billfish. Thus, the retention rates of blue marlin and swordfish are likely to be high. However, observer and logsheet effort are not evenly distributed among fleets or areas and thus differences are expected. Further, the coverage rates on newly develop longline fisheries targeting swordfish and striped marlin (e.g. Australia, Bromhead et al. 2003) are not currently known.

3.3 Catches of billfishes by major flags

Japan, Korea and Taiwan have dominated the catches of billfishes since 1990 (Figure 16). Japanese flagged vessels have captured more than 80% of all striped marlin and 50–60% of all swordfish from the WCPFC region since 1990 (Figure 16). However, Japanese catches of striped marlin and swordfish have declined since 1990, as Japanese longline effort in the WCPO has also declined. Korean vessels have captured more blue marlin than other species of billfish The total annual catches of swordfish, striped marlin and black marlin by Korean vessels have remained at similar levels since 1990.

Taiwanese catches of billfishes have been dominated by black marlin (Figure 16), with more than 60% of all black marlin catches from the WCPFC region since 1997 being reported by this fleet. Taiwanese vessels also captured a high proportion of total Indo-Pacific sailfish and, since 2000, a relatively high proportion of swordfish.

United States (US) flagged vessels have captured a very high proportion of total shortbill spearfish catches from the WCPFC area (Figure 16). Swordfish catches by US vessels were relatively high in the early 1990s but have declined in recent years. Australian and New Zealand vessels have reported high catches of shortbill spearfish in recent years, with increasing catches of striped marlin and swordfish since the mid 1990s.

While the total catches of billfish by Pacific Islands States and Territories (PICs) have been relatively low compared to other fleets (Figure 16), the catches by PICs have increased in recent years. For example, catches of blue marlin, striped marlin, Indo-Pacific sailfish and swordfish by PICs have all increased since the mid to late 1990s. This is likely a result of the development of domestic fleets by PICs during this period. It is likely that domestic fleets of PICs will increase in the future and thus catches of billfishes by PICs will also increase.

Estimated total catches of most species have varied among years (Figure 16). However, catches of striped marlin have steadily declined since 1994 (Figure 16). The decline in total catches of striped marlin may be due to changes in gear configurations, areas fished and seasonality of fishing activities by the fleets of the WCPFC area. However, declines in abundance of striped marlin may also be occurring. A stock assessment of striped marlin is currently underway for the south-western region of the WCPFC.

3.4 Size of billfishes.

Limited length and weight data were available at SPC for most billfish species. Length-frequency data for Indo-Pacific sailfish (Figure 3) indicted that the modal size has decreased since 1999 with most fish in subsequent years being less than 200 cm LJFL. In contrast, the size frequency data for black marlin have been relatively stable or increasing since 1995 (Figure 5). While large blue marlin were reported in all years between 1993 and 2004, recent years have recorded a higher proportion of smaller fish (Figure 7). The length-frequency data for striped marlin have fluctuated greatly among years (Figure 9). In most years between 1997 and 2003, a strong mode was identified around 210 cm LJFL. However, in 2001, much smaller fishes dominated the longline catches, with the largest peak identified at 125 cm LJFL. Swordfish also displayed stable length-frequency distributions between 1996 and 2001 (Figure 12), with a higher proportion of smaller fish reported in recent years. However, relatively low number of swordfish have been measured since 2002. Limited length information was available for the other billfish species in the length-frequency database.

Annual average weights of each billfish species captured by longline fleets in the WCPO were calculated (Figure 17). The average weights for all three marlin species and swordfish have shown steady declines since the early 1980s. The average weights of swordfish and Indo-Pacific sailfish are much lower than for other species and no clear trends in average weights were apparent. The lower average weights highlight the lower maximum sizes of shortbill spearfish and Indo-Pacific sailfish compared to other billfish species.

3.5 Fishery variables potentially affecting catch rates and catches of billfish by longline fisheries of the WCPFC.

Similar to other species, a wide range of fishery variables are likely to influence catch rates and catches of billfish (Bigelow et al. 1999).

3.5.1 Flag

Billfish CPUEs (kg.hhooks^{-1}) were calculated from logsheet data for major flags for the period 1978–2004 (Tables 4–9). The CPUEs for most billfish species for each flag were generally higher early in earlier years of each time series. However, there were major differences among flags of CPUEs for each species.

Japanese CPUEs for most billfish species were relatively high until the mid 1980s before CPUEs steadily declined (Tables 4–9). This is likely a result of changes in gear configurations used by many vessels in the Japanese fleet, with increasing HBF used in order to better target deeper species such as bigeye. As a result, the CPUEs declined for species that prefer the upper reaches of the water column, such as billfishes.

The CPUEs for black marlin appeared to be declining during recent years for most flags (Table 4). Black marlin CPUEs for the Japanese fleet have steadily declined, likely a result of the preference for deeper sets (more HBF) in recent years. The CPUE for black marlin by the Korean fleet have been relatively stable for most years. For the Taiwanese fleet, the CPUEs have been relatively low in all years but tended to decline further in recent years. Declining CPUEs for black marlin were also obvious since the mid to late 1990s for New Zealand, French Polynesian and Tongan vessels. The overall lower CPUEs for all fleets in recent years suggested that a stock-wide decline in the abundance of black marlin is likely to have occurred. Most fleets operated in discrete areas in the WCPO and reported similar changes in CPUE of black marlin. Thus the CPUE data supports the concept of a single black marlin stock, at least for the WCPFC region.

Blue marlin CPUEs were much higher than black marlin CPUEs for most years and flags (Table 5). Blue marlin CPUEs recorded by the Japanese fleet have been relatively high for most years, although major fluctuations were recorded. Relatively high CPUEs were recorded by most fleets in the mid to late 1990s. However, most fleets reported declining CPUEs in recent years, with CPUEs since 2000 being low but stable for most fleets. Similar patterns of changes and declines in blue marlin CPUEs were reported at similar times by most fleets, suggesting that stock-wide changes in abundance has occurred. Similar to black marlin, the patterns of CPUE changes support the existence of a single stock in at least the WCPFC area.

The CPUEs recorded for striped marlin were also generally higher earlier in the time-series for most fleets (Table 6). Similar to the other species of marlin, recent striped marlin CPUEs have been relatively low. The exception is for Australian vessels which have reported increased CPUEs in recent years, a result of targeted fishing for striped marlin by a proportion of the fleet. Relatively high striped marlin CPUEs have been reported by vessels from the Cook Islands, New Caledonia, French Polynesia and Tonga, which may reflect the high relative abundances of striped marlin in those regions. However, very low CPUEs for striped marlin were reported in recent years by Samoan and American Samoan longline vessels.

The CPUEs for striped marlin reported by most fleets increased in the mid to late 1990s, especially for Australian and New Caledonian vessels (Table 6). This suggests that striped marlin in the southern WCPO may also comprise a single stock.

The CPUEs recorded for Indo-Pacific sailfish were much lower than for any species of marlin, with nearly all annual CPUEs being less than 1 kg.hhooks^{-1} (Table 7). The relatively low CPUEs for Indo-Pacific sailfish are due to the relatively small size of this species and relatively low abundances compared to the species of marlin. Indo-Pacific sailfish CPUEs have declined for all flags, with very low CPUEs reported in recent years by all fleets. The exception is the relatively high CPUEs reported by Japanese vessel since the late 1990s. This may be a result of changes in the areas of operation of the fleet. However, this may also be due to better identification of Indo-Pacific sailfish and the reporting of Indo-Pacific sailfish from shortbill spearfish since the mid 1990s, as occurred in the EPO (Okamoto and Bayliff 2003).

The CPUEs for shortbill spearfish have been very low (Table 8), potentially a result of poor identification and the pooling of Indo-Pacific sailfish and shortbill spearfish by at least the Japanese fleet until the mid 1990s. Shortbill spearfish CPUEs have increased in recent years for some fleets, especially for fleets operating in some southern temperate areas (e.g. Cook Islands, New Caledonia). However, other temperate fleets have not shown increases in shortbill spearfish CPUE, including vessels from French Polynesia, Tonga, American Samoa and Samoa. However, the data for shortbill spearfish were very sparse.

The CPUEs for swordfish reported by fleets in the WCPO were of a similar magnitude to blue marlin CPUEs for most years (Table 9). However, swordfish CPUEs have exceeded blue marlin CPUEs for most fleets in recent years. This is likely a result of longline fisheries developing to specifically target swordfish in the WCPO (e.g. Australia, New Zealand).

Vessels from Papua New Guinea have also reported increasing swordfish CPUEs but have not reached the levels of CPUEs reported by more temperate fleets. This is likely due to the temperate distribution of swordfish in the WCPFC, south of the main areas of operations of most Papua New Guinean flagged vessels.

Swordfish CPUEs for other fleets have declined in recent years, including vessels from Japan, Korea, French Polynesia, American Samoa, Samoa, Fiji and New Caledonia (Table 9). Swordfish CPUEs reported by vessels from the Solomon Islands, Vanuatu and Tonga have all been much lower but relatively stable in recent years.

3.5.2 Position of capture

The starting positions of longline sets recorded on logsheets in which one or more of each billfish species were captured were plotted in relation to the WCPFC area. Due to the large number of records (Table 2), data were restricted to the 2002 year. This year represented the most recent year with a significant number of records for all species (Table 2) (data for 2003-2004 were likely to be incomplete at this stage). However, logsheet data currently held by SPC does not have full coverage of the WCPFC region and most starting positions for longline sets in the logsheet database were south of 10ºN. Thus the northern distributions of each species were not accurately represented north of approximately 10ºN in figures 18–23.

Black marlin were frequently reported from longline sets west of 170ºW (Figure 18). The range of black marlin catches extended to approximately 30ºS. Blue marlin were also frequently captured west of 170ºW (Figure 19). Few recorded of blue marlin existed for sets south of 30ºS.

While striped marlin were also captured over a wide geographic range, most records were reported south of the equator (Figure 20). Nearly all records were in a 20º latitudinal band that ran from approximately 20º–40ºS at 150ºE, to 0º–20ºS at 150ºW. Although less data were available, Indo-Pacific sailfish and shortbill spearfish were also more likely to be captured in temperate regions (Figures 21 and 22). Most records of Indo-Pacific sailfish captures by the longline method fisheries of the WCPFC were reported west of 170ºW. Information of the northern range of these species (Figures 20–22) were not available for this report.

Swordfish were reported from longline sets over a wider geographical range than any other species of billfish examined (Figure 23). However, few records of swordfish captures north of 5ºN were available at the time of writing this report. The range of swordfish captured by the longline fishery extended more southerly in the WCPFC region east of 180ºW.

3.5.3 Latitude

The distribution of catch positions for each species suggested that abundances of individual billfish species varied between tropical and temperate waters. To examine the effect of latitude, logsheet data held within the CES system at SPC were divided into a tropical longline fishery (15ºN–10ºS) and a temperate longline fishery (10ºS–31ºS) which encompassed the southern boundaries of the EEZs of the Pacific Island States and Territories, with the exceptions of Australia and New Zealand. Quarterly catch rates in numbers and weights (kg) per hundred hooks ($hhooks^{-1}$) were examined for each species within each fishery.

3.5.3.1 Tropical longline

Black marlin catch rates from the tropical longline fishery were relatively stable, fluctuating around a mean of approximately 0.008 fish per hundred hooks ($hhooks^{-1}$) (Figure 24). CPUEs of weights showed a similar pattern, fluctuating around a mean of approximately 0.3

kg.hhooks^{-1}. Similarly, striped marlin CPUEs were also relatively stable throughout most years, fluctuating around levels of less than 0.005 fish.hhooks^{-1} and 0.15 kg.hhooks^{-1}.

The CPUEs for blue marlin were the highest of any billfish species in this fishery suggesting that the abundances of blue marlin were much higher than for other billfish species in the tropical fisheries. Blue marlin CPUEs from the tropical longline fishery showed two distinct phases. Higher CPUEs were reported between 1980 and 1989, with much lower and more stable CPUEs since 1990. Indo-Pacific sailfish CPUEs displayed a similar pattern to the CPUEs of blue marlin, but at lower levels.

Swordfish CPUEs have increased since the early 1980s and have approached 1.0 kg.hhooks^{-1} in recent years (Figure 24), although the CPUE in kg.hhooks^{-1} has steadily declined since the mid 1990s, suggesting that smaller swordfish have been captured in later years (e.g. Figure 12).

Shortbill spearfish data revealed relatively low CPUEs until the mid to late 1990s. In recent years, shortbill spearfish CPUEs have fluctuated around means of approximately 0.08 kg.hhooks^{-1} and less than 0.01 fish.hhooks^{-1}.

3.5.3.2 Temperate longline

CPUEs for all billfish species were approximately one order of magnitude higher in the temperate Pacific longline fishery than in the tropical longline fishery (Figure 25). With the exception of shortbill spearfish, all CPUE series displayed declining CPUEs since the early 1990s. In contrast, shortbill spearfish have showed increased CPUEs since the late 1990s, although this may be due to better identification of this species (Okamoto and Bayliff 2003).

The CPUEs for most species in the temperate fishery peaked in the late 1980s. The exception was for swordfish. While swordfish CPUEs were generally high during the 1980s, swordfish CPUEs declined to reach their lowest levels in the mid 1990s. In 1995 however, swordfish CPUEs increased dramatically from less than 1.0 kg.hhooks^{-1} to more than 5 kg.hhooks^{-1} (Figure 25). The increased CPUEs during the mid to late 1990s are likely a result of the development of longline fisheries specifically targeting swordfish in the temperate WCPO, particularly by some PICs. However, swordfish CPUEs steadily declined since the late 1990s in the temperate regions.

The quarterly CPUE data suggested seasonal movements of some billfish species. For example, while swordfish CPUEs in tropical areas were much lower than in temperate areas, CPUEs tended to increase during the middle of the year (Figures 24 and 25). This suggested that the geographical range of swordfish increased northwards during the cooler time of the year, supporting the biological information of temperature tolerances. Blue marlin and striped marlin CPUEs tended to increase in the later quarters of the year in the tropics (Figures 24 and 25).

Black marlin CPUEs were much higher in the first quarters of each year in both fisheries (Figure 24 and 25), suggesting summer movements into the WCPFC region and supporting the likelihood of a single stock of black marlin in the Pacific Ocean. Indo-Pacific sailfish abundances tended to increase from the first to third quarters of year in both fisheries, again suggesting a single stock with strong seasonal migrations at least in the WCPFC area. While shortbill spearfish CPUE data were limited to after 1995, seasonal changes in abundances in both fisheries were noted. Shortbill spearfish were captured at higher CPUEs towards the middle of the year in both fisheries.

The CPUE data suggested seasonal patterns in billfish abundances in the WCPFC area. Some species increased their range northward during cooler times of the year (swordfish, striped and blue marlin). The CPUEs for other species suggested that black marlin, Indo-Pacific sailfish and shortbill spearfish moved (migrated) seasonally through the WCPFC. While long distance movements of all billfish species have been reported, records of seasonal movements and the identification of potential migration pathways are limited due to limited tag-recaptures for these species. Further, if movement of some billfish species into and out of the WCPFC area occurs at a high rate, then management of these billfish species will only be effective if the entire Pacific Ocean is considered (i.e. with the integration of other management agencies, such as IATTC). However, due to the limited tagging and recapture data available for all billfishes species, the extent of movements are highly uncertain.

3.5.4 Gear configuration

Latitude is clearly an important factor in the examination of billfish abundances and catch rates. However, the gear configurations of the longline fisheries vary within each of the two latitudinal regions defined. One way in which longline gear configurations vary is through the number of hooks between floats (HBF). Briefly, increasing the number of HBF results in a higher proportion of hooks being placed deeper in the water column, with hook depths often exceeding 250 m (Beverly at al. 2004). The deeper setting of hooks is to increase the CPUE for deeper species, particularly bigeye tuna. As most billfish species have been reported to spend most of their time in the upper reaches of the water column (typically, less than 120 m), billfish CPUEs from longline gears with high HBF are likely to be relatively low. Thus, HBF is likely to strongly influence CPUEs of most billfish species (Ward and Myers 2005).

Extensive HBF records existed for longline sets within the longline database. The tropical fishery (15ºN–10ºS) was divided into a shallow longline fishery (less than 10 HBF) and a deep longline fishery (10 or more HBF), as deeper sets are commonly used in the tropical regions in order to better target bigeye tunas. A single temperate longline fishery (10ºS–31ºS) was defined but all HBF categories were examined. The CPUEs of all commonly captured species varied among the three fisheries (Appendix 2).

The CPUE (numbers per hhooks^{-1}) of each species of billfish were examined against each HBF category for each of the three fisheries (Figures 26–28). Highest billfish CPUEs were recorded from longline gears with 4–5 HBF in the tropical shallow longline fishery (Figure 26), confirming the shallow distribution of most billfish species in this region. However, increasing CPUEs were recorded for most species at gear configurations with seven or more HBF.

In the tropical deep longline fishery, highest CPUEs for each species of billfish tended to be reported with 15–30 HBF (Figure 27), with catch rates declining rapidly for sets with greater than 30 HBF. Moderate to low CPUEs were reported in sets with less than 15 HBF. High CPUEs were recorded for striped and blue marlin from sets with more then 30 HBF but the data were limited for very high HBF categories

Longline sets with less than 10 HBF recorded relatively high CPUEs for all billfish species in the temperate longline fishery (Figure 28). However, similar ranges of CPUEs were reported from the temperate longline fishery from gears with 10–40 HBF. Swordfish showed the strongest responses to HBF within the temperate longline fishery, with much higher CPUEs from gears with less the 15 HBF (Figure 28). Very few billfish of any species were captured from longline gears with more than 35 HBF, although relatively few sets with more than 35 HBF were in the database.

3.5.5 Set time

The CPUE of billfish species in relation to HBF data confirmed that most billfish species remained in the upper reaches of the water column. However, recent archival tagging data suggested that at least some species of billfish display major differences in vertical distributions between day and night.

As a result, the HBF data for each fishery were divided into day and nighttime sets based on the starting time of each set. Logsheet starting times were not evenly distributed among times (Appendix 3). Day sets were defined as having staring times recorded between 06:00 h and 18:00 hours, with nighttime sets starting outside this period. While this broadly represents an average diurnal period, actual day and night times will vary seasonally and latitudinally. Thus the divisions used here for day and night are relatively broad. Further, billfish and other fishes that show diurnal movements often respond to light levels. Thus the influence of the lunar cycle can be important (Bigelow et al. 1999) but was not taken into account.

Daytime starting times dominated the set start times for all three longline fisheries. Higher billfish CPUEs were reported in sets with less than 7 HBF during both day and nighttime sets. However, the CPUEs of black and blue marlin and Indo-Pacific sailfish were as high or higher from nighttime sets as for daytime sets over the full range of HBF from the tropical shallow fishery (Figure 29). The CPUEs of striped marlin and shortbill spearfish were similar between both day and nighttime sets. Swordfish CPUEs were similar during both day and nighttime sets with less than 6 HBF.

The CPUEs of most billfish species were much lower in nighttime sets from the tropical deep longline fishery than in daytime sets (Figure 30). Very few records of billfish catches existed for nighttime sets below 30 HBF. The data suggested either that billfish species moved into surface waters at night and were more likely to be captured at night in longline sets with less than 10 HBF. Alternatively, billfish may decrease feeding activities at night. As most billfish species have well developed eyes and are thus visual predators, decreased feeding activity at night is likely for most species. The exception is for swordfish which are capable of feeding at night and is often captured in nighttime longline sets where light-sticks are used to attract swordfish to baited hooks (e.g. Bigelow et al. 1999).

CPUEs for each billfish species were similar for daytime and nighttime sets in the temperate albacore fishery (Figure 31). Shortbill spearfish CPUEs from the temperate longline fishery were higher than the nighttime CPUEs from the tropical deep longline fishery and all sets from the tropical shallow longline fishery. Swordfish CPUEs from the temperate longline fishery were relatively high in all sets with less than 10 HBF (Figure 31). From anecdotal evidence, swordfish CPUEs are generally much higher at night in shallow sets. However, the recent developments of swordfish fisheries in the temperate longline fisheries of the WCPFC means that relatively few logsheets have been submitted.

3.6 Summary

Billfish catches reported on logsheets were dominated by catches of blue marlin and swordfish and it is likely that these species are more abundant than other billfish species in the WCPO. However, observer data suggests that blue marlin were less common than indicated by logsheet data. Thus, underreporting of billfish catches on logsheets is likely to have occurred.

While all species of billfishes were reported from longline sets throughout the are of the WCPFC examined, swordfish, striped marlin, Indo-Pacific sailfish and shortbill spearfish had higher CPUEs in temperate areas, south of approximately 10ºS. These species appeared to move northward during the cooler times of the year. In contrast, blue and black marlin appeared to be tropical species.

CPUEs of each species were heavily influenced by latitude and HBF. This is a result of the geographical distribution of each species and the preferred position of each species in the water column. Set time influenced the CPUEs to a lesser extent. This may be a result of most billfish species being visual predators and thus feeding activity is reduced at night. However swordfish are also nocturnal predators and it was expected that nighttime sets would show increased in CPUE in gears with lower HBF. While this was not observed in the data, it is likely that the assigning of sets to day and night times needed to be performed on a finer scale, taking into account latitude and season. Further, the effect of lunar phase and other variables (Bigelow et al. 1999) should also be considered in future analyses on billfish species.

4. Status of billfish stocks in the WCPFC

4.1 Blue marlin

A stock assessment for blue marlin in the Pacific Ocean considered all blue marlin to form a single stock (Kleiber et al. 2003). The assessment concluded that the blue marlin in the Pacific Ocean are not overfished. However, the assessment suggested that the blue marlin stocks in the Pacific Ocean are likely to be fully exploited (Kleiber et al. 2003). While the assessment for blue marlin used MULTIFAN-CL, the fishery and biological data available for blue marlin were much lower than data available for the four species of tuna also assessed using this programme. As a result, the assessment of blue marlin remains more uncertain than for the tuna species, although it is accepted that the Pacific stocks of blue marlin are not likely to be overfished (IATTC 2004). Nonetheless, it was concluded that blue marlin are a high priority for future assessment in the WCPFC area (SCG 2004).

4.2 Black marlin

There have been no formal stocks assessments undertaken for black marlin in the EPO (IATTC 2004) of WCPFC area. Status of stocks remain uncertain.

4.3 Striped marlin

Two stock assessments for Pacific Ocean striped marlin are currently underway. The most relevant one to the Commission is the assessment of the stock in the south-east Pacific (0º–40 ºS, and east to approximately 140ºW). No preliminary results are available at this stage and the current status of the stock is uncertain. However, Bromhead et al. (2004) suggested that relative abundances of striped marlin may be declining in the western Pacific.

It was recently concluded that striped marlin in the EPO are under-exploited. However, the number of stocks in the EPO is still uncertain (IATTC 2004), as are the relationships among stocks in the Pacific Ocean (Bromhead et al. 2004).

4.4 Indo-Pacific sailfish

No stock assessments currently exist for Indo-Pacific sailfish in the WCPFC area. There have been no formal stocks assessments undertaken for Indo-Pacific sailfish in the EPO (IATTC 2004). The status of stocks remain uncertain.

4.5 Shortbill spearfish

No stock assessments exist for shortbill spearfish in the WCPFC area or in the EPO (IATTC 2004). The status of stocks remain uncertain.

4.6 Swordfish

Assessments of swordfish stocks in the EPO have been undertaken. The results suggested that both the northern and southern stocks of swordfish in the EPO are not over-exploited at the level of fishing effort in 2003 (IATTC 2004). However, fisheries targeting swordfish in the EPO are expanding.

A preliminary assessment of swordfish stocks in the north Pacific (north of 10ºN) have been undertaken using MULITFAN-CL (Kleiber and Yokawa 2002). Further assessments of this stock are currently underway (Sun et al. 2003). Assessments of south-western Pacific swordfish are also underway.

4.7 Summary

Formal stock assessments of billfishes are rare. As a result, the status of most billfish stocks in the WCPFC region are uncertain. However, billfish stocks continue to be exploited and targeted fisheries for some billfish species are being developed (e.g. swordfish fishery in the temperate western Pacific; striped marlin fishery in the eastern Australian EEZ, D. Bromhead, pers. comm.). Further, sportfisheries are developing throughout the WCPFC region (Whitelaw 2001) and are likely to influence the stock status of billfish stocks in the future. As a result, further assessments of the status of billfish stocks are likely to be required. Thus stock assessments of billfishes are an important issue for the WCPFC (SCG 2004).

It is likely that refinements to the stock assessments for blue marlin (SCG 2004) and swordfish will continue in the future. Further, the reporting of the striped marlin assessment for the south-western Pacific Ocean is due in 2006. These three species represent the bulk of the observer and longline records for billfish in the WCPFC area and the entire Pacific Ocean. All reports of billfish assessments to date have indicated that data (biological and fisheries data) were limited, increasing uncertainties and assumptions in the assessments.

Data for the other three billfish species were much more limited. For example, the number of observer records for black marlin in the SPC logsheet database is approximately 50% lower than for striped marlin (Table 2) and the data for Indo-Pacific sailfish and shortbill spearfish were even more limited. The number of black marlin records in the observer database is also much lower than for other marlin species and swordfish (Table 3). However, the number of observer records for shortbill spearfish are similar to those of blue marlin.

Based on the number of observations of each species, it is likely that black marlin will be the next billfish species to be considered for a stock assessment. However, this will be in additional to the assessments for swordfish and striped marlin that are currently underway, and the need for further refinement of the blue marlin assessment.

5. Uncertainties and knowledge gaps of exploited billfish species in the WCPFC

Billfish species in the WCPFC region are commercially important at least to the industrialised longline fisheries of the equatorial and southern temperate areas. Further, most species of billfishes are the prime target species of sportfisheries throughout the region.

With the exception of blue marlin, stock assessments of the other billfish species in the WCPFC region are not currently available. While an assessment for striped marlin is being developed for the WCPFC, preliminary results are not currently available. Assessments of swordfish stocks in the region are also underway. However, the timing of assessments for the other species of billfishes have not been considered.

While assessments are critical in understanding stock status and therefore the sustainable management of exploited species, data available for most billfish species captured in the WCPFC were relatively limited. Further, data were not centralised. Thus, a first step in assessment of billfish species will be to review the data currently available for each species. Based on the amount of available data, a decision should be made as to whether an assessment is possible, and/or what level of assessment is possible and useful.

However, details of some aspects of the basic biology and ecology for most billfish species are currently limited or missing. For example, the stock structures of most species in the Pacific Ocean are currently unknown or debated (e.g. striped marlin, Bromhead et al. 2004, IATTC 2004). Age and growth estimates remain uncertain or missing (e.g. no age estimates are currently available for shortbill spearfish). Further, while tagging studies have demonstrated the ability for all billfish species to move great distances, the current level of tagging information does not provide enough information on seasonality of movements or the existence of migration routes for any species. Finally, the habitat preferences of billfishes are poorly described. Habitat preferences (e.g. preferred depth) are critical in understanding the ecology of billfish species and to standardise time-series of CPUE and other data (e.g. standardising for changes in HBF through time). Additional work using archival or PSAT tags would greatly assist future assessments of billfish stocks in the region.

Finally, while some sportfisheries in the WCPFC have existed for decades, the further development of sportfishing in the region is likely to continue. While total annual catches of billfishes by sportfisheries are relatively low compared to commercial longline fisheries, the commercial returns of sportfisheries are relatively high. Thus, sportfishers can be considered a commercial fishery in their own right (Whitelaw, 2001). Interactions between sportfisheries and commercial fisheries (especially longlines) have occurred in the past (e.g. Bromhead et al. 2004) and are likely to be an issue in the WCPFC region in the future. While catch data were available for some sportfisheries in the WCPFC area (e.g. Marshalls Billfish Club, www.billfishclub.com), catch data for other sportfisheries were not readily available. Further, effort data were not generally reported in a systematic way. As a result, detailing the interactions between sportfisheries and commercial fisheries in the WCPFC is currently limited. As sportfisheries develop in the future, efforts should be made to establish catch and effort databases for these fisheries within individual countries

6. Conclusions

Billfish stocks contribute a small but significant component to longline fisheries of the WCPFC area. While biological, ecological and stock assessment information are limited, billfish-specific longline fisheries have developed in recent years and are likely to expand in the future. Billfishes also are the major target group of sportfisheries in the WCPFC region and interactions between industrialised fisheries and sportfisheries are likely to increase.

Billfish catches have been dominated by blue marlin, swordfish and striped marlin. Most catches have been taken by distant water longline fleets of Japan, Korea and Taiwan. However, recent development of longline fisheries by PICs have increased the proportion of billfish catches by this sector of the longline fishery. Further, Japanese longline catches (and effort) have declined in recent years. Australia and New Zealand also take relatively large catches of some billfish species.

Stock assessments of the six billfish species in the WCPFC are limited and thus the status of most stocks are uncertain. Limited biological and ecological information confounds assessments of billfish stocks in the WCPFC area. Efforts should be made to collect age, habitat preference and movement data in preparation for future assessments. Based on the current levels of available data, it is likely that black marlin will be the next species to be considered for a stock assessment.

Catch rate data that currently existed showed strong flag, latitudinal, HBF and set-time effects and future assessment should take into consideration at least these variables in order to standardise time series of catch and effort.

The biology and ecology of each species would be greatly improved by the collection of more information on movements of billfishes. This would not only be though conventional tagging studies (for geographical movements to assist in the identification of movement pathways and frequencies) but also via archival tags to allow the collection of information of vertical movements. Both types of movement data would greatly assist any future assessments of billfish species by providing estimates of movement rates, distances moved and habitat preferences. Further, extensive tagging of billfishes would also allow the estimation of mortality rates.

In addition, further work on ageing billfishes is required. Accurate age estimation is required for the estimation of growth rates of all species, which are critical as most species of billfishes display sexual dimorphism in growth. Further, information on the timing of critical biological processes, such as age at first reproduction, would provide more information on the effects of fishing on billfish stocks. Finally, more effort should be focussed on the identification of billfish stocks in the Pacific Ocean as there are currently uncertainties in the number and extent of billfish stocks for each species in the WCPFC and Pacific Ocean.

7. Acknowledgements

Many thanks go to Colin Millar and Manu Schneiter for assistance with data supply and queries. Thanks to Adam Langley and John Hampton for comments on drafts of this paper.

8. References

Beverly, S. Robinson, E. and Itano, D. 2004. Trial setting of deep longline techniques to reduce turtle bycatch and increase targeting of deep-swimming tunas. Working Paper FTWG–7a. 17th Meeting of the Standing Committee on Tuna and Billfish, Majuro, Republic of the Marshall Islands.

Bigelow, K. A., Boggs, C. H. and He, X. 1999. Environmental effects on swordfish and blue shark catch rates in the US north Pacific longline fishery. *Fisheries Oceanography*. 8: 178–198.

Brill, R. W., Holts, D. B. Chang, R. K. C., Sullivan, R. K. S., Dewar, H. and Carey, F. G. 1993. Vertical and horizontal movement of striped marlin (*Tetrapturus audax*) near the Hawaiian Islands, determined by ultrasonic telemetry, with simultaneous measurement of oceanic currents. *Marine Biology*. 117: 567–574.

Bromhead, D. A. and Pepperell, J. 2004. Biology and ecology of striped marlin. p 15–38. In: Bromhead, D., Pepperell, J., Wise, B., and Findlay, J (eds.) Striped marlin: biology and fisheries. Bureau of Rural Sciences. Canberra, Australia.

Bromhead, D., Pepperell, J., Wise, B., and Findlay, J (eds.). 2004. Striped marlin: biology and fisheries. Bureau of Rural Sciences. Canberra, Australia.

Collette, B., B. and Nauen, C. E. 1983. FAO species catalogue. Volume 2. Scombrids of the World. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. Volume 2. FAO Fisheries Synopsis. No. 125 (2). 137 pp.

DeMartini, E. E., Uchiyama, J. H. and Williams, H. A. 2000. Sexual maturity, sex ratio, and size composition of swordfish, *Xiphias gladius*, caught by the Hawaii-based pelagic longline fishery. *Fishery Bulletin*. 98: 498–506.

Domeier, M. L., Dewar, H. and Nasby-Lucas, N. 2003. Mortality rate of striped marlin (*Tetrapturus audax*) caught with recreational tackle. *Marine and Freshwater Research.* 54**,** 435–445.

Ehrhardt, N. M. 1992. Age and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. *Bulletin of marine Science.* 50: 292–301.

IATTC. 2004. Tuna and billfishes in the eastern Pacific Ocean in 2003. Fishery Status Report No. 2. Inter-American Tropical Tuna Commission, La Jolla, California. 109 pp.

Kailola, P. Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A. and Grieve, C. 1993. Australian fishery resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation, Canberra, Australia.

Kleiber, P., Hinton, M. G. and Uozumi, Y. 2003. Stock assessment of blue marlin (*Makaira nigricans*) in the Pacific using MULTIFAN-CL. Marine and Freshwater Research. 54: 349–360.

Kleiber, P. and Yokawa, K. 2002. Stock assessment of swordfish in the North Pacific using MULTIFAN-CL. Working Paper BBRG-3. 15th Meeting of the Standing Committee on Tuna and Billfish, Hawaii, United States of America, 22−27 July 2002.

Lawson, T. 2004. Status of data collection, compilation and dissemination. Working Paper SWG–1. 17th Meeting of the Standing Committee on Tuna and Billfish, Majuro, Republic of the Marshall Islands, 9−18 August 2004.

Megalofonou, P., Dean, J. M., De Mitrio, G., Wilson, C. and Berkelev, S. 1995. Age and growth of juvenile swordfish, *Xiphias gladius* Linneaus, from the Mediterranean Sea. *Journal of Experimental Marine Biology and Ecology.* 188: 79–88.

Nakamura, I. 1985. FAO species catalogue. Volume 5. Billfishes of the World. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Volume 5. FAO Fisheries Synopsis. No. 125 (5), 65 pp.

Nakano, H., Okazaki, M. and Okamoto, H. 1997. Analysis of catch depth by species for tuna longline fishery based on catch and branch lines. *Bulletin of the National Institute of Far Seas Fisheries.* 34, 43–62.

Okamoto, H. and Bayliff, W. H. 2003. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1993-1997. *Inter-American Tropical Tuna Commission Bulletin*. 22(4), 218 pp.

Prince, E. D., Lee, D. W., Wilson, C. A. and Dean, J. M. 1986. Longevity and age validation of a tag-recaptured Atlantic sailfish, *Istiophorus platypterus*, using dorsal spines and otoliths. *Fishery Bulletin*. 84: 493 –502.

SCG. 2004. Report of the third meeting of the scientific coordinating group. Working paper WCPFC/PrepCon/41. Seventh session of the preparatory conference for the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the western and central Pacific. Pohnpei, Federated States of Micronesia, 6–7th December 2004.

Skillman, R. A. 1990. Status of Pacific billfish stocks, p 179–195. In: Stroud, R. H. (ed), Planning the Future of Billfishes: Research and Management in the 90s and Beyond. Part 2: Contributed Papers. Proceedings of the Second International Billfish Symposium, Kailua-Kona, Hawaii, August 1-5, 1988. Marine Recreational Fisheries 13. National Coalition for Marine Conservation, Inc., Savannah, Georgia.

Sun, C., Lin, H., and Yeh, S. 2002. Age and growth of the young swordfish *Xiphias gladius* L. in Taiwan waters using otolith. Working Paper BRG-8. 15th Meeting of the Standing Committee on Tuna and Billfish, Honolulu, Hawaii, United States of America, 22-27 July 2002.

Sun, C-L., Punt, A., Wang, S.-P., Yeh, S.-Z., Yokawa, K. and Kleiber, P. 2003. A Framework for Assessing the North Pacific Stock of Swordfish using an Age- and Sex-Structured Population Dynamics Model. Working paper BBRG–11. 16th Meeting of the Standing Committee on Tuna and Billfish, Mooloolaba, Australia, 9−16 July 2003.

Takahashi, M. Okamura, H., Tokawaw, K. and Okazaki, M. 2003. Swimming behaviour and migration of a swordfish recorded by archival tag. *Marine and Freshwater Research.* 54: 527–534.

Ward, P. A and Myers, R. A. 2005. Inferring the depth distribution of catchability for pelagic fishes and correcting for variations in the depth of longline fishing gear. *Canadian Journal of Fisheries and Aquatic Sciences*. 62: 1130–1142.

Whitelaw, W. 2001. Country guide to gamefishing in the western and central Pacific. Secretariat of the Pacific Community, Noumea, New Caledonia.

Williams, P. 2003. Estimates of annual catches for billfish species taken in commercial fisheries of the western and central Pacific Ocean. Working Paper SWG–3. 17th Meeting of the Standing Committee on Tuna and Billfish, Majuro, Republic of the Marshall Islands, 9−18 August 2004.

Young, J, Drake, A., Brickhill, M., Farley, J. and Carter T. 2003. Reproductive dynamics of broadbill swordfish, *Xiphias gladius*, in the domestic longline fishery off eastern Australia. *Marine and Freshwater Research.* 54: 315–332.

9. Tables

Table 1. Summarised biological and ecological information for billfish species in the WCPO. References for the sources of information are available within the text for each species. Sizes are as EFL or LJFL as appropriate for each species (see text). ?, indicates major uncertainties.

Variable	Indo-Pacific sailfish	Black marlin	Blue marlin	Striped marlin	Short-bill spearfish	Broadbill swordfish
Code	SFA	BLM	BUM	MLS	SSP	SWO
Length (LJFL cm)	300	400	450	350	200	310
Max weight (kg)	100	750	906	440	52	540
Longevity (years)	15	18	28	10	?	12+
Age and size at first maturity	♂: 2–4 years, 130–140 cm, 20–25 kg ♀: 3–5 years, 150–160 cm, 30–35 kg	♂: 2–4 years, 130–140 cm, 30 kg; ♀: 3–5 years, 200 cm, 100 kg	♂: 2–4 years, 130–140 cm, 30–35 kg; ♀: 3–5 years, 200 cm, 47–80 kg	2–4 years; 140-180 cm, 30 kg.	Age ?; 115–125 cm EFL; 20–25 kg	♂: 1 year ~ 90 cm, 14 kg; ♀: 4 years, 150 cm, 76 kg
Reproduction	Year-round in tropics	Multiple spawners. Only in WCPO	Year-round in tropics; Summer in sub-tropics. Only in WCPO	Single spawner; Late-spring in both hemispheres. Only in western Pacific	Winter or year-round spawning	Year-round in tropics; spring-summer in subtropics
Size at recruitment to fishery	100–150 cm	150 cm	150 cm	80 cm	80–135 cm	90 cm
Natural mortality rate	1.1	0.9	0.2–0.5	0.4–0.8	?	0.22
Sexual dimorphism in growth	Yes	Yes ♂< 200 cm ♀ > 400 cm	Yes ♂< 230 cm ♀ > 400 cm	No	Unknown	Yes. ♂< 200 cm ♀ > 226 cm
Habitat	Depth < 100 m; Common close to coasts and islands	Tropical and subtropical; depth < 120 m; Common close to coasts and islands.	Tropical; West of 130ºW; depth < 100 m; Found with floating objects	Temperate; 10–35º north and south; depth < 100 m;	Oceanic surface waters	Higher abundances in temperate regions. 0–300 m or more.
Movement	More localised than other billfishes	Pan-oceanic; Seasonal?	Pan-oceanic; Seasonal?	Seasonal to remain with temperature preference;	Follows 28ºC isotherm	Seasonal to remain with temperature preference;
Stock structure in Pacific Ocean	Two stocks, east and west	Single stock (?)	Single stock	1 to 3 stocks, (south western, north-western and eastern).	Two stocks (north and south)	1 to 3 stocks (western, north-eastern and south-eastern).

Table 2. Annual number of billfish records from logsheets of longline sets in the WCPFC region, 1990–2004. Source: SPC logsheet database. Data for 2003 and 2004 are incomplete. Species codes: BLM, black marlin; BUM, blue marlin; MLS, striped marlin; SFA, Indo-Pacific sailfish; SSP, shortbill spearfish; SWO, swordfish; NI, unidentified billfish.

	Species						
Year	**BLM**	**BUM**	**MLS**	**SFA**	**SSP**	**SWO**	**NI**
1990	3,000	10,817	5,373	1,247	5	10,943	74
1991	2,339	10,056	3,362	1,119	0	8,063	36
1992	3,435	12,019	3,861	1,398	0	9,972	94
1993	7,072	19,011	5,656	1,987	0	16,416	42
1994	6,315	25,479	7,484	2,379	1	21,692	158
1995	4,127	32,092	8,644	1,797	0	18,724	249
1996	2,189	18,833	5,931	703	58	13,942	208
1997	3,921	15,786	8,068	1,150	331	14,696	559
1998	4,265	15,901	9,342	1,694	728	16,554	201
1999	4,934	22,935	13,038	1,821	1,450	25,928	109
2000	6,396	22,993	10,711	1,389	1,316	28,326	71
2001	5,639	22,678	9,927	1,742	1,820	30,302	133
2002	5,505	18,531	9,560	2,576	6,404	26,936	80
2003	6,049	18,023	10,577	2,518	2,812	18,273	12
2004	1,443	6,209	2,291	823	1,552	3,949	0
Totals	66,629	271,363	113,825	24,343	16,477	264,716	2,026

Table 3. Number of observer records of billfish from longline sets in the WCPFC region, 1990–2004. Source: SPC logsheet database. Data for 2003 and 2004 may be incomplete. Species codes: BLM, black marlin; BUM, blue marlin; MLS, striped marlin; SFA, Indo-Pacific sailfish; SSP, shortbill spearfish; SWO, swordfish; NI, unidentified billfish.

	Species						
Year	**BLM**	**BUM**	**MLS**	**SFA**	**SSP**	**SWO**	**NI**
1990	0	7	31	0	2	153	0
1991	20	24	111	0	106	331	0
1992	29	48	145	5	138	385	0
1993	55	77	179	21	106	491	4
1994	89	226	337	34	251	636	40
1995	45	297	484	48	322	584	43
1996	34	311	529	66	313	731	35
1997	73	323	472	112	270	797	24
1998	166	449	384	239	320	826	22
1999	110	265	377	144	292	643	12
2000	86	490	462	105	474	771	23
2001	102	486	949	185	814	492	47
2002	143	355	163	413	58	352	1
2003	80	240	118	232	161	188	0
2004	112	265	129	195	138	318	0
Totals	1,144	3,863	4,870	1,799	3,765	7,698	251

Table 4. Catch per unit effort (kg.hhooks^{-1}) of black marlin by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0.656										
1979						12.172										
1980						0.851	0							0.117		
1981						0.764	0.733					2.232		0.067		
1982						1.553	1.687					1.716	2.063	0.077		
1983						1.053	1.03	2.718				1.148	1.204	0.147		
1984						1.342	0.216	0.611				1.775	0	0.198		
1985		0.531				0.785	0.29	3.972				3.939	14.756	0.336		
1986		0.81				0.408	0.072	5.723					1.774	0.08		
1987		0.879				1.095	0.276	5.887					0	0		
1988		0.614				0.902	0.371	7.171					4.583	0.1		
1989		0.053			1.137	0.511	0.348	5.6	0				6.032	0.18		
1990		0.488			0.023	0.317	0.423	2.962	0				4.006	0.538		
1991		1.014			0.059	0.211	0.247	3.217	0				4.083	0.069		
1992		0.408			0.004	0.243	0.181	2.255	0	0.781			3.374	0.024		
1993		0.08			0.023	0.339	0.035	3.011	0	0.085			2.72	0.039		0
1994		0.193	3.066		0.423	0.624	0.352	2.203	0	0.263	0		4.194	0.076		0
1995		0.216	0.704		0.061	0.343	0.191	1.537	0.007	0.044	0.167	0.137		0.014	0.449	
1996	1.177	0.321	0.856		0.031	0.188	0.377	1.378	0.005	0.456	0.412	0.441	0	0.004	0.402	
1997	0.336	0.009	0		0.265	0.021	0.286	1.524	0	0.273	0.321	0.177	1.018	0.088	0.638	
1998	0.103	0.025			0.269	0.633	0.397	0.882	0.036	0.057	0.109	0.102	0.308	0.03		0.371
1999	0.624				0.151	0.307	0.563	0.814	0.02	0.057	0.153	0.096	0.467	0.009		0.468
2000	0.379				0.17	0.643	0.287	0.789	0.005	0.003	0.496	0.253	0.339	0.017	0	0.857
2001	0.047		0.791	0	0.141	0.21	0.216	0.749	0.001	0.04	0.215	0.116	0.111	0.019	0.151	0.195
2002	0.003		0.04	0.705	0.155	0	0.439	0.667	0.001	0.008	1.082	0.088	0.162	0.01	0.029	0.242
2003	0.001		0.132	0.106	0.121	0.039	0.296	0.637	0	0.007	0.26		0.165	0.024	0.042	0.013
2004	0.002		0.144	0.103	0.125	0	0.183	0.595	0.009	0.004	0.196		0.247	0.022	0.035	0

Table 5. Catch per unit effort (kg.hhooks^{-1}) of blue marlin by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0.383										
1979						2.585										
1980						0.819	0							0		
1981						1.158	0.968					3.738		1.007		
1982						1.941	0.28					2.987	1.933	0.422		
1983						1.178	0.583	8.534				2.311	0.905	0.874		
1984						1.392	0.542	3.403				5.081	0	0.419		
1985		0				1.438	1.213	3.157				4.678	0	0.329		
1986		0				1.386	1.81	1.646					0	0.264		
1987		2.638				0.956	1.154	1.849					0	0		
1988		1.706				2.1	0.752	1.452					0.406	0.905		
1989		0.035			0.432	2.129	1.308	1.657	0				0.06	1.325		
1990		0.717			0.034	1.673	1.615	0.6	0				0.012	0		
1991		0.212			1.433	0.809	1.382	0.312	0				0	0.127		
1992		0.403			1.059	0.905	2.315	0.76	0	4.365			0	0.332		
1993		0.173			1.546	1.037	3.82	0.945	0	6.856			0	0.311		0
1994		0.254	1.266		1.232	1.482	1.853	0.92	0	7.015	4.615		0	0.47		0
1995		0.339	2.907		1.343	1.792	2.149	0.677	0	6.467	0.262	1.646		0.225	3.276	
1996	7.14	0.289	2.205		1.487	0.613	1.26	0.592	0.005	6.05	0.054	1.435	0	0.147	1.866	
1997	4.11	0.017	3.75		2.537	0.769	1.662	0.546	0	3.978	0.233	1.753	1.664	0.555	1.97	
1998	2.734	0.002			1.602	1.327	1.29	0.233	0.002	3.49	0.394	1.21	0.239	0.251		0.823
1999	2.404	0			1.838	4.785	1.308	0.327	0.014	2.324	1.095	0.704	0.26	0.477		0.92
2000	1.751	0			1.519	4.697	1.259	0.791	0.009	1.983	0.486	1.85	0.615	0.226	0	2.825
2001	0.583	0	0.134	0	0.677	1.276	1.572	0.465	0.004	1.938	1.336	0.537	0.498	0.22	0.11	0.416
2002	0.208	0	0.902	0.184	0.494	0.238	1.224	0.331	0.002	1.938	1.033	0.206	0.287	0.211	0.348	0.519
2003	0.15	0	0.79	0.408	0.355	0.902	1.914	0.238	0.01	1.694	1.61		0.239	0.135	0.56	0.013
2004	0.145	0	0.742	0.302	0.337	14.285	0.866	0.279	0.012	1.021	1.259		0.201	0.218	0.741	0

Table 6. Catch per unit effort (kg.hhooks^{-1}) of striped marlin by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0										
1979						11.111										
1980						2.634	0							0		
1981						3.927	0.241					0.109		1.609		
1982						6.01	0.275					0.083	0.035	0.297		
1983						2.7	0.4	23.205				0.334	0	0.426		
1984						4.403	1.071	7.827				0.096	0	0.447		
1985		0				4.201	0.434	11.905				0.333	1.22	0.38		
1986		0				2.771	0.485	12.533					0.334	0.366		
1987		3.214				3.049	0.811	6.219					0	0		
1988		3.359				2.28	0.456	5.93					0	0.474		
1989		0.644			0.717	4.206	1.4	8.361	0				0	0.354		
1990		2.408			0	2.787	0.529	5.649	5.358				0.495	0.749		
1991		1.35			0.704	2.261	0.395	2.659	0.024				0.381	0.187		
1992		1.076			0.361	1.41	1.095	3.63	0	4.082			0	0.22		
1993		1.48			0.455	2.406	0.853	2.516	0.027	0.069			0.429	0.345		4.116
1994		2.325	3.989		0.793	3.363	0.59	8.163	0.4	2.197	0		1.315	0.222		2.633
1995		2.461	2.035		0.241	2.219	0.56	4.404	0.704	2.567	0.666	0.095		0.298	0.493	
1996	1.13	3.821	2.695		0.434	1.557	0.223	5.551	2.448	1.976	0.146	0.123	3.062	0.205	0.651	
1997	0.147	3.446	0		0.769	3.333	0.747	3.928	0.821	1.689	0.071	0.074	1.69	0.315	0.056	
1998	0.188	5.151			1.175	3.545	0.491	4.378	1.185	0.968	0.163	0.03	1.546	0.225		0.364
1999	0.267	5.078			0.581	0.343	0.46	2.011	2.628	1.314	0.082	0.019	1.184	0.345		0.487
2000	0.21	6.532			0.652	0.096	0.233	2.052	0.922	0.785	1.247	0.026	1.782	0.203	0.38	0.053
2001	0.129	7.035	0.607	0	0.248	0.079	0.972	1.368	0.275	0.702	0.825	0.049	0.591	0.13	0.131	0.268
2002	0.028	5.339	0.955	0.085	0.196	0	0.188	1.097	0.132	0.601	0.222	0.027	0.473	0.098	0.174	0.155
2003	0.039	3.51	0.93	0.208	0.196	0	0.198	1.066	0.282	0.641	0.205		0.298	0.166	0.27	0.005
2004	0.034	2.994	0.688	0.127	0.158	0	0.174	1.025	0.87	0.511	0.165		0.365	0.176	0.265	0

Table 7. Catch per unit effort (kg.hhooks^{-1}) of Indo-Pacific sailfish by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0										
1979						0.755										
1980						0.228	0							0		
1981						0.192	0					4.57		0.373		
1982						0.269	0.003					7.177	0.104	0.2		
1983						0.149	0	1.4				1.213	0.064	0.138		
1984						0.176	0.032	0.891				0.911	0	0.04		
1985		0				0.173	0.06	0.749				1.047	0.203	0.057		
1986		0				0.109	0.013	1.204					0.025	0		
1987		0				0.227	0.044	0.717					0	0		
1988		0				0.199	0.01	1.245					0	0.038		
1989		0			0.539	0.085	0.015	0.836	0				0.425	0.03		
1990		0			0.109	0.031	0.02	0.327	0				1.006	0		
1991		0			0.282	0.049	0.019	0.85	0				0.717	0.049		
1992		0			0.53	0.068	0	0.58	0	0.698			0.283	0.188		
1993		0			0.807	0.044	0.025	0.552	0	0.031			0.535	0.048		2.516
1994		0	0		0.398	0.102	0	0.879	0	0.242	0.897		0	0.05		1.22
1995		0	0.044		0.337	0.111	0.02	0.919	0.036	0.157	0.548	0.183		0.005	0.207	
1996	0.418	0	0		0.258	0.021	0.039	0.37	0	0.073	0.535	0.173	0	0	0.025	
1997	0.304	0.005	0		0.513	0	0.05	0.379	0	0.044	0.147	0.036	0.079	0.01	0	
1998	0.082	0.027			0.485	0.347	0.053	0.155	0	0.038	0.077	0.075	0.023	0.02		0.295
1999	0.03	0.024			0.339	0.671	0.031	0.367	0.001	0.086	0.055	0	0.077	0.006		0.406
2000	0.033	0.049			0.101	0.128	0	0.32	0	0.092	0.034	0.05	0.125	0.002	0	0.159
2001	0.024	0.038	0	0	0.099	0.359	0.002	0.188	0	0.037	0.225	0.036	0.084	0.042	0	0.18
2002	0.013	0.068	0.114	0.046	0.148	0	0	0.129	0	0.026	0.12	0.022	0.079	0.03	0.071	0.169
2003	0.009	0.027	0.059	0.038	0.104	0	0	0.099	0	0.061	0.012		0.057	0.026	0.045	0.021
2004	0.008	0.01	0.035	0.023	0.054	0	0	0.08	0	0.029	0.008		0.06	0.081	0.01	0

Table 8. Catch per unit effort (kg.hhooks^{-1}) of shortbill spearfish by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0										
1979						0.001										
1980						0.005	0							0		
1981						0.001	0.041					0		0		
1982						0.002	0					0	0	0		
1983						0.002	0.041	0				0	0	0		
1984						0.004	0.022	0				0	0	0		
1985		0				0.002	0.004	0				0	0	0		
1986		0				0.004	0	0					0	0		
1987		0				0.006	0	0					0	0		
1988		0				0	0.001	0					0	0		
1989		0			0	0	0	0	0				0	0		
1990		0			0	0	0	0	0				0	0		
1991		0			0	0	0	0	0				0	0		
1992		0			0	0	0	0	0	0			0	0		
1993		0			0	0	0	0	0	0			0	0		0
1994		0	0		0	0	0	0	0	0.001	0		0	0		0
1995		0	0		0	0	0	0	0	0	0	0		0	0	
1996	0.05	0.01	0.488		0	0	0	0.017	0	0	0	0	0	0	0	
1997	0.021	0.044	0		0.235	0	0	0.18	0.002	0	0	0	0	0	0	
1998	0.036	0.054			0.26	0	0	0.117	0	0	0	0	0.021	0		0.275
1999	0.017	0.049			0.132	0	0	0.127	0	0.141	0	0	0.069	0		1.593
2000	0.005	0.032			0.036	0	0.01	0.07	0	0.143	0	0	0.053	0	0	2.101
2001	0.007	0.09	0.238	0	0.04	0	0	0.304	0.001	0.126	0.004	0	0.063	0	0	0.066
2002	0.006	0.167	0.24	0	0.069	0	0	0.195	2.51	0.047	0	0	0.023	0	0.004	0.038
2003	0.007	0.111	0.209	0.007	0.08	0	0	0.119	0.001	0.089	0.001		0.011	0.002	0.023	0.001
2004	0.003	0.122	0.136	0.002	0.114	0	0	0.184	0.004	0.054	0		0.099	0	0.033	0

Table 9. Catch per unit effort (kg.hhooks^{-1}) of swordfish by major flags in the longline method fisheries of the WCPO, 1978–2004. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; JP, Japan; KR, Korea; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; SB, Solomon Islands; TO, Tonga; TW, Taiwan; VU, Vanuatu; WS, Western Samoa. Data for 2003 and 2004 are incomplete.

	Flag															
Year	**AS**	**AU**	**CK**	**CN**	**FJ**	**JP**	**KR**	**NC**	**NZ**	**PF**	**PG**	**SB**	**TO**	**TW**	**VU**	**WS**
1978						0.445										
1979						4.163										
1980						5.384	0							0		
1981						5.121	0.417					0.484		1.074		
1982						7.222	0.759					0.075	0.274	0.48		
1983						5.088	0.026	2.33				0.071	0.277	0.301		
1984						6.12	0.44	2.031				0.079	0	0.274		
1985		0				7.46	0.279	0.932				0.318	1.607	0.217		
1986		0.936				6.929	0.54	2.021					1.149	0.043		
1987		1.1				8.301	0.49	1.027					0.317	0		
1988		0.911				7.804	0.499	0.449					0.356	0.254		
1989		2.589			0.674	4.078	0.153	0.469	0				0.961	0.215		
1990		1.659			0.097	3.491	0.644	0.452	0.815				0.804	0.559		
1991		2.297			0.371	4.255	1.005	0.547	1.163				0.792	0.139		
1992		1.847			0.35	5.676	1.374	0.448	4.894	1.323			0.81	0.265		
1993		1.916			0.436	3.189	1.45	0.589	2.903	0.893			0.89	0.142		0
1994		1.666	11.782		2.045	3.312	1.335	0.328	4.286	1.222	0		0.621	0.087		0
1995		1.53	5.014		0.55	2.095	1.176	0.517	2.929	1.092	0.072	0.075		0.151	0.363	
1996	0.482	12.335	4.399		0.857	3.139	0.595	0.533	5.708	1.461	0.072	0.172	1.169	0.154	0.271	
1997	0.832	24.654	3.75		0.695	4.189	1.028	0.559	7.196	0.685	0.165	0.262	0.279	0.335	0.188	
1998	0.378	20.248			0.686	0.682	0.855	0.695	9.443	0.61	0.214	0.197	0.401	0.252		0.466
1999	0.543	19.496			0.689	0.649	0.736	0.37	8.816	0.561	0.188	0.087	0.472	0.15		0.901
2000	0.251	20.293			0.503	0.453	1.182	0.343	8.221	0.434	0.348	0.165	0.878	0.139	0.118	0.235
2001	0.457	18.634	1.639	0	0.409	0.104	0.762	0.302	9.829	0.621	0.341	0.145	0.643	0.1	0.204	0.262
2002	0.367	17.962	0.967	0.447	0.336	0.479	0.384	0.265	17.508	0.531	0.482	0.133	0.329	0.189	0.287	0.226
2003	0.269	10.374	3.673	0.337	0.315	0.235	0.275	0.279	7.289	0.642	0.276		0.262	0.174	0.313	0.032
2004	0.226	11.426	3.54	0.231	0.275	1.508	0.318	0.27	9.966	0.378	0.191		1.784	0.238	0.361	0

10. Figures

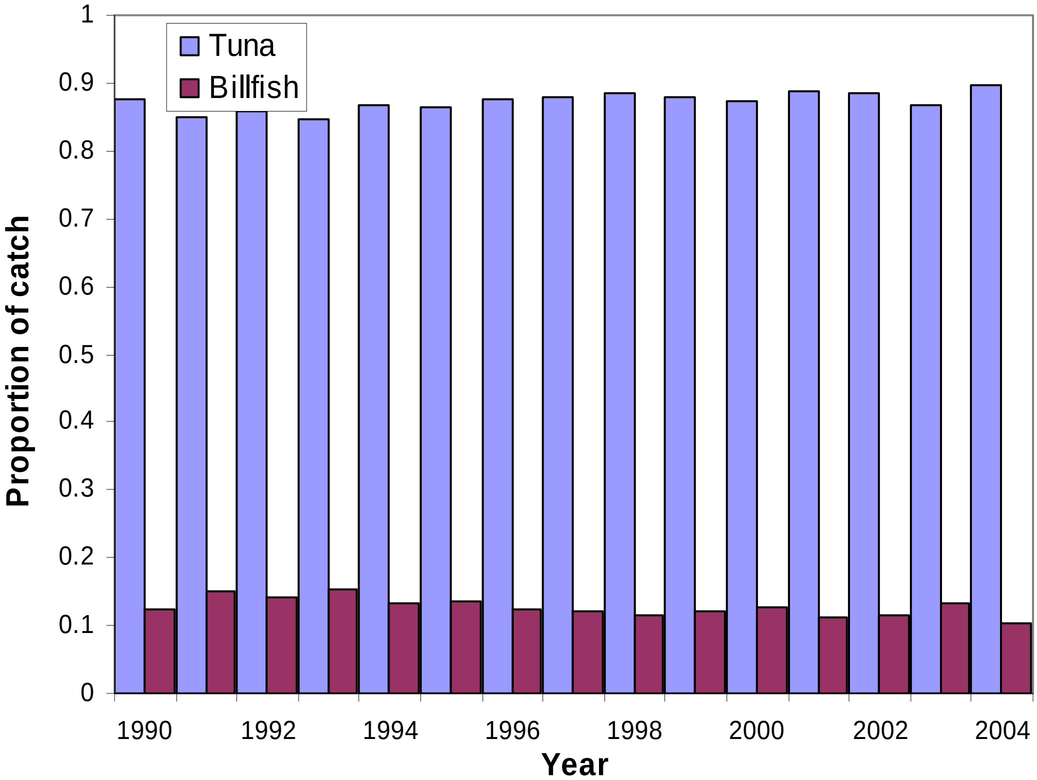


Figure 1. Proportions of tunas and billfishes in the annual catches by longline method fisheries in the WCPFC area, 1990–2004. Source: SPC raised logsheet data.

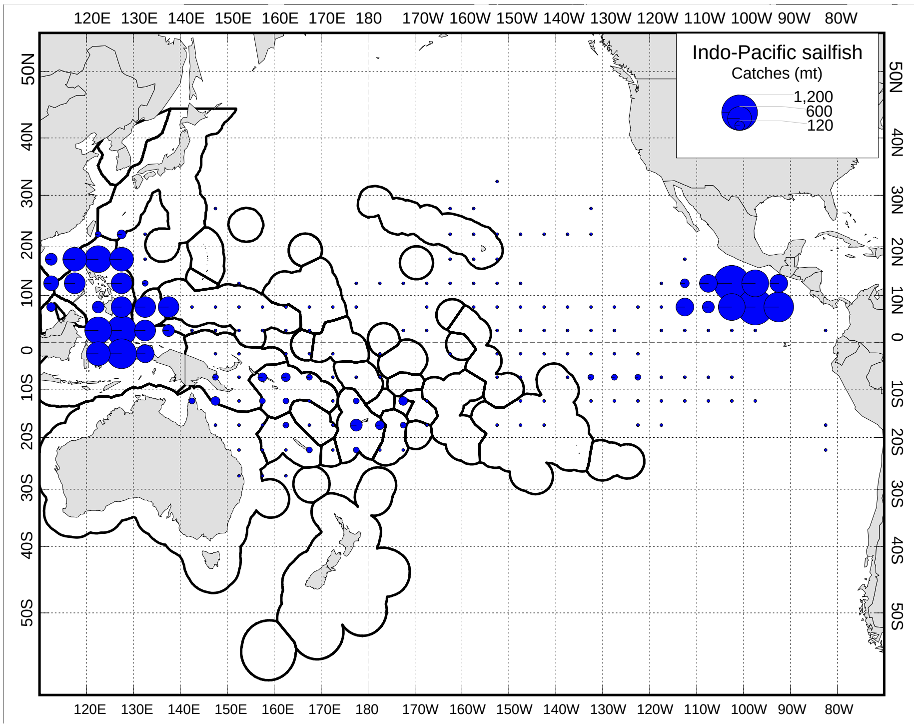


Figure 2a. Indo-Pacific sailfish catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

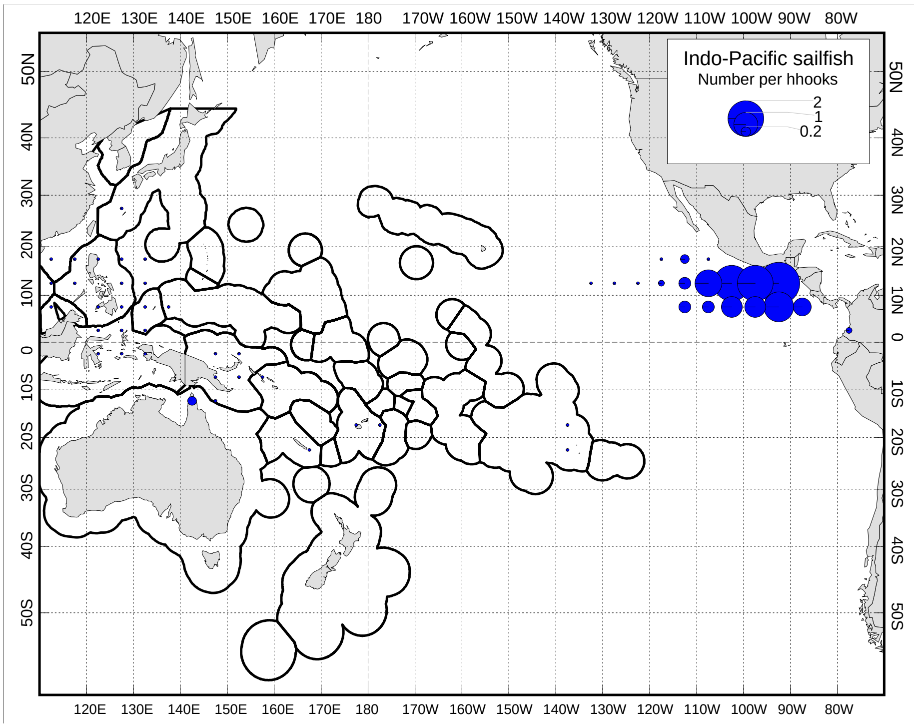


Figure 2b. Indo-Pacific sailfish CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

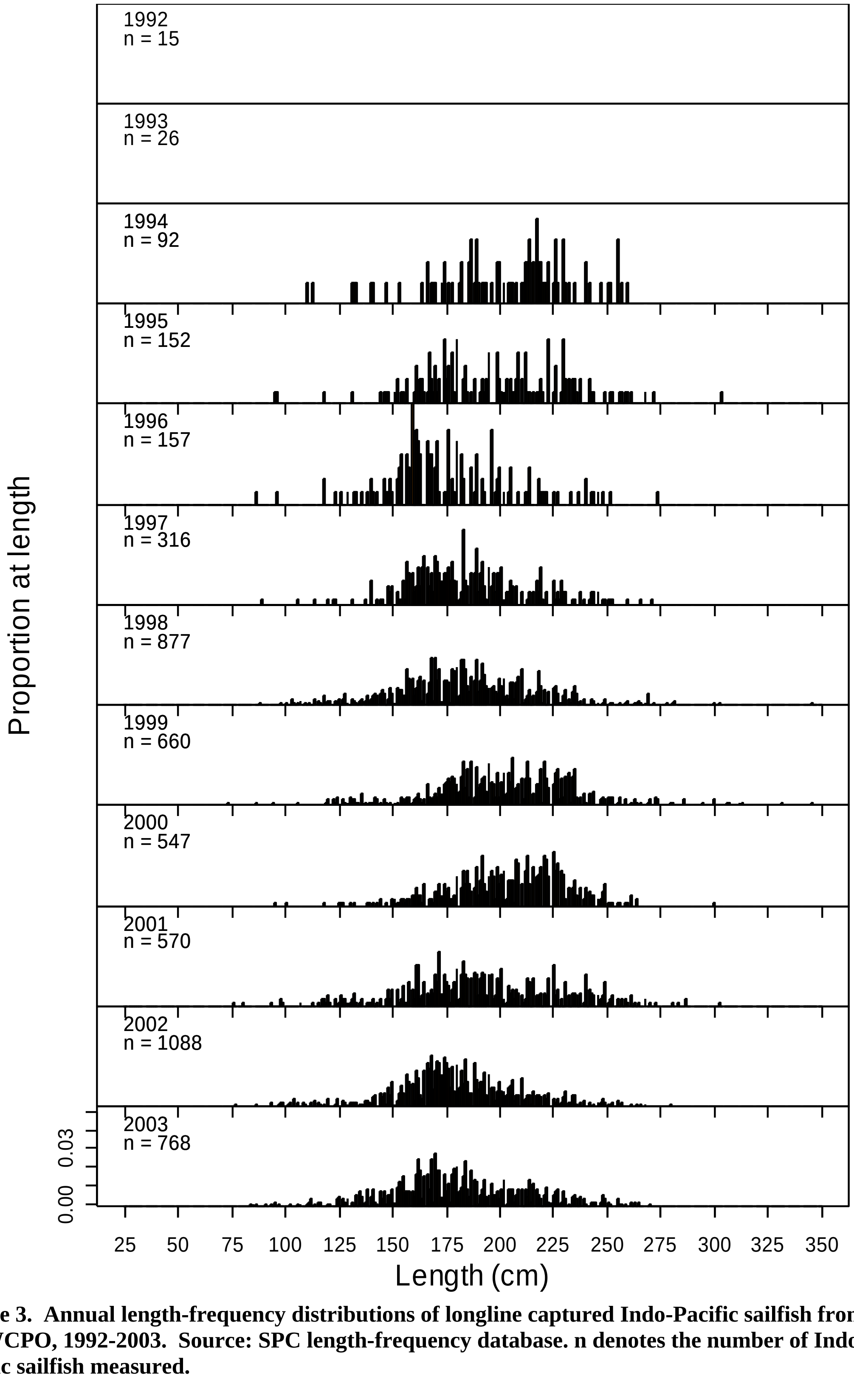


Figure 3. Annual length-frequency distributions of longline captured Indo-Pacific sailfish from the WCPO, 1992-2003. Source: SPC length-frequency database. n denotes the number of Indo-Pacific sailfish measured.

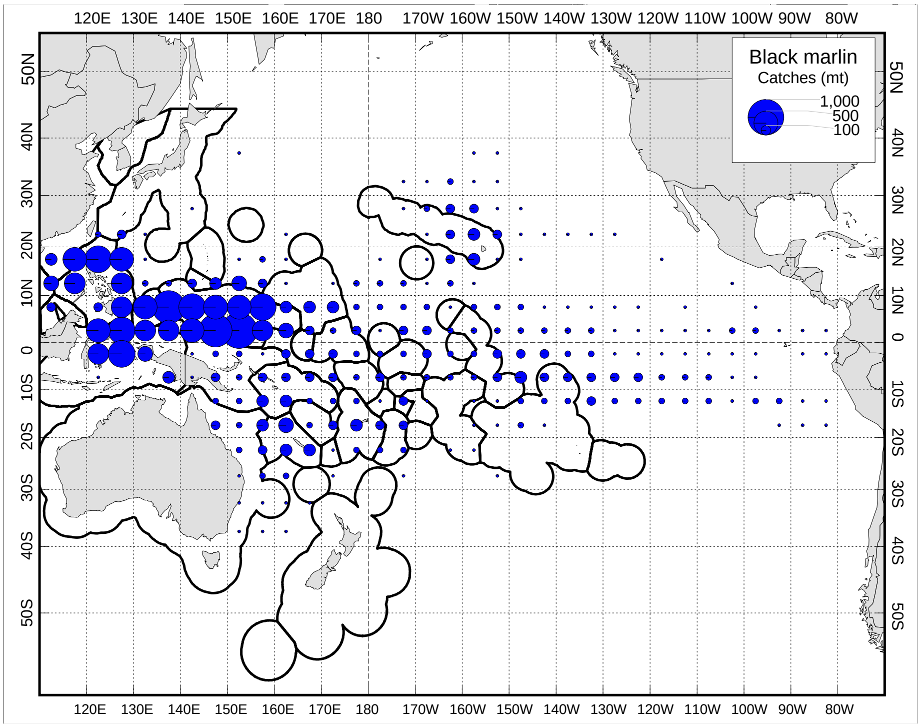


Figure 4a. Black marlin catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

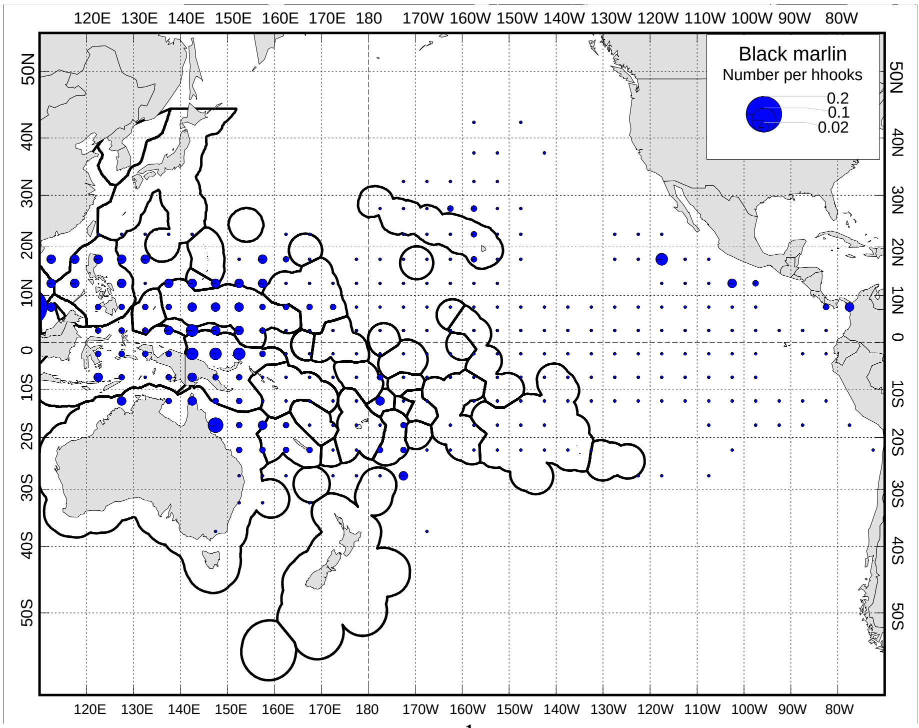


Figure 4b. Black marlin CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

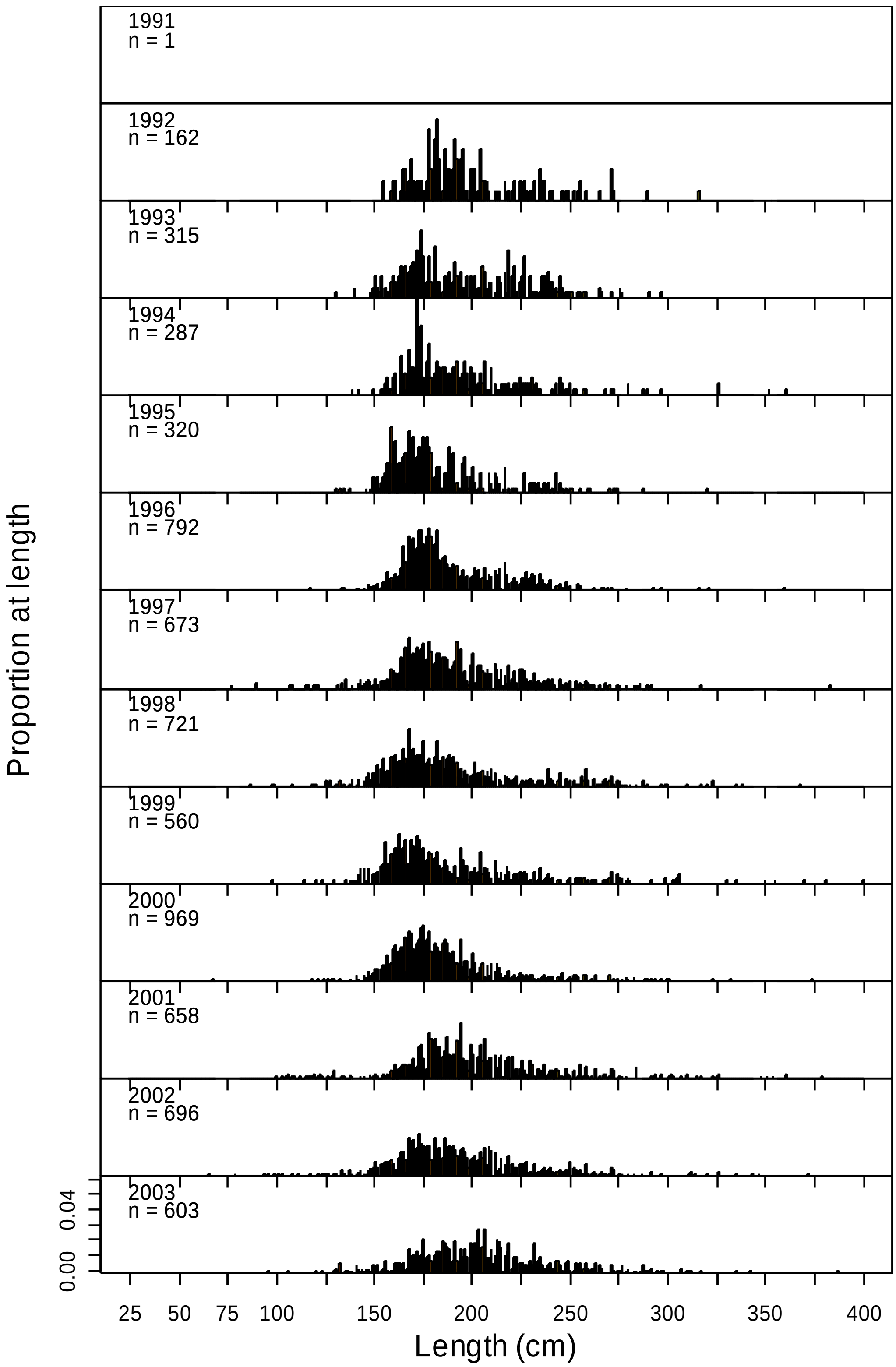


Figure 5. Annual length-frequency distributions of longline captured black marlin from the WCPO, 1991-2003. Source: SPC length-frequency database. n denotes the number of black marlin measured.

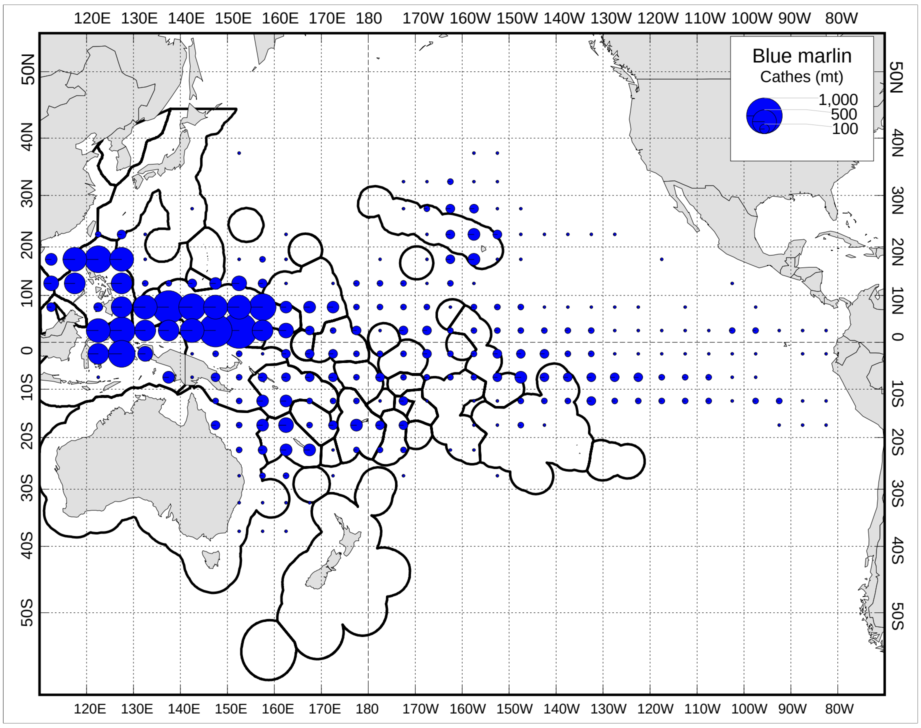


Figure 6a. Blue marlin catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

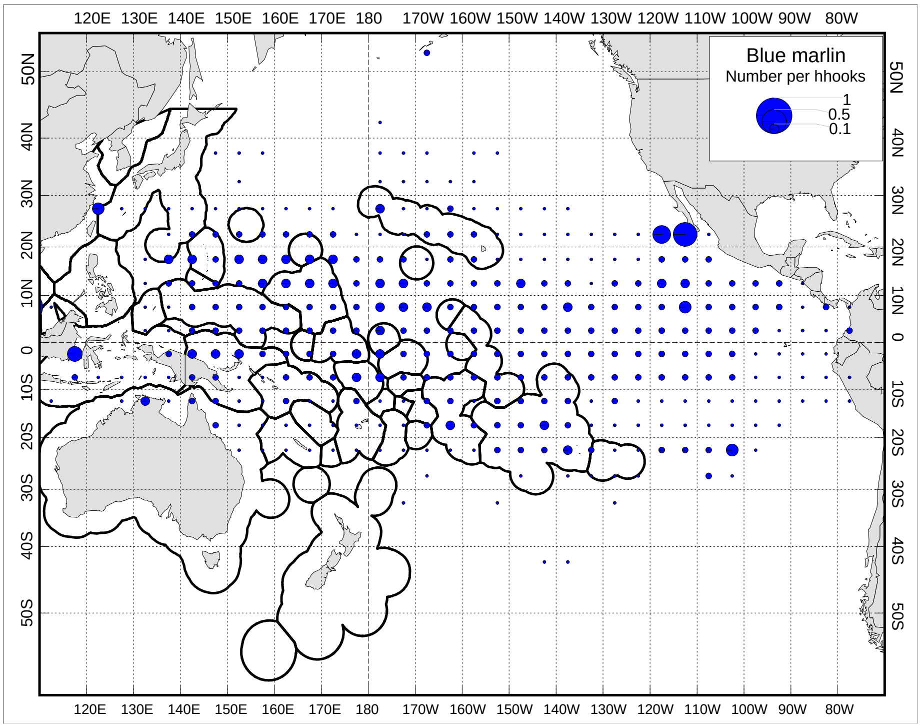


Figure 6b. Blue marlin CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

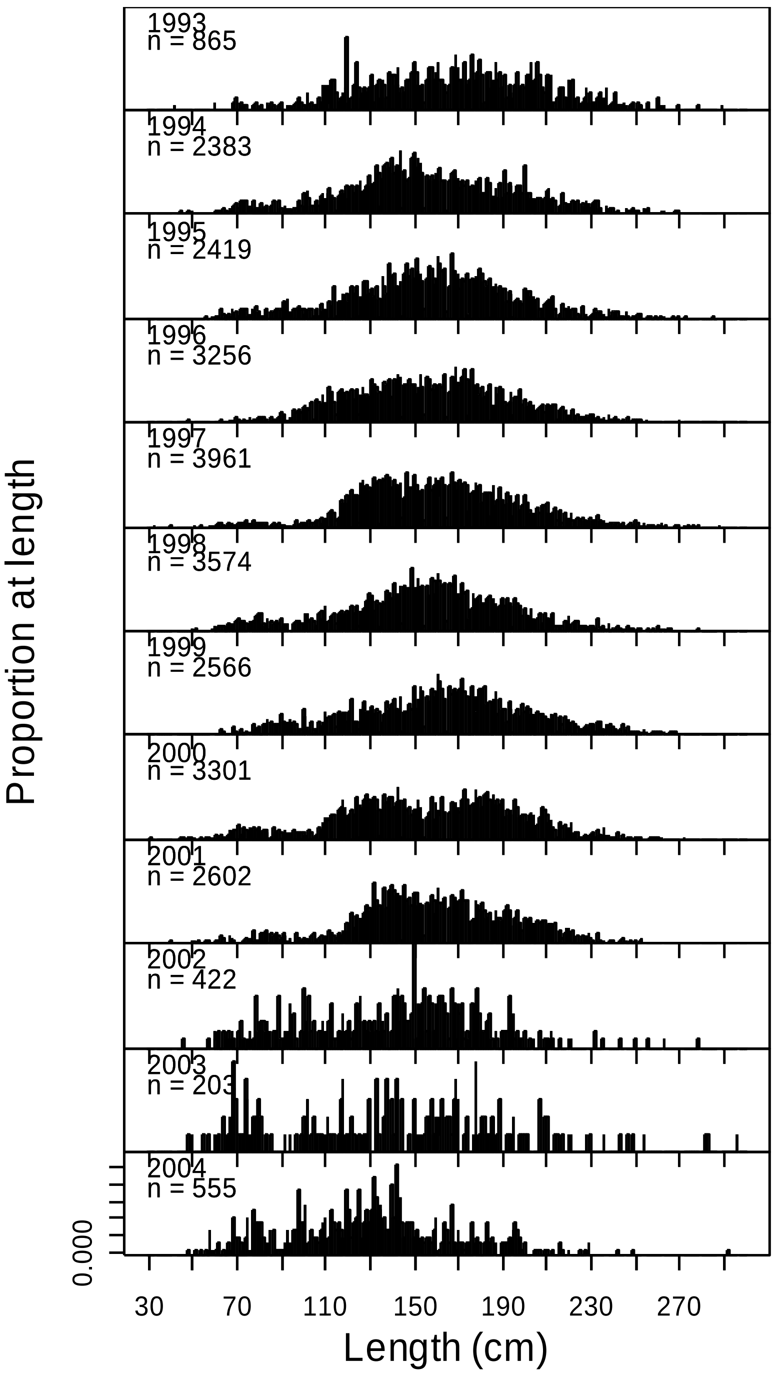


Figure 7. Annual length-frequency distributions of longline captured blue marlin from the WCPO, 1993-2003. Source: SPC length-frequency database. n denotes the number of blue marlin measured.

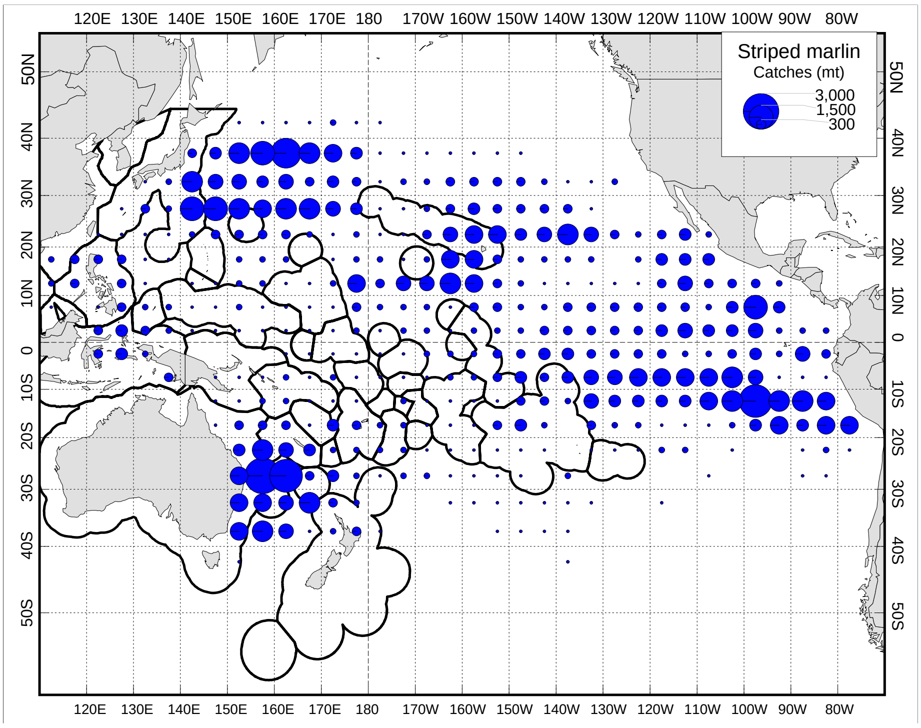


Figure 8a. Striped marlin catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

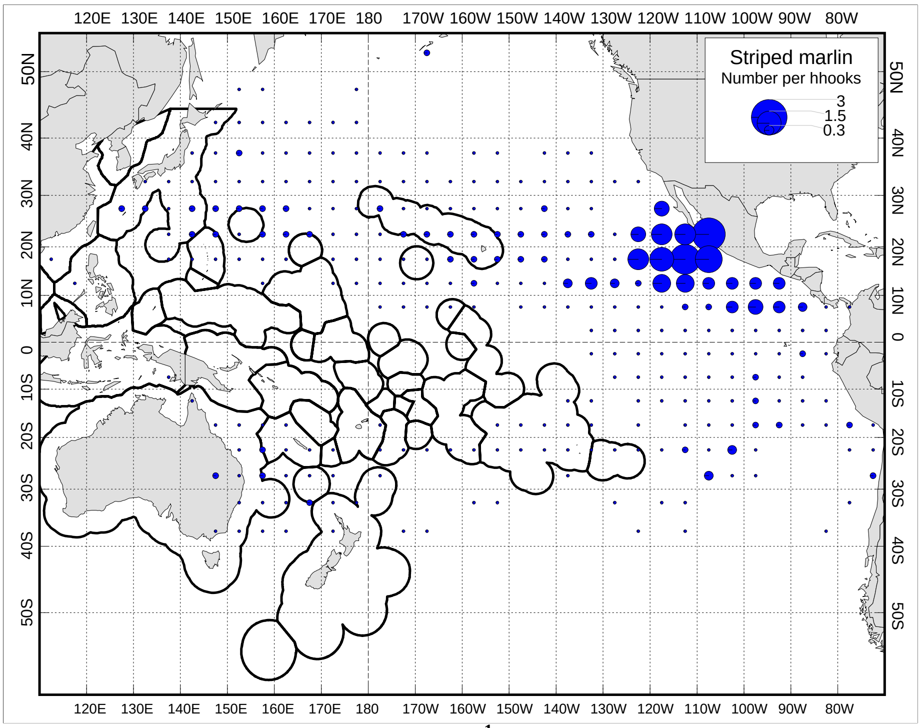


Figure 8b. Striped marlin CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

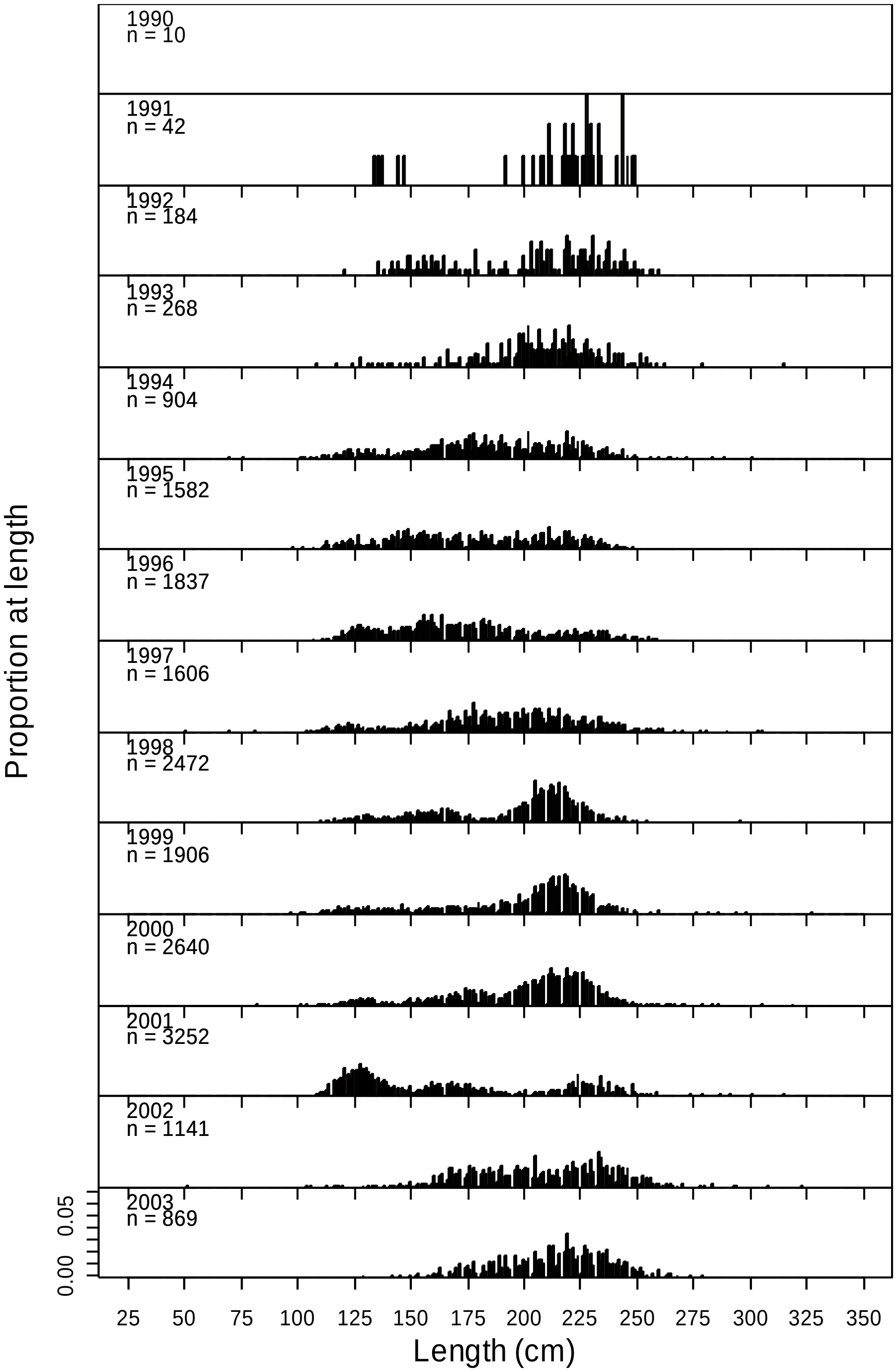


Figure 9. Annual length-frequency distributions of longline captured striped marlin from the WCPO, 1990-2003. Source: SPC length-frequency database. n denotes the number of striped marlin measured.

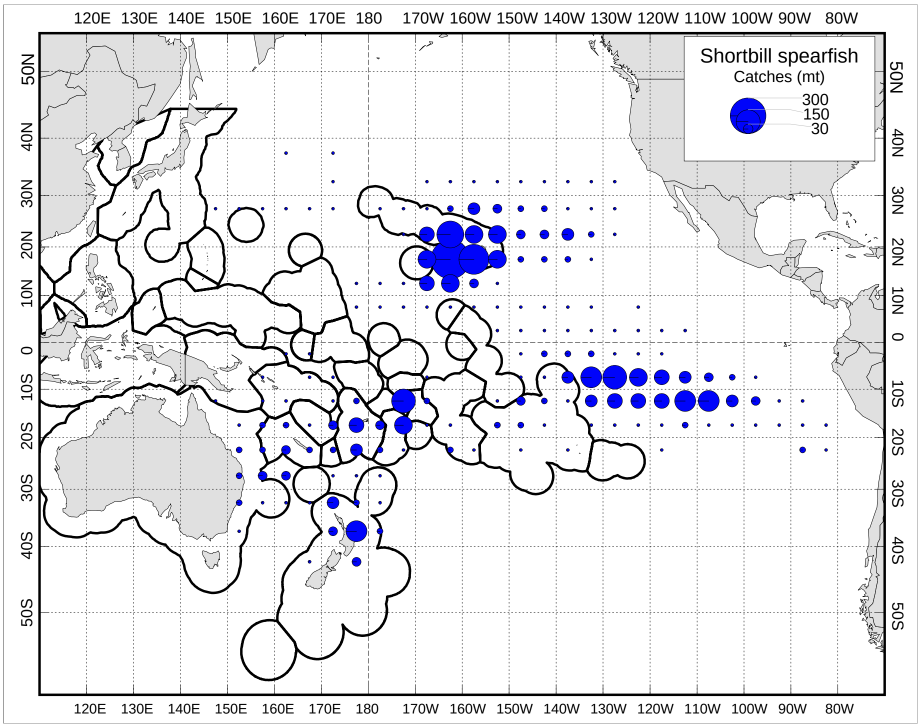


Figure 10a. Shortbill spearfish catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

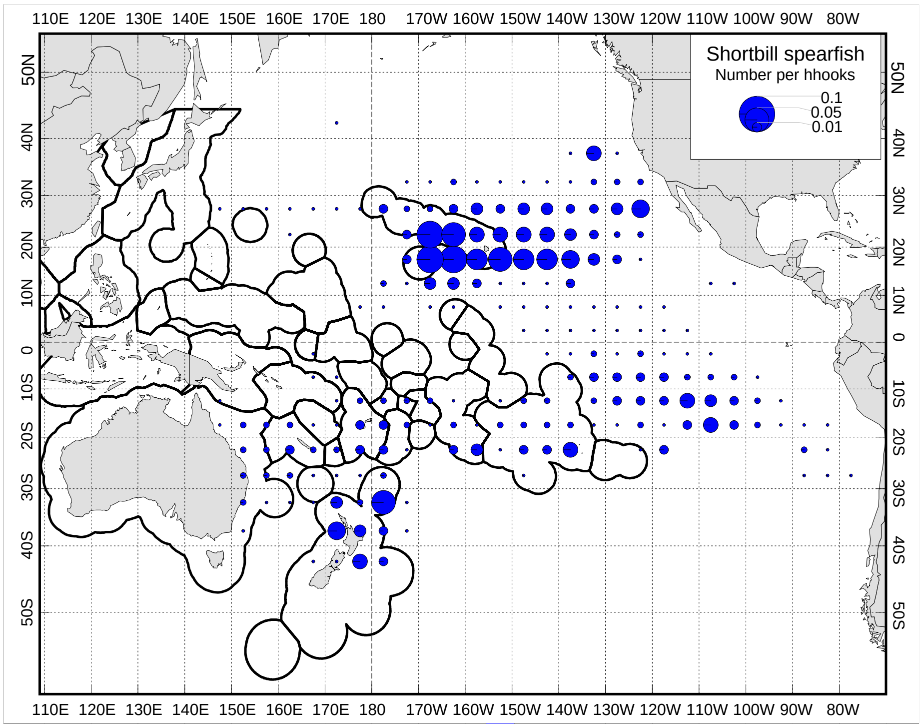


Figure 10b . Shortbill spearfish CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

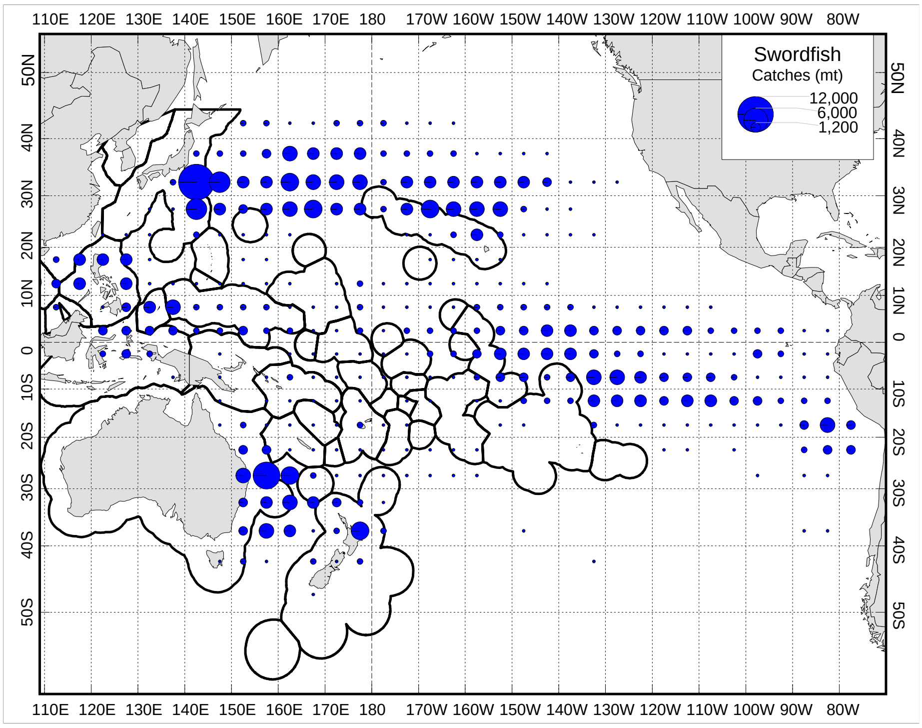


Figure 11a. Swordfish catches by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

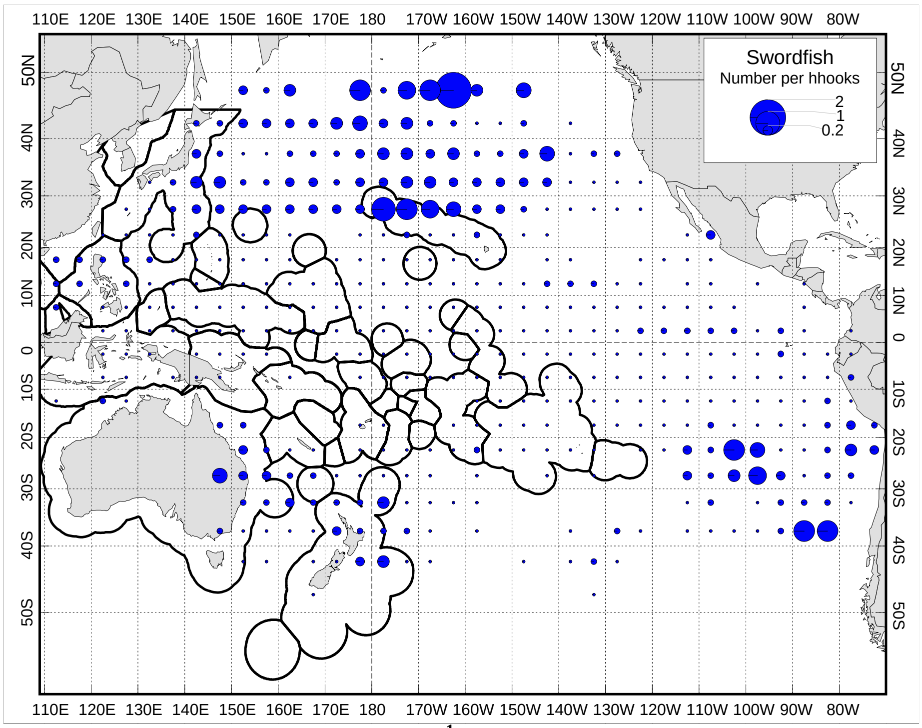


Figure 11b. Swordfish CPUE (number .hhooks^{-1}) by longline fisheries in the WCPO, 1990–2004. Source, CES raised data held by the SPC.

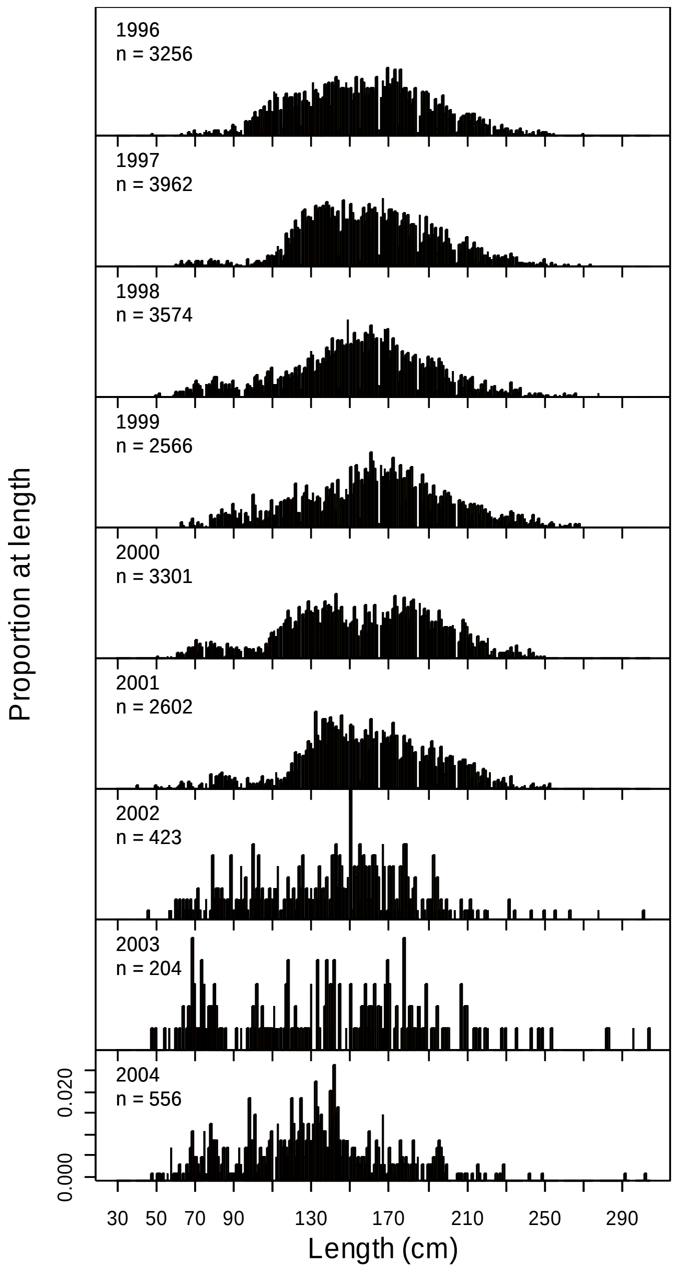
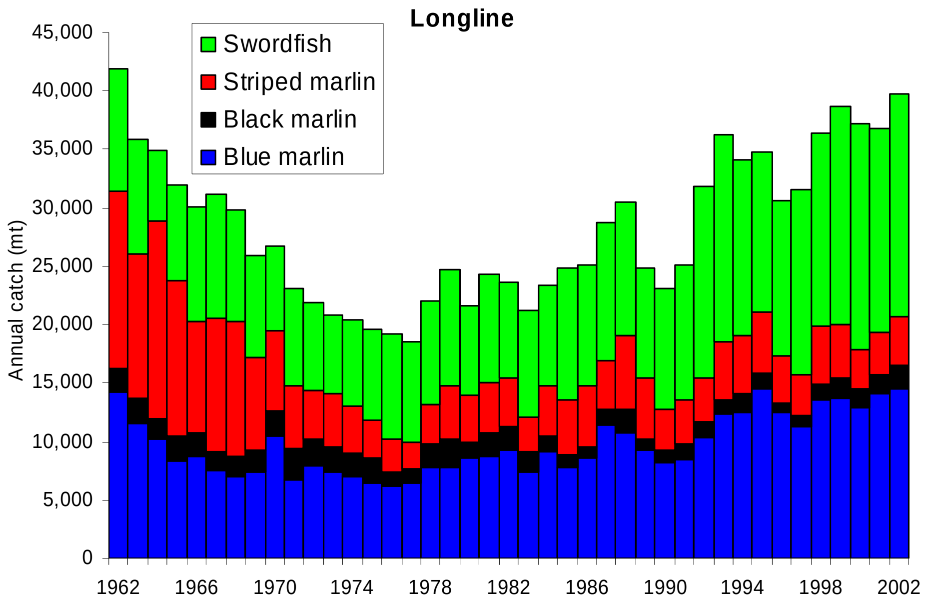


Figure 12. Annual length-frequency distributions of longline captured swordfish from the WCPO, 1996-2004. Source: SPC length-frequency database. n denotes the number of swordfish measured.



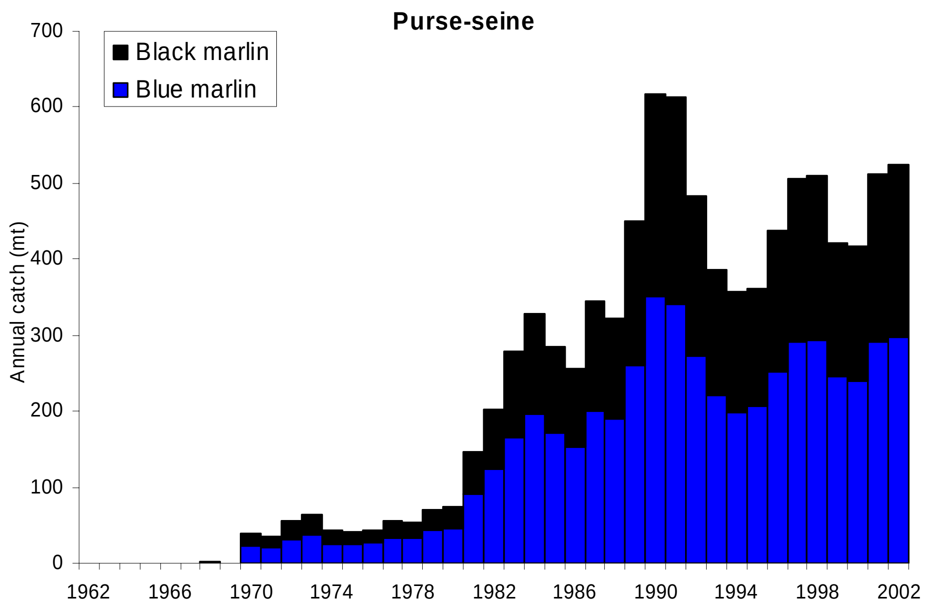
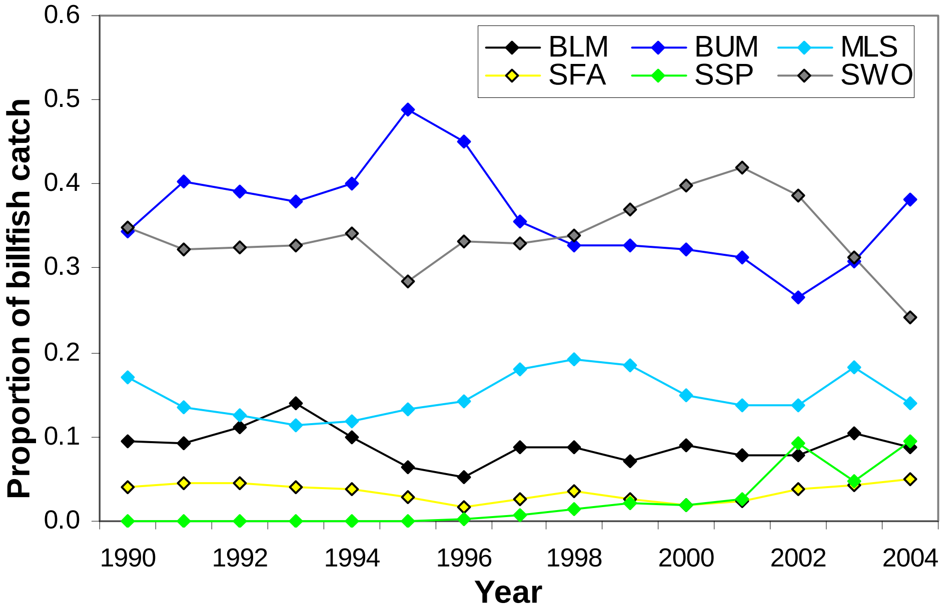


Figure 13. Estimated total billfish catches by longline and purse-seine fleets in the WCPO, 1962–2002. Source: estimates from Williams (2003).



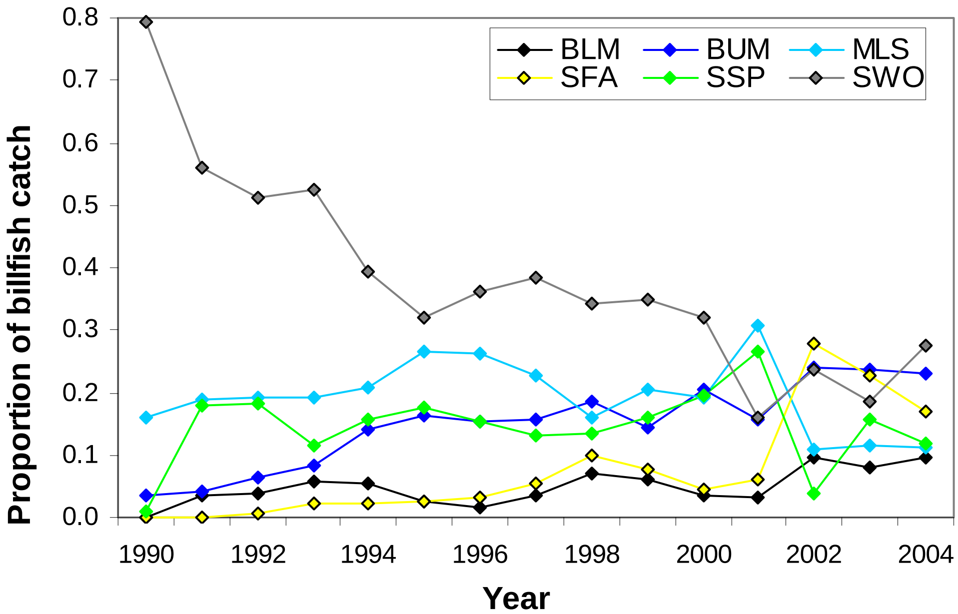


Figure 14. Proportions of billfish species in logsheet (upper figure) and observer (lower figure) records for the longline fisheries of the WCPO, 1990–2004. Source, logsheet database and observer database held at SPC.

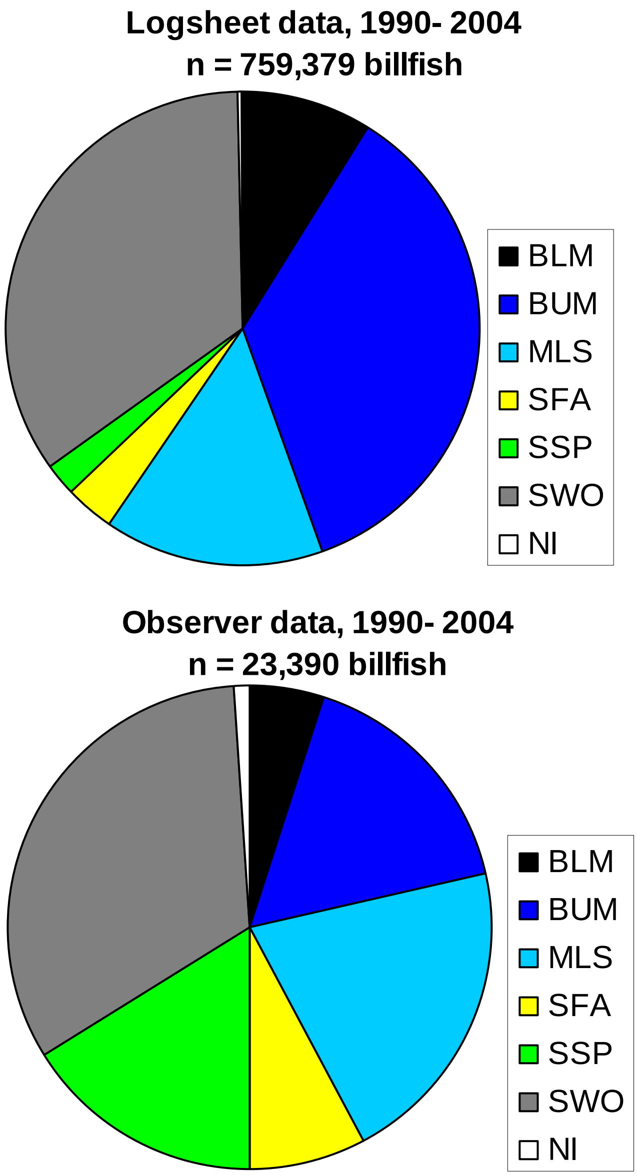


Figure 15. Proportions of billfish species in logsheet (upper figure) and observer (lower figure) records for the longline fisheries of the WCPO, 1990–2004. Source, logsheet database and observer database held at SPC.

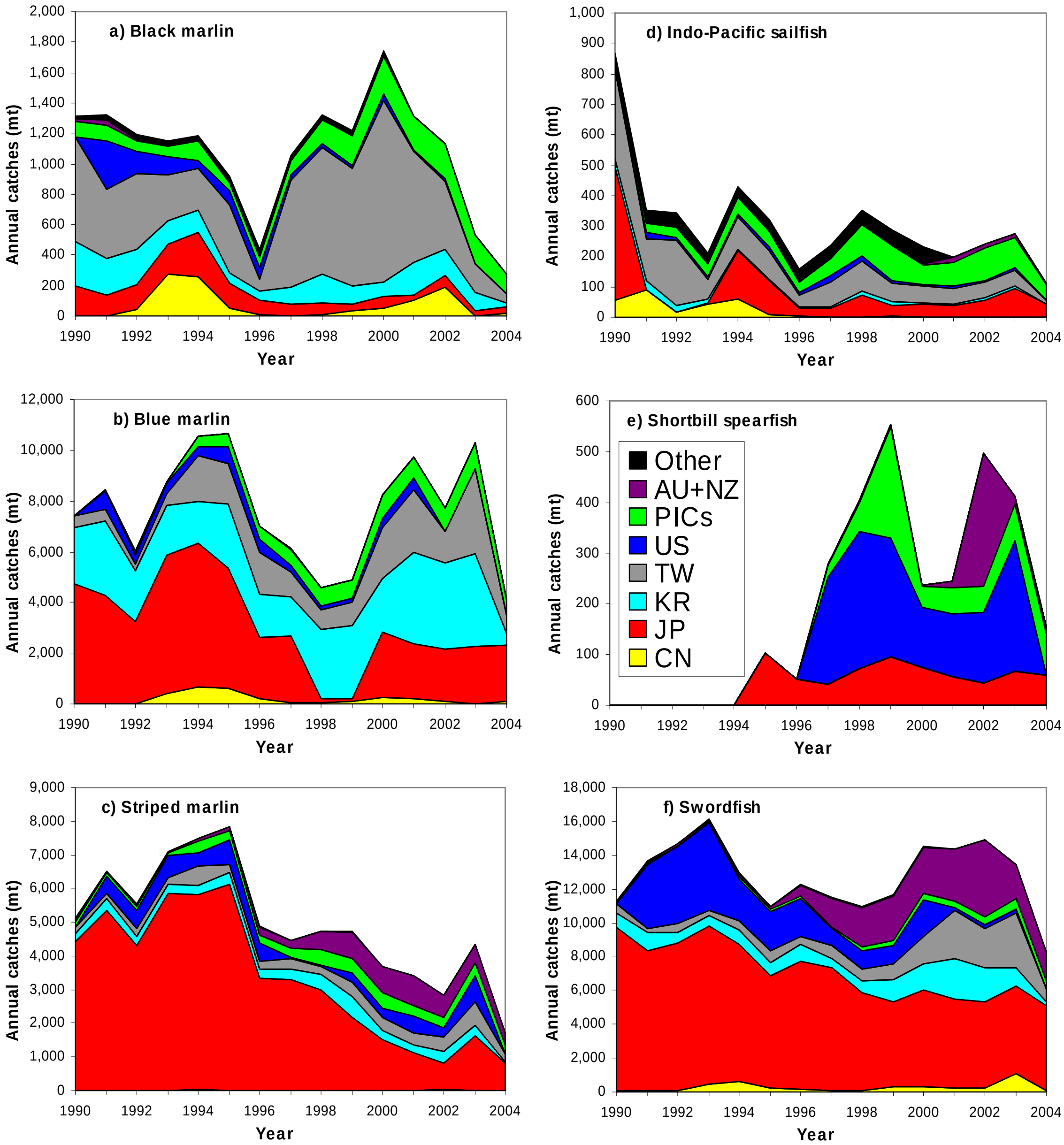


Figure 16. Estimated total annual billfish catches by major flag in the WCPFC region, 1990–2004. Flag codes: CN, China; JP, Japan; KR, Korea; TW, Taiwan; US, United States excluding America Pacific territories; PICs, Pacific Island Countries, American Samoa, Cook Islands, Fiji, Federated States of Micronesia, Guam, Kiribati, Marshall Islands, New Caledonia, French Polynesia, Papua New Guinea, Palau, Solomon Islands, Tonga, Vanuatu and Samoa; AU+NZ, Australia and New Zealand; Other, Indonesia and the Philippines. Source: CES raised database held at SPC. Data for 2003 and 204 are likely to be incomplete.

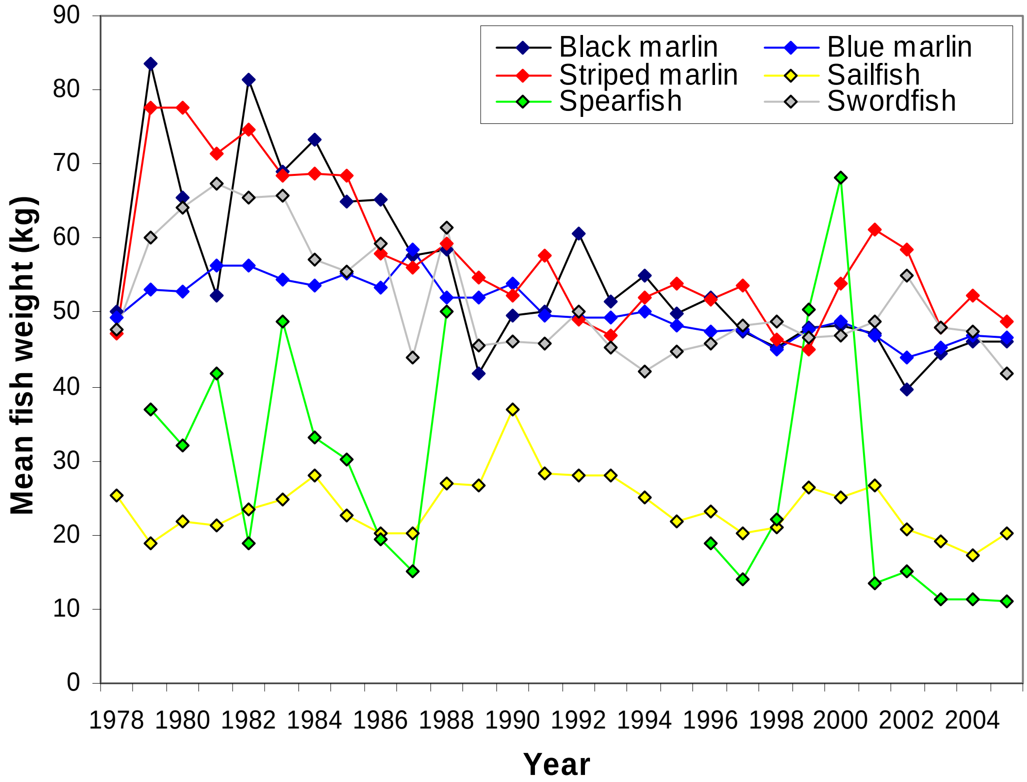


Figure 17. Estimated average weights of billfish captured in the WCPO, 1978-2003. Source: logsheet data held at SPC.

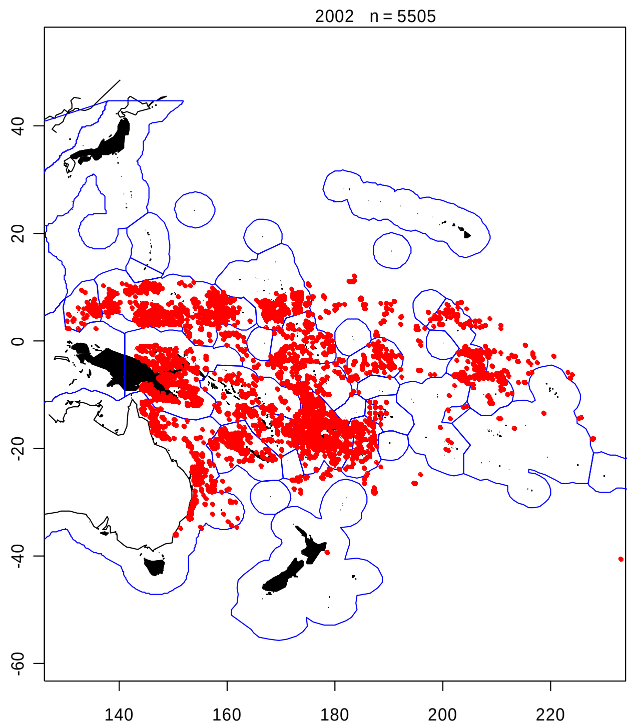


Figure 18. Position of longline sets capturing one or more black marlin in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of black marlin captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.

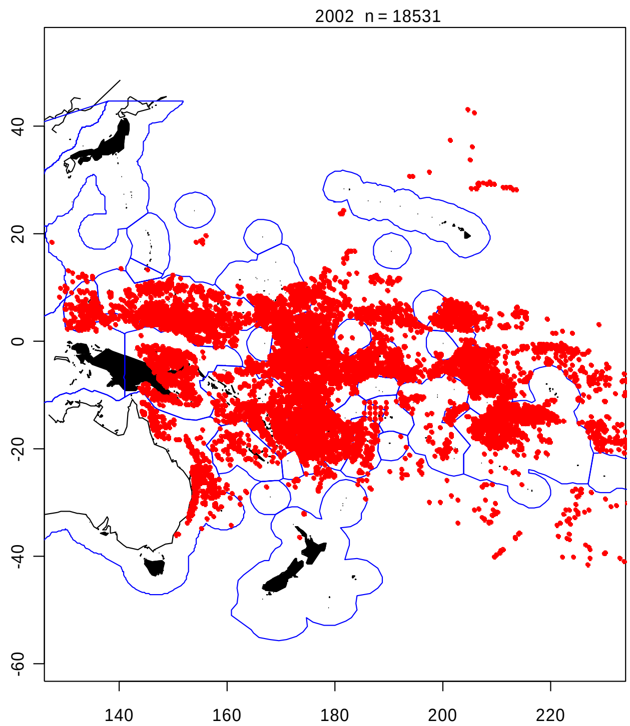


Figure 19. Position of longline sets capturing one or more blue marlin in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of blue marlin captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.

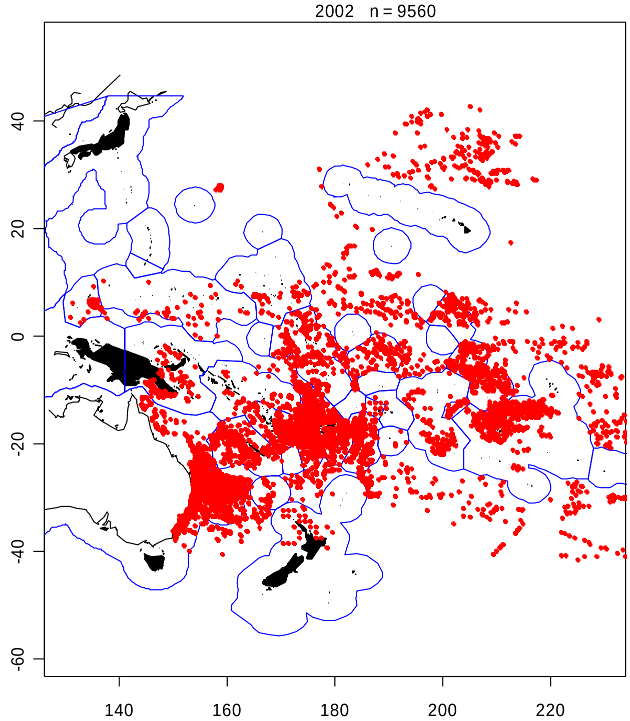


Figure 20. Position of longline sets capturing one or more striped marlin in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of striped marlin captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.

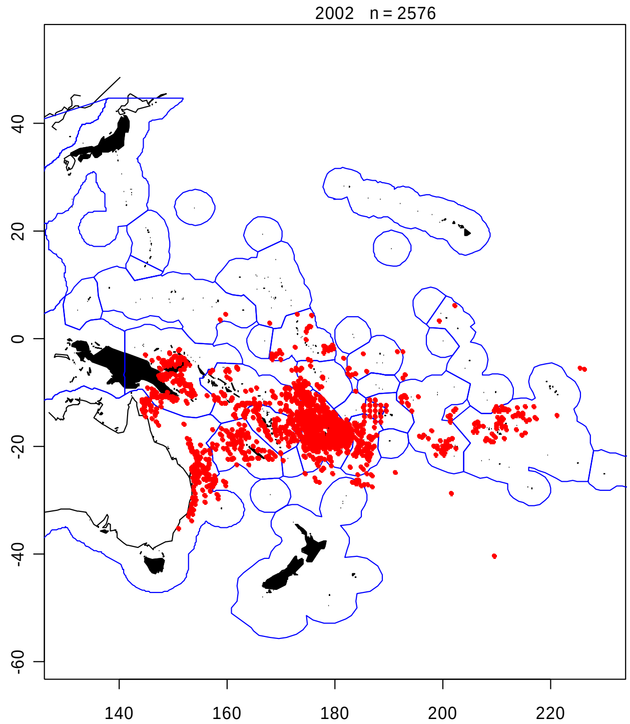


Figure 21. Position of longline sets capturing one or more Indo-Pacific sailfish in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of Indo-Pacific sailfish captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.

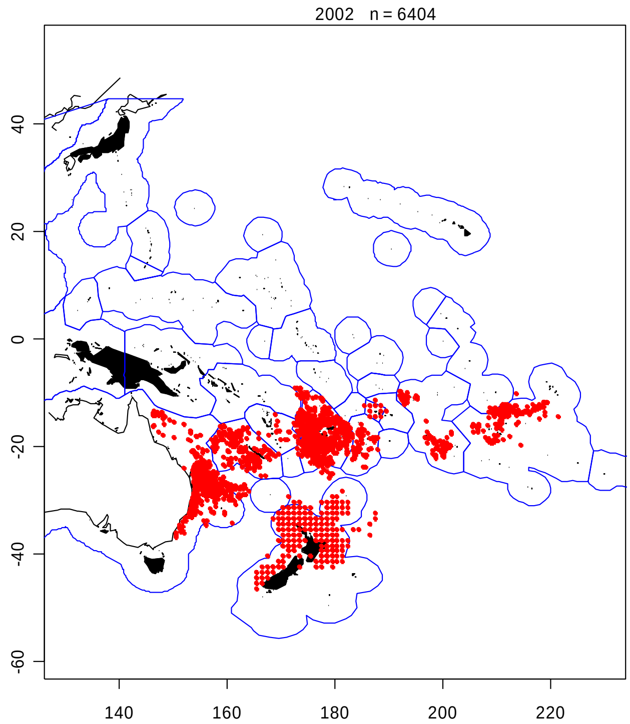


Figure 22. Position of longline sets capturing one or more shortbill spearfish in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of shortbill spearfish captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.

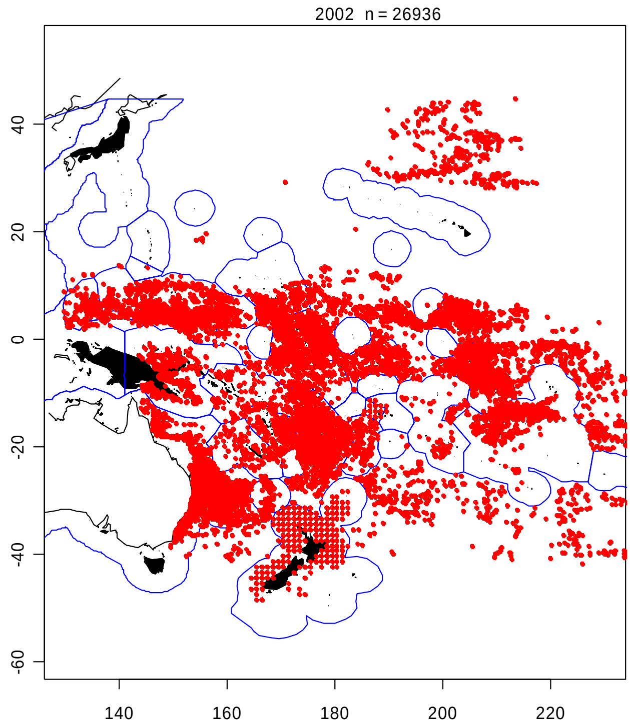
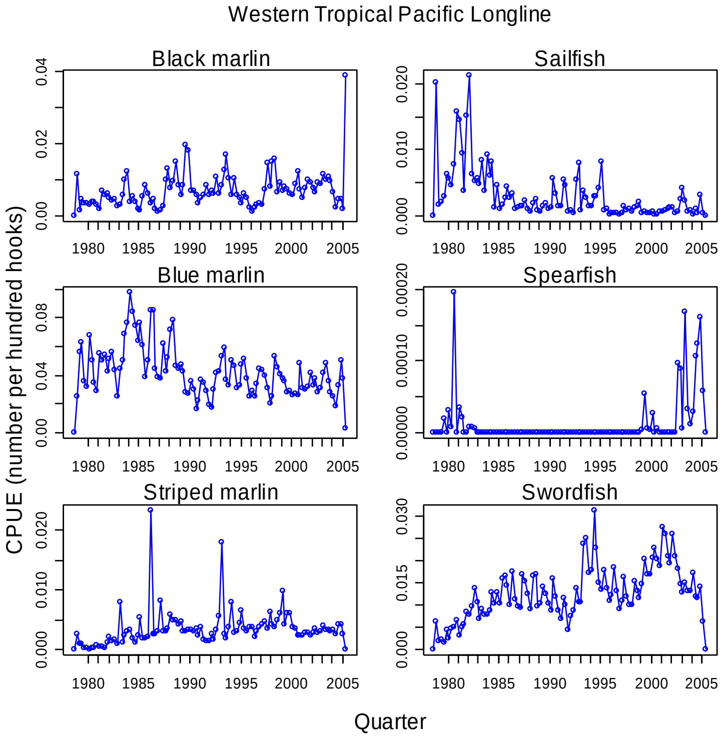


Figure 23. Position of longline sets capturing one or more swordfish in the WCPFC area, 2002. Source: logsheet database held at SPC. n, number of swordfish captured. Data north of approximately 15ºN were unavailable and the northern range of this species is not accurately displayed in this figure.



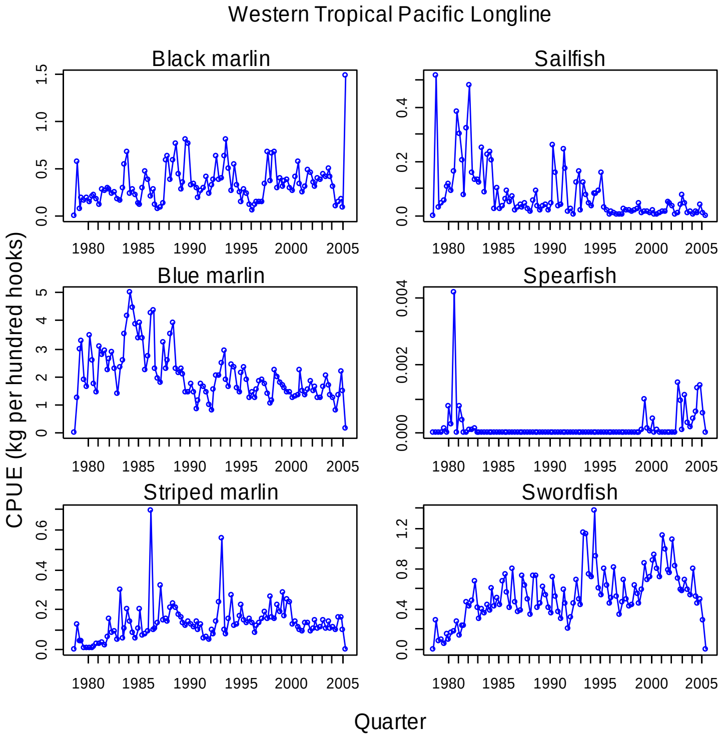
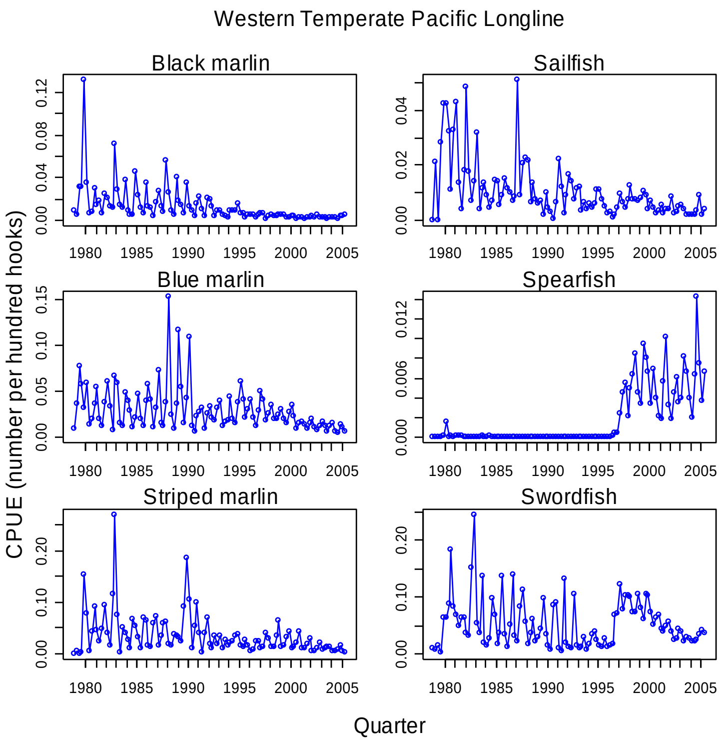


Figure 24. Logsheet CPUEs in numbers (upper figure) and kilograms (lower figure) per hundred hooks for billfish species for the western tropical Pacific longline fishery, 1978–12004. Source, CES data held at SPC.



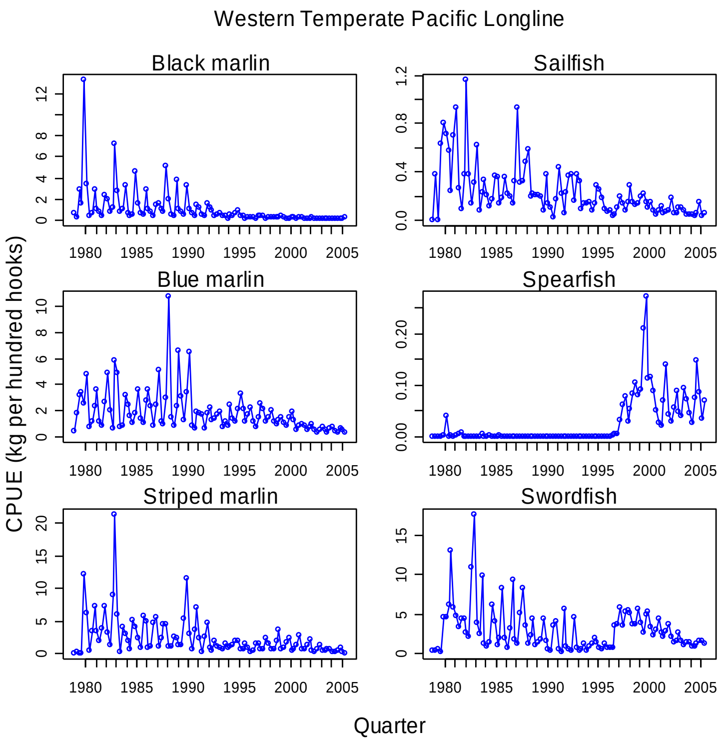


Figure 25. Logsheet CPUEs in numbers (upper figure) and kilograms (lower figure) per hundred hooks for billfish species for the western temperate Pacific longline fishery, 1978–12004. Source, CES data held at SPC.

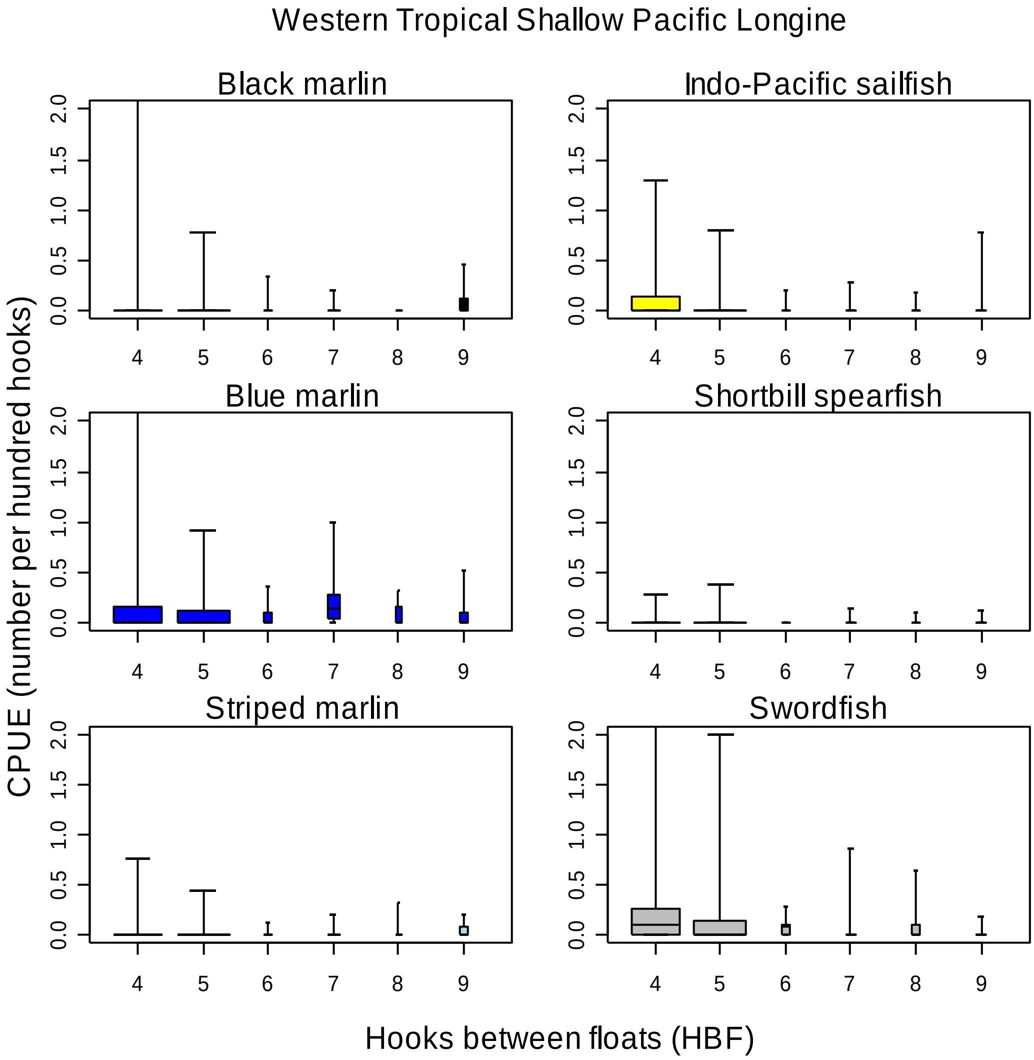


Figure 26. Catch per unit effort of billfish species in the tropical shallow longline fishery on longline gears with different HBF configurations, 1990–2004. Source: observer data held at SPC. Data is from 1,965 longline sets. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.

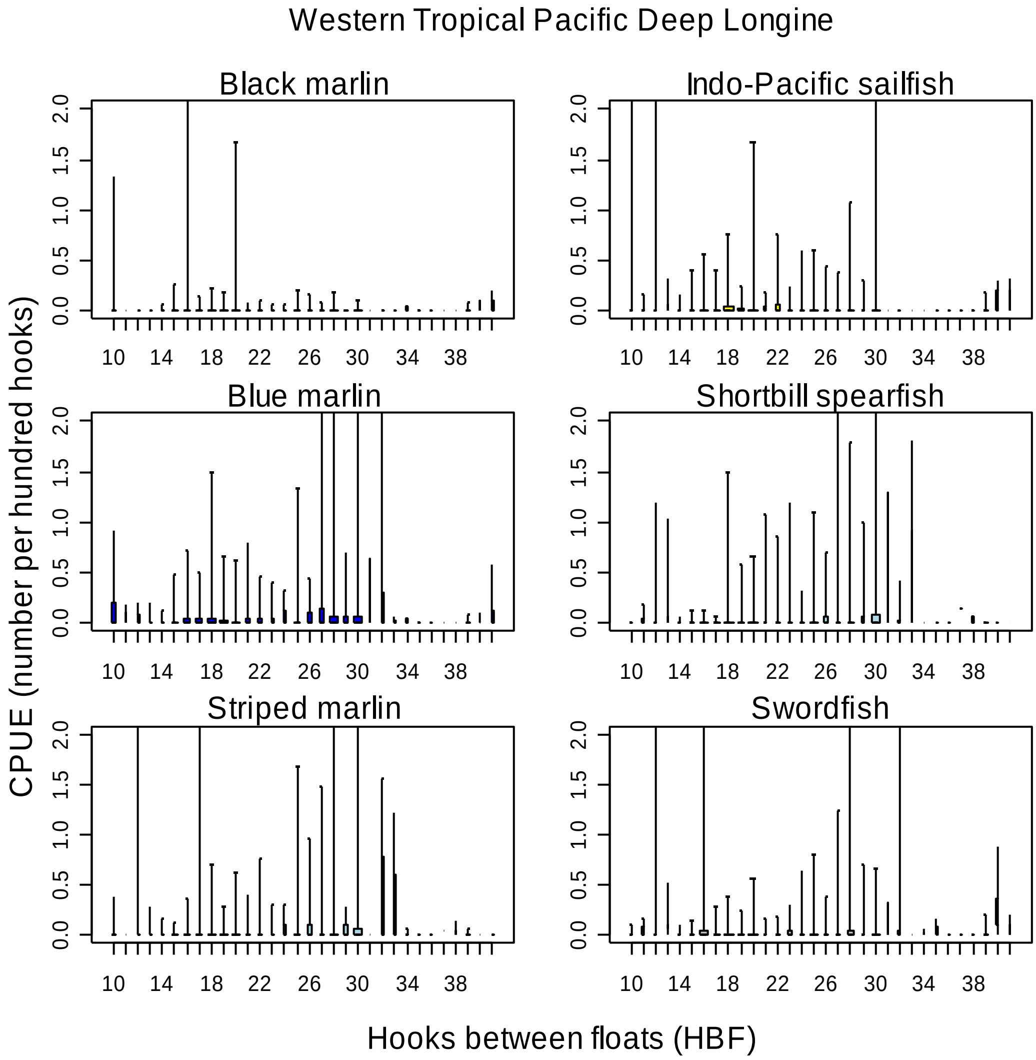


Figure 27. Catch per unit effort of billfish species in the tropical deep longline fishery on longline gears with different HBF configurations, 1990–2004. Source: observer data held at SPC. Data is from 3,905 longline sets. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.

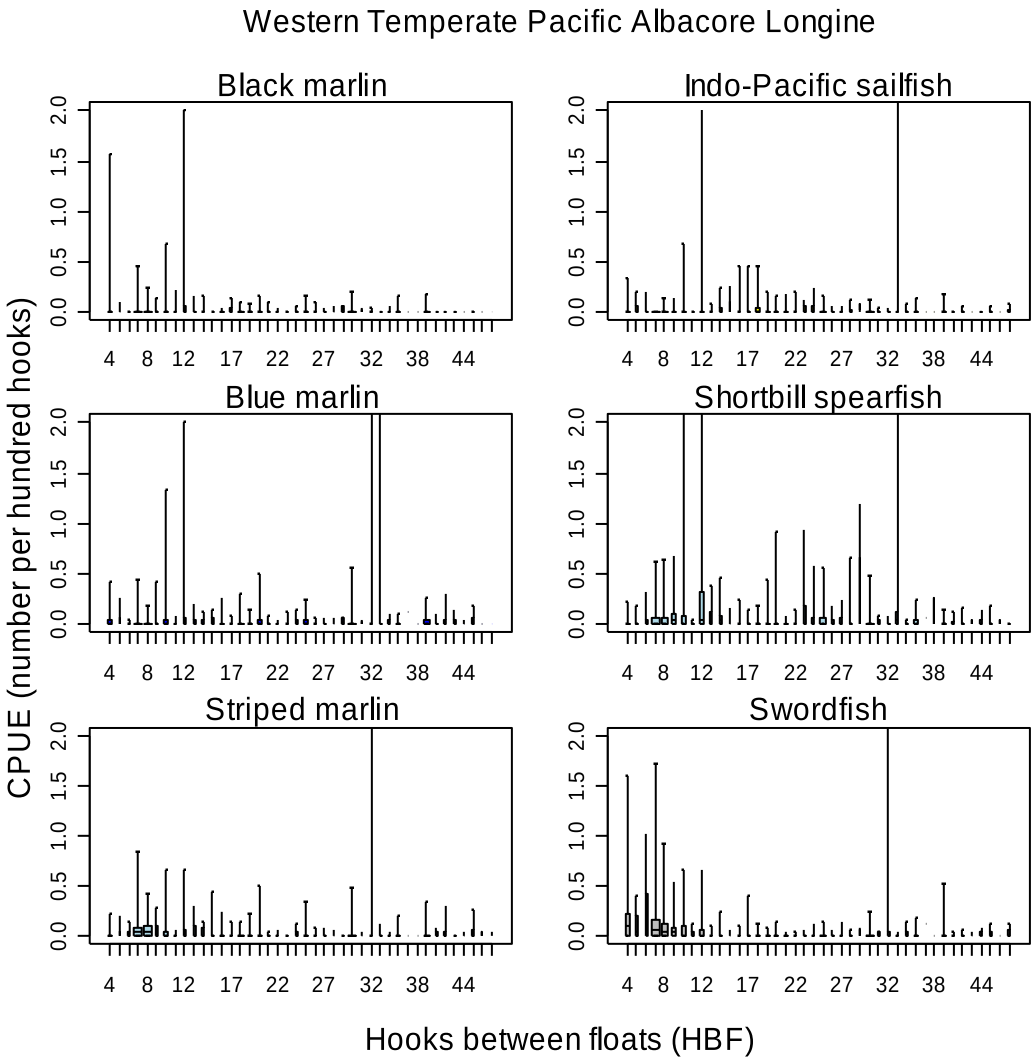


Figure 28. Catch per unit effort of billfish species in the temperate albacore longline fishery on longline gears with different HBF configurations, 1990–2004. Source: observer data held at SPC. Data is from 3,728 longline sets. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.

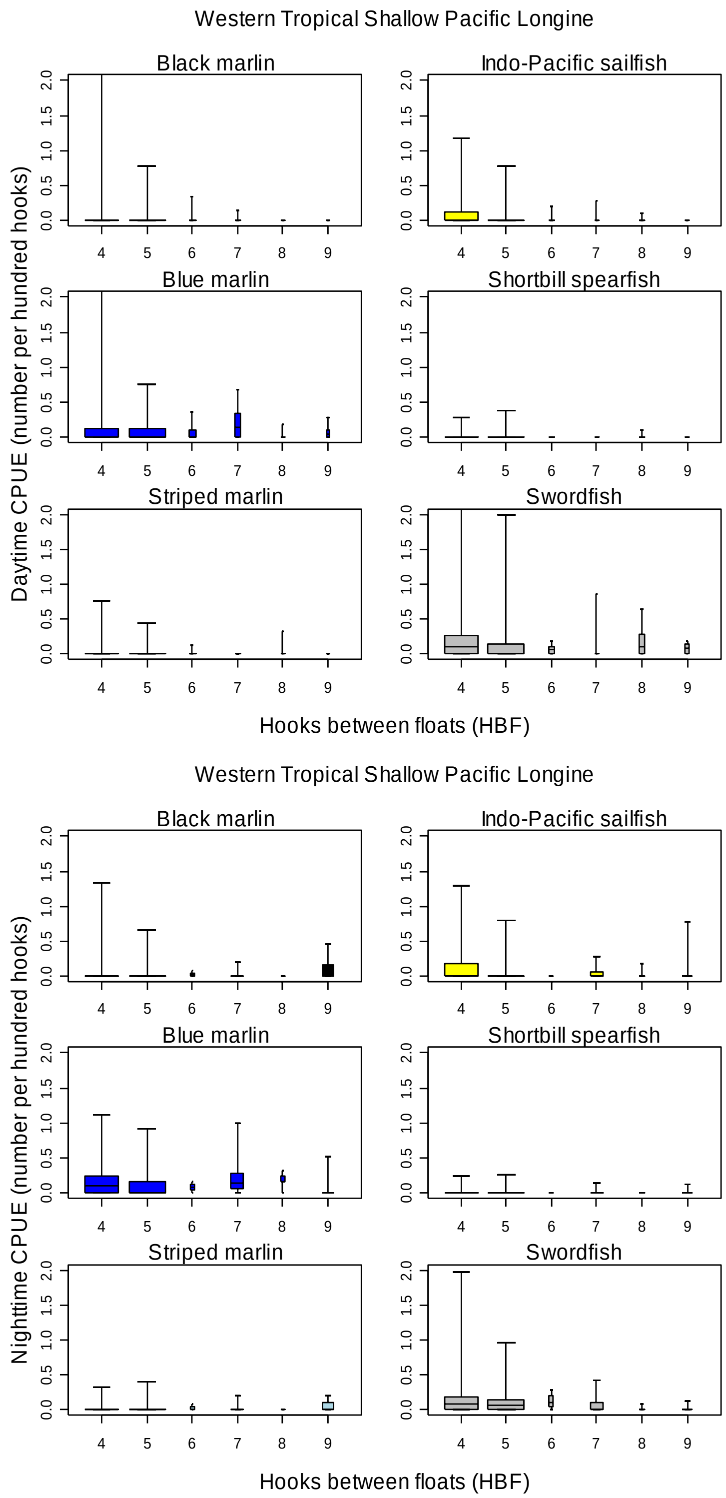
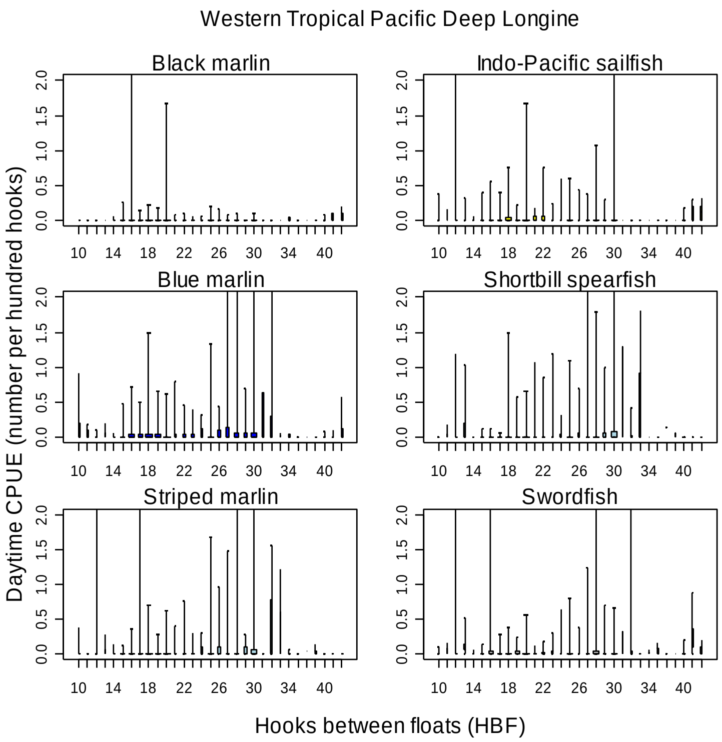


Figure 29. Catch per unit effort of billfish species in the tropical shallow longline fishery on longline gear using different number of HBF configurations, 1990–2004. Daytime sets (upper figure, n=1,351 sets) and nighttime sets (lower figure, n= 614 sets) shown separately. Source: observer data held at SPC. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.



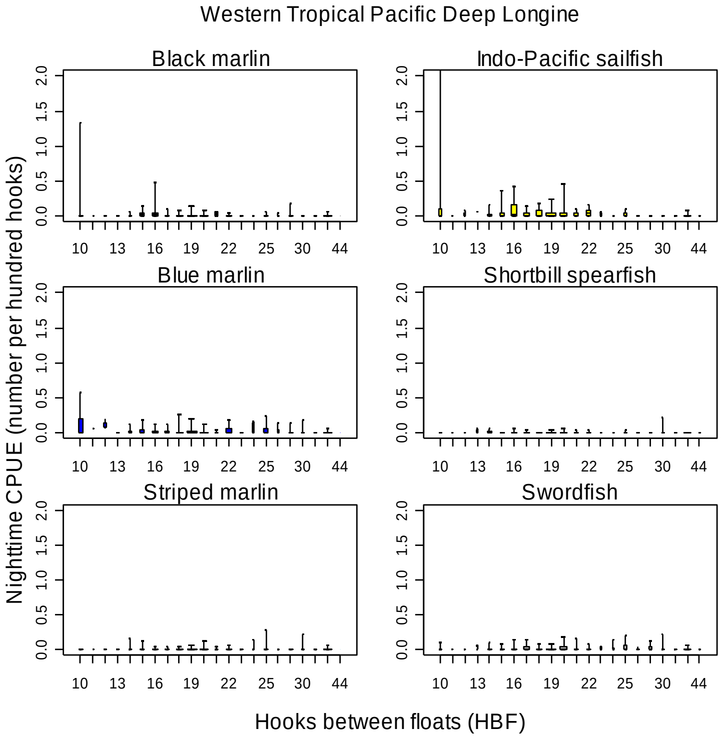


Figure 30. Catch per unit effort of billfish species in the tropical deep longline fishery on longline gear using different number of HBF configurations. Daytime sets (upper figure, n=3,377 sets) and nighttime sets (lower figure, n= 528 sets) shown separately. Source: observer data held at SPC. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.

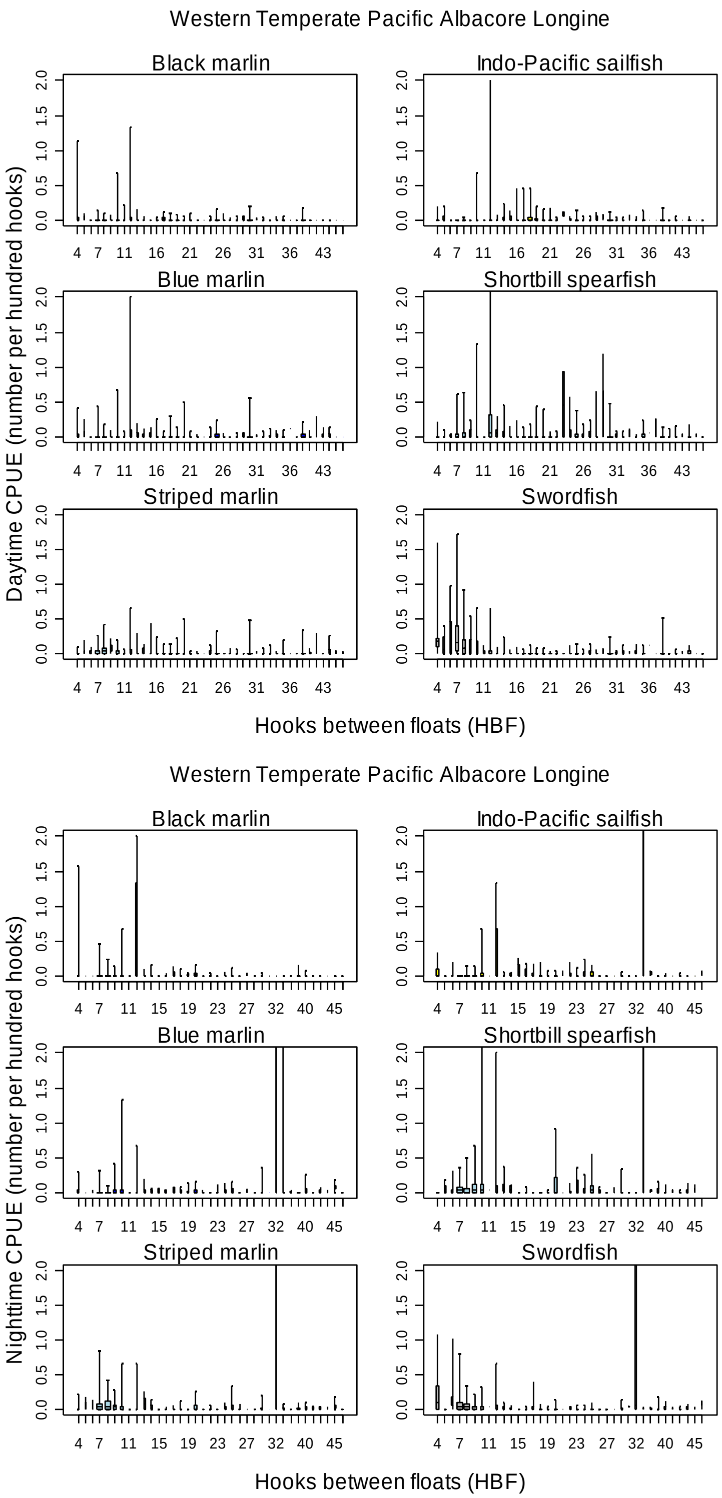


Figure 31. Catch per unit effort of billfish species in the TAL fishery on longline gear using different number of HBF configurations, 1990–2004. Daytime sets (upper figure, n=2,533 sets) and nighttime sets (lower figure, n= 1,195 sets) shown separately. Source: observer data held at SPC. Boxes represent the upper and lower 25th percentile of the CPUE for each HBF category. Vertical lines represent the range of the data. Widths of boxes are proportional to the number of observations for each category. Maximum CPUE set at 2.0 billfish per hundred hooks to aid comparisons.

11. Appendices

Appendix 1. Summaries of the logsheet data held in CES database at SPC.

Table A1. Annual number of longline sets reported by flag for the longline fisheries in the WCPO, 1990–2004 Source, SPC observer database. Flag codes: AS, American Samoa; AU, Australia; CK, Cook Islands; CN, China; FJ, Fiji; FM, Federated States of Micronesia; GU, Guam; ID, Indonesia; JP, Japan; KI, Kiribati; KR, Korea; MH, Marshall Islands; NC, New Caledonia; NZ, New Zealand; PF, French Polynesia; PG, Papua New Guinea; PH, Philippines; PW, Palau; SB, Solomon Islands; TO, Tonga; TW, Taiwan; US, United States; VU, Vanuatu; WS, Western Samoa.

Year	AS	AU	CK	CN	FJ	FM	GU	ID	JP	KI	KR	MH	NC	NZ	PF	PG	PH	PW	SB	TO	TW	US	VU	WS	Total
1990	0	2,650	0	1,793	429	0	0	0	33,017	0	6,649	0	711	297	0	0	0	0	0	164	5,747	0	0	0	51,457
1991	0	4,559	0	3,530	616	45	0	0	26,222	0	4,577	0	395	612	0	0	0	0	0	153	6,591	7	0	0	47,307
1992	0	6,214	0	8,294	1,453	476	41	0	23,597	0	5,681	213	369	871	569	0	0	0	0	195	8,043	0	0	0	56,016
1993	0	6,120	0	30,152	1,263	539	0	0	22,317	0	6,753	361	467	1,376	157	27	0	0	0	57	12,805	0	0	81	82,475
1994	0	6,253	144	40,879	2,472	611	0	0	20,519	0	17,141	9	236	2,047	1,269	83	0	0	0	415	11,711	0	0	29	103,818
1995	0	5,720	368	39,650	2,528	524	569	0	27,317	34	20,367	48	340	2,957	2,325	213	0	0	709	0	10,670	0	125	0	114,464
1996	0	6,085	130	25,521	1,365	438	714	0	17,926	2	14,317	0	240	2,154	2,476	375	0	0	1,066	70	8,708	0	388	0	81,975
1997	0	8,503	2	13,388	3,529	903	321	0	13,996	0	9,845	0	299	2,425	3,310	1,074	38	0	1,858	318	11,645	26	243	0	71,723
1998	0	11,179	0	8,839	4,710	1,666	392	0	11,128	0	11,875	0	1,498	3,663	3,750	1,170	7	0	929	331	8,802	61	47	4,439	74,486
1999	0	11,385	0	12,424	4,367	1,551	606	0	16,223	0	21,182	0	1,826	6,143	4,508	2,072	0	0	823	508	9,701	0	0	5,743	99,062
2000	0	11,047	0	13,394	6,915	2,365	245	0	14,388	0	20,939	0	2,327	6,461	4,917	2,884	0	166	1,027	1,242	13,941	0	0	1,065	103,323
2001	0	12,420	18	12,970	10,165	2,079	0	0	10,061	0	19,642	0	1,788	8,034	4,489	4,136	0	45	713	1,844	12,875	0	0	2,366	103,645
2002	35	13,054	800	9,672	14,855	1,884	0	0	6,309	0	11,964	0	1,730	8,314	4,509	5,246	31	0	807	2,510	17,433	0	323	3,268	102,744
2003	22	13,240	2,694	11,530	16,961	2,204	0	0	6,721	106	1,807	0	2,369	1	6,333	5,900	30	0	0	2,441	18,828	0	1,073	2,030	94,290
2004	0	0	1,367	5,919	10,852	975	0	108	133	9	45	19	2,498	0	5,646	3,401	0	8	0	880	5,439	0	193	0	37,492
Total	*57*	*118,429*	*5,523*	*237,955*	*82,480*	*16,260*	*2,888*	*108*	*249,874*	*151*	*172,784*	*650*	*17,093*	*45,355*	*44,258*	*26,581*	*106*	*219*	*7,932*	*11,128*	*162,939*	*94*	*2,392*	*19,021*	*1,224,277*

Appendix 2. CPUEs of commonly captured fishes from the longline fisheries of the WCPO, 1978–2004.

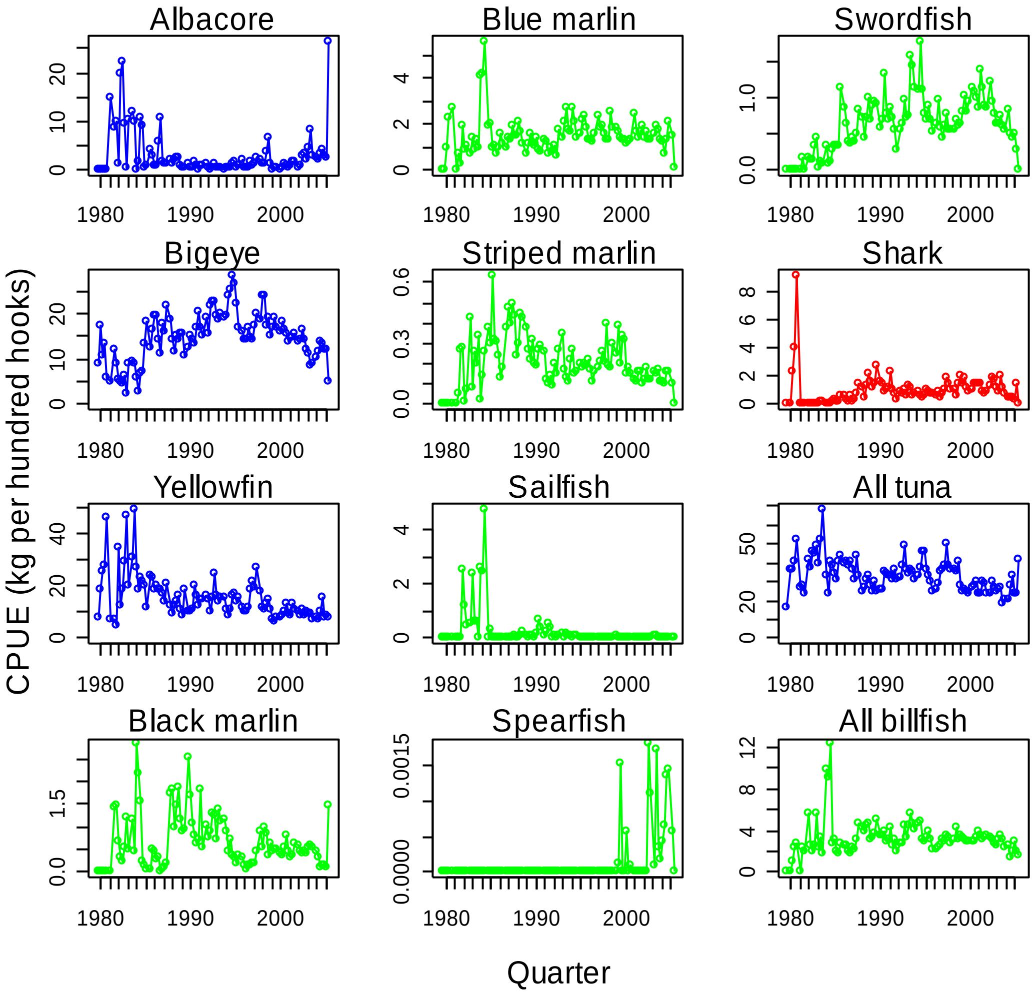


Figure A2.1. Quarterly CPUE (kg.hhooks^{-1}) of tuna and billfish species in the western tropical Pacific shallow longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

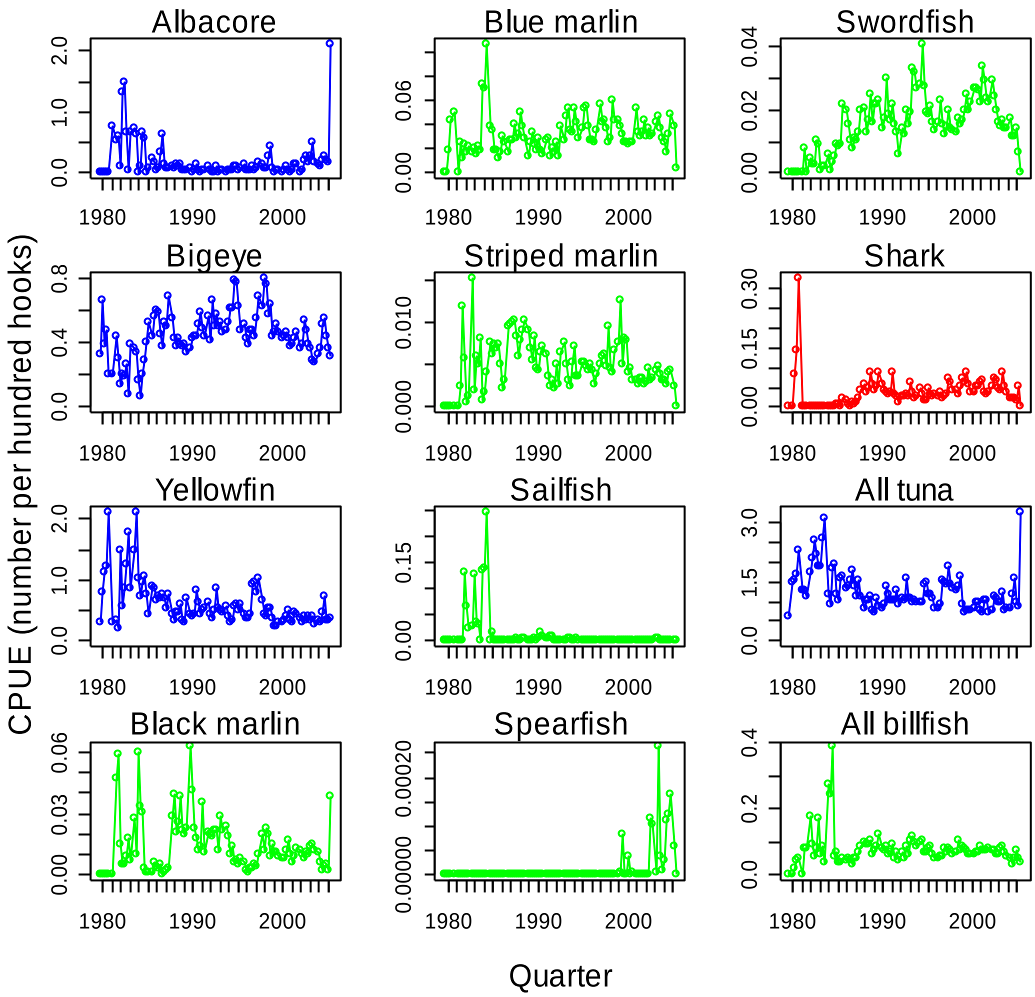


Figure A2.2. Quarterly CPUE (number.hhooks^{-1}) of tuna and billfish species in the western tropical Pacific shallow longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

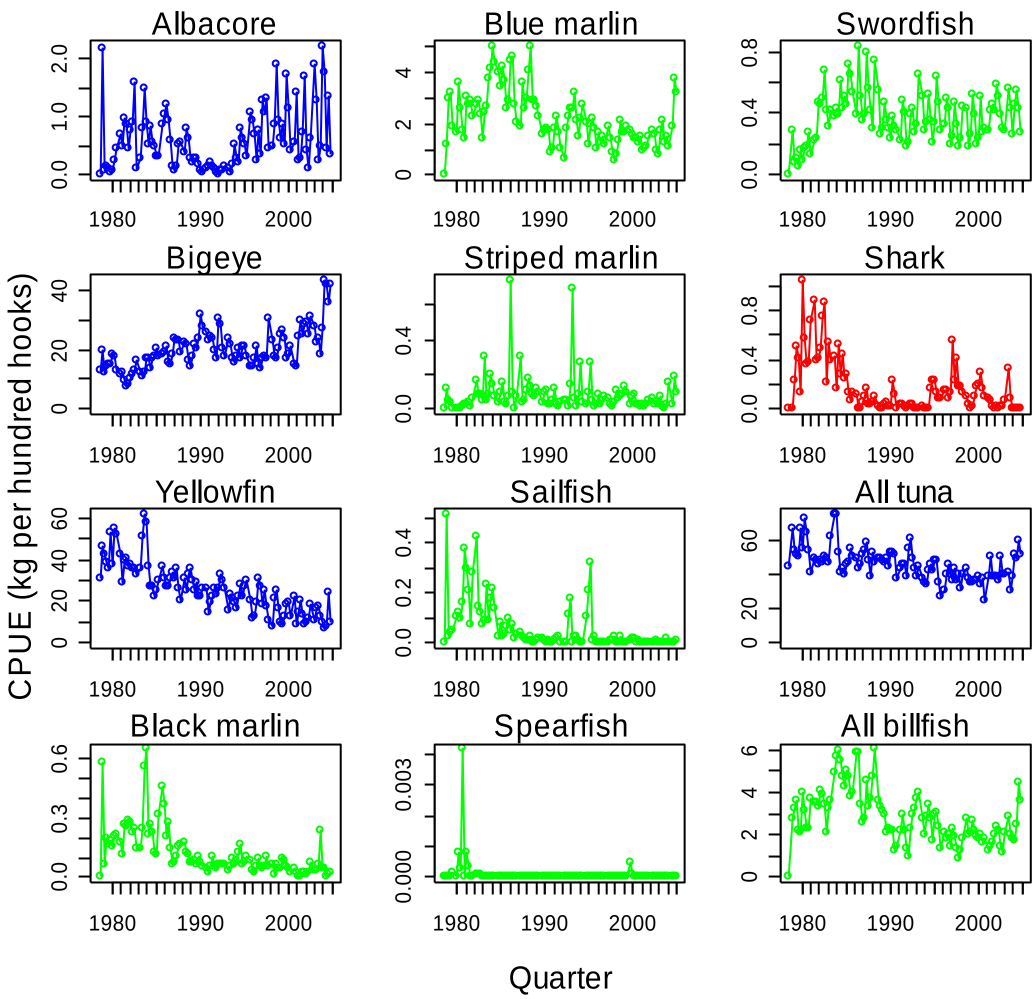


Figure A2.3. Quarterly CPUE (kg.hhooks^{-1}) of tuna and billfish species in the western tropical Pacific deep longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

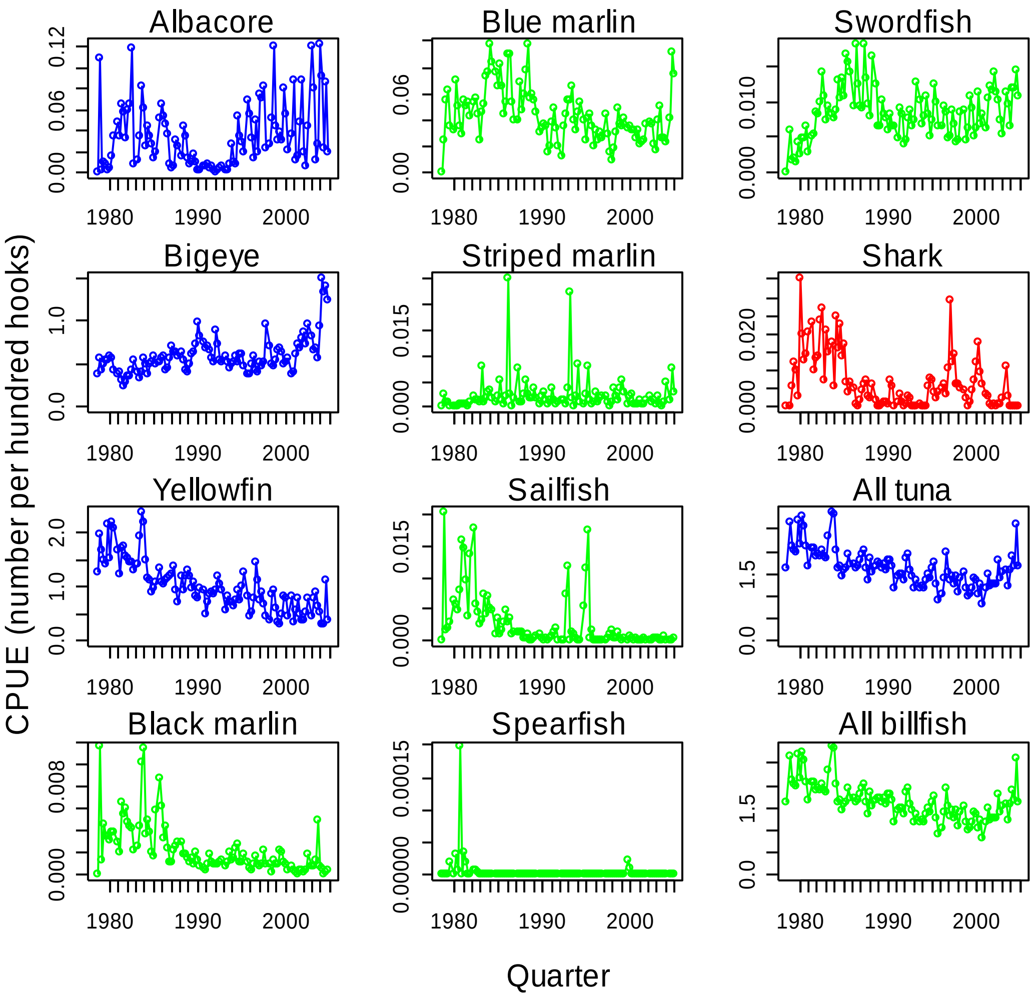


Figure A2.4. Quarterly CPUE (number.hhooks^{-1}) of tuna and billfish species in the western tropical Pacific deep longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

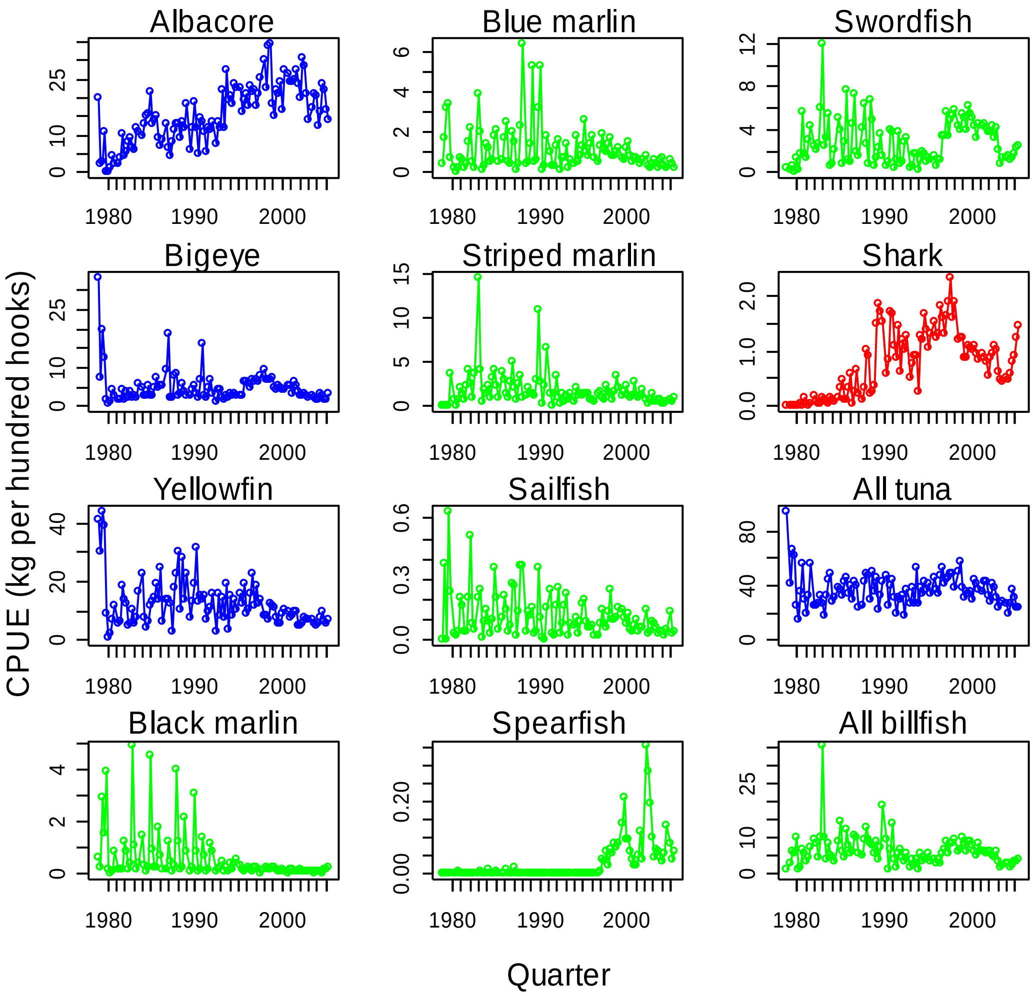


Figure A2.5. Quarterly CPUE (kg.hhooks^{-1}) of tuna and billfish species in the western temperate Pacific albacore longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

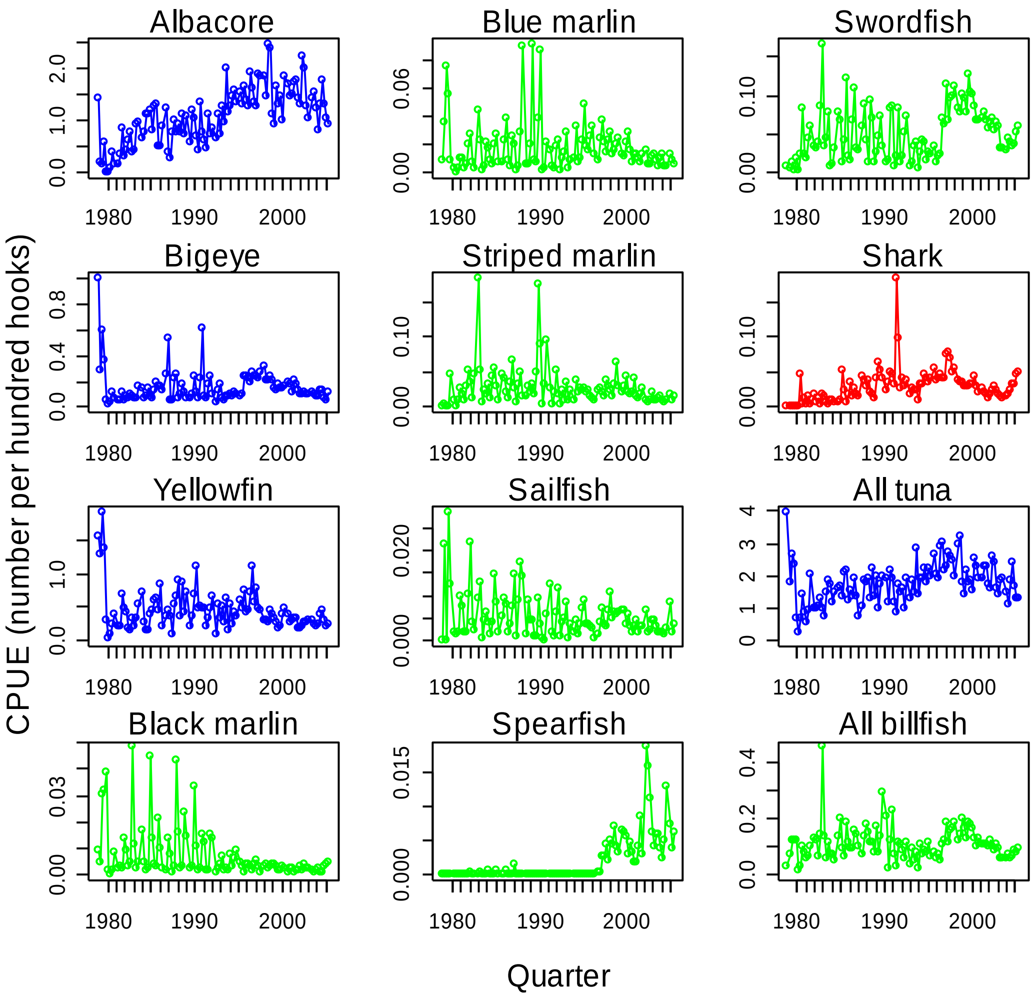


Figure A2.6. Quarterly CPUE (number.hhooks^{-1}) of tuna and billfish species in the western temperate Pacific albacore longline fishery, 1978–2004. Source: logsheet data held by SPC. The y-axes vary among species.

Appendix 3. Distribution of observer and logsheet records of starting times of longline sets in the WCPO, 1990–2004.

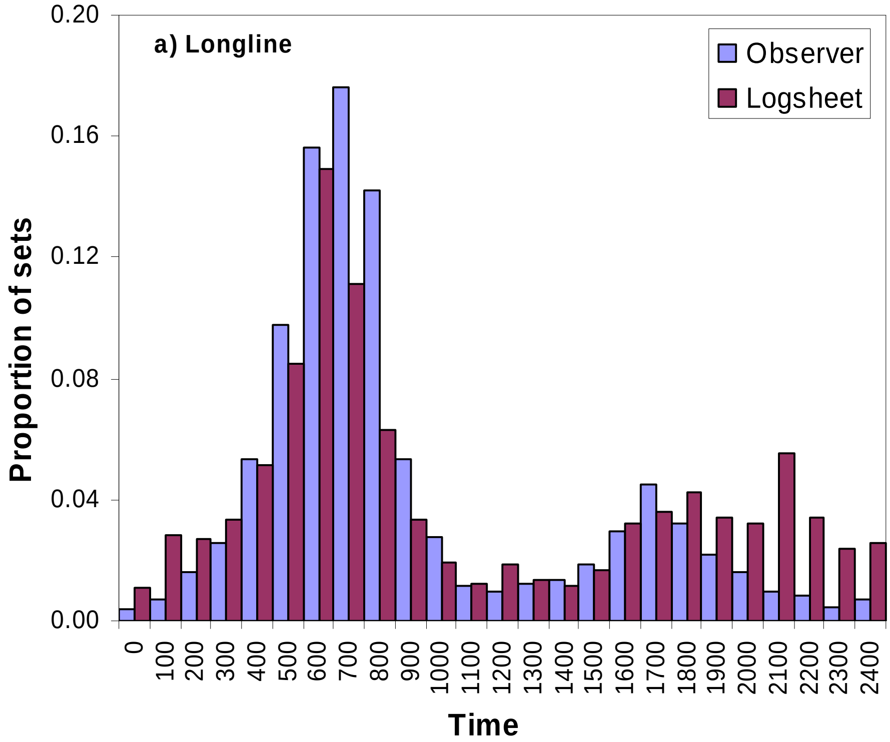


Figure A3.1. Proportion of observed and logsheet set start times for the longline fishery of the WCPO, 1990–2004. Source, SPC observer and logsheet data.