A review of Australia's pelagic shark resources

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1. NON-TECHNICAL SUMMARY

98/107	A review of Australia's pelagic shark resources

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Objectives:

The original objectives of this study were to review and collate information on the pelagic sharks of Australia; specifically to:

1. Document the species found in Australian waters and describe their local and broader distributions
2. Document Australian and overseas catch rates and catches
3. Review their biology in terms of productivity, spatial structure, movements and stock structure
4. Review information on population dynamics, stock status, vulnerability to fishing and management of these species from areas where they are fished.
5. Where possible, determine the impacts of fishing on the stocks in Australian waters using logbook and observer catch and effort data
6. To tag blue sharks on Japanese longliners operating inside the EEZ through the observer program
7. Make recommendations for future research on pelagic sharks in Australia

Non-Technical Summary:

Currently, there is considerable international concern over the status of shark and ray populations around the world. Conservation and management plans under development by international fora have identified the catch of pelagic sharks in tuna longline fisheries as a priority issue. Dramatic increases in the prices paid for fins have increased the incentive to kill and fin sharks. There are two main issues; the sustainability of the catch and the poor data quality of the catch.

For the purposes of this report, pelagic sharks have been defined as those species taken by pelagic longline fishing targeted at tuna and billfish. Information on the species composition, distribution, catches, catch rates, population structure, biology, impacts of fishing on, and management of pelagic sharks both from Australia and overseas was reviewed and collated using both published literature and unpublished data. Available information in the form of logbook returns and observer catch monitoring from domestic and Japanese pelagic longlining in the Australian EEZ was analysed.

The principal shark species taken by pelagic longlining in Australia is the blue shark; other commonly caught sharks are porbeagle, shortfin mako, crocodile and, probably, silky and oceanic whitetips. The extent to which these latter species occur in the catch is currently uncertain because of observer problems in the identification of whaler sharks in the genus *Carcharhinus*. Species taken in smaller numbers are thresher sharks (three species), dogfish (Family Squalidae), school, hammerhead, tiger and longfin mako shark. These data on species composition in Australia are in agreement with similar data reported from other areas. Blue sharks and shortfin makos have an extensive distribution throughout tropical and temperate waters, porbeagles are taken in southern temperate areas and silky and oceanic whitetips mainly in tropical waters.

Combining observer catch rates with total Japanese fishing effort indicates that some 430,000 blue sharks were caught over a five-year period by Japanese longliners during the fishing season in the Australian EEZ. This equates roughly to 1,100 t per season; logbook records show that domestic vessels caught some 45 t in 1997, but comparison of domestic and Japanese catch rates imply that domestic logbooks considerably under-report the catch of blue sharks. A comparison of observer and Japanese logbook catch rates suggests that Japanese logbook data under-report the catch by about 14%. Blue shark catch rates on the east coast of Australia vary with latitude from about 1.3 sharks per 1000 hooks at 10-30°S to about 7.7 at 40-50°S. Estimates indicate that nearly 138,000 t of blue sharks were caught by high-seas longline fleets in the Pacific in 1994. The size of blue shark's decrease to the south on the Australian east coast and a greater proportion of females are found to the south. Sex and size segregation is very apparent in blue shark populations from other areas and varies with latitude and region.

Catch rates of shortfin mako by Japanese vessels in the Australian EEZ average about 0.2 sharks per 1000 hooks while catch rates for porbeagles are about 0.5 (south of 39°S). Some 3,100 shortfin makos are caught by Japanese longliners in the Australian EEZ each season, and about 4,800 porbeagles a season south of 39°S. Comparison of observer catch rates with logbook records suggest the Japanese under-reported shortfin mako catches by about 10%, but porbeagle catches by 47%. For shortfin mako, catch rates and fish size showed no obvious trend with latitude; more males were caught south of 30°S on the east coast. The porbeagle catch comprised mainly one-year old fish with about 48% of the catch being female. Catch rates for minor shark species were less than 0.5 individuals per 1000 hooks.

The biology of blue sharks has been relatively well studied and they are one of the more productive elasmobranchs. Males reach sexual maturity in 4-6 years at 173-213 cm TL while females take 5-7 years and are 187-213 cm TL. Longevity is around 20 years and maximum recorded length is 380 cm TL. Litter size averages 35 with a maximum of 135, gestation lasts 9-12 months and the young are born in spring or summer at 35-50 cm TL. However, annual fecundity of females is not known. Blue sharks are highly migratory with tagging studies demonstrating extensive movements including trans-oceanic migrations, which are probably assisted by utilising major current systems. Long-distance movements appear to be linked to a complex reproductive cycle with spatially separated mating and pupping areas. Little is known about stock structure in blue sharks. The extensive distributions, relatively high natural abundance, highly migratory behaviour and relatively productive biology may provide blue sharks with a greater resilience to fishing pressure than most elasmobranchs. The limited fishery assessments carried out to date have shown no evidence of a declining trend in catch rates with time in the Atlantic or Indian Oceans, but a 20% decrease was evident in the North Pacific between the periods 1971-1982 to 1983-1993. No consistent decline in catch rates through the fishing season was evident for Japanese longliners fishing in Australian waters.

The biology of the other pelagic sharks taken by pelagic longlining is reviewed but our knowledge of their basic life-history data are fragmentary with even the important population parameters of age, growth and annual fecundity poorly studied. Resilience to fishing pressure is almost certainly lower for these species when compared to blue sharks, and this is evident from the history of target fishing for some of these species such as porbeagle and thresher sharks. Few countries have any form of management measures for their pelagic shark resources. The effects on the oceanic ecosystem of removing large numbers of these top predators are unknown.

The combination of poor biological information and limited time series of catch and effort data for pelagic sharks make it vital to maximise on available data. Considerable benefit could be obtained though co-operative assessment studies with high-seas fishing nations, particularly Japan, who have extensive catch-effort data sets from both commercial and research vessels.

Keywords

Pelagic sharks, longlining, species productivity, fishery impacts.

2. BACKGROUND

This report deals with pelagic sharks caught primarily during pelagic longline fishing targeted at tunas and billfish in the Australian Exclusive Economic Zone (EEZ). These sharks are mostly the same as those taken during high-seas longlining, so as well as being pelagic they are also mainly oceanic species. When pelagic longlining occurs relatively close to the coast a few additional species may be represented. Of the 166 species of shark present in Australian waters (Last and Stevens 1994), less than a dozen are commonly caught by pelagic longlines. While these sharks are not generally targeted, increasing prices paid for shark fins together with decreased availability of some of the desired tuna and billfish makes this by-catch more valuable.

Concerns over the impact of fishing on shark populations around the world are currently being raised at an international level through a number of fora. The Species Survival Commission of the IUCN - The World Conservation Union- has formed a Shark Specialist Group (SSG) which is preparing a global Action Plan for the conservation and management of sharks. The Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) took an unprecedented action in 1994 by mandating a review of the status and trade in sharks, a group of animals not currently listed on the CITES Appendices. As part of this process, the United Nations Food and Agriculture Organisation (FAO) formed a Technical Working Group (TWG) on sharks to develop guidelines and an action plan for global conservation and management of shark stocks. Both the SSG and the TWG have listed the by-catch of pelagic sharks in tuna fisheries as a priority issue.

There are two main issues relating to pelagic shark by-catch; the poor data quality of the recorded catch, and the sustainability of the actual catch. Poor data quality has arisen because sharks have historically been of low economic value in most countries. As research priorities are usually linked to economic value of the fisheries this has resulted in relatively little research being carried out on this group. There have been few requirements and little incentive to record shark by-catch from tuna fisheries in most countries. More recently, the dramatic increase in prices paid for fins has increased the incentive to kill and fin sharks. As the bodies are often discarded this increases problems in species identification if this is attempted other than at sea. Compounding the problem is the oceanic and highly migratory nature of many of the species placing them outside the responsibility of individual countries, and outside the mandate of international bodies, which were mostly set up for management of tunas.

Much of the shark by-catch of high-seas tuna fleets is comprised of blue (*Prionace glauca*), oceanic whitetip (*Carcharhinus longimanus*) and silky shark (*Carcharhinus falciformis*). Shortfin mako (*Isurus oxyrinchus*), thresher (*Alopias* spp.) and porbeagles (*Lamna* spp.) are also taken (Stevens in press).

In recent times, domestic and Japanese vessels have exploited the southern bluefin tuna (*Thunnus maccoyii*) resource in the Australian EEZ. Australian and Japanese longliners are required to record shark by-catch in their logbooks. The Commonwealth Observer Program collects data on shark by-catch from the Japanese vessels; observers are not placed on domestic vessels at present. Currently there are no regulations limiting the finning of sharks by domestic vessels in Australia. In most cases, the carcasses are dumped because of their low value compared to tuna and billfish. However for Japanese vessels fishing inside Australia's EEZ, regulations introduced in 1991 prevented them from retaining fins unless the whole carcass was retained. Currently there is little regulation or even requirement for reporting of by-catch in the oceanic zone. International bodies such as the International Commission for the Conservation of Atlantic Tunas (ICCAT), Inter-American Tropical Tuna Commission (IATTC) and South Pacific Commission (SPC) were set up for the management of highly migratory tuna and did not have a mandate for sharks. More recently there have been attempts to include sharks under the umbrella of these organisations. Even within the EEZ's of most Pacific Rim countries there is little monitoring or management of pelagic shark by-catch. Sharks are particularly vulnerable to fishing pressure, a consequence of their specialised life history strategies with generally slow growth, late attainment of sexual maturity, high longevity, low fecundity and natural mortality, and close stock-recruitment relationship. Once overfished, many shark species can take decades to recover. Given their vulnerability to fishing pressure and their likely important role in the oceanic ecosystem this is cause for concern.

By 1960, eastern Australian waters were an important component of Japanese longlining operations for tuna and billfish in the South Pacific. However, introduction of the 200 mile Australian Fishing Zone in 1979 led to progressive restrictions on Japanese access as domestic fisheries developed and concerns grew over the effects of longlining on billfish stocks fished by the recreational sector. Ward (1996) provides a comprehensive history of Japanese longlining in eastern Australian waters.

3. NEED

Along with a growing international concern over the status of pelagic shark stocks, the by-catch of pelagic sharks in Australia's tuna longline fisheries is a management issue that is rapidly gaining momentum. There is a need to collate available information on Australian stocks which can serve as the starting point of an information base for management, should this be necessary.

Currently there are restrictions on the landing of shark fins by Japanese vessels fishing inside the EEZ unless the whole carcass is landed, but no such restrictions apply to domestic vessels. At present there is only a small demand for pelagic shark meat. There is, however, some recent interest in target fishing for pelagic sharks and this raises issues over the activation of latent effort if suitable markets are developed for the meat. No specific research has been carried out on pelagic oceanic sharks in Australia and nothing is currently known about the level of fishing that the stocks can support. While logbook information on pelagic shark catches is probably of limited value there is a considerable volume of catch and size data collected through the observer program; these data have not been subject to any detailed analysis.

In assessing the impacts of fishing on pelagic sharks in Australia, there is a need for information on movements and stock structure. Some limited tagging of blue and mako sharks has being carried out by research fishing off south-east Tasmania, and through the New South Wales co-operative game-fish tagging project.

Pelagic sharks were one of the 1997/98 research priorities for Southern Tuna and Billfish Management Advisory Committee (STBMAC) under the category of ecologically related species.

4. OBJECTIVES

The original objectives of this study were to:

To review and collate information on the pelagic sharks of Australia; specifically to:

1. Document the species found in Australian waters and describe their local and broader distributions
2. Document Australian and overseas catch rates and catches
3. Review their biology in terms of productivity, spatial structure, movements and stock structure
4. Review information on population dynamics, stock status, vulnerability to fishing and management of these species from areas where they are fished
5. Where possible, determine the impacts of fishing on the stocks in Australian waters using logbook and observer catch and effort data
6. To tag blue sharks on Japanese longliners operating inside the AFZ through the observer program

   This objective could not be met due to the exclusion of Japanese longliners from the Australian EEZ in 1997
7. Make recommendations for future research on pelagic sharks in Australia

5. METHODS

5.1 Literature review

Information on the species composition, distribution, catches, catch rates, population structure, biology, impacts of fishing on, and management of pelagic sharks both from Australia and overseas was reviewed and collated using both published literature and unpublished data.

5.2 Analysis of Australian data

5.2.1 Japanese longline fishery

Part of the conditions for access of Japanese longline vessels to Australian EEZ waters are procedures for reporting positions, catch and fishing effort, and the acceptance of observers onboard their vessels. Since 1979, Australia has issued Japanese longliners with three different logbooks (Ward 1996). The more recent TL04 logbook contained a shark supplement from November 1991 that required information (on a daily basis) on "numbers of the four common shark species and 'other' shark species discarded and retained, and the weight of those retained". Shark categories provided were blue whaler, short finned mako, bronze whaler, porbeagle and other. Logbook data from Japanese vessels licensed to fish in the Australian EEZ are stored on the Australian Fisheries Zone Information System (AFZIS) and were made available by the Australian Fisheries Management Authority (AFMA). Analyses were carried out on a copy of these data held in the CSIRO Marine Research Consolidated SBT Database (Betlehem et al. 1998). Essentially, data comprised catch (in number) of pelagic sharks and effort as number of sets or hooks set. Catch per unit effort (cpue) is expressed throughout this report as catch in number per 1000 hooks.

Data from the Commonwealth Observer Program from boardings of Japanese vessels consisted of catch and effort for observed fishing periods, together with species composition, length and sex information. The length data presented are in fork length (FL) except in Table 14 and section 6.5 where total length (TL) is used. Conversions for FL/TL and length/weight, where available, are given in Appendix 3. Observers were trained in shark identification (usually by attending an annual course at CSIRO Marine Laboratories in Hobart). In many cases observers took photographs of sharks they were uncertain of, or retained whole specimens or jaws for examination, and these were identified at CSIRO. However, there are undoubtedly some identification problems in these data, particularly with *Carcharhinus* species (see section 6.2.2). Most of the analyses carried out in this report use the common names for species or species groups applied by the observers. These names, together with their respective scientific names are given in Table 1.

No data on pelagic sharks were available from the Real Time Monitoring Program (RTMP) on Japanese vessels outside the Australian EEZ.

5.2.2 Domestic longline fishery

A number of logbook types have been used in the domestic tuna longline fishery. The most recent AL04 logbook contains separate entry lines for bronze whaler, blue whaler, shortfin mako, blacktip, tiger, and hammerhead shark, as well as an 'others' category. Information required for these species is number of fish kept, estimated total weight kept (kg) and number of fish released. There is also a separate entry for white sharks (*Carcharodon carcharias*), which are protected in all Australian waters, which requires number caught and life status at release. Logbook data from domestic tuna longliners were made available by AFMA and comprised catch (in number) of pelagic sharks and effort as number of sets or hooks set. Catch per unit effort is expressed throughout this report as number of fish per 1000 hooks. No observer data are available from domestic tuna longliners.

5.2.3 Other fisheries

Minor quantities of pelagic sharks are taken by other fisheries, notably the Southern Shark Fishery (demersal gillnets and longlines), the Western Australian shark fishery (demersal gillnets and longlines) and the recreational fishery (Stevens, 1984; Pepperell 1992). Catches from these fisheries are not covered in this report.

6. DETAILED RESULTS & DISCUSSION

6.1 Species composition

From 1992-1996, 405,710 sharks were recorded in the logbook data from Japanese longline vessels fishing within the Australian EEZ. Only four species were recorded; blue whaler (blue shark *Prionace glauca*) comprised 91.5% of the total shark catch, shortfin mako (*Isurus oxyrinchus*) 3.4%, porbeagle (*Lamna nasus*) 3.0% and bronze whaler (see section 6.2.2) 2.1%. By contrast, observer data from the same fishery and time period recorded 16 species categories based on an observed catch of 44,306 sharks. The species composition from these observer data are shown in Table 1.

Blue sharks dominate the shark by-catch from this fishery occurring in 76.8% of longline sets according to the logbook data, and 83.4% of observed sets. Blue sharks are more abundant in temperate waters (see section 6.2.1) and it should be noted that 81.4% of Japanese fishing effort was in waters south of 30°S (logbook data) and that 83.4% of observed fishing effort was south of 30°S. The number of Japanese longline sets and the number of hooks capturing different species of sharks, both from the logbook data and from observer coverage, are shown in Table 2 for the period 1992-96.

Table 1. Species composition of sharks taken by Japanese longline vessels fishing in the Australian EEZ from 1992-96, based on observer data

Observer name	Scientific name	% composition
Blue whaler	*Prionace glauca*	84.7
Porbeagle	*Lamna nasus*	5.5
Shortfin mako	*Isurus oxyrinchus*	3.3
Crocodile	*Pseudocarcharias kamoharai*	2.1
Dusky	*Carcharhinus obscurus*	0.7
Oceanic whitetip	*Carcharhinus longimanus*	0.6
Bigeye thresher	*Alopias superciliosus*	0.6
School	*Galeorhinus galeus*	0.5
Bronze whaler	See section 6.2.2	0.5
Velvet dogfish	*Zameus squamulosus*	0.5
Common thresher	*Alopias vulpinus*	0.4
Dogfish	Family Squalidae	0.3
Hammerhead	*Sphyrna* spp.	0.1
Tiger	*Galeocerdo cuvier*	0.1
Pelagic thresher	*Alopias pelagicus*	<0.1
Longfin mako	*Isurus paucus*	<0.1

A number of studies have examined the by-catch of sharks in longline fisheries targeting tunas and billfish. These include fisheries operating on the high seas as well as those in more coastal areas. Bonfil (1994) provides a general overview of longline shark by-catch, while regional information on species composition is available for the north-east Atlantic (Castro and Mejuto 1995; Buencuerpo et al. 1998), north-west Atlantic (Witzell 1985; Hoff and Musick 1990), south-west Atlantic (Hazin et al. 1990; Amorim et al. 1998), Indian Ocean (Sivasubramanian 1964; Taniuchi 1990), North Pacific (Nakano 1994; Matsunaga and Nakano 1999) and South Pacific (Stevens 1992; Williams 1997; Francis et al. 1999). All these studies showed that blue shark was the most frequently caught species, particularly in temperate areas. In tropical regions, silky (*Carcharhinus falciformis*) and oceanic whitetip (*Carcharhinus longimanus*) sharks usually comprised a large proportion of the catch. Other frequently taken species in these studies were shortfin makos, thresher sharks (*Alopias* spp.), crocodile sharks

(*Pseudocarcharias kamoharai*) and, in cool temperate areas, porbeagles and salmon sharks (*Lamna ditropis*). Hammerheads (*Sphyrna* spp.), tiger sharks (*Galeocerdo cuvier*), dogfish (Family Squalidae), school sharks (*Galeorhinus galeus*), longfin mako (*Isurus paucus*) and a number of *Carcharhinus* species were caught more occasionally.

6.2 Distribution

6.2.1 Blue sharks

Blue sharks have the most extensive distribution of any chondrichthyan (sharks, rays and chimaerids) occurring in all major oceans from about 60°N to 50°S (Last and Stevens 1994). They prefer water temperatures of 12-20°C and are found at greater depths in tropical waters.

Table 2. The number of Japanese longline sets and hooks capturing different species of sharks in the Australian EEZ from 1992-96, together with total fishing effort and observed effort

Species	logbook sets	logbook hooks	observer sets	observer hooks
Blue whaler	18,821	371,187	2,604	37,512
Shortfin mako	7,437	13,969	880	1,471
Porbeagle	4,869	12,195	1,012	2,440
Common thresher			151	180
Oceanic whitetip			139	242
School			116	222
Tiger			52	64
Crocodile			164	943
Bigeye thresher			205	283
Pelagic thresher			4	12
Longfin mako			4	5
Bronze whaler	2521	8,359	94	200
Dusky			69	312
Hammerhead			47	60
Dogfish			53	119
Velvet dogfish			97	241
TOTAL EFFORT	24,495	77,804,152	3,121	6,790,451

Blue sharks are oceanic and pelagic being found from the surface to a depth of about 350 m. They may occur close inshore where the continental shelf is narrow. They are found throughout Australian waters with the exception of the Arafura Sea, Gulf of Carpentaria and Torres Strait (Last and Stevens 1994). The distribution of blue shark catches from Japanese and domestic longlining in Australia is shown in Fig. 1. These catches essentially reflect the distribution of longline fishing with the greatest effort occurring on the east coast between latitudes 40-50°S.

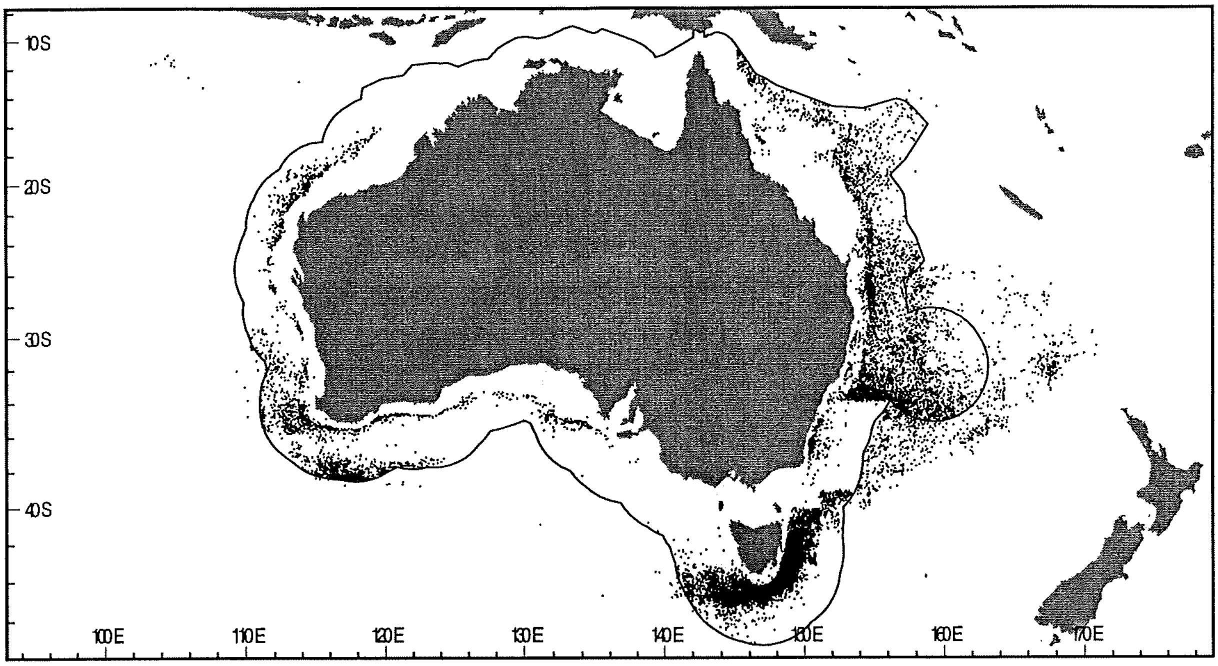
6.2.2 Other species

Shortfin makos have a similar oceanic and pelagic distribution to blue sharks. However, they are seldom found in waters below 16°C and mostly occur from about 50°N to 45°S (Last and Stevens 1994), although they have been taken at more than 50°S in 10°C surface temperatures (Yatsu 1995). They range from the surface to at least 150 m depth, and like the blue shark occasionally occur close inshore where the continental shelf is narrow. They are found throughout Australian waters with the exception of the Arafura Sea, Gulf of Carpentaria and Torres Strait (Last and Stevens 1994). Shortfin mako catches reported from Japanese and domestic longline logbook data in Australia are shown in Fig. 2a.

Porbeagles have an anti-tropical distribution in the North and South Atlantic, South Pacific and southern Indian Oceans. They are found both in coastal and oceanic waters and have been recorded from the surface down to 370 m depth (Last and Stevens 1994). Because of their well-developed thermoregulatory abilities they are able to penetrate into boreal waters and have been recorded above the 70°N parallel in the North Atlantic, and to 54°S in waters down to 1°C (Last and Stevens 1994; Francis and Stevens in press). In Australia, they have been recorded north to southern Western Australia and to near the Tropic of Capricorn in Queensland (23°44'S). Captures off Queensland occurred only in winter during lower than average sea temperatures (Francis and Stevens in press). In the South Pacific, a seasonal shift in abundance to higher latitudes during the warmer months was noted by Yatsu (1995). Porbeagles were rarely recorded from Australian waters until observers, trained in shark identification, were placed on Japanese longline vessels. The distribution of porbeagle catches based on observer data from Japanese longlining in Australian waters is shown in Fig. 2b.

Silky sharks have a circumtropical distribution being found in water temperatures above 23°C in all major oceans. They may move into warm temperate areas on a seasonal basis. Silky sharks are oceanic and pelagic but are most abundant offshore but close to land masses, and along the edges of continental and insular shelves (Last and Stevens 1994). They occur from the surface to at least 500 m depth. In Australia, they are found north of Sydney on the east coast and Lancelin on the west coast, but are rare in the Gulf of Carpentaria (Last and Stevens 1994). No silky sharks were recorded either in the logbook or observer data from Japanese longlining in Australia. However, this reflects an identification problem as they are certainly taken. It is likely that sharks recorded as 'bronze whaler' in both the logbook and observer data (Fig. 3a)

Figure 1. Distribution of blue shark catches (Japanese and domestic logbook data)



are mostly silky sharks, certainly those taken north of about 32°S. Bronze whalers recorded from around Tasmania are most probably school sharks as *Carcharhinus* spp. are very rarely taken in Tasmania, with the exception of the Bass Strait coast. Bronze whalers recorded south of about 32° on the Western Australian coast are likely to be dusky sharks, *C. obscurus,* and the true bronze whaler, *C. brachyurus.* Species recorded as 'dusky shark' in the observer data (Fig. 3b) are also likely to comprise a mixture of silky, dusky, bronze whaler and school shark, depending on latitude.

The oceanic whitetip shark has a distribution which extends throughout tropical and warm temperate waters of all oceans between 30-40°N and S. They occur around northern Australia (except in the Arafura Sea, Gulf of Carpentaria and Torres Strait) south to southern New South Wales and Perth. One specimen was recorded offshore from Port Lincoln, South Australia (Glover 1974). They are oceanic and pelagic being found from the surface to at least 150 m depth, and prefer water temperatures above 20°C (Last and Stevens 1994). Oceanic whitetip's were not recorded in the Japanese logbook data but were identified by observers; their distribution in the catches is shown in Fig. 4a.

Crocodile sharks have an oceanic distribution in tropical and sub-tropical waters of all oceans, occasionally occurring inshore; they range between the surface and

Figure 2a. Distribution of shortfin mako catches (Japanese and domestic logbook data)

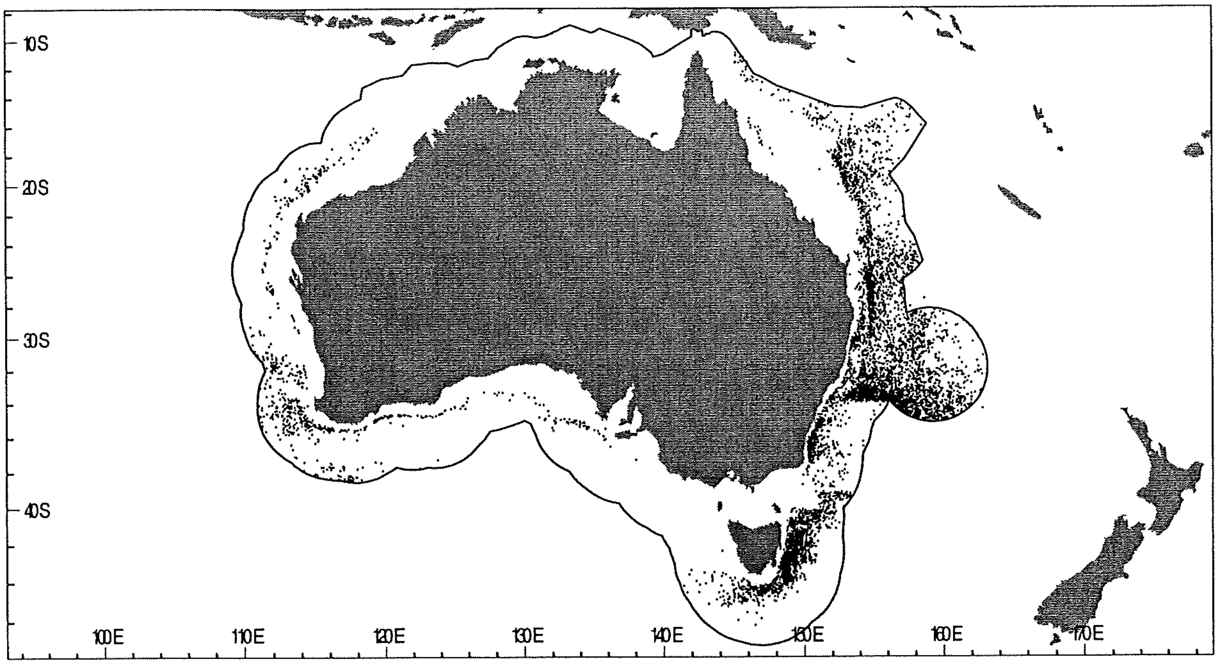


Figure 2b. Distribution of porbeagle catches (observer data)

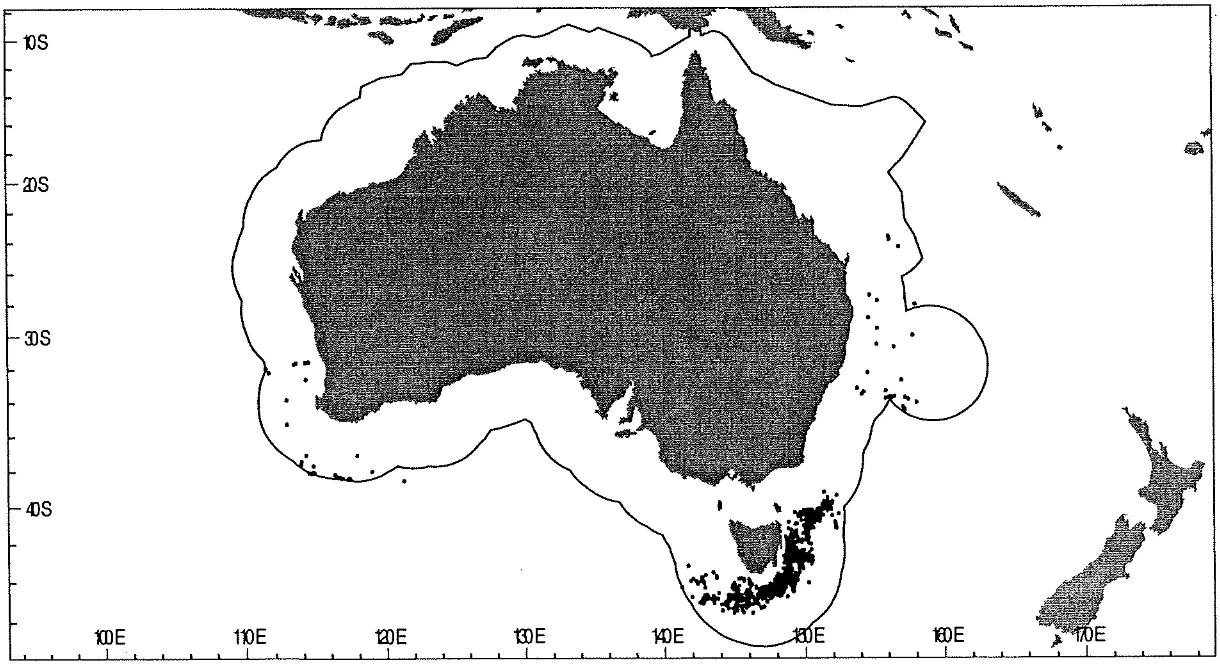


Figure 3a. Distribution of bronze whaler catches (observer data)

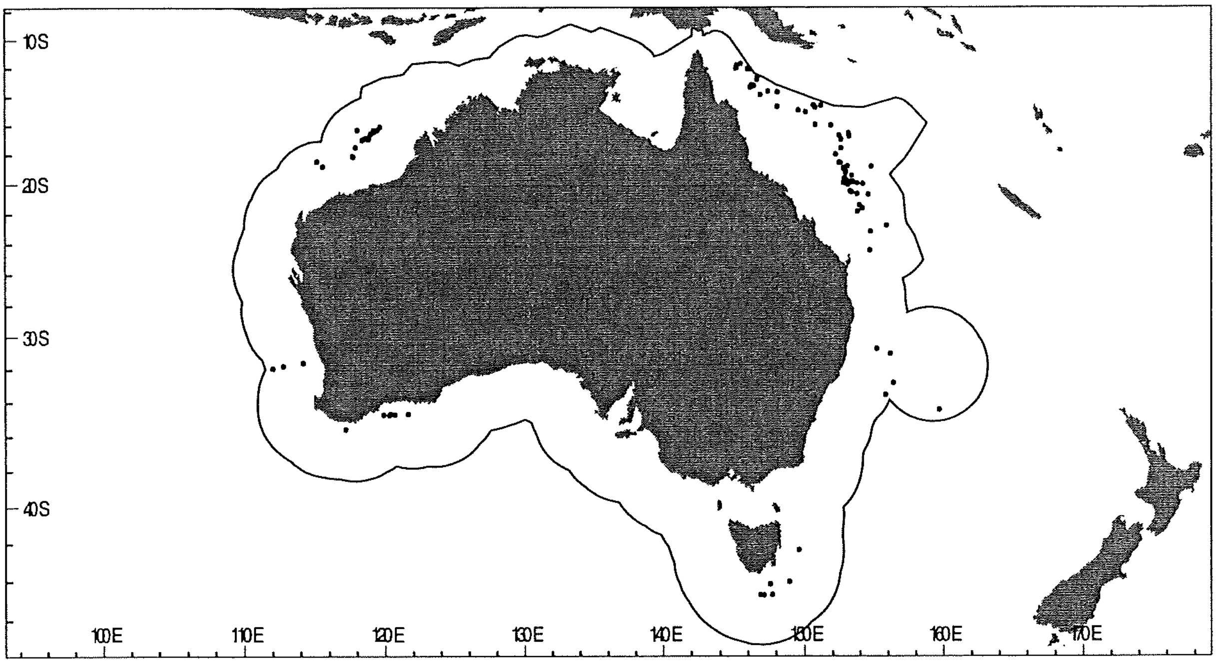


Figure 3b. Distribution of dusky shark catches (observer data)

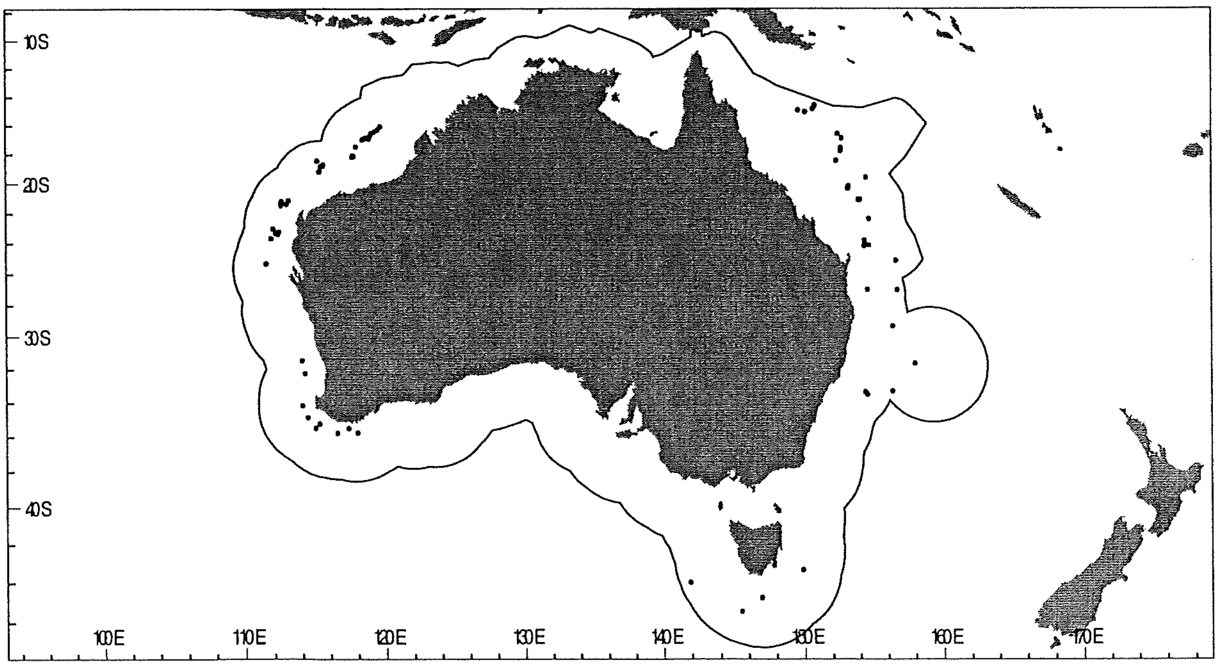


Figure 4a. Distribution of oceanic whitetip catches (observer data)

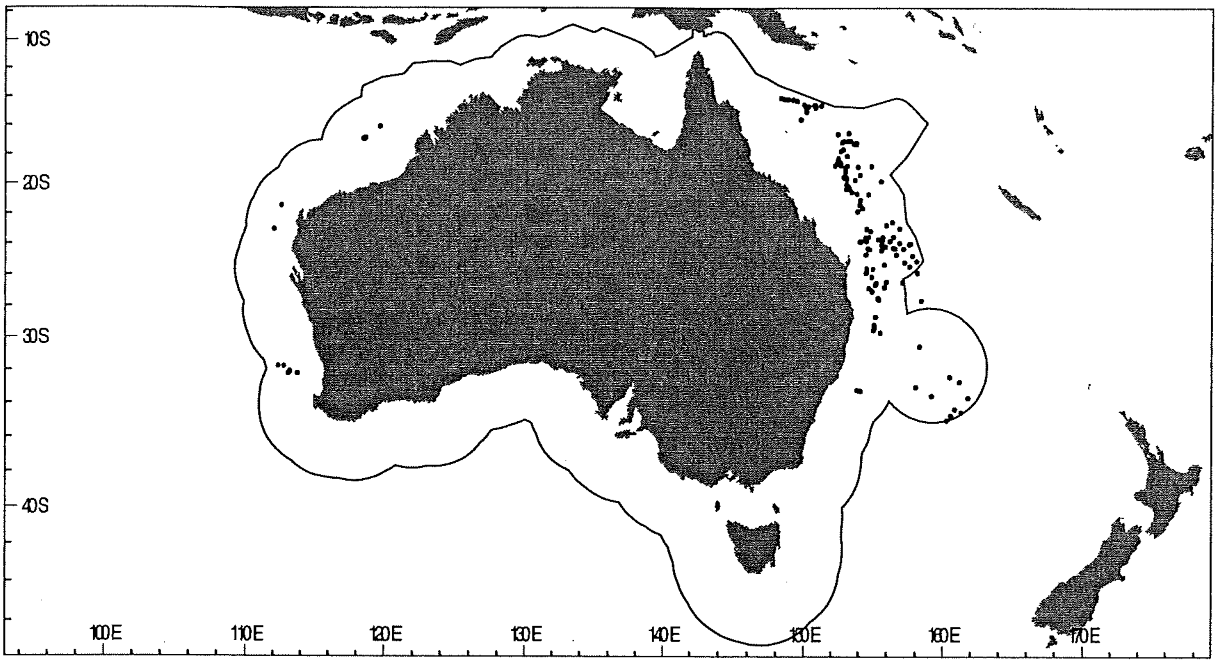
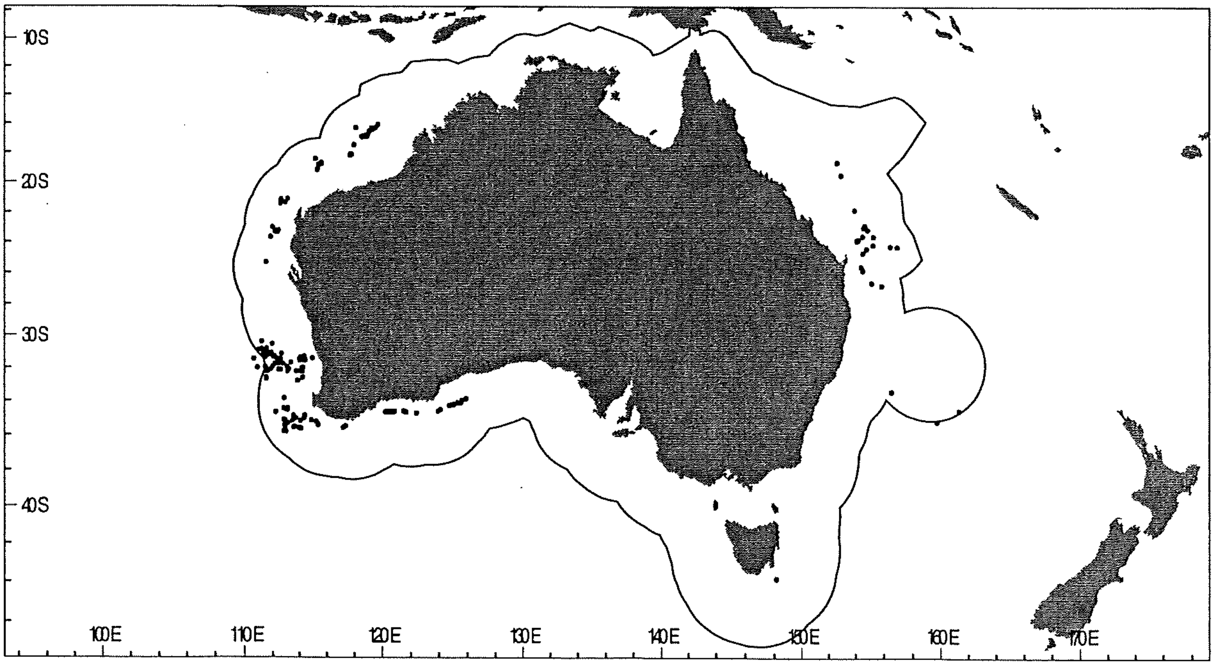


Figure 4b. Distribution of crocodile shark catches (observer data)



at least 590 m. In Australia, they have been recorded from the Queensland coast (Last and Stevens 1994). Crocodile sharks were not recorded in the Japanese logbook data but were identified by observers. Fig. 4b shows their catch distribution that suggests this species is more widespread in Australian waters. Records extend from northern Western Australia down the west coast and into the western end of the Great Australian Bight. There are also a few records from near Lord Howe Island, and one from Tasmania. However, while the crocodile shark is a fairly distinctive species, the majority of these observer identifications have not been verified.

All three species of thresher sharks (thresher, *Alopias vulpinus;* bigeye thresher, *A. superciliosus;* pelagic thresher, *A. pelagicus*) occur in Australian waters. The thresher has been recorded around the southern half of the country from Brisbane to central Western Australia, including Tasmania. Threshers are coastal and oceanic; elsewhere, they are found throughout temperate and tropical seas from about 60°N to 50°S and from the surface to 370 m (Last and Stevens 1994). Bigeye threshers are oceanic and coastal in all tropical and warm temperate seas from about 40°N to 40°S. In Australia, they have been recorded from the North West Shelf of Western Australia, Middleton Reef, Queensland, New South Wales and South Australia (Last and Stevens 1994). They occur from the surface to at least 500 m deep. The pelagic thresher has a more restricted, mainly oceanic distribution occurring in the tropical and sub-tropical Indo-Pacific from about 30°N to 30°S. They have been recorded from the North West Shelf of Western Australia (Last and Stevens 1994). Pelagic threshers are found from the surface to at least 150 m deep. No thresher sharks were recorded in the Japanese logbook data, but all three species were identified in the catches by observers and their distributions are shown in Figs. 5 & 7b. These data extend the known distributions of thresher sharks to about 17°S off Western Australia and 19°S off Queensland. Catches of bigeye threshers suggest this species occurs throughout Australian waters from northern Queensland to northern Western Australia, probably including Tasmania (although this species is fairly distinctive, these records have not been verified). Only 12 pelagic threshers were recorded, all from tropical Queensland waters.

Additional species identified by observers from Japanese longline catches (but not recorded in the logbook data) are school shark, tiger shark (*Galeocerdo cuvier*), longfin mako (*Isurus paucus*), hammerheads (*Sphyrna* spp.), velvet dogfish (*Zameus squamulosus*) and dogfish (Family Squalidae). Catch distributions for these species are shown in Figs. 6-8. School shark and velvet dogfish catches were restricted to Tasmanian waters. Tiger shark records were within the known range of the species (Last and Stevens 1994) with the exception of one 1993 record off north eastern Tasmania. While this has not been verified it should be noted that in March 1995 a tiger shark was recorded from Flinders Island. Hammerhead records are likely to be a mixture of the scalloped hammerhead, *Sphyrna lewini* and the smooth hammerhead, *S. zygaena*. The great hammerhead, *S. mokarran* is also common in northern waters but is mainly coastal and less likely to occur on offshore longline sets. The single record from Tasmania would almost certainly be a smooth hammerhead, and this more temperate species is probably responsible for the records on the south coast of Western Australia. Dogfish

Figure 5a. Distribution of thresher shark catches (observer data)

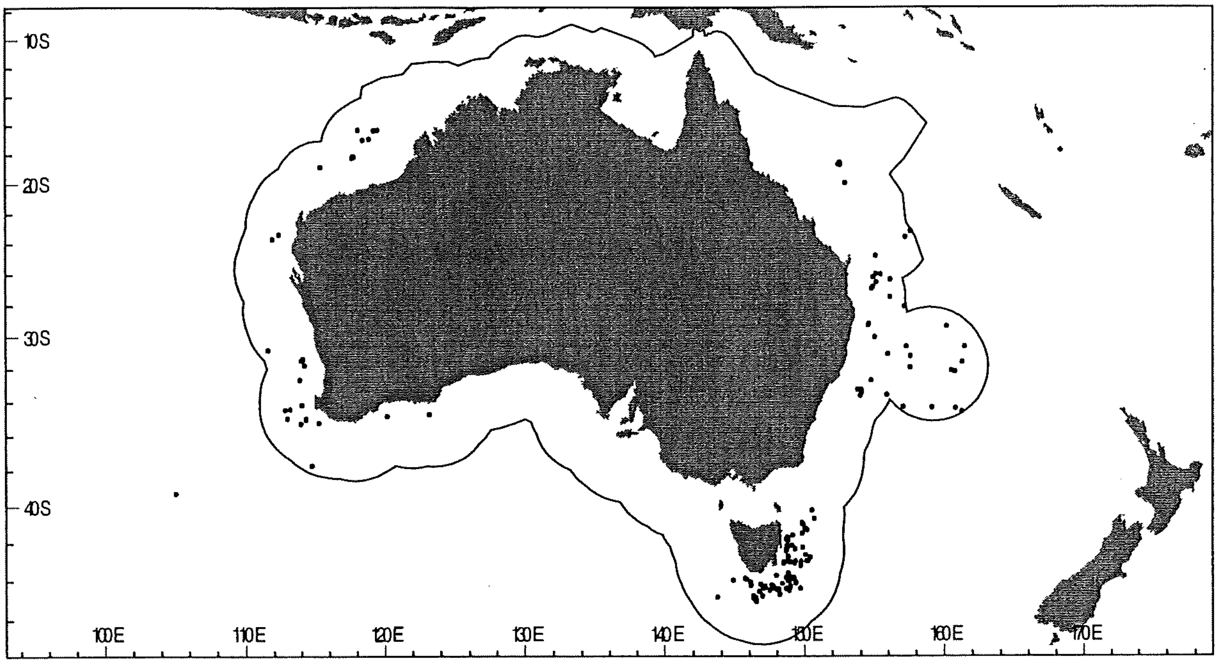


Figure 5b. Distribution of bigeye thresher catches (observer data)

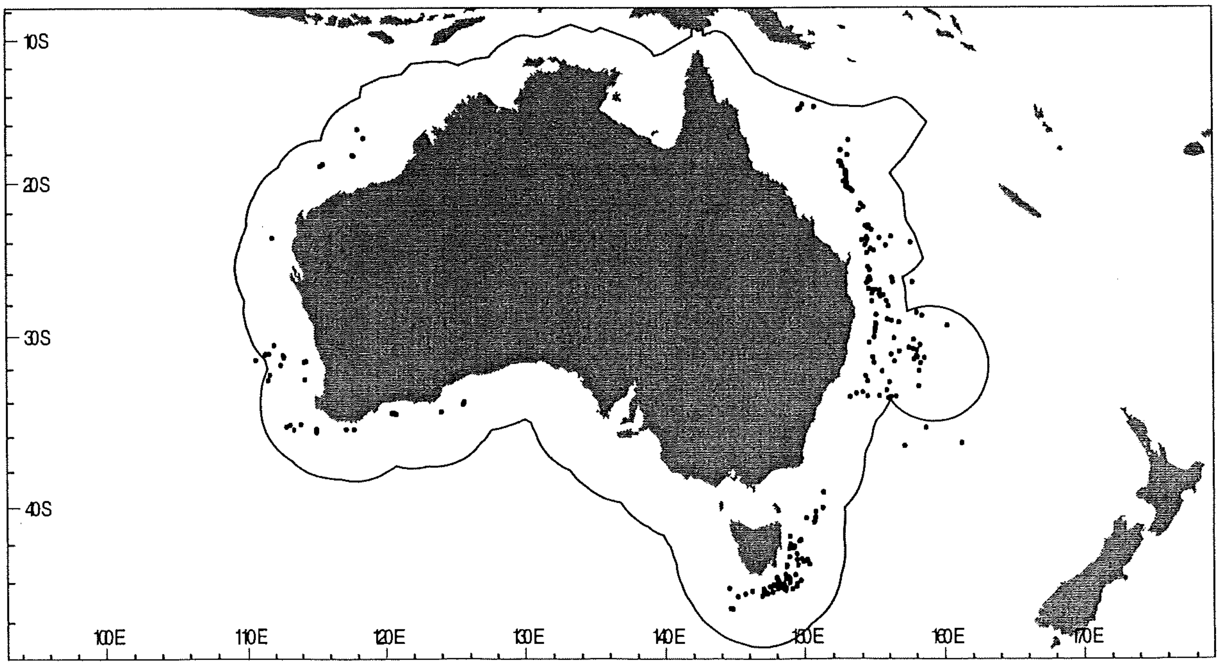


Figure 6a. Distribution of school shark catches (observer data)

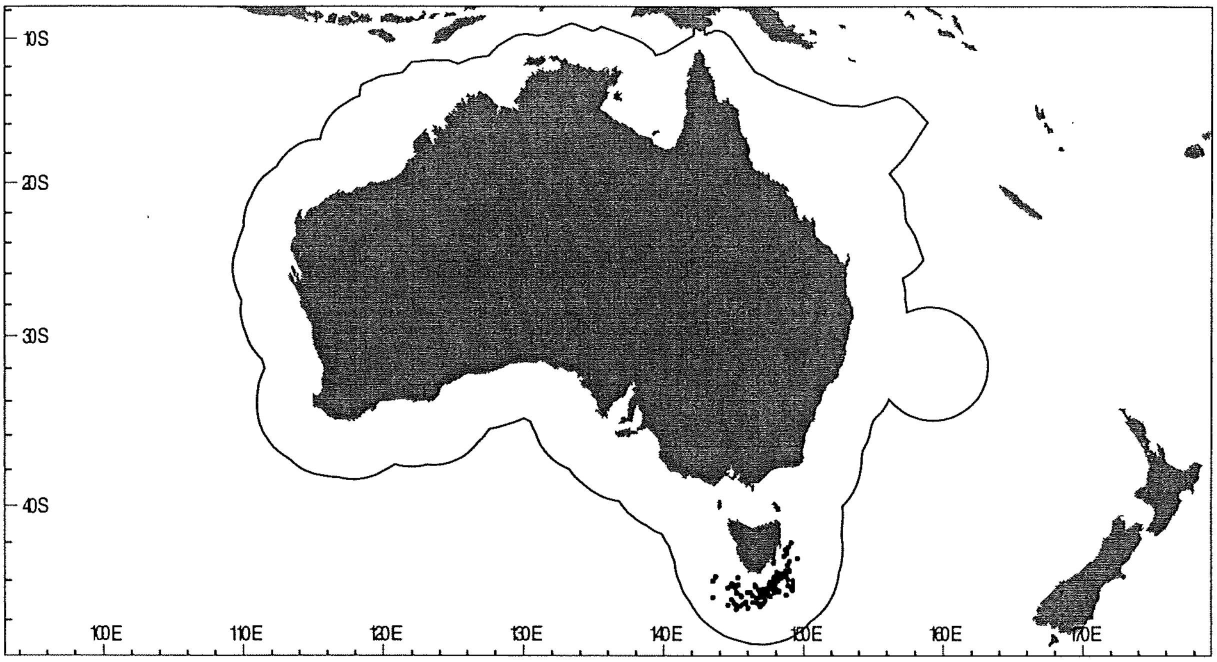


Figure 6b. Distribution of tiger shark catches (observer data)

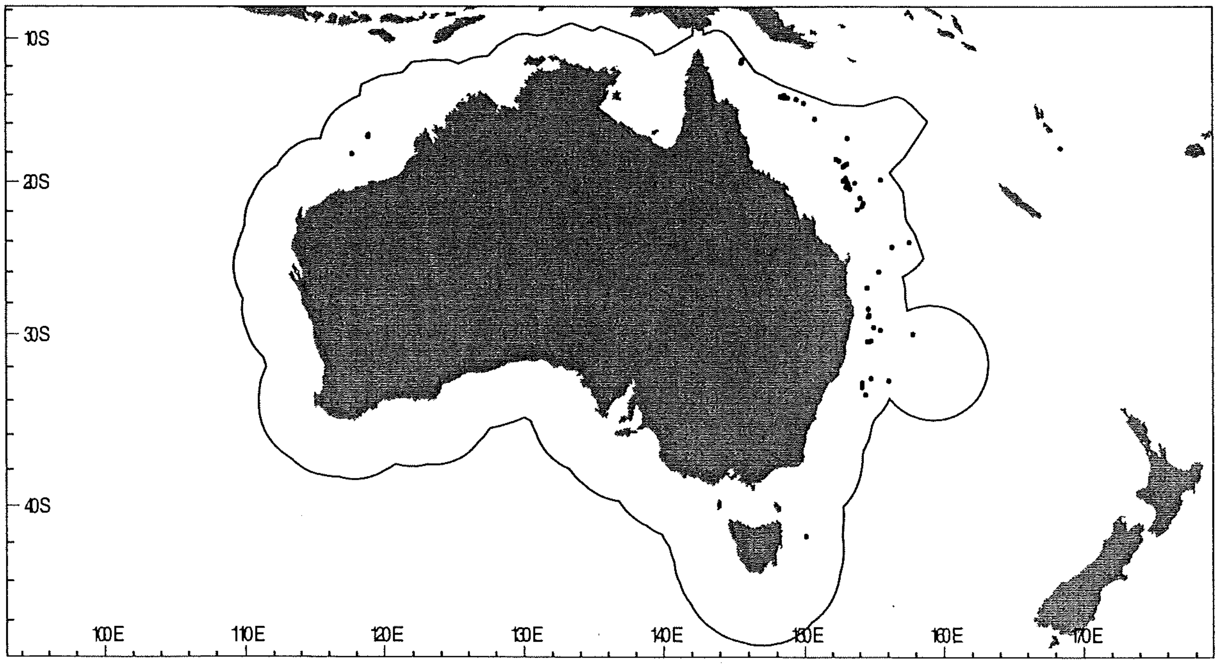


Figure 7a. Distribution of hammerhead catches (observer data)

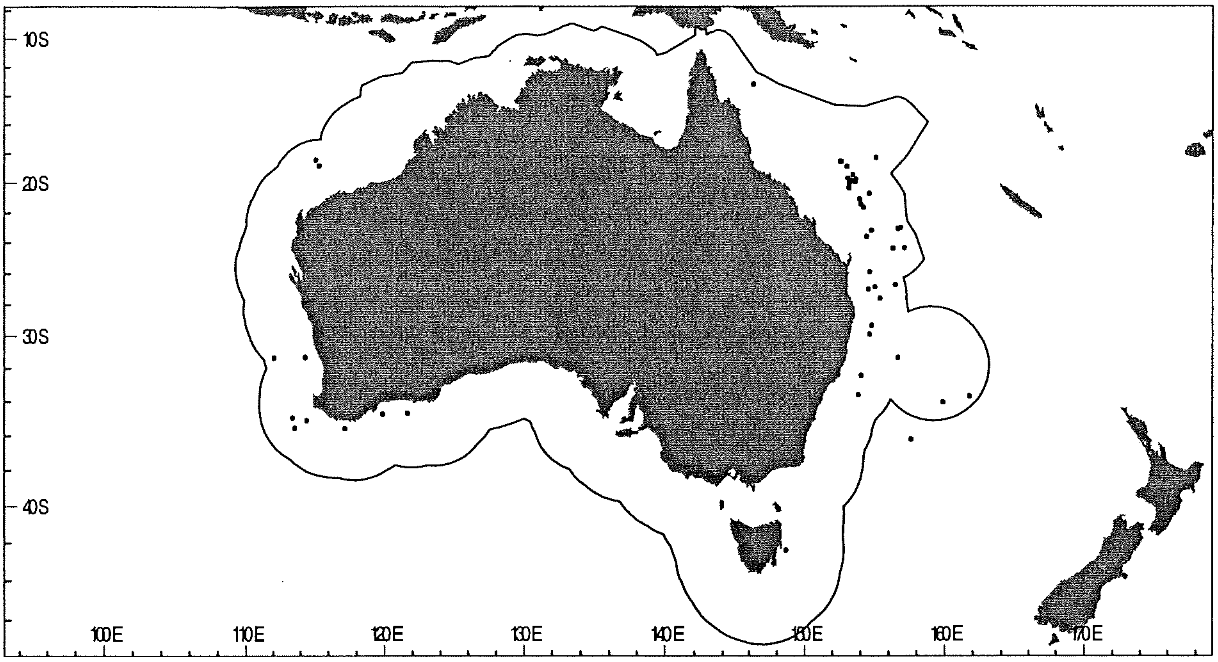


Figure 7b. Distribution of longfin mako catches (4 circles) and pelagic thresher catches (4 triangles) (observer data)

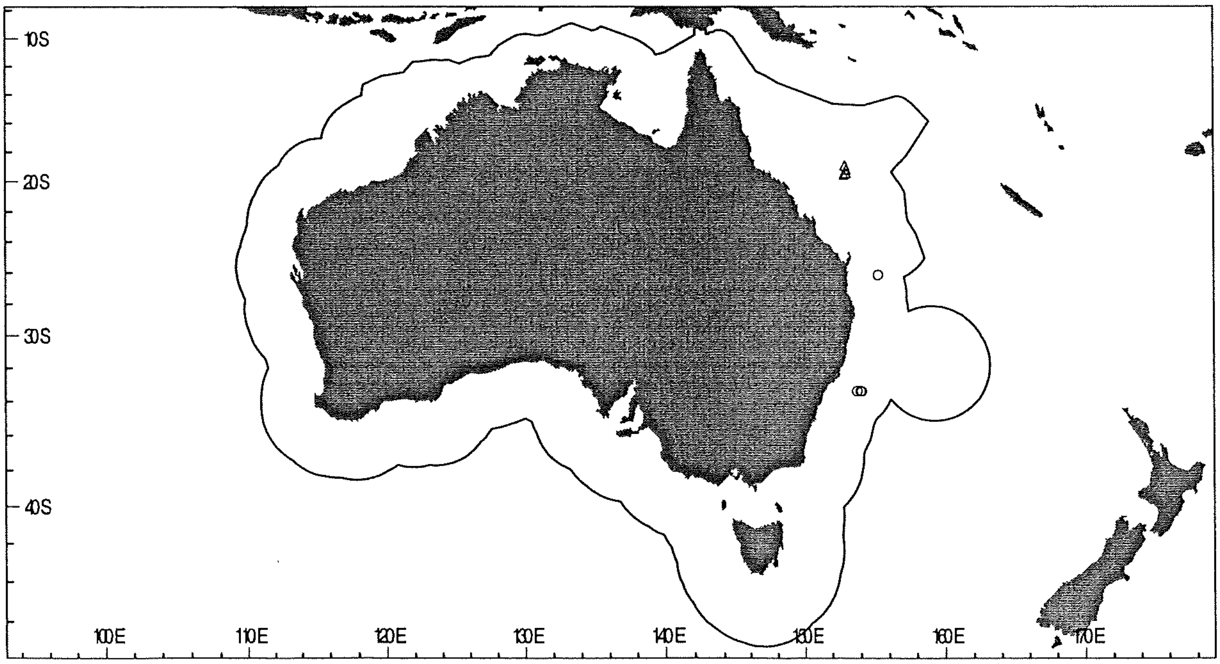


Figure 8a. Distribution of velvet dogfish catches (observer data)

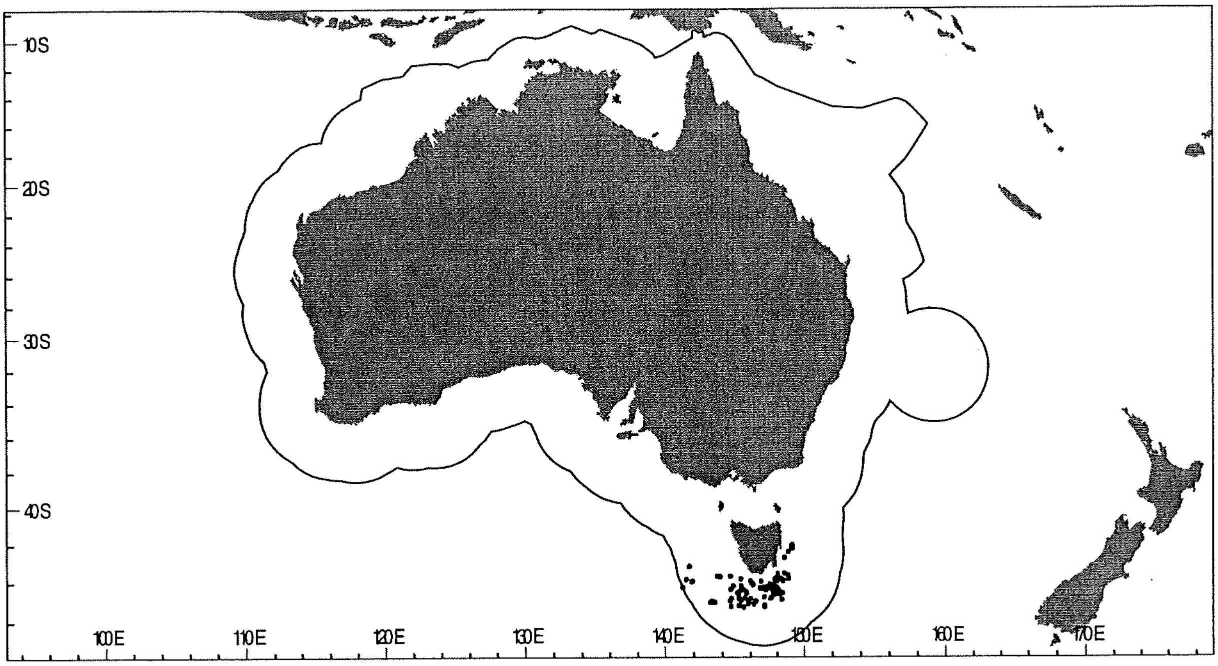
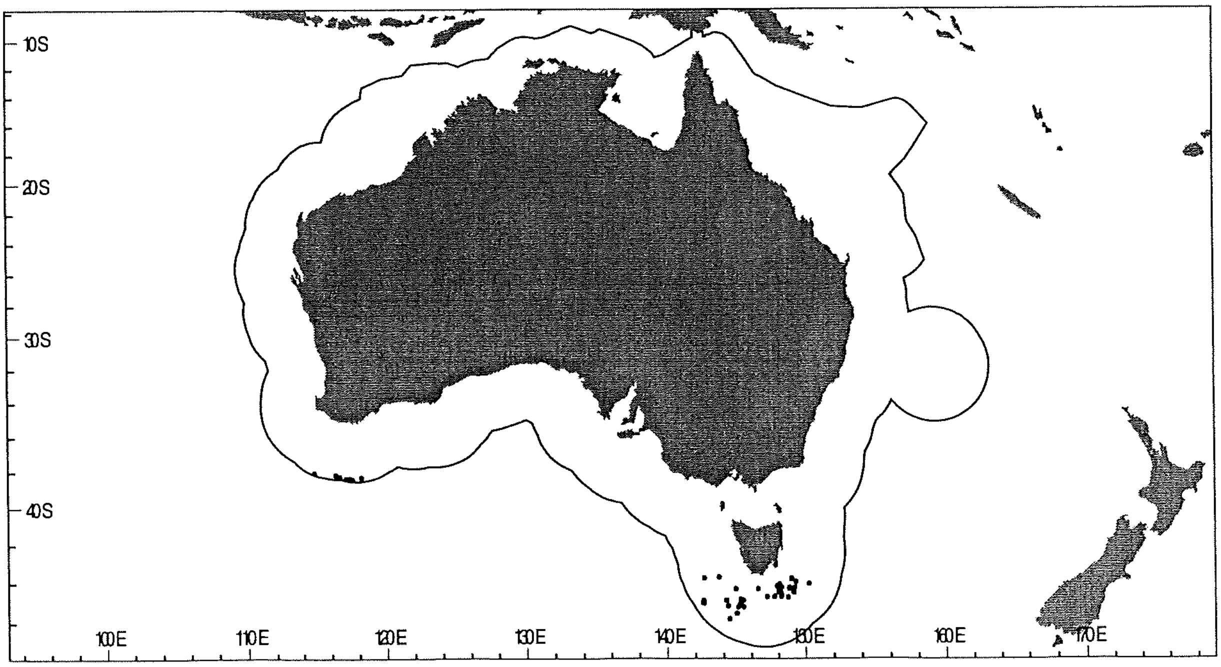


Figure 8b. Distribution of dogfish catches (observer data)



records (with the exception of velvet dogfish which may also be included in this category) are likely to comprise, among others, the whitetail dogfish, *Scymnodalatias albicauda*.

6.3 Catches and catch rates

6.3.1 Blue sharks

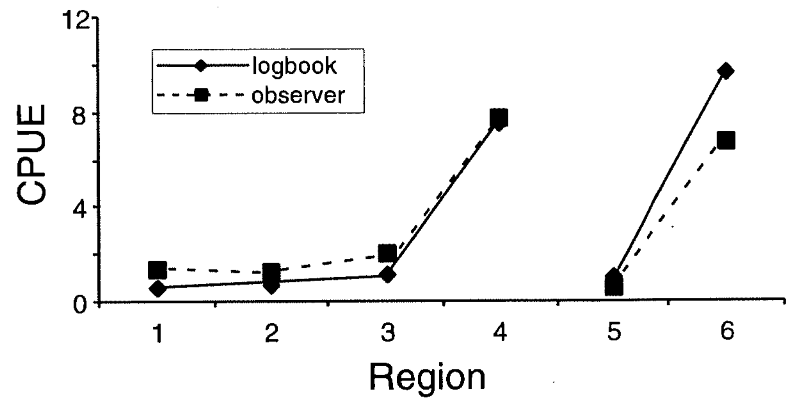
Catch rates derived from logbook and observer data for Japanese longlining in the Australian EEZ were compared for the period 1992-96. Data were examined by latitudinal bands as blue shark abundance can vary with latitude (Stevens 1992; Stevens in press). In general, there was reasonable agreement between logbook and observer catch rates over this time period (Table 3, Fig. 9). The average catch rate from all regions combined was 4.77 from logbook data and 5.52 from observer data. Using the total Japanese effort of 77,814,152 hooks (Table 2) together with the observer catch rate suggests a total catch of 429,534 blue sharks over five years, and that the logbook data under-report the catch by about 13.6%. In an earlier analysis of shark by-catch from Japanese longlining off south eastern Australia, Stevens (1992) suggested there was considerable under-reporting in the period 1988-1990. In contrast, Francis et al. (1999) found reasonable agreement between catch returns and observer estimates of blue shark in 1988-90, however, they noted gross under-reporting since 1990-91. They suggested this was due to concerns raised by conservation groups over the global sustainability of shark fisheries, together with Australia's 1991 ban on the finning of sharks by Japanese vessels (if the carcasses were not also retained).

Table 3. Comparison of blue shark catch rates from logbook and observer data from Japanese longlining in the Australian EEZ between 1992-96. Data separated by 10° latitude bands on the east coast and north and south of 30° on the west coast. Catch is number of sharks, effort is number of hooks and cpue is number of sharks per 1000 hooks

Region		Logbook data			Observer data		
Longitude	Latitude	Catch	Effort	CPUE	Catch	Effort	CPUE
E	10-20°S	3,205	6,073,973	0.53	443	333,870	1.33
E	20-30°S	5,816	8,359,356	0.70	1,000	792,942	1.26
E	30-40°S	18,554	16,988,093	1.09	2,224	1,130,660	1.97
E	40-50°S	269,893	36,076,252	7.48	30,295	3,935,932	7.70
W	<30°S	2,844	2,949,272	0.96	44	79,261	0.56
W	>30°S	70,875	7,367,206	9.62	3,506	517,786	6.77

Fig. 10 shows a comparison of catch rates from logbook and observer data by year for each of the regions. The most noticeable variations in the data occurred in region 20-30°S on the east coast in 1995 (observer cpue 6.29, logbook cpue 0.62) and 40-50°S on the east coast in 1991 (observer cpue 9.02, logbook cpue 0.75) and 1996

Figure 9. Comparison of blue shark catch rates from logbook and observer data from Japanese longlining in the Australian EEZ 1992-96 (regions in sequence from Table 3, region 1 = east coast 10-20°S; cpue is number per 1000 hooks)



(observer cpue 18.37, logbook cpue 6.54). An abundance index for blue sharks available from standardised research fishing at 43°S, 147°E is shown in Fig. 11. The trend line for this index for the 1991-96 period correlates more closely with the observer data trend line in the 40-50°S region in Fig. 10.

Blue shark catch rates in Table 3 and Fig. 9 show a general increasing trend with increasing latitude. Highest catch rates on the east coast were in the 40-50°S latitude band and on the west coast in the >30°S region. More limited logbook data from domestic longliners shows a similar trend on the east coast; few data are available for the west coast (Table 4). This increased catch of blue sharks in higher latitudes on the east coast was noted by Stevens (1992) in an earlier analysis of shark by-catch in the Japanese longline fishery off Australia. A similar trend has been reported elsewhere in the Pacific, and from other oceans (Strasburg 1958; Sivasubramanian 1964; Hazin et al. 1990; Nakano 1994). However, Francis et al. (1999) found no clear latitudinal trend in abundance of blue sharks in New Zealand over the range examined (about 30°-50°S).

A number of author's report catch rate data for blue sharks from both commercial and research longline fishing. In the Pacific, the data of Nakano (1994) in particular, and Strasburg (1958) provide reasonable spatial and seasonal coverage. Stevens (in press) used these data to derive a mean catch rate of 4.30 for the area 20°N-20°S and 27.60 for the area >20°N. A catch rate of 10.40 was estimated for the region >20°S (Stevens 1992). Stevens (in press) used these catch rates, in conjunction with fishing effort and blue shark average weights stratified into the same latitudinal areas, to estimate a catch of 137,800 t of blue shark from high-seas longline fleets in the Pacific in 1994. Stevens (in press) estimated an additional blue shark catch of 2,300 t from high-seas purse-seining in the Pacific in 1994 and

Figure 11. Annual abundance index of blue sharks in Storm Bay, Tasmania (43°S, 147°E)

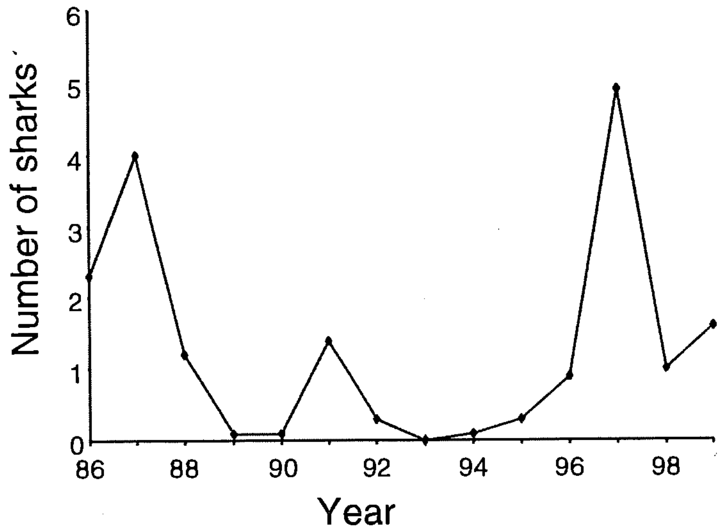


Table 4. Blue shark catch rates from logbook data of domestic longline vessels in the Australian EEZ between 1996-97. Data separated by 10° latitude bands on the east coast and north and south of 30° on the west coast. Catch is number of sharks, effort is number of hooks and cpue is number per 1000 hooks

Region		Logbook data		
Longitude	Latitude	Catch	Effort	CPUE
E	10-20°S	117	1,735,703	0.07
E	20-30°S	606	3,591,818	0.17
E	30-40°S	1,278	4,286,144	0.30
E	40-50°S	2,506	1,258,109	1.99
W	<30°S	348	77,7071	0.45
W	>30°S	4	70,913	0.06

2,260 t from coastal fisheries of Pacific countries. While relatively insignificant in comparison to the high-seas catch, this coastal figure may be a gross under-estimate. The FAO Fishery Statistics Yearbook did not record any catch of blue sharks in the Pacific for this period. Although high-seas driftnetting mostly ceased in 1992, previous removals may still be affecting shark populations. Bonfil (1994) calculated that 21,152 t of blue shark was taken by high-seas driftnet fleets in the Pacific during the 1989-90 period. Bonfil (1994) recognised the large discrepancy between reported landings of elasmobranchs and the total catch, estimating that discards and unreported by-catch probably accounts for an additional 50% of world catches. He estimated a blue shark catch from the South Pacific Commission (SPC) zone in the central and south Pacific of some 8,200 t. Similar calculations made by Bonfil (1994) for an area of the North Pacific north of the SPC Zone suggested about 39,000 t of blue sharks were caught in 1988. Nakano and Watanabe (1992) estimate that the high-seas fisheries of the North Pacific caught 5 million blue sharks during 1988; assuming an average weight of 25 kg this represents some 125,000 t.

Blue shark catch rates reported from commercial longlining in the Atlantic Ocean range in average values from 2.9-100 (Mejuto 1985; Mejuto and Iglesias 1988; Hazin et al. 1990; Rey and Munoz-Chapuli 1991; Buencuerpo et al. 1998; Cramer 1998), while average catch rates as high as 145.0 have been recorded from research longlining (A. da Silva, Universidade dos Açores, Portugal). Few data on catch rates of blue sharks in the Indian Ocean are available; Stevens (1992) reported a catch rate of 8.3 for a Taiwanese research longliner off south western Australia. Bonfil (1994) estimates that 4 million blue sharks were caught annually by world high-seas longline fisheries and 6.2-6.5 million by all high-seas fisheries.

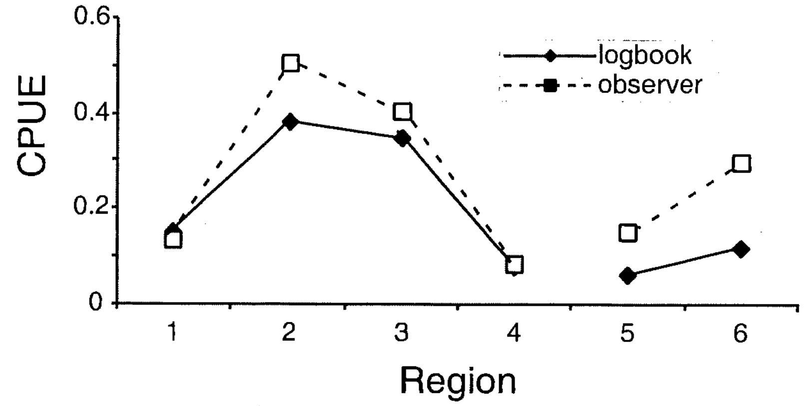
6.3.2 Other species

A comparison of logbook and observer catch rate data for shortfin mako sharks taken by Japanese longliners in Australia is shown in Table 5 and Fig. 12. The catch rate for all areas combined (Table 5) is 0.18 from logbook data and 0.20 from observer data. Using the total Japanese effort of 77,814,152 hooks, together with the observer catch rate, suggests a total catch of 15,563 shortfin makos over the five year period and a 10% under-reporting rate from the logbook data. Logbook and observer catch rates by year and region for shortfin mako taken by Japanese longlining are shown in Fig. 13. The largest discrepancies between the two data sources were for the west coast at >30°S latitude, however, observer data from this region were limited. For the west coast region at <30°S latitude there were insufficient data for an annual comparison.

Highest catch rates in the Japanese fishery occurred in the 20-30° and 30-40°S regions on the east coast, and in the >30°S region on the west coast, but there was no clear latitudinal trend in the data. In the more limited domestic data (Table 6) the highest catch rates were in the 30-40° and 40-50°S regions. Francis et al. (1999) found no clear trend in abundance of shortfin makos with latitude in New Zealand.

The majority of porbeagle sharks were caught offshore from Tasmania and so the comparison of logbook and observer catch data were restricted to the east coast area south of 39°S (Table 7, Fig. 14). The average catch rate in this area from logbook data was 0.25 compared to 0.54 from observer data over the period 1991-96. This suggests a total catch of 24,213 porbeagles were taken around Tasmania by an effort of 44,839,313 hooks over the five year period, and that the logbook data may under-estimate the catch by about 47%. There is a general increase in catch rate of porbeagles by year from both data sets. This probably reflects improved awareness and identification of porbeagles in the catch. In the late 1980s, most observers did not differentiate porbeagle from shortfin makos. The catch rate of

Figure 12. Comparison of shortfin mako catch rates from logbook and observer data from Japanese longlining in the Australian EEZ between 1992-96 (regions in sequence from Table 5, region 1 = east coast 10-20°S; cpue is number per 1000 hooks)



porbeagles from domestic vessels in 1997 from 40-50°S on the east coast (the only area and year for which sufficient data were available) was 0.70.

Table 5. Comparison of shortfin mako catch rates from logbook and observer data from Japanese longlining in the Australian EEZ between 1992-96. Data separated by 10° latitude bands on the east coast and north and south of 30° on the west coast. Catch is number of sharks, effort is number of hooks and cpue is number of sharks per 1000 hooks

Region		Logbook data			Observer data		
Longitude	Latitude	Catch	Effort	CPUE	Catch	Effort	CPUE
E	10-20°S	914	6,073,973	0.15	45	333,870	0.13
E	20-30°S	3,173	8,359,356	0.38	400	792,942	0.50
E	30-40°S	5,946	16,988,093	0.35	454	1,130,660	0.40
E	40-50°S	2,889	36,076,252	0.08	322	3,935,932	0.08
W	<30°S	182	2,949,272	0.06	12	79,261	0.15
W	>30°S	865	7,367,206	0.12	154	517,786	0.30

The majority of porbeagle sharks were caught offshore from Tasmania and so the comparison of logbook and observer catch data were restricted to the east coast area south of 39°S (Table 7, Fig. 14). The average catch rate in this area from logbook data was 0.25 compared to 0.54 from observer data over the period 1991-96. This suggests a total catch of 24,213 porbeagles were taken around Tasmania by an effort of 44,839,313 hooks over the five year period, and that the logbook data

Figure 13. Comparison of shortfin mako catch rates by region and year from logbook and observer data from Japanese longlining in the Australian EEZ

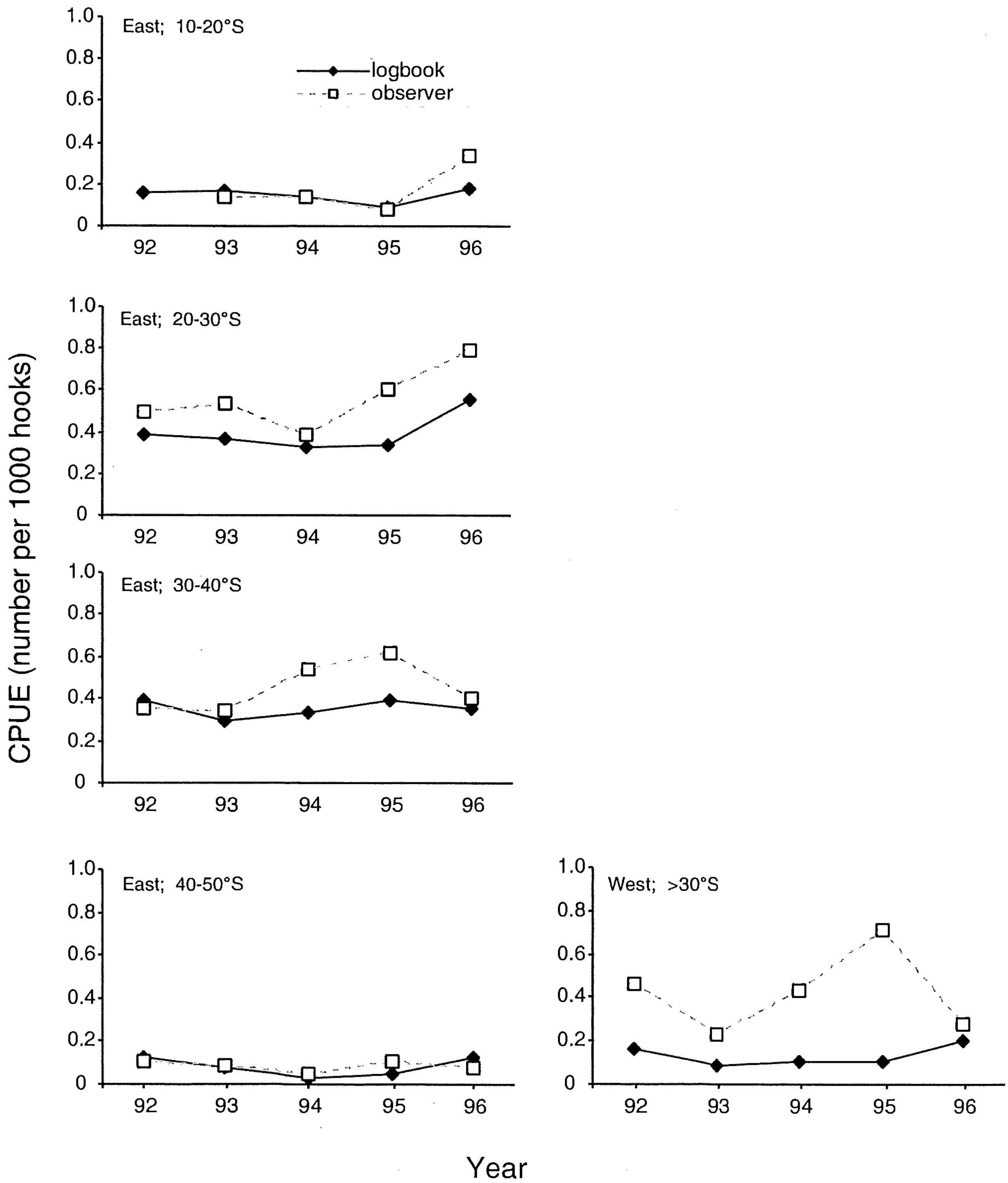


Figure 14. Comparison of porbeagle catch rates from logbook and observer data from Japanese longlining south of 39° and east of 138° in the Australian EEZ during 1991-95 (cpue is number per 1000 hooks)

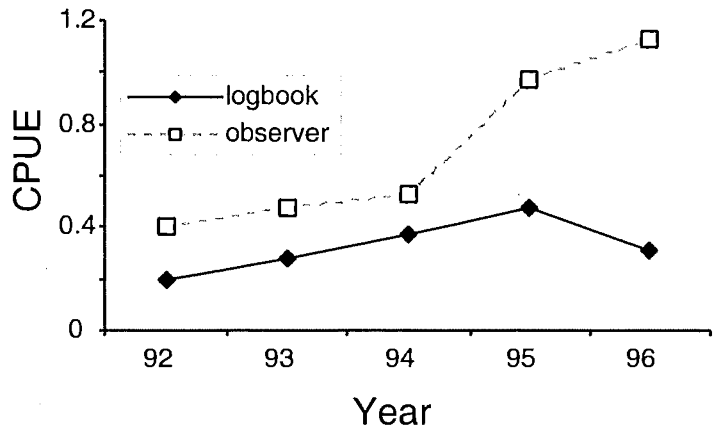


Table 6. Shortfin mako shark catch rates from logbooks of domestic longline vessels in the Australian EEZ between 1996-97. Data separated by 10° latitude bands on the east coast and north and south of 30° on the west coast. Catch is number of sharks, effort is number of hooks and cpue is number per 1000 hooks

Region		Logbook data		
Longitude	Latitude	Catch	Effort	CPUE
E	10-20°S	45	1,735,703	0.025926
E	20-30°S	419	3,591,818	0.116654
E	30-40°S	1,628	4,286,144	0.379829
E	40-50°S	329	1,258,109	0.261504
W	<30°S	56	777,071	0.072065
W	>30°S	0	70,913	0

may under-estimate the catch by about 47%. There is a general increase in catch rate of porbeagles by year from both data sets. This probably reflects improved awareness and identification of porbeagles in the catch. In the late 1980s, most observers did not differentiate porbeagles from shortfin makos. The catch rate of porbeagles from domestic vessels in 1997 from 40-50°S on the east coast (the only area and year for which sufficient data were available) was 0.70.

Information on catches and catch rates of some minor species taken by Japanese longliners in Australian waters are shown in Table 8. To minimise problems associated with species identification, effort data was not used for years prior to the one in which a species was first recorded in the catch. Data from areas considered to be outside the species normal distribution were excluded. However, identification problems may still exist in the data and these catch rates should only be considered as very approximate. As noted in section 6.2.2 species identified by observers as dusky shark and bronze whaler from areas 1, 2 and 5 are probably silky sharks. Catches of dusky and bronze whalers have been combined to give a rough estimate of catch rates for silky shark of 0.36. This is similar to the catch rate of 0.40 for bronze whalers recorded in the Japanese logbook data from areas 1, 2 and 5. In addition to the species in Table 8, 60 hammerheads and 119 dogfish were recorded by observers from Japanese catches.

Table 7. Porbeagle catch, effort and cpue from logbook and observer data from Japanese longline vessels fishing south of 39° and east of 138° in the Australian EEZ during 1991-96. Catch is number of sharks, effort is number of hooks and cpue is number per 1000 hooks

	Logbook data			Observer data		
Year	Catch	Effort	Cpue	Catch	Effort	Cpue
1991	202	7,834,638	0.03	331	928,205	0.36
1992	2124	10,592,667	0.20	335	837,227	0.40
1993	3083	11,102,076	0.28	700	1,460,931	0.48
1994	3321	9,004,924	0.37	508	965,786	0.53
1995	2073	4,344,429	0.48	363	373,188	0.97
1996	618	1,960,579	0.32	435	385,091	1.13

Reported average catch rates for shortfin makos vary from 0.3-3.4 (Mejuto 1985; Mejuto and Iglesias 1988; Hazin et al. 1990; Rey and Munoz-Chapuli 1991; Stevens 1992; Costa et al. 1996; Buencuerpo et al. 1998; Francis et al. 1999). Stevens (in press) used stratified catch rates derived from Shomura and Otsu (1956), Strasburg (1958) and Stevens (1992) in conjunction with fishing effort and average weights to estimate a catch of 4,100 t of shortfin mako caught by high-seas longlining in the Pacific in 1994. A coastal drifnet fishery for juvenile shortfin mako shark developed during the late 1970s in California; landings reached 242 t in 1982, fluctuated between 102-278 t from 1983-91 and declined to less than 100 t after 1991 (Holts et al. 1998). In 1987, an experimental coastal longline fishery targeting makos was started and catches from 1988-91 varied between 50-120 t before the fishery was closed.

Table 8. Catch (number of sharks), effort (number of hooks) and cpue (number per 1000 hooks) of minor species taken by Japanese longlining in the Australian EEZ

Species	Period	Area	Catch	Effort	Cpue
Velvet dogfish	1992-96	4	241	3,935,932	0.06
School shark	1993-96	4	222	3,098,705	0.07
Crocodile	1992-96	1-2 & 5-6	935	1,723,859	0.54
Thresher	1992-96	1-6	139	6,790,451	0.02
Bigeye thresher	1991-96	1-6	283	6,790,451	0.04
Oceanic whitetip	1992-96	1-2	203	1,126,812	0.18
Bronze whaler	1992-96	1-2, 5	434	1,206,073	0.36
Tiger	1993-96	1-2	49	614,375	0.01
Hammerhead	1992-96	1-3 & 5-6	59	2,854,519	0.02

Bonfil (1994) estimated that 5,932 shortfin makos were caught by Korean longliners in the (mainly equatorial) Atlantic in 1989 and that 1,988 (135 t) were caught by the Spanish swordfish fishery in the Mediterranean and 9, 277 (628 t) in the Atlantic.

Equatorial catch rates for oceanic whitetips show a large variation in average value between the data of Strasburg (1958) and Sivasubramanian (1963) (11.4 and 10.3, respectively) and Matsunaga and Nakano (1996) and Saika and Yoshimura (1985) (1.2 and 3.0, respectively). Stevens (in press) used the average of the pair of higher and lower estimates, together with fishing effort and average weights, to calculate that between 45,100-232,400 t of oceanic whitetip were caught by high-seas longliners and 7,000 t by purse-seiners in the Pacific in 1994. Similarly, using Strasburg's (1958) catch rates of 3.4 for the region 20°N-20°S and 0.01 for >20°N or S, Stevens (in press) estimated a high-seas longline catch of 72,400 t, and purse seine catch of 11,700 t, of silky sharks in the Pacific in 1994. Bonfil (1994) estimated a catch of 19, 897 t of silky sharks and 10, 799 t of oceanic whitetips from tuna longline fisheries in the SPC zone in the Pacific in 1989. Outside the Pacific, Rey and Munoz-Chapuli (1991) noted a catch rate for silky sharks of 6.3 from the deep-set swordfish longline fleet in the south-east Atlantic and Hazin et al (1990) and Sivasubramanian (1963) reported catch rates for oceanic whitetips of 0.06 and 2.3 from commercial and research longlining, respectively, in the Atlantic.

Reported catch rates for thresher sharks are generally between 0.01-0.25 (Strasburg 1958; Hazin et al. 1990; Buencuerpo 1998), although Rey and Munoz-Chapuli (1991) recorded an average catch rate of 3.4 for bigeye threshers taken in the deep-set longline fishery for swordfish in the south-east Atlantic. Stevens (in press) estimated a by-catch of 2,700 t of thresher shark in high-seas longline fisheries in the Pacific in 1994. A coastal drifnet fishery for juvenile threshers developed during the late 1970s in California; landings reached 1,087 t in 1982 before declining to less than 200 t after 1991 (Holts et al. 1998).

Catch rates for other shark species (porbeagles, crocodile sharks, hammerheads, school shark and deep-water dogfish) taken by pelagic longliners are generally less than 0.5 (Hazin et al. 1990; Rey and Munoz-Chapuli 1991; Buencuerpo 1998; Francis et al. 1999). However, an average catch rate of about 2.2 for porbeagles was reported by Francis et al. (1999) from New Zealand and 20.6 for night sharks (*Carcharhinus signatus*) by Rey and Munoz-Chapuli (1991) from the south-east Atlantic.

6.4 Size and sex composition

6.4.1 Blue sharks

Information on the composition of blue shark catches by sex was obtained from observer coverage of Japanese longliners fishing in the Australian EEZ from 1991-96. No clear trend was evident with latitude, but the highest proportion of females was present at 40-50°S on the east coast (Table 9). In contrast, a greater proportion of females were found to the north of the 30° parallel on the west coast (Table 9).

Table 9. Sex composition by area of blue shark catches from Japanese longlining (1991-96 observer data)

Longitude	Latitude	Males	Females	% female	p #
E	10-20°S	170	165	49	ns
E	20-30°S	664	330	33	**
E	30-40°S	873	710	45	**
E	40-50°S	7,460	19,262	72	**
W	<30°S	35	55	61	*
W	>30°S	822	428	34	**

χ^2 test on variance from 1:1 sex ratio; ns not significant, * $p<0.05$, ** $p<0.01$

The length composition of blue sharks taken by Japanese longliners are shown by latitude and sex for the east and west coast in Fig. 15. There were too few data to display for the west coast area north of 30°S. On the east coast, the size of blue sharks decrease to the south. In the 10-20° and 20-30°S areas, the length frequency

Figure 15a. Length composition by area and sex of blue sharks taken by Japanese longliners off the east coast of Australia from 1991-96 (observer data)

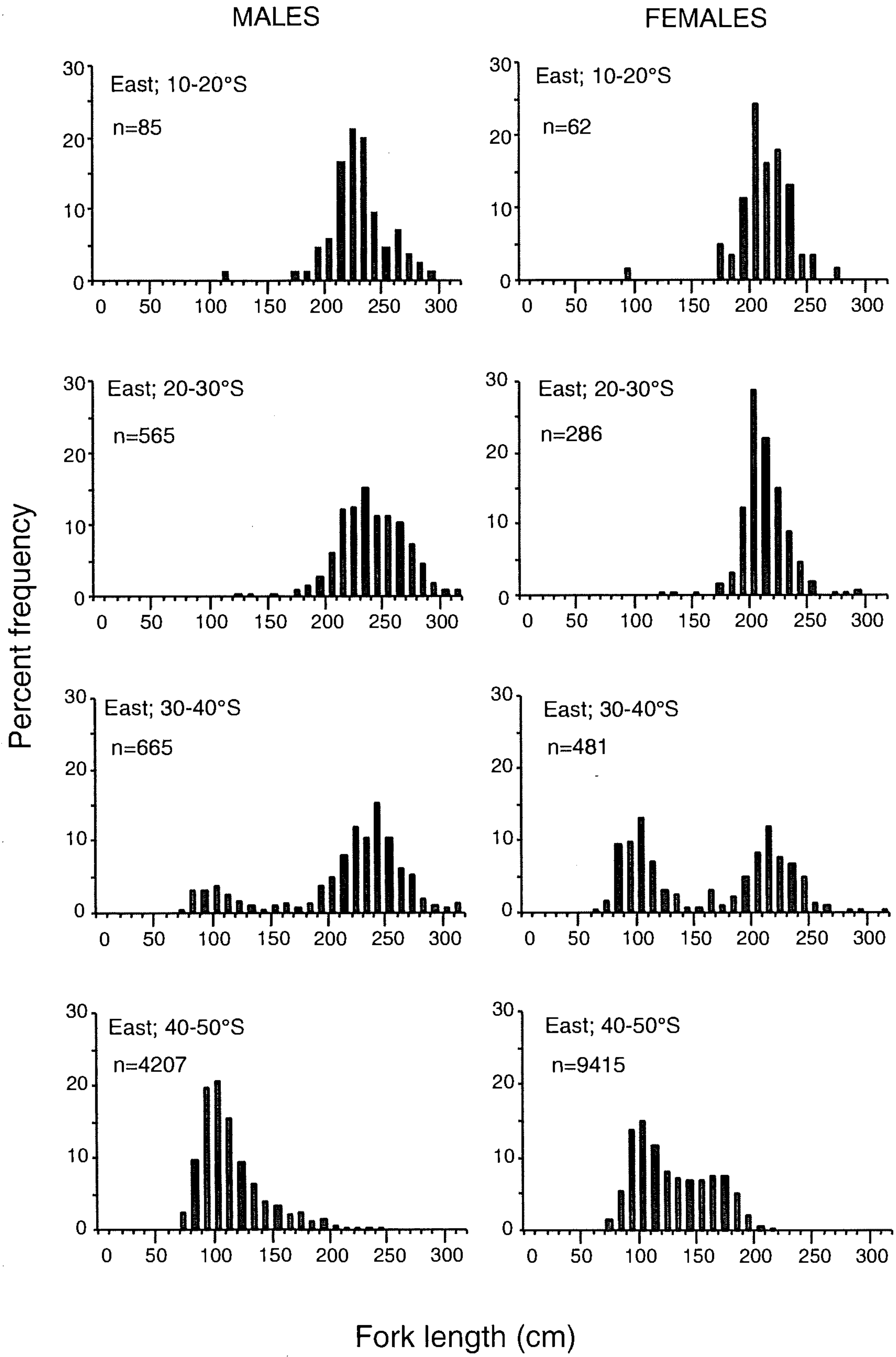
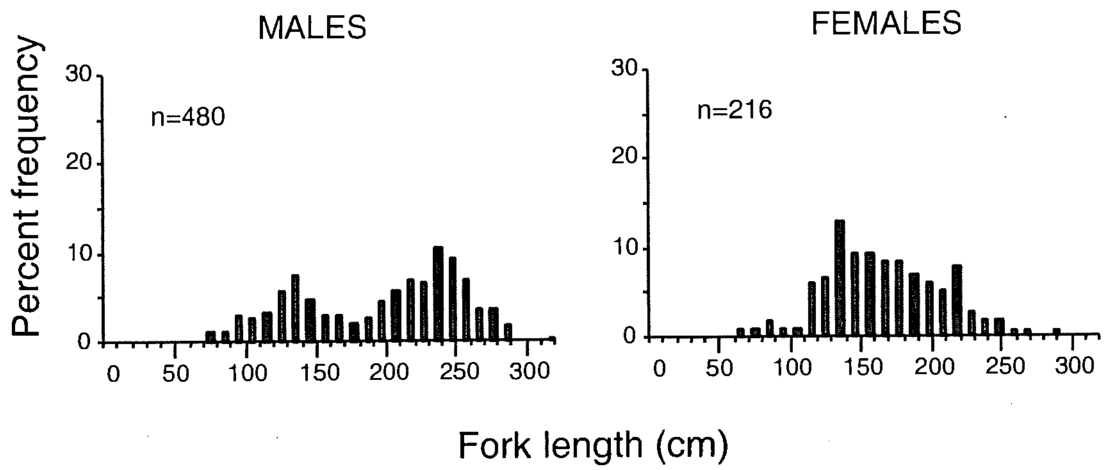


Figure 15b. Length composition by sex of blue sharks taken by Japanese longliners of the west coast of Australia, south of 30°S, from 1991-96 (observer data)



consists of relatively large fish with a single mode for both sexes between 200-220 cm. At 30-40°S, these larger fish are present but there is an additional group of smaller fish of both sexes with a modal length of about 100 cm. At 40-50°S, only these smaller fish are present and there are very few individuals of more than 200 cm; for females, however, there is another mode at 160-170 cm. These intermediate sized fish are consistently represented each year from 1991-96; however, they are not present in significant numbers in any of the other areas. On the west coast south of 30°S, the size composition of males is bimodal and is most similar to the 30-40°S area on the east coast; the female size distribution is more similar to that at 40-50°S on the east coast. Based on the east coast area 40-50°S, there appears to be relatively little inter-annual variation in modal length within a given area (Table 10).

To see if there were any seasonal variations in size, the length composition of females at 30-40°S and 40-50°S on the east coast was separated into autumn and spring periods (Fig. 16). Little seasonal variation was apparent at 30-40°S with the same two modes (about 100 and 225 cm) dominating. At 40-50°S, the autumn sample mirrored the overall sample, but the spring sample comprised larger fish with a mode at about 170 cm.

6.4.2 Other species

The sex ratio of shortfin makos from Japanese catches in Australian waters was examined using observer data (Table 11). More females were caught north of 30°S on the east coast, and more males south of 30°S (Table 11). On the west coast, however, more females were caught in the southern region (Table 11). The data on length composition of the catch, by region, are shown in Fig. 17; no obvious trend in size with latitude is apparent.

Figure 16. Size composition by season of female blue sharks taken by Japanese longliners off the east coast of Australia from 1991-96 (observer data)

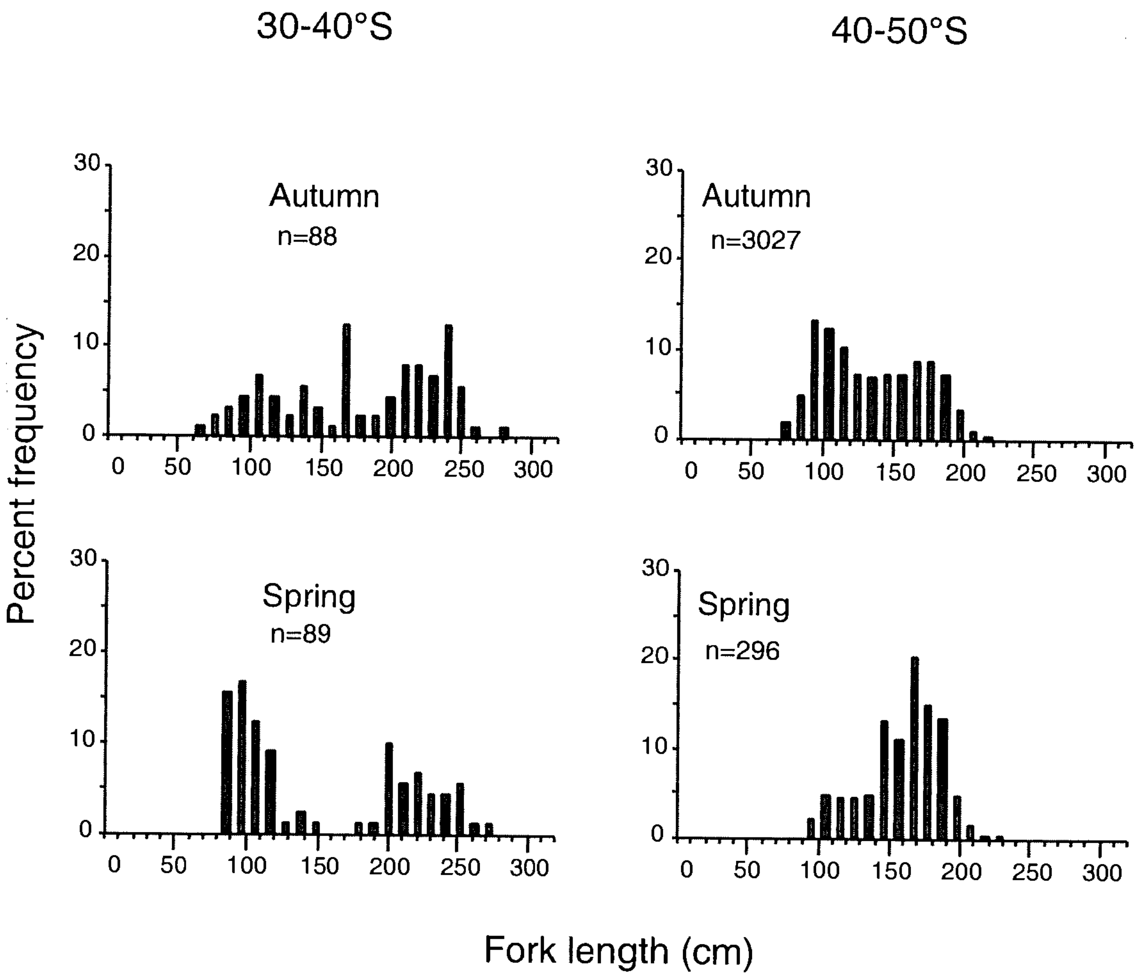
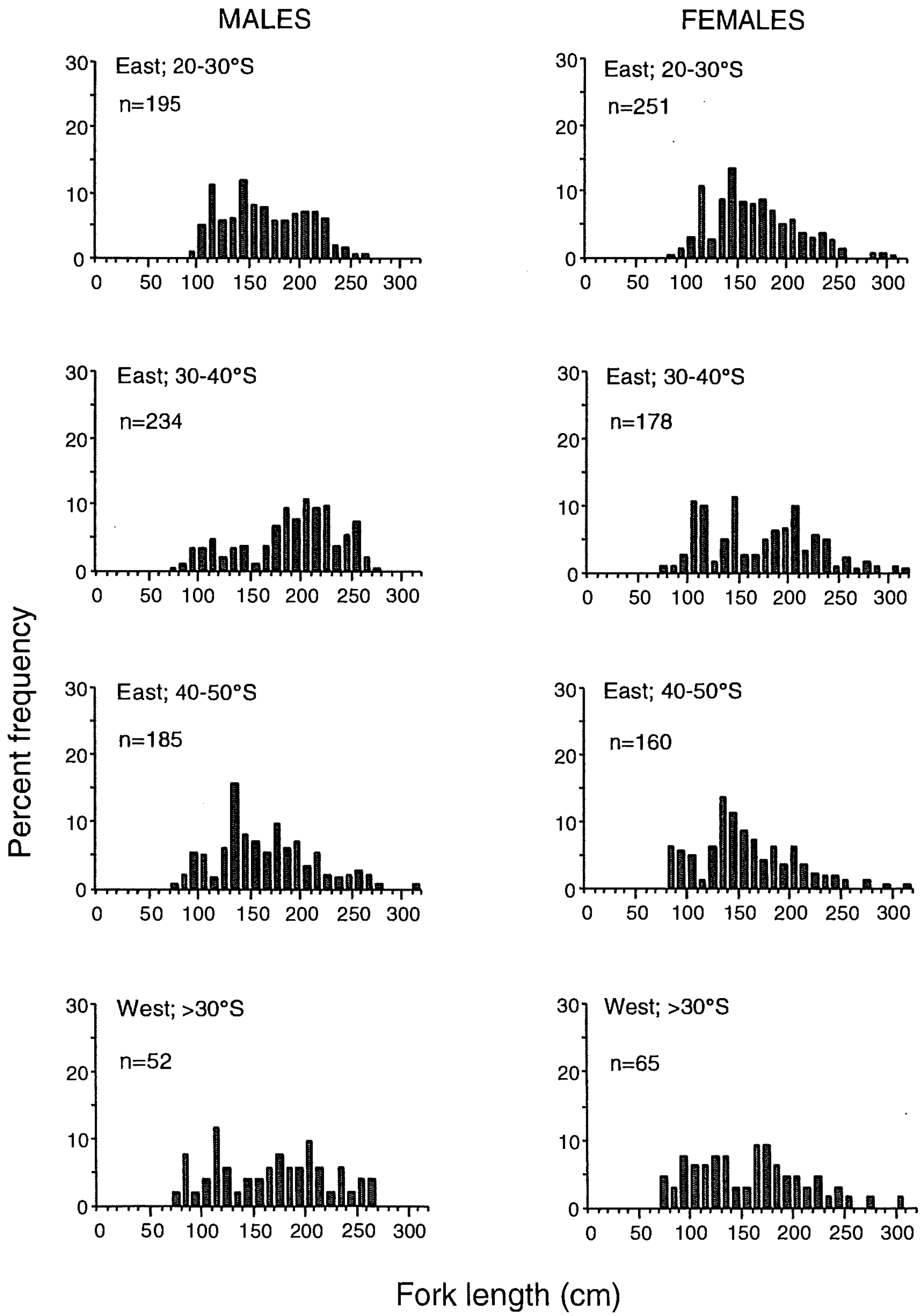


Table 10. Length (FL) composition data for blue sharks taken by Japanese longlining off the east coast of Australia at 40-50°S

Year	Min M	Min F	Max M	Max F	Mode M	Mode F	n M	n F	% female #
1991	61	47	257	292	103	96	1995	4283	68
1992	63	59	230	215	92	88	260	776	75
1993	50	54	285	247	91	89	841	1902	69
1994	46	54	248	320	89	91	537	1402	72
1995	45	58	247	257	87	96	220	405	65
1996	40	62	243	197	91	92	354	647	65

All sex ratios significantly different from 1:1 (χ^2 test; $p<0.01$)

Figure 17. Length composition by area and sex of shortfin mako sharks taken by Japanese longliners off the east coast of Australia from 1991-96 (observer data)



The size distributions for each region and for each sex are relatively similar, except for area 30-40°S on the east coast where the modal length of males is much larger (Table 12, Fig. 17). Data were too few for areas 10-20°S on the east coast and <30°S on the west coast.

Table 11. Sex composition by area of shortfin mako catches from Japanese longlining (1991-96 observer data)

Longitude	Latitude	Males	Females	% female	p #
E	10-20°S	19	23	55	ns
E	20-30°S	220	288	57	**
E	30-40°S	259	206	44	*
E	40-50°S	225	186	45	ns
W	<30°S	7	1	13	*
W	>30°S	56	72	56	ns

χ^2 test on variance from 1:1 sex ratio; ns not significant, * $p<0.05$, ** $p<0.01$

Of the 1,255 porbeagles examined by observers onboard Japanese longliners in the EEZ, 47.6% were female (χ^2 nsd 1:1). The length composition of these sharks is shown in Fig. 18; the modal length for both sexes was about 85 cm which represents fish of about one year old (Francis and Stevens in press). Individuals over 125 cm were relatively rare in the catch.

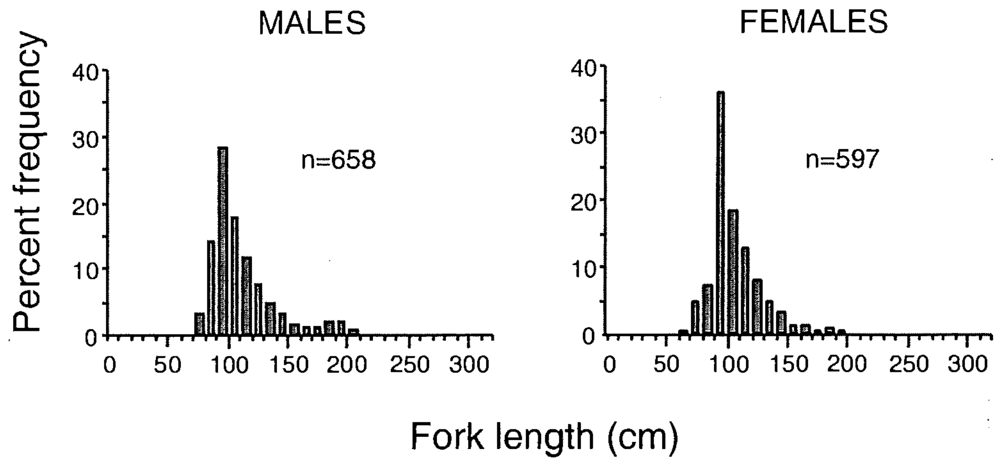
Table 12. Length (FL) composition data by area and sex for shortfin makos taken by Japanese longliners in the EEZ from 1992-96

Long.	Lat.	Min. M	Min. F	Max. M	Max. F	Mode M	Mode F	n M	n F
E	10-20								
E	20-30	82	77	252	295	98	162	195	251
E	30-40	67	65	265	327	193	104	234	178
E	40-50	67	73	350	305	126	130	185	160
W	<30								
W	>30	68	61	256	296	107	174	52	65

Length frequency distributions, size data and sex ratios for other shark species caught by Japanese longliners and examined by observers are shown in Table 13 and Figs. 19-21.

In addition to the other shark species in Table 13, two longfin makos, a 59 cm male and a 66 cm female, and eight pelagic threshers, two males and six females all of about 180 cm, were recorded in the data. Identification of the thresher sharks to the species level were not verified and some may be questionable. It is
Fig 18

Figure 18. Size composition by sex of porbeagles taken by Japanese longliners south of 39°S and east of 138°E from 1991-96 (observer data)



known that additional specimens of the longfin mako were caught which do not appear in the data (Stevens 1995).

With one exception, the sizes recorded in Table 13 are within known ranges for these species (Last and Stevens 1994). The bronze whaler recorded at 483 cm is almost certainly an error, as no *Carcharhinus* species attain this length.

Table 13. Observer data on length (FL) and sex ratio of sharks caught by Japanese longliners in the EEZ from 1992-96

Species	Min. M	Min. F	Max. M	Max. F	Mode M	Mode F	n M	n F	% F	P #
V dog	-	56	-	80			0	51	100	**
Dogfish	-	66	-	93			0	14	100	**
School	98	96	146	135	116	120	38	31	44.9	ns
Crocodile	61	60	100	102	85	91	167	67	28.6	**
Thresher	128	168	293	293	207	205	41	34	45.3	ns
Bigeye T	74	170	383	383	205	186	78	69	46.9	ns
OWT	116	98	187	282	147	147	80	67	45.6	ns
BrW	99	65	250	239	178	193	65	66	50.4	ns
Dusky	124	135	205	195	135	154	124	23	15.6	**
Tiger	82	125	195	231			6	6	50	ns
Hammer	200	174	303	281			10	23	69.7	*

V dog, velvet dogfish; bigeye T, bigeye thresher; OWT, oceanic whitetip; BrW, bronze whaler; hammer, hammerhead. # χ^2 test on variance from 1:1 sex ratio; ns not significant, * $p<0.05$, ** $p<0.01$

Figure 19. Size composition by sex of shark species taken by Japanese longliners from 1991-96 (observer data)

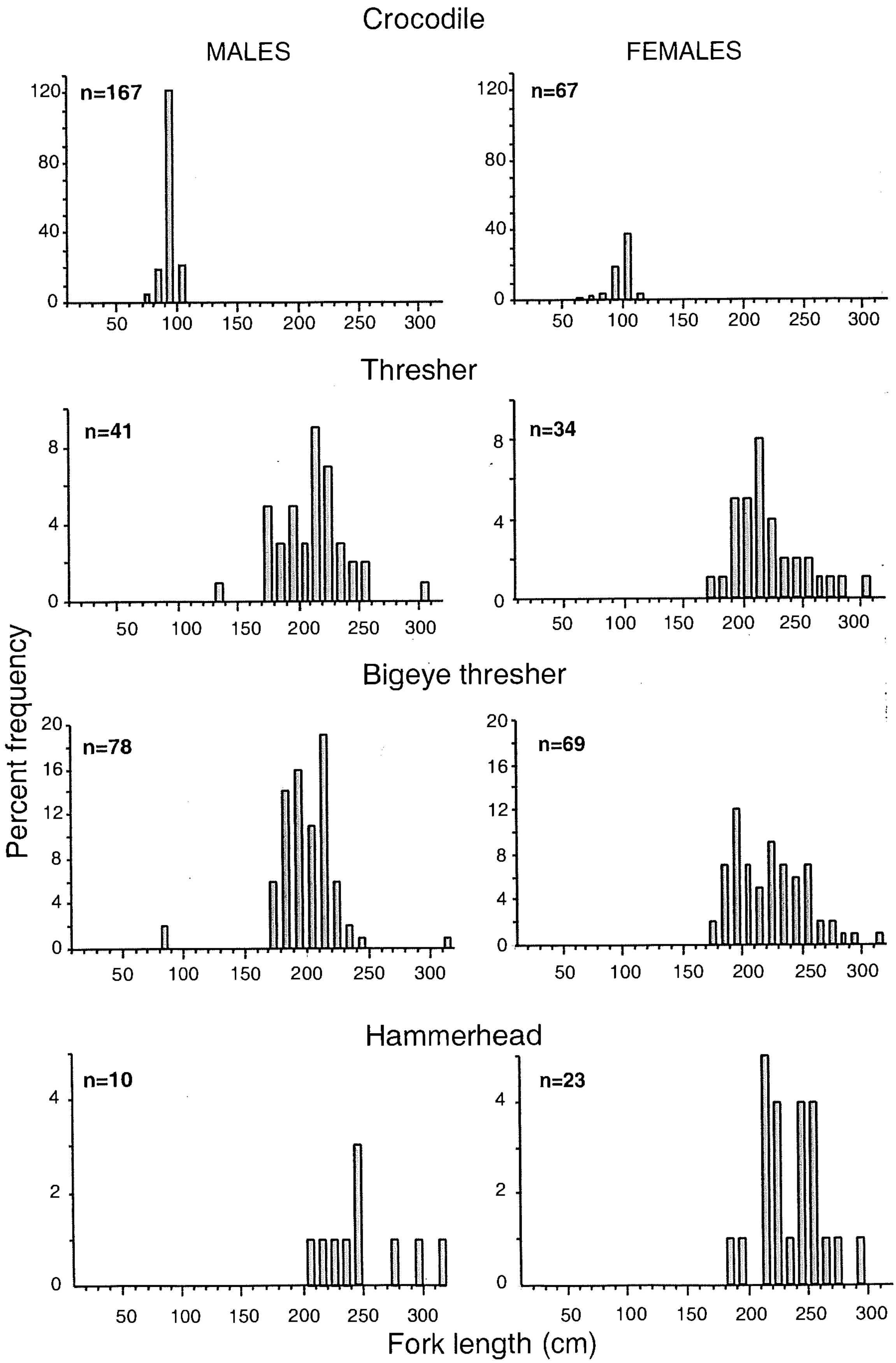


Figure 20. Size composition by sex of shark species taken by Japanese longliners from 1991-96 (observer data)

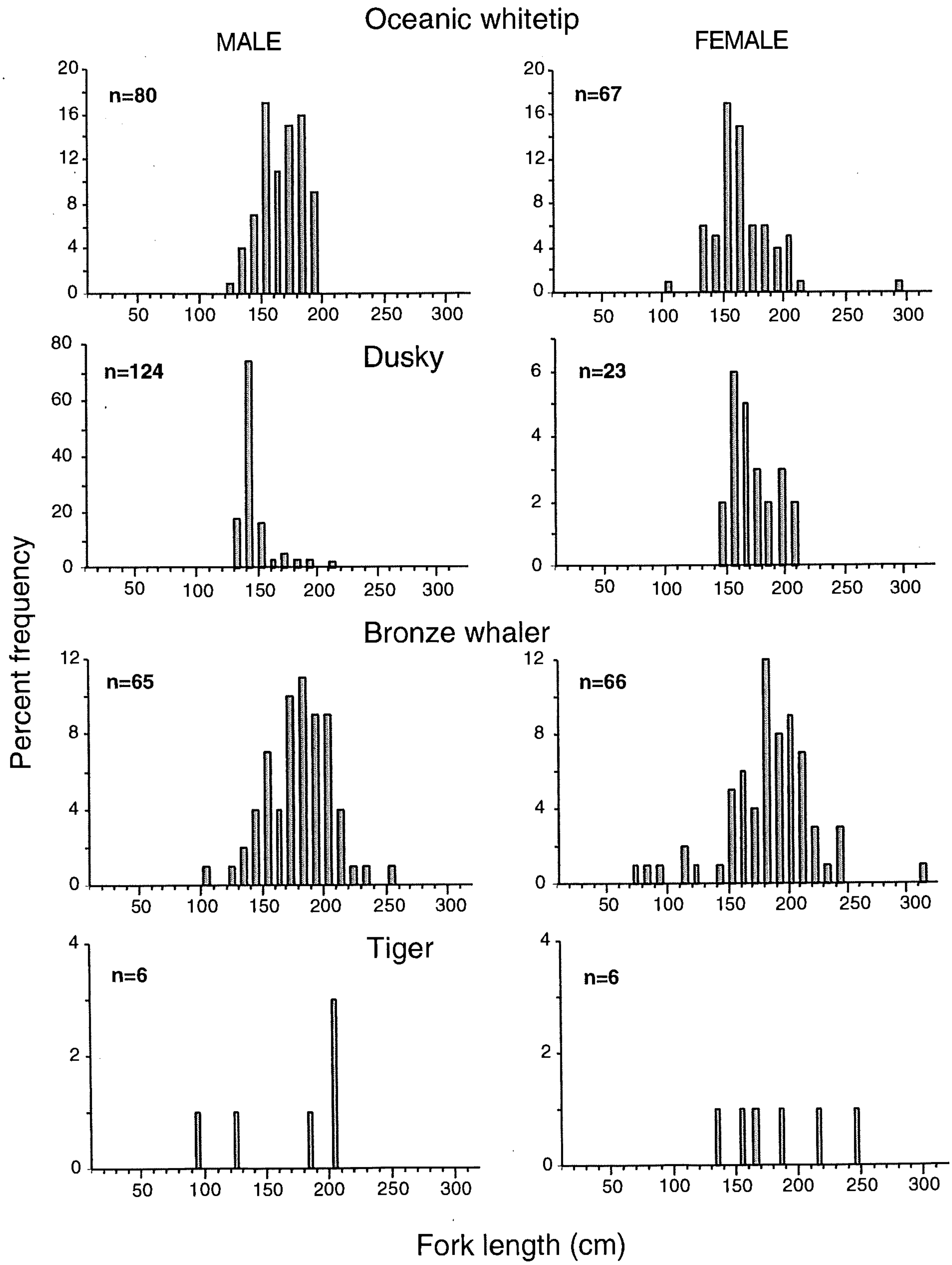
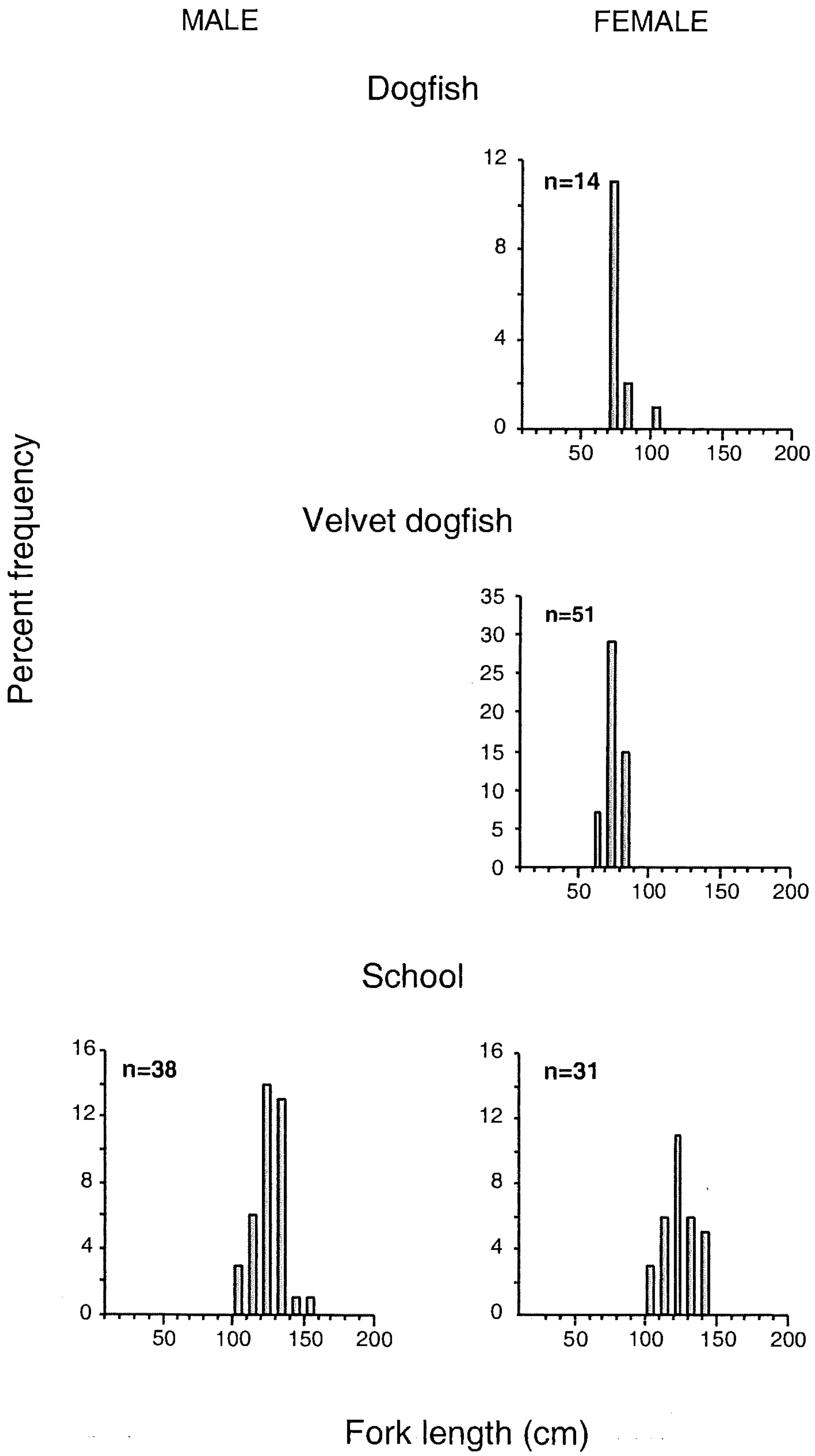


Figure 21. Size composition by sex of shark species taken by Japanese longliners from 1991-96 (observer data)



6.5 Biology

6.5.1 Blue sharks

Reproduction in blue sharks is viviparous, the young being nourished via a yolk sac placenta. Stevens (1984) suggested the following reproductive cycle for blue sharks in coastal waters off New South Wales, based on sportfishing catches. Males are present throughout the year. Testes weights are highest from March to August and mating probably occurs from September to December. Pregnant females move into the area in September and give birth mainly in October; they then mate and move out of the area around December. Smaller non-pregnant females arrive in October when, if they have not already done so just prior to arriving, they mate. The ova of these fish enlarge until January-February when these individuals leave the area. Off the Sydney area, 36% of males of 222-250 cm TL and 100% longer than 280 cm TL were mature. All females examined (218-316 cm TL) by Stevens (1984) were mature. Mature non-pregnant fish ranged from 218-249 cm TL (mean 231 cm) and pregnant or spent individuals were between 241-316 cm TL (mean 267 cm). Litter sizes averaged 32 with a maximum of 57. Cephalopods, and to a lesser degree, fish, formed the main items in the diet, occurring in 61 and 42% of stomachs containing food, respectively (Stevens 1984).

Stevens and McLoughlin (1991) examined nine adult females from the north-western continental slope of Western Australia; eight of these (232-300 cm TL) were pregnant. Seven of these, caught in April 1982, contained pups between 2.7-13.2 cm TL (average 7.9 cm), while one had 59 eggs in utero. A female caught in June 1983 was pregnant with pups of 13 cm TL. Litter sizes of these fish averaged 34, with a maximum of 49. These data suggest a seasonal cycle off Western Australia, with ovulation occurring about March. If gestation lasts 9-12 months (Suda 1953; Pratt 1979) birth would occur between December and March.

Outside Australia, information in the literature suggests that male blue sharks mature at age 4-6 at 173-213 cm TL and females at age 5-7 at 187-213 cm TL. Longevity is about 20 years and maximum length 380 cm TL. Litter size averages 35 with a maximum of 135, gestation lasts 9-12 months and the young are born in spring or summer at 35-50 cm TL (Stevens 1975; Pratt 1979; Cailliet et al. 1982; Compagno 1984; Nakano 1994). The diet consists mainly of small pelagic fish and cephalopods (Last and Stevens 1994).

Blue sharks are highly migratory with complex movement patterns and spatial structure related to reproduction and the distribution of prey. Sex and size segregation is very apparent and varies with latitude and geographical area. There tends to be a seasonal shift in population abundance to higher latitudes associated with oceanic convergence or boundary zones as these are areas of higher productivity. Tagging studies of blue sharks have demonstrated extensive movements in the Atlantic with numerous trans-Atlantic migrations which are probably accomplished by swimming slowly and utilising the major current systems (Stevens 1976; Casey 1985; Stevens 1990; Kohler et al. 1999). More limited tagging in the Pacific has also shown extensive movements of up to 9,200 km (Davies and Hartill 1998; Hartill and Davies 1999; Hartill 1999; L. Laughlin, California Department of Fish & Game, Long Beach, personal communication; K. Thompson, FRI, Sydney, personal communication; Stevens unpublished data). A blue shark tagged off Tasmania was recaught off Madagascar, demonstrating a trans-Indian Ocean migration (Stevens unpublished data). Substantial data from the North Atlantic on the distribution, movements and reproductive behaviour of different segments of the population suggest a complex reproductive cycle which involves major oceanic migrations associated with mating areas in the north western Atlantic and pupping areas in the north eastern Atlantic (Pratt 1979; Casey 1985; Stevens 1990). Nakano (1994) suggested a movement model for the North Pacific; birth occurs in early summer in nursery grounds which are located at 30-40°N. Age 2-5 females generally move north, while age 2-4 males move south. Adults occur mainly from equatorial waters to the south of the nursery grounds. Mating takes place in early summer at 20-30°N, and pregnant females migrate to the parturition grounds by the next summer. The pupping and nursery areas are located in the sub-arctic boundary where there is a large prey biomass for the juveniles.

6.5.2 Other species

Information on the reproductive biology and age and growth of porbeagle, shortfin mako, thresher, school, oceanic whitetip and silky sharks are summarised in Table 14. For each species, the range in values encompasses most of the regional differences reported; however, some studies based on limited data or from restricted areas are not included.

Results from a large tagging study in the north-west Atlantic show that shortfin makos make extensive movements of up to 4,500 km with 36% of recaptures caught at greater than 550 km from their tagging site (Casey and Kohler 1992). However, only one fish crossed the mid-Atlantic ridge suggesting that trans-Atlantic migrations are not as common as in blue sharks. Casey and Kohler (1992) suggest that the core distribution of shortfin makos in the western North Atlantic is between 20-40°N and is bordered by the Gulf Stream in the west and the mid-Atlantic ridge in the east. More limited data from the Pacific also show large movements of up to 4,630 km (Davies and Hartill 1998; Hartill and Davies 1999; Hartill 1999; L. Laughlin, California Department of Fish & Game, Long Beach, personal communication; K. Thompson, FRI, Sydney, personal communication; Stevens unpublished data). Sex and size segregation is apparent and varies with latitude and geographical area. Nursery areas appear to be situated close to the coast.

Little is known of the spatial structure or movements of oceanic whitetips, silky or thresher sharks, other than that sex and size segregation occurs and that nursery areas for threshers seem to be close to the coast. Based on about 50 tag returns from the Atlantic, silky sharks show relatively restricted movements with 46% moving distances between 0-200 km, 39% moving between 200-800 and 15% travelling distances greater than 800 km (maximum 1,339 km) (Anon. 1977-1995; Kohler et al. 1999). None of these species showed the extensive oceanic movements typical of blue sharks, confirming that silky sharks are more strictly semi-oceanic and tend to be associated with land masses. Tag recaptures for oceanic whitetips are limited, but still demonstrate their capacity for extensive movements. The average distance moved from eight recaptures (mainly from the Atlantic) was 1,278 km, with a maximum of 2,811 km (Somalia to Sri Lanka) (Anon. 1977-1995; Kohler et al. 1999).

Genetic studies on school shark from southern Australia suggest a homogenous stock which is in agreement with the fairly extensive movements shown by tagging. There are greater genetic differences from New Zealand fish which together with a number of recent trans-Tasman tag returns suggests mixing on feeding grounds but little inter-breeding (Ward and Gardner 1997; Hurst et al. 1999).

The diet of the sharks covered in Table 14 is summarised in Last and Stevens (1994) and consists mainly of teleost fish and cephalopods.

Little is known about the biology of crocodile sharks. Their reproductive method is oophagy, usual litter size is four and size at birth is about 40 cm TL. Mature males of 74 and mature females of 89 cm TL have been reported. The large eyes suggest a nocturnal activity pattern, or deep-water existence (Last and Stevens 1994). Bigeye thresher sharks are oophagous producing litters of two pups (exceptionally four) which are 100-140 cm TL at birth (Moreno and Morón 1992; Gilmore 1993; Chen et al. 1997). Pregnant females have been recorded throughout the year suggesting there is no seasonal birth period. Males mature at 270-288 cm and females at 332-340 cm TL; female age at maturity is estimated at 13-14 years (Chen et al. 1997; Liu et al. 1998). Almost nothing is known about the biology of velvet dogfish other than they attain about 85 cm TL and that males mature at about 47 cm (Last and Stevens 1994).

A number of additional shark species were recorded in relatively low numbers in the catches; their biology is not reviewed here but the relevant literature is provided for each species or species group. While 312 dusky sharks were recorded by observers between 1992-96, as discussed in section 6.2.2, most of these (along with bronze whalers) are probably mis-identifications of the silky shark. The reproductive biology of Australian hammerhead sharks is documented by Stevens and Lyle (1989), age and growth of the scalloped hammerhead is reported on by Branstetter (1987) and Chen et al. (1990) and Liu and Chen (1999) provide a demographic analysis of this species. A review of tiger shark biology is given by Randall (1992) and Branstetter et al. (1987) provide additional information on age and growth. Gilmore (1983, 1993) summarises what is known of reproductive biology in the longfin mako and Gilmore (1993) and Liu et al. (1999) describe age, growth and reproduction in the pelagic thresher. Information on the biology of the dusky shark in Australia is given in Simpfendorfer et al. (1996) and from elsewhere by Natanson et al. (1995) and Natanson and Kohler (1996).

Table 14. Biological parameters of selected shark species (M = male, F = female, NH = northern hemisphere, SH = southern hemisphere)

Parameter	Porbeagle[1]	Oceanic WT[2]	Silky[3]	SF mako[4]	Thresher[5]	Soupfin[6]
Length at birth (cm TL)	68-78	60-75	70-85	70	115-150	30-35
Length at Maturity (cm TL)	F 185-229 M 150-200	M 175-195 F 175-200	200-210	M 195 F 265-280	M 320-340 F 260-400	M 107-135 F 118-150
Maximum length (cm TL)	300	300	330	400	600	155-200
Age at maturity (years)	F 7-12 M 4-8	4-5	6-7	M 2.5 F 6	M 4-5 F 3-7	M 8-10 F 10-15
Longevity	20-30	20?	20	20	45	40-60
Reproduction	Oophagy	Placental viviparity	Placental viviparity	Oophagy	Oophagy	Aplacental viviparity
Litter size (number)	Avg. 4	Avg. 6 Max 15	Avg. 7 Max. 15	Avg. 12 Max 25	2-4	Avg. 23-35 Max. 54
Gestation (months)	8-9	9-12	?	15-18	9	12
Breeding frequency (years)	1-2	2?	?	3	?	1-3
Pupping season	Winter (SH) spring-summer (NH)	Protracted	Throughout the year	Spring	Birth in spring or summer	Birth in summer

[1]Aasen 1963; Francis and Stevens in press
[2]Compagno 1984; Gubanov 1978; Seki et al. 1998
[3]Strasburg 1958; Branstetter 1987; Last and Stevens 1994
[4]Stevens 1983; Pratt and Casey 1983; Mollet et al. in press
[5]Gubanov 1978; Cailliet et al. 1983; Hanan et al. 1993
[6]Ripley 1946; Olsen 1984; Capape and Mellinger 1988; Peres and Vooren 1991; Ferreira and Vooren 1991; Francis and Mulligan 1998; Hurst et al. 1999

6.6 Fishery impacts

Any assessment of the impact of Japanese longlining on stocks of pelagic sharks in Australian waters is limited by the current restricted time series of catch and effort data. In addition, species-specific catches are really only sufficient for blue sharks. Most of the Japanese effort is concentrated between 40 and 50°S on the east coast between May and July. Consequently, we were interested in how the catch rates of blue sharks changed in this area during the fishing season. If fishing was having an impact on the stock it might be expected that the catch rate would decline as the season progressed. This assumes that there is minimal immigration or emigration of blue sharks over this period. Total effort (from the logbook data), observed effort and catch rate for each week of the fishing season is shown in Figs. 22-24. No consistent trend was apparent with catch rates showing a general increase with time in 1992 and 1993, an initial decline followed by a subsequent increase in 1994 and 1995 and a general decline (at least in the observed effort) in 1996.

Nakano and Watanabe (1992) provide an assessment of the impact of high-seas fisheries on blue shark stocks. By estimating catches and using cohort analysis, they believe that the catch rates of the late 1980s did not have a significant impact on North Pacific populations. However, Wetherall and Seki (1992) consider that appropriate information for this kind of assessment is lacking. Matsunaga and Nakano (1996) examined species composition and cpue data from Japanese tuna longline research vessels in the Pacific from different time periods and latitudinal zones. The proportion of blue shark in the catch did not change significantly between the periods 1967-1970 and 1992-1995 in the areas 10-20°N or 0-10°N, although a higher proportion of thresher and lower proportion of oceanic whitetips were caught in the later time period. They noted that total shark cpue showed no trend from 1973-1993 and inferred from this that blue shark cpue (as the most abundant shark) showed no trend between the two time periods. While thresher cpue showed an increase and oceanic whitetip cpue a decrease over time, the authors suggested this was due to differences in gear depth between the time periods rather than a change in species abundance. Nakano (1996) used Japanese longline logbook data to examine standardised cpue for sharks between 1971-1993, assuming that this mainly reflected blue shark catches. He reported no evidence of a declining trend with time in the Atlantic or Indian Oceans, but noted a 20% decrease in the North Pacific from the period 1971-1982 to 1983-1993.

Figure 22. Japanese longline fishing effort at 40-50°S on the east coast of Australia between May 1 and July 30

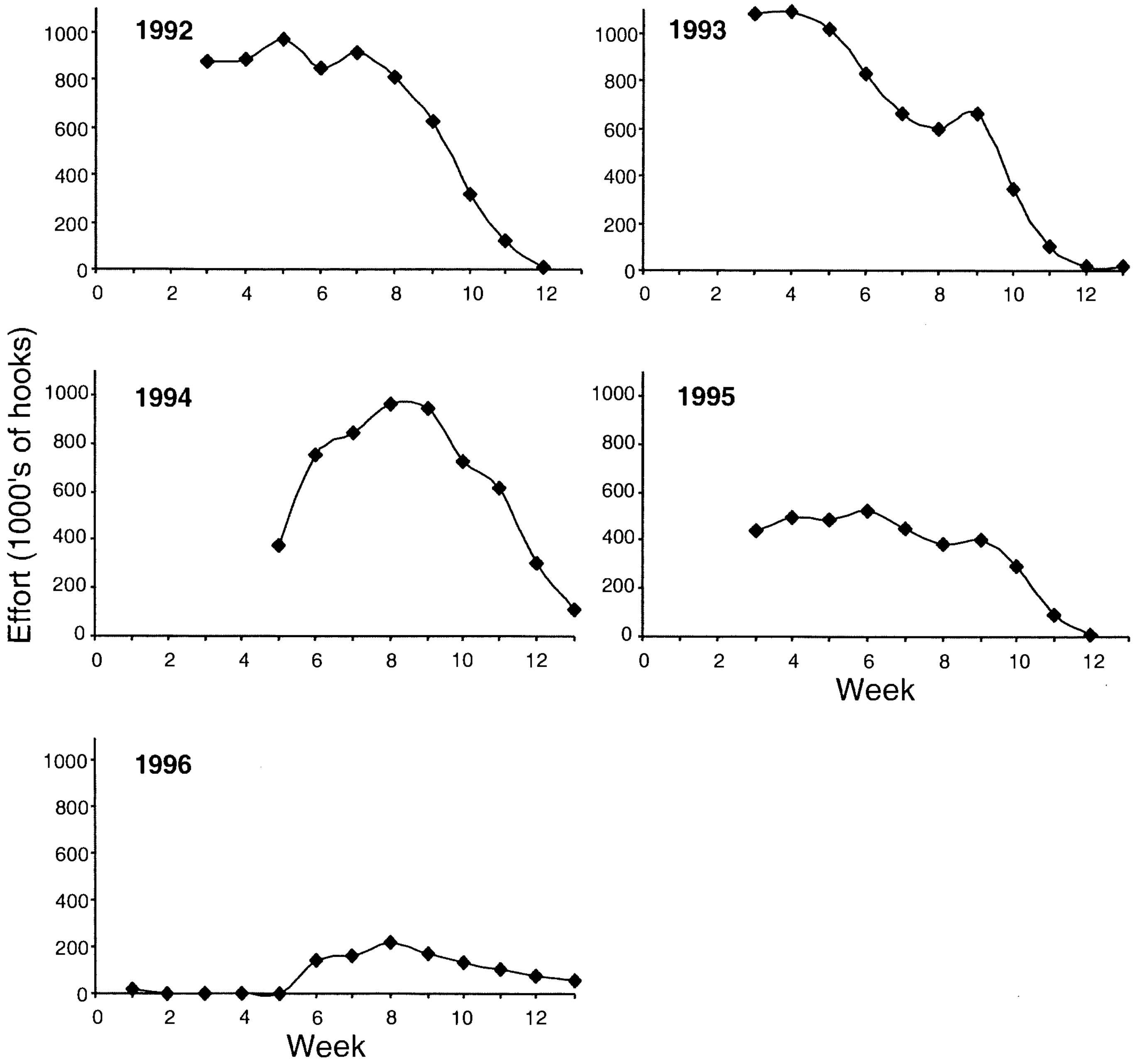


Figure 23. Percentage of Japanese longline fishing effort observed at 40-50°S on the east coast of Australia between May 1 and July 30

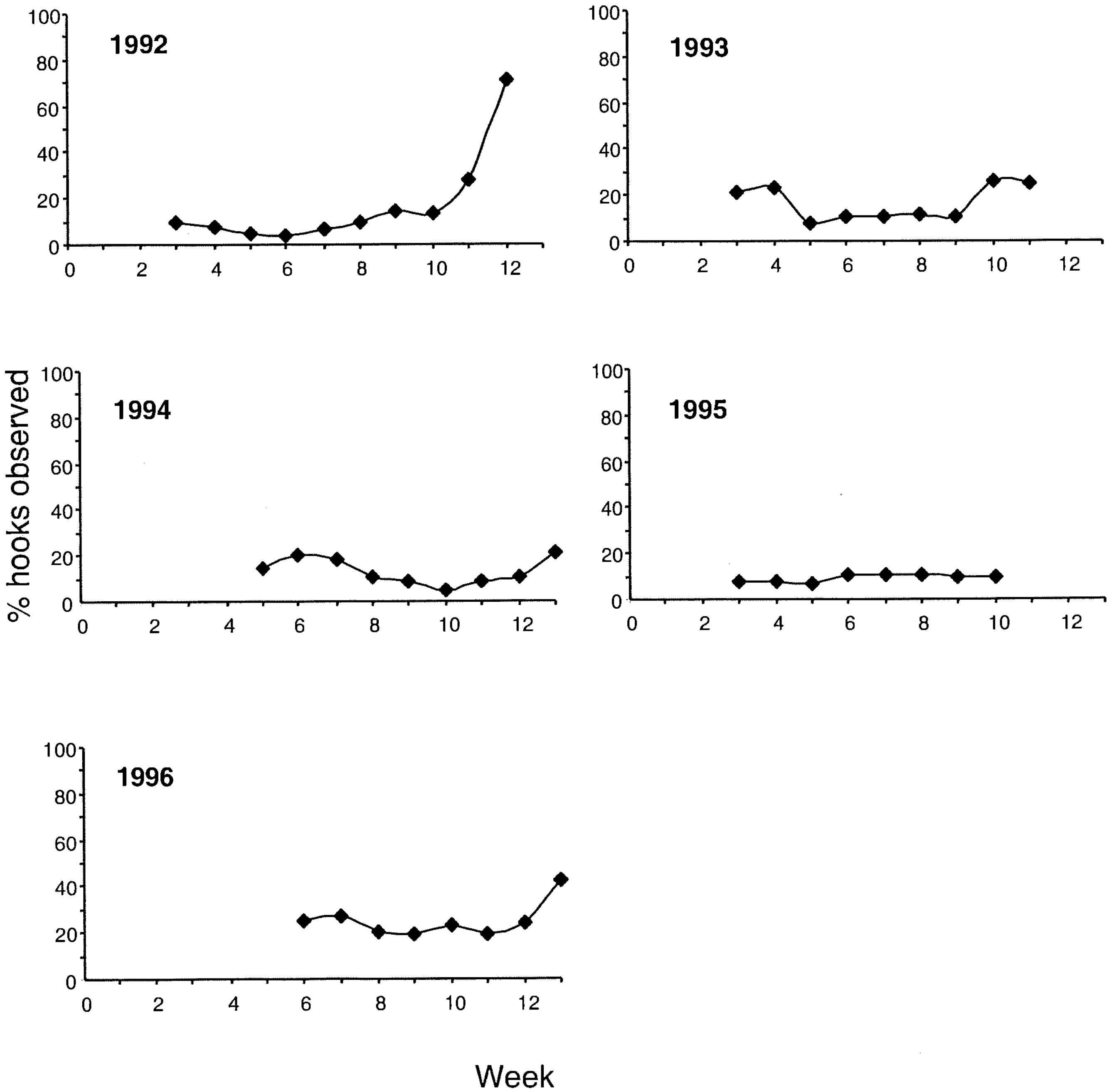
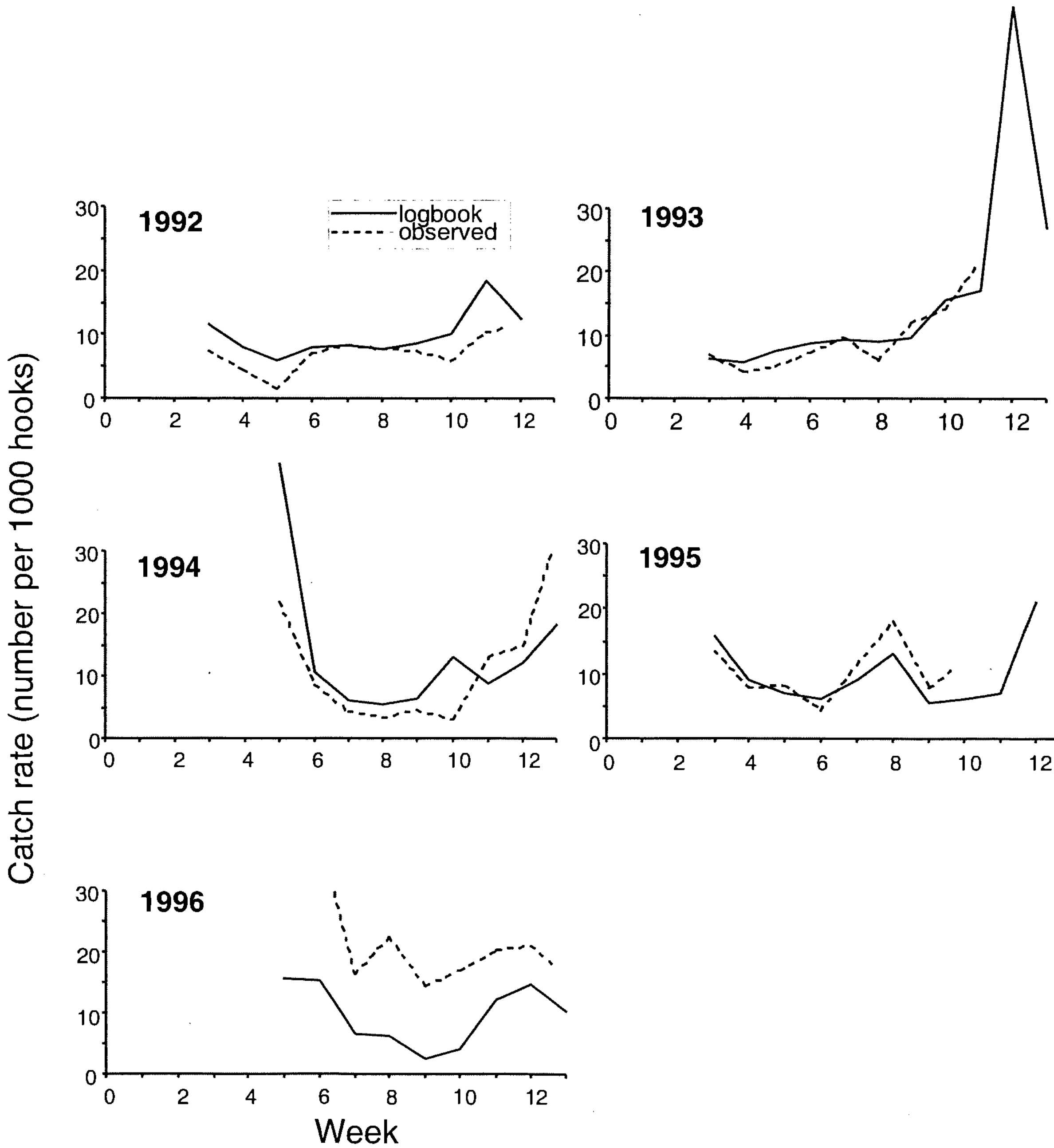


Figure 24. Japanese longline cpue for blue sharks at 40-50°S on the east coast of Australia between May 1 and July 30



While nothing is known about the impact of pelagic longline catches on porbeagle stocks in the South Pacific, target longline fishing has caused over-fishing in the North Atlantic. Catches of Norwegian and Danish vessels declined from about 6,000 t in 1947 to about 1,500 t during the 1950s in the north-east Atlantic. Norwegian and Faroese fishers then moved into the north-west Atlantic and catches showed a rapid increase during the early 1960s peaking at 8,114 t in 1964, mainly reflecting the intensive Norwegian longline fishery (Hurley 1998). Subsequently catches dropped rapidly to 1-2,000 t by 1966. Anderson (1985) reported that Norwegian catch rates declined from 9.1 sharks per 100 hooks in 1961 to 2.9 in 1964. Faroese catch rates showed a similar decline a few years later, accompanied by a decrease in the mean size of fish caught (Anderson 1985). Between 1991 and 1995, Canadian catches have increased to 1,200-1,800 t annually. This pattern of fishing suggests that initial depletion of northeastern Atlantic stocks was followed by a move to unexploited stocks in the western North Atlantic. Following high catches for five years in the 1960s, the resource apparently collapsed. Lower catches of around 350 t per year were sustained from about 1970-90. The recent rises in catch in Canadian waters have been associated with apparent declines in spring catch rates suggesting local abundance may be declining (O'Boyle et al. 1998).

A drift gillnet fishery for thresher sharks increased rapidly in the late 1970s off California, reaching a peak in 1982 of about 1,000 t (dressed weight). Catches, catch rates and average size, subsequently declined prompting the introduction of management controls. The population is not considered to be large, with immigration insufficient to sustain the fishing effort of the early 1980s (Holts 1988).

Bonfil (1990) used a yield per recruit model to show growth overfishing of the silky shark stock on the Campeche Bank in the Gulf of Mexico. High catches of new-born and juvenile individuals are taken in the local red grouper fishery in that area. Silky sharks are one of the most important commercial species on the Pacific coast of Mexico, but no population assessments have been attempted for that area.

The small catches of school sharks made by Japanese (and presumably domestic) longliners are unlikely, on there own, to be significantly impacting the stock. However, school sharks are currently considered to be over-fished in the target demersal gillnet and longline fishery in southern Australia. The 1998 catch was about 700 t live weight and stock assessments based on catch rates and stochastic age-structured models put the mature biomass at 13-45% of virgin levels. An immediate reduction in effort of 42% was required to have an 80% probability that the level of mature biomass in the year 2011 is above the 1996 level (Punt and Walker 1998). The most recent assessment based on spatially-structured models greatly reduced the range of uncertainty and indicates pup production at the start of 1997 is 12-18% of the pre-exploitation equilibrium size (Punt et al. in press).

Management measures implemented for pelagic shark resources are limited. In 1991, Australia brought in legislation which prevented Japanese longliners fishing in the EEZ from landing shark fins unless they were accompanied by the carcass. Because of limited freezer space on these tuna vessels this effectively prevented them from retaining shark fins while in Australian waters. However, no such legislation currently applies to domestic tuna longliners. Since 1993, shark fisheries in Atlantic and Gulf of Mexico waters in the U.S. have been managed by the National Marine Fisheries Service (NMFS) under the Fishery Management Plan for Sharks of the Atlantic Ocean. The plan set commercial quotas for 10 species of pelagic sharks at 580 t dressed weight annually, with recreational bag limits also applied. An annual shark permit is required by commercial fishers each year, and finning is prohibited. Catch trends reported by NMFS raise concern over stocks of makos and threshers. States, particularly in the northeast, have expressed concern about the virtual disappearance of mako sharks in their recreational catch (Camhi 1998). The 1995 Fisheries Management Plan for pelagic sharks in Atlantic Canada established precautionary catch levels for porbeagle (1,500 t), shortfin mako (250 t) and blue (250 t) sharks in the target shark fishery. License limitation, a ban on finning, restrictions on gear, area and seasons, by-catch limits and restrictions on recreational fishers permitting hook and release only were also implemented (Hurley 1998). These precautionary catch levels were not based on stock assessments but approximated to the 1992 catch. The porbeagle TAC was reduced to 1,000 t in 1997 (O'Boyle et al. 1998). On the west coast of the US, declines in the thresher shark fishery led to management actions which were initiated in 1985. Management now comprises limited entry, mandatory logbooks, and specific time-area closures. An experimental longline fishery targeting shortfin makos was terminated (Hanan et al. 1993; Holts et al. 1998). In Mexico, pelagic sharks are taken by a drift net fleet and by small boats or pongas using both gillnets and longlines. A third fishery taking pelagic sharks, a high-seas longline fishery, was banned within the EEZ in 1990 (Holts et al. 1998). In 1983, a 'sportfishing zone' was established within 93 km of the Baja peninsula; this was intended to exclude the driftnet fleet to protect billfish resources. However, Holts et al. (1998) report that this protected zone is often violated. In the ponga fishery there are currently 50 shark permits, representing 180 officially licensed pongas in the Mexican State of Baja California (Holts et al. 1998).

7. GENERAL DISCUSSION

Pelagic sharks are likely to be a key species in the oceanic ecosystem. However, lack of knowledge prevents any assessment of the impacts of annually removing large quantities of them on the oceanic ecosystem or on the shark populations, either in Australia or globally. Nothing is known of pelagic shark stock structure or population sizes. While blue sharks are among the more productive of elasmobranchs the general life history characteristics of this group limit their ability to withstand heavy fishing pressure.

Consideration of the distribution, initial abundance, movements and biological productivity of the main shark species taken as by-catch by pelagic longlining suggests that blue sharks are likely to be the most resilient to fishing pressure. They have probably the most extensive distribution of any shark species, have high initial abundance levels, are highly migratory and are relatively fast growing and fecund. Porbeagles have a more restricted distribution but are common in the catch where pelagic longlining is carried out in relatively high latitudes. Female age at maturity appears to be moderately high (although further ageing studies are required) and fecundity is low. The history of target fishing for this species in the North Atlantic suggests they can be easily over-fished. Shortfin makos have a slightly less extensive distribution than blue sharks, they are not quite as highly migratory and they occur at a lower initial abundance. Growth appears to be relatively fast, although further studies are required outside the North Atlantic. Although litter sizes are higher than in porbeagles, annual fecundity may be similar. Oceanic whitetips and silky sharks have a moderately high initial abundance within their essentially tropical distributions; information on movements are limited but silky sharks in particular appear less highly mobile than blue or shortfin makos. Age at female maturity is apparently low for oceanic whitetips (4-5) and somewhat higher for silky sharks (6-7) but further studies are required to confirm growth rates in these species. Litter sizes are similar and relatively low in both species but breeding frequency of females is uncertain so annual fecundity is not known. Thresher sharks have an extensive distribution while bigeye thresher are restricted more to warm-water areas; both have a relatively low initial abundance. Fecundity in both species is low and age at female maturity is reported to be relatively low in the thresher (3-7) and high in the bigeye thresher (13-14); further ageing studies are required on both species.

The capacity of a particular species to withstand fishing pressure will depend both on its vulnerability to the fishing gear and its biological productivity, including its capacity for density-dependent change. Hoenig and Gruber (1990) suggested it might be possible to rank shark species on their ability to withstand exploitation based on critical aspects of their life history. They considered that natural mortality rate, age at maturity, fecundity and, in particular, the intrinsic rate of population increase, *r*, might be useful for this purpose. Pratt and Casey (1990) reviewed reproductive and growth parameters of shark species which, they suggested, could be used to indicate species vulnerability to fisheries. The productivities of 26 species of shark were ranked by Smith et al. (1998) according to their intrinsic rate of population increase, providing a relative measure of their recovery ability from exploitation ('rebound' potential). Their method incorporated density-dependence as *r* depended on the level of fishing mortality and the resulting decrease in population size. Productivity was strongly affected by age at maturity, and little affected by maximum age. According to Smith et al. (1998), sharks with the highest recovery potential tended to be smaller, early maturing, relatively short-lived inshore coastal species such as gummy or smoothhounds (*Mustelus* spp.), sharpnose sharks (*Rhizoprionodon* spp.) and the bonnethead (*Sphyrna tiburo*). Those with the lowest recovery potential tended to be larger sized, slow growing, late maturing and long-lived coastal sharks such as dusky, sandbar (*C. plumbeus*), bull (*C. leucas*) scalloped hammerhead, lemon (*Negaprion brevirostris*) and broadnose sevengill (*Notorhynchus cepedianus*). The smaller-sized spiny dogfish (*Squalus acanthias*) and school shark were also in this group. The pelagic species such as blue, thresher, oceanic whitetip, mako and silky tended to be in the mid-range of the productivity spectrum. However, the biological data on which Smith et al's. (1998) study is based are often inadequate.

For example, their rebound potential is most sensitive to age at maturity, yet growth data for many pelagic shark species is still fragmentary. Their method does not properly address fecundity and takes no account of species distributions and mixing rates. Smith et al. (1998) noted that oceanic pelagic species might be less prone to fishery depletion because of the greater likelihood of continual 'seeding' by conspecifics from other areas within their extensive ranges. However, to properly assess the impact of exploitation on these pelagic sharks we need information on their stock structure, habitats and spatial population structure. As noted above, the biology of many species is still poorly understood and, in particular, we need further studies on age and growth together with information on the breeding frequency of females so that annual fecundity can be calculated. Currently, there is a large market for fins from pelagic sharks but there are insufficient data to assess the catch levels and few regulations or requirements for reporting that catch.

8. BENEFITS

Pelagic sharks are a large by-catch component of pelagic longline fisheries targeting tuna and billfish and there is considerable domestic and international concern over the impact of these catches on the stocks. The majority of the by-catch of pelagic sharks are finned and the carcasses discarded. Rapidly rising prices in Asia for shark fin are likely to increase the pressure on pelagic shark resources and this issue has been highlighted by the IUCN draft Action Plan for sharks and by the FAO Technical Working Group on sharks. One of the stated objectives of AFMA, which reflects the opinions of the general community, is to manage the tuna fishery in accordance with the principals of ecologically sustainable development. Shark fins are a lucrative by-catch in the domestic tuna longline fishery and there has also been interest in targeting pelagic sharks for their meat and fins from other industry sectors, including the Southern Shark Fishery. As outlined in the original project application, the industry would benefit from greater knowledge of the pelagic shark resource and its sustainability, as would the general community over its conservation concerns.

9. FURTHER DEVELOPMENT

The main species of pelagic sharks dealt with in this report have a highly complex population structure; they have extensive distributions, are highly migratory and have a complicated spatial structure with size and sex segregation. In many ways they resemble the populations of tunas. However, unlike the tunas these species have received relatively little attention from fisheries biologists (as much a factor of economics as anything else) and relatively little is known even of their basic life-histories let alone their stock structure and population dynamics. Related to their by-catch status, few long-term time series of catch and effort data exist with the exception of some high-seas fishing nations such as Japan. With increasing concerns over the population status of pelagic sharks, the challenge for fisheries biologists is to provide meaningful assessments for these species.

The biology of the blue shark, the principal by-catch species, has been relatively well studied in the Atlantic and Pacific, but there have been few studies on Indian Ocean populations. However, important information on annual fecundity for all populations is still missing. While litter sizes are readily available, there is no information on the frequency with which individual females breed. While tagging studies (mainly in the Atlantic) have demonstrated extensive movements, virtually nothing is known of stock structure in terms of management units. For the remaining species, basic life-history data are fragmentary with even the important population parameters of age and growth poorly studied. The combination of poor biological information and limited time series of catch and effort data make it vital to maximise on available data. Considerable benefit could be obtained though co-operative assessment studies with high-seas fishing nations, particularly Japan, who have extensive catch-effort data sets from both commercial and research vessels.

10. CONCLUSION

The objectives of this study were to review and compile information on Australia's pelagic shark resource. For the purposes of this report, pelagic sharks are defined as those species taken by pelagic longline fishing targeted at tuna and billfish. Both local and overseas data on species composition, distribution, catches, catch rates, population structure, biology, impacts of fishing on, and management of pelagic sharks was reviewed. Available logbook and observer data from domestic and Japanese pelagic longlining in the EEZ was analysed. Some recommendations for future research on pelagic sharks in Australia were made. It was also hoped to tag blue sharks on Japanese longliners operating inside the Australian EEZ through the observer program. Unfortunately, this last objective could not be met as Japanese tuna vessels were excluded from the EEZ in 1997.

The principal shark species taken by pelagic longlining in Australia and overseas is the blue shark and the majority of information presented in this report relates to that species. Other commonly caught sharks are porbeagle, shortfin mako, crocodile and, probably, silky and oceanic whitetips. The extent to which these latter species occur in the Australian catch is currently uncertain because of observer problems in the identification of whaler sharks in the genus *Carcharhinus*. Species taken in smaller numbers in Australia are thresher sharks (three species), dogfish (Family Squalidae), school, hammerhead, tiger and longfin mako shark.

Analysis of available data indicates that some 430,000 blue sharks were caught over a five year period from 1992-96 by Japanese longliners in the Australian EEZ during their fishing season. This equates roughly to 1,100 t per season. Logbook records show that domestic vessels caught some 45 t of blue shark in 1997, but comparison of domestic and Japanese catch rates imply that domestic logbooks considerably under-report the catch of blue sharks. A comparison of observer and Japanese logbook catch rates suggest that Japanese logbook data under-reported the catch by about 14%. Estimates indicate that nearly 138,000 t of blue sharks were caught by high-seas longline fleets in the Pacific in 1994. Some 3,100 shortfin makos are caught by Japanese longliners in the Australian EEZ each season, and about 4,800 porbeagles a season south of 39°S. Comparison of observer catch rates with logbook records suggest the Japanese under-reported shortfin mako catches by about 10%, but porbeagle catches by 47%.

The extensive distribution, relatively high natural abundance, highly migratory behaviour and relatively productive biology of blue sharks may provide them with a greater resilience to fishing pressure than most elasmobranchs. The limited fishery assessments carried out to date have shown no evidence of a declining trend in catch rates with time in the Atlantic or Indian Oceans, but a 20% decrease was evident in the North Pacific between the periods 1971-1982 to 1983-1993. No consistent decline in catch rates through the fishing season was evident for Japanese longliners fishing in Australian waters. Resilience to fishing pressure is almost certainly lower for other pelagic sharks when compared to blue sharks. This is evident from the history of target fishing for some of these species, such as porbeagle and thresher sharks. The effects on the oceanic ecosystem of removing large numbers of these top predators are unknown. Few countries have any form of management measures for their pelagic shark resources.

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13. APPENDICES

13.1 Appendix A: intellectual property

No commercial intellectual property arose from this work.

13.2 Appendix B: staff

John Stevens	CSIRO CSOF7
Sally Wayte	CSIRO CSOF5

13.3 Appendix C: length-weight conversions

Table 15. Fork length-total length and weight-length relationships for selected pelagic sharks (lengths in cm, weights in kg)

Species	n	Equation	R^2	Reference
Blue whaler	554	$FL=1.739 + 0.830TL$	0.995	Pratt 1979
	134	$TW=3.113 \times 10^{-6} TL^{3.04}$	0.938	Stevens 1984
Shortfin mako	199	$FL=0.929TL - 1.710$	0.997	Casey and Kohler 1992
	110	$TW=5.755 \times 10^{-6} TL^{3.06}$	0.984	Stevens 1984
Porbeagle	173	$FL=0.881TL - 0.567$	0.967	Francis and Stevens in press
	641	$TW=8.912 \times 10^{-6} FL^{3.128}$	0.956	
Silky	22	$FL=0.84TL - 4.02$	0.996	Stevens and McLoughlin 1991
	23	$TW=4.66 \times 10^{-3} TL^{3.05}$	0.990	
Oceanic WT	17	$TW=1.405 \times 10^{-7} TL^{3.72}$	0.930	Stevens 1984