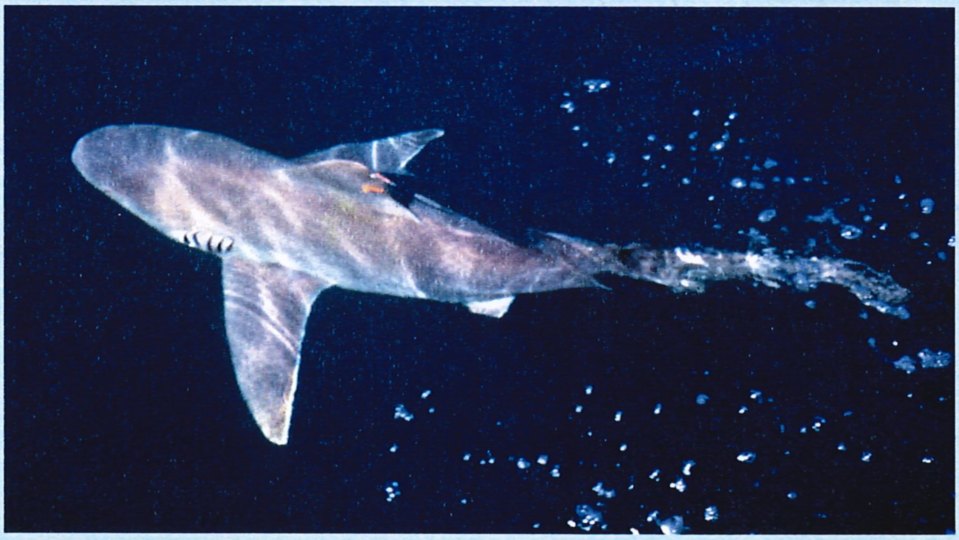
FISHERIES RESEARCH REPORT

No. 151, 2005

Biology and stock assessment of the thickskin (sandbar) shark, *Carcharhinus plumbeus*, in Western Australia and further refinement of the dusky shark, *Carcharhinus obscurus*, stock assessment

Final FRDC Report – Project 2000/134

R. McAuley, R. Lenanton, J. Chidlow, R. Allison and E. Heist



Department of Fisheries

Australian Government
Fisheries Research and Development Corporation

Southern Illinois University Carbondale

Fish for the future

Western Australian Fisheries and Marine Research Laboratories

FISHERIES RESEARCH REPORT NO. 151, 2005

Biology and stock assessment of the thickskin (sandbar) shark, *Carcharhinus plumbeus*, in Western Australia and further refinement of the dusky shark, *Carcharhinus obscurus*, stock assessment

Final FRDC Report – Project 2000/134

R. McAuley, R. Lenanton, J. Chidlow, R. Allison and E. Heist*

**Principal Investigator*

Department of Fisheries

Australian Government
Fisheries Research and Development Corporation

Southern Illinois University Carbondale

Fish for the future

Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH
Western Australia 6920

Fisheries Research Report

Titles in the fisheries research series contain technical and scientific information that represents an important contribution to existing knowledge, but which may not be suitable for publication in national or international scientific journals.

Fisheries Research Reports may be cited as full publications. The full citation is:
McAuley, R., Lenanton, R., Chidlow, J., Allison, R. and Heist, E. 2005. *Biology and stock assessment of the thickskin (sandbar) shark,* Carcharhinus plumbeus*, in Western Australia and further refinement of the dusky shark,* Carcharhinus obscurus*, stock assessment, Final FRDC Report – Project 2000/134*, Fisheries Research Report No. 151, Department of Fisheries, Western Australia, 132p.

Numbers 1-80 in this series were issued as Reports. Numbers 81-82 were issued as Fisheries Reports, and from number 83 the series has been issued under the current title.

Enquiries

Department of Fisheries
3rd floor The Atrium
168-170 St George's Terrace
PERTH WA 6000
Telephone (08) 9482 7333
Facsimile (08) 9482 7389
Website: http://www.fish.wa.gov.au

Department of Fisheries
Government of Western Australia

Fish for the future

Published by Department of Fisheries, Perth, Western Australia. December 2005.
ISSN: 1035 - 4549 ISBN: 1 877098 75 2

An electronic copy of this report will be available at the above website where parts may be shown in colour where this is thought to improve clarity.

Fisheries Research in Western Australia

The Fisheries Research Division of the Department of Fisheries is based at the Western Australian Fisheries and Marine Research Laboratories, PO Box 20, North Beach (Perth), Western Australia, 6920. The Fisheries and Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

Research programs conducted by the Fisheries Research Division and laboratories investigate basic fish biology, stock identity and levels, population dynamics, environmental factors, and other factors related to commercial fisheries, recreational fisheries and aquaculture. The Fisheries Research Division also maintains the State data base of catch and effort fisheries statistics.

The primary function of the Fisheries Research Division is to provide scientific advice to government in the formulation of management policies for developing and sustaining Western Australian fisheries.

Contents

Biology and stock assessment of the thickskin (sandbar) shark, *Carcharhinus plumbeus*, in Western Australia and further refinement of the dusky shark, *Carcharhinus obscurus*, stock assessment

Final FRDC Report – Project 2000/134

Principal investigator: Rod Lenanton

Address: Department of Fisheries
Research Division
PO Box 20
North Beach
Western Australia, 6920
Telephone: (08) 9203 2111 Facsimile: (08) 9203 0199

Email: rlenanton@fish.wa.gov.au

Non Technical Summary

The purpose of this project was to collect the biological and fishery information necessary to conduct a stock assessment of the sandbar (known locally as ‘thickskin’) shark, *Carcharhinus plumbeus* and to improve and update the existing stock assessment for the dusky shark, *Carcharhinus obscurus*. Results from this project have already been used by the Western Australian Department of Fisheries to determine appropriate management arrangements for the State’s shark fisheries to ensure the sustainable exploitation of these species. Results have also assisted the WA target-shark fisheries in conducting Ecologically Sustainable Development (ESD) assessment in order to meet Department of Environment and Heritage ecological assessment requirements for maintaining the fisheries’ export approval.

During the mid to late 1990s, changes in targeting practices of vessels operating in the west coast zone of the temperate WA target-shark fisheries caused rapidly escalating sandbar shark catches. By 1998, sandbar sharks had overtaken dusky sharks as the primary component of the west coast fishery’s catch and had become the 3rd largest component of the temperate fisheries’ total catch. At the same time, a demersal longline fishery, targeting sandbar shark off the Pilbara and Kimberley coasts began to develop and sandbar catches also began to increase dramatically in the State’s north. Given this species’ demonstrated vulnerability to overfishing, a formal assessment of the status of this stock and sustainable levels of exploitation became imperative.

The current project therefore collected the biological and fishery-related data that was necessary for accurate stock assessment and developed assessment models appropriate for this long-lived species. Extensive sampling was undertaken in the target fisheries, as well as in those fisheries that were identified as having a significant bycatch of sharks. Additional research was conducted through a series of cruises on board the WA Department of Fisheries research vessels *Flinders* and *Naturaliste*. Commercial sampling involved the collection of operational data from the various fisheries, e.g. fishing locations, dates, set times, depths, gear characteristics, etc., as well as identifying and measuring catches, collection of biological data

and samples and tagging large numbers of sharks. Fishery independent sampling allowed data to be collected from areas in which commercial vessels are prohibited from operating, in areas where commercial fishers choose not to operate and with fishing gear-types in areas where commercial vessels are not permitted to use them.

Previous FRDC funded research into WA's shark stocks (projects 93/067 and 96/130) focussed on the traditional target species of the State's temperate target-shark fisheries, i.e. dusky shark, *C. obscurus*, gummy shark, *Mustelus antarcticus*, and whiskery shark, *Furgaleus macki*. One of the key findings of this previous research was that, whilst the exploitation of dusky sharks in the target fisheries was likely to be sustainable, their sustainability was dependent on a very low level of mortality of older sharks outside the temperate shark fisheries. Since this research was undertaken, several potential and developing sources of adult dusky shark mortality were identified. Consequently, the assumption that there was a negligible level of exploitation of older dusky sharks could no longer be relied upon and further advice on the status of this species was required. In addition, it was necessary to update the biological parameters and exploitation rates used in the previous assessment with new data, derived from project 96/130 and the current study.

Objectives

1 Study the biology of sandbar sharks in Western Australian waters, including:

(i) Movement patterns

(ii) Age and growth

(iii) Reproductive biology

(iv) Diet

(v) Stock Discrimination

2 Determine the level of mortality and exploitation of sandbar, dusky and related oceanic shark species in Western Australian waters by all fishing methods

3 Conduct stock assessments, including risk assessment of management options for sandbar sharks and refine the assessment of the status of the dusky shark stock.

Outcomes achieved to date

All biological and fishery data for sandbar and dusky sharks have been collected, analysed and incorporated into stock assessments. Results from these assessments have been used to develop and implement new management arrangements for the Western Australian target shark fisheries. Key results of this project are outlined below.

Western Australian *C. plumbeus* were found to attain smaller maximum sizes and sizes at maturity than have been reported for this species elsewhere. The stock is mainly distributed between Cape Leveque (16º 30'S, 123ºE) in the north and Point D'Entrecasteaux (116ºE) on the south coast. Juvenile sharks tended to occur in temperate waters, while mature-sized sharks predominantly occurred in tropical waters. Unlike other regions, juveniles were found in offshore continental shelf waters rather than shallow waters of estuaries and marine embayments. Sharks are born at 40-45 cm FL during autumn after a 12 month gestation. Parturition appears to occur throughout the stock's range, although the majority of observed neonates were caught in temperate latitudes. Mean litter size was 6.5 embryos, 60% of which were females.

Vertebral growth bands were validated as being formed annually in sharks up to 17 years by analysis of calcein-marked centrum sections. Due to the high variability in the observed growth of tagged sharks, growth rates determined from vertebral analysis were judged to provide a more reliable description of age and growth than those derived from the tagging data. Males were estimated to reach maturity at approximately 14 years and females at 16. Maximum age was estimated to be between 30 and 40 years of age. Additional reproductive data for dusky sharks (*Carcharhinus obscurus*) obtained during this project indicated that females of this species takes longer to reach maturity (*ca.* 30 years) than previously believed (*ca.* 19 years).

Tagging data indicated that juvenile sandbar sharks born in the south west of the State remained in temperate waters for several years and slowly migrated northwards to join the breeding stock in the north-west as sub-adults or adults. Due to the broad size-selectivity of the mesh sizes used in the temperate ‘shark’ fisheries and the relative abundance of most juvenile age-classes in waters off the southern half of the west coast of Western Australia, demersal gillnet catches of sandbar sharks were primarily comprised of sharks of between 2 and 10 years of age. The catch in the WA North Coast Shark Fishery, however, contained mainly adult-sized sharks. The area between Steep Point and North West Cape, which has effectively been closed to shark fishing since 1993, was found to afford no significant or long-term protection to this stock.

Demographic analysis confirmed that the WA sandbar shark population has a very limited biological capacity to withstand fishing mortality. Using stochastically estimated biological and natural mortality parameters, the stock was estimated to have a potential rate of population growth of 0.025 (2.5%) per year, in the absence of fishing. This is at the lower end of population growth rate estimates for this species and indicates that the stock is more susceptible to population depletion than previously thought. Furthermore, the estimated generation and population doubling times of approximately 23 years, indicated a lengthy recovery period for the stock should it be reduced to lower than acceptable levels. The best estimates of age-specific fishing mortality resulted in population growth rates of -3.2% per year, -0.9% per year and -4.9% per year in 2001/02, 2002/03 and 2003/04, respectively, and were predicted to result in population growth of –7.8% per year in 2004/05.

Several potential combinations of fishing mortality that would deliver neutral or positive population growth rates were identified from the demographic model. As both of the target fisheries (temperate demersal gillnet and longline fishery and the WA North Coast Shark Fishery) contributed to the over-exploitation of this stock, appropriate levels of harvest in either fishery could not be determined independently of the other. The model indicated that to achieve the capacity for positive growth in the population, and thus reverse the current declining trend in this stock, major reductions in fishing mortality are necessary in both of the target fisheries, unless the fishing mortality in one or other fishery is reduced to zero.

Re-assessment of the status of the dusky shark, *Carcharhinus obscurus*, using the new demographic analysis techniques developed for sandbar sharks also indicated that this stock is less resilient to fishing than was previously estimated. However, the model also indicated that the rates of age-specific fishing mortality experienced by sharks released as neonates in 1994 and 1995 were probably sustainable, as long as there was negligible additional fishing mortality (less than 1-2% per year) outside the temperate demersal gillnet and longline fisheries. The lower estimate of the sustainable level of external fishing mortality is in keeping with recent analyses of dusky shark CPUE data from the demersal gillnet and longline fisheries, which indicate that the breeding stock of dusky sharks has been in decline for some years and has caused a reduction in recruitment of neonates to the fishery.

1.0 Background

1.1 Western Australian shark fisheries

Commercial shark fishing began in Western Australia in 1941 with a single boat setting demersal longlines in the Leschenault Inlet, primarily targeting the gummy shark, *Mustelus antarcticus* (Whitely, 1943). The fishery expanded throughout the late 1940s and early 1950s to other ports including Albany, Fremantle and Geraldton but remained a largely part-time occupation for most fishers. Throughout the 1960s, demersally set multifilament gillnets began to replace longlines as the preferred method for catching shark and catches rose steadily until the early 1970s, when public concern over the level of mercury in shark flesh contributed to a dramatic decrease in demand for shark (Heald, 1987; Simpfendorfer and Donohue, 1998). Following research carried out by the WA Fisheries Department, the WA Health Department introduced regulations in 1974 prohibiting the sale of shark flesh with mercury concentrations in excess of 0.5 parts per million (Hancock and Edmonds, 1977) and consumer confidence gradually returned. As the market for shark flesh began to recover and the introduction of new management regulations restricted vessels' access to other fisheries, effort in the shark fisheries began to rise dramatically.

Throughout the 1980s, shark fishing became an increasingly full-time occupation. Operators began using larger and faster vessels equipped with satellite navigation systems and colour sounders, which enabled them to operate further offshore and in areas that had previously been out of range. Additionally, monofilament gillnets and powered net-reels significantly increased the amount of net that fishers were able to operate. Fishing effort was previously reported to have peaked in 1987 at 787,000 km gillnet hours, more than four times the effort exerted in 1980. However, this is now thought to be an unrealistically high estimate due to the likelihood of some operators overestimating their fishing effort as they tried to demonstrate an established use of the shark resource ahead of proposed management of the fishery.

Increased fishing effort, together with declining catch rates, prompted the introduction of the first management plan for Western Australia's shark fishery in 1988. Under an agreement between the State and Commonwealth governments, the area between 33°S (Cape Bouvard) and the South Australian border (Figure 1.1.) was declared the Joint Authority Southern Demersal Gillnet and Demersal Longline Limited Entry Fishery (JASDGDLF). This fishery was split into 2 zones: Zone 1 between 33°S and Chatham Island (116° 30'E) and Zone 2 from Chatham Island (116° 30'E) to the W.A./S.A. border (129°E). Entry to this fishery was restricted to fishers who could demonstrate a historical use of the stock and access is currently limited to 57 licenses. Effort in the newly managed fishery was limited by the allocation of time/gear units, with each unit allowing an operator to use 600m of demersal gillnet or 200 longline hooks for one month. As a result of two FRDC-funded research projects (no. 93/067 and no. 96/130), stock assessments for the three main shark species caught by this fishery (dusky sharks, *Carcharhinus obscurus;* gummy sharks, *Mustelus antarcticus;* and whiskery sharks, *Furgaleus macki*) were conducted in the mid-late 90s. These indicated that stocks were either fully or over exploited. Consequently, as a means of reducing effort in the JASDGDLF, the amount of fishing gear that each unit allows has gradually been reduced to 270m of net or 90 hooks (45% of the original allowance).

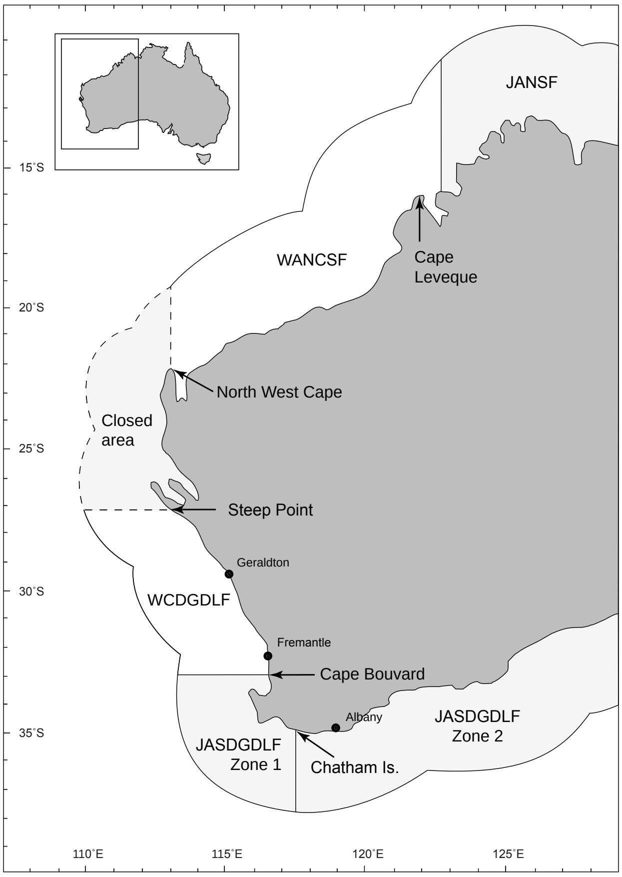


Figure 1.1. Boundaries of the Western Australian target-shark fisheries. Abbreviations: JASDGDLF = Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery; JANSF = Joint Authority Northern Shark Fishery WANCSF = Western Australian North Coast Shark Fishery; WCDGDLF = West Coast Demersal Gillnet and Demersal Longline Fishery.

Following the restriction of shark fishing in southern waters, the amount of demersal gillnet effort north of 33° S increased steadily during the late 1980s and early 1990s. The first regulation of shark fishing on the west coast occurred in 1993, when the area between Steep Point (26° 30'S) and North West Cape was closed to shark fishing in an attempt to protect breeding stocks of dusky sharks, *Carcharhinus obscurus*, (Simpfendorfer and Donohue, 1998). An interim management plan for the West coast fishery, based on the JASDGDLF plan, was introduced in 1997. This plan designated the area between Cape Bouvard and North West Cape as the West Coast Demersal Gillnet and Demersal Longline (Interim Managed) Fishery (WCDGDLF) giving it similar management arrangements to the JASDGDLF, although the northern sector remained closed. Access to the west coast fishery was limited to 26 licenses.

In 1995, under the Offshore Constitutional Settlement, management of the Australian northern shark fishery was handed to the respective state and territory authorities under Joint Authority agreements. The management boundaries of the Western Australian north coast shark fisheries depend upon the type of gear used. The WA State government was charged with managing dropline fishing for shark from longitude 114°06′E to the WA/NT border (129°E) and longline fishing for shark from longitude 114°06′E to 123°45′E as the WA North Coast Shark Fishery (WANCSF). Management of longline and gillnet fishing for shark from longitude 123°45′E to the WA/NT border was undertaken by Joint Authority between Western Australia and the Commonwealth as the Joint Authority Northern Shark Fishery (JANSF).

Catches and fishing effort remained low in the northern shark fisheries until the late 1990s, when larger and better-equipped longline vessels began full-time fishing for sharks in the WANCSF. Despite the flesh from the generally larger sharks caught in this fishery having a low commercial value, effort continued to increase in the WANCSF as more dedicated shark longline vessels entered the fishery in response to the high value of shark fins. In September 2003, the use of droplines in the WANCSF was prohibited and the eastern boundary of the State-managed sector was redefined as 123° 45’. A total of 13 fishers have licensed access to one or more zones of the WA northern shark fisheries.

The combined annual value of the southern and west coast demersal gillnet and longline fisheries during the 2002/03 season, was estimated at approximately $5.5 million (Gaughan and Chidlow, 2005a). For the same period, the combined value of the northern fisheries was estimated to be approximately $1.4 million (Gaughan and Chidlow, 2005b).

1.2 Dusky and sandbar shark catch histories

Catch and effort data have been collected from the Western Australian temperate shark fisheries since 1975. Since reporting began in WA, dusky sharks have been reported using the descriptive name of ‘bronze whaler’, which also includes a small quantity (*ca.* 3%) of the similar, copper shark, (*Carcharhinus brachyurus*). Bronze whaler catches climbed steadily through the 1970s and early 1980s before beginning to decline in the early 1990s (Figure 1.2.). Until 2001/02, when they were replaced by gummy sharks, bronze whalers were the most important component of the catch, both in terms of weight and value, in the State’s temperate demersal gillnet and longline fisheries. Historically, due to the selectivity of the permitted mesh sizes and the size composition of the stock in the areas of the JASDGDLF and WCDGDLF, most of this catch comprised first year (neonate) and young juvenile sharks. During the mid 1990s, approximately 45% (by weight) of bronze whalers caught in these fisheries were neonates (McAuley, 2004). The total reported catch of bronze whalers in the JASDGDLF and WCDGDLF during 2002/03 was 266.5 tonnes (McAuley, 2004; Gaughan and Chidlow, 2005a), of which 103.3 tonnes were caught in Zone 1 of the southern fishery, 83.0 tonnes in Zone 2 and 80.1 tonnes in the WCDGDLF.

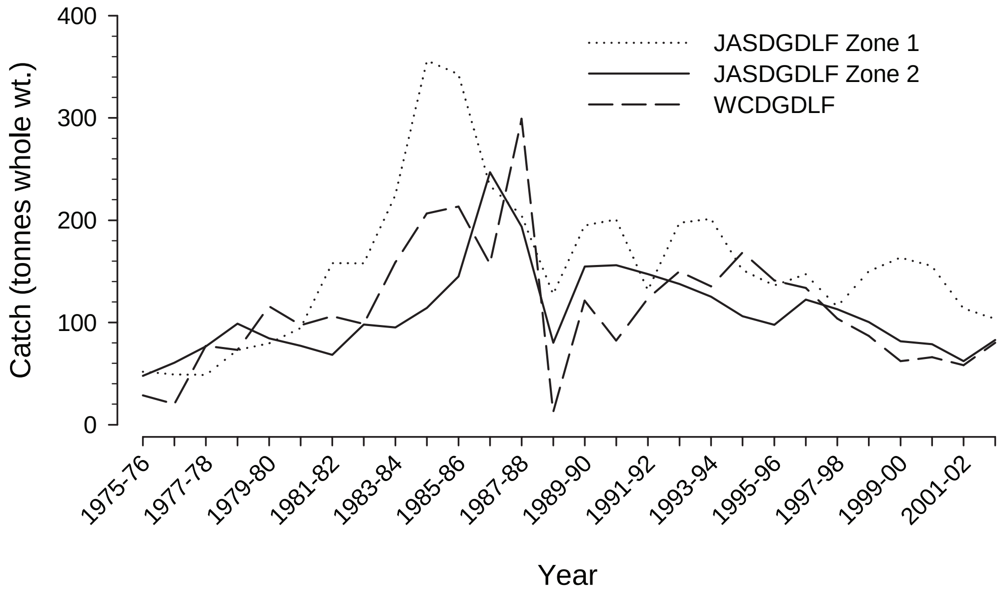


Figure 1.2. Reported annual ‘bronze whaler’ shark catches in the Western Australian temperate demersal gillnet and demersal longline fisheries.

Records of sandbar shark catches in WA began in 1985/86, when the species was given its own code in the Department's Catch and Effort Statistics Section's (CAESS) database. However, fishers did not routinely separate their catches of this species until the mid 1990s, thus early records are considered to be underestimated. In the four years preceding 1999, when funding for this project was sought, the total catch of *C. plumbeus* nearly trebled in Western Australia (Figure 1.3). Since then, the species has been the dominant component of the shark catch in the WCDGDLF and in the developing WANCSF. In 2002-03, the most recent year for which data are available, the WCDGDLF catch was 133.7 tonnes (live weight), which constituted 38.9% of the fishery's total shark catch (McAuley, 2004, Gaughan and Chidlow 2005a). In the same year, the catch of sandbar sharks in the WA North Coast Shark Fishery was 87.7 tonnes (17.9% of the shark catch). The Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery catch remained proportionately small at 29.9 tonnes (3.4%) in 2001/02 and in 2002/03 was zero. However, as sandbar sharks have historically been of minor commercial importance to most southern shark fishers, actual catches in the JASDGDLF are believed to have been somewhat under-estimated due to fishers reporting them as unidentified shark in monthly fishing returns.

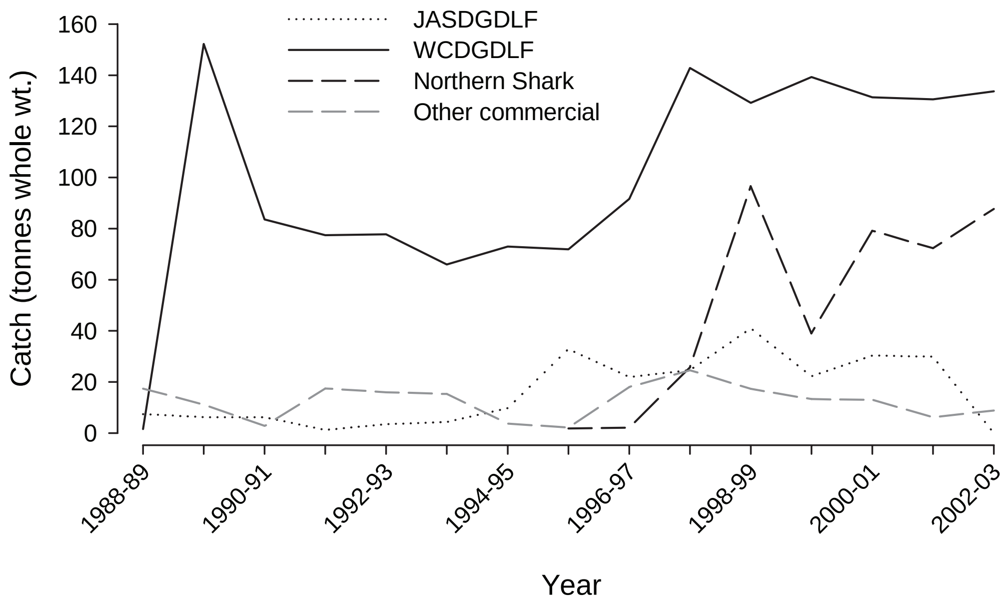


Figure 1.3. Reported annual sandbar shark catches in Western Australian fisheries.

The true level of *C. obscurus* and *C. plumbeus* catches by other commercial fishing sectors in Western Australia is harder to ascertain due to identification problems and possible underreporting. In 2002/03, 55.3 tonnes of dusky shark and 9 tonnes of sandbar shark were reported to have been landed by fishers operating outside the target-shark fisheries, virtually all of which was from vessels operating without specific access to other fisheries, referred to as 'wetline' catch (McAuley, 2004). However, it is probable that a proportion of the remaining 377 tonnes of other sharks, which included 112 tonnes of unidentified sharks, caught by 'non-target' fisheries in 2002/03 were also *C. obscurus* and *C. plumbeus* (McAuley, 2004). Additionally, both dusky and sandbar sharks are known components of the bycatch of the Commonwealth-managed Southern and Western Tuna and Billfish (pelagic longline) Fishery (SWTBF) that operates off the Western Australian coast (McAuley, unpublished data). Whilst the reported bycatch of these species in SWTBF log books is currently low, the gear employed in these fisheries is known to be highly suitable for catching medium to large sized carcharhinid sharks (Stevens and Wayte, 1999; Francis et al., 2000). In earlier years, when this fishery was developing in waters adjacent to the continental shelf and vessels used metal trace wire, it is believed that levels of *C. obscurus* and *C. plumbeus* bycatch were considerably higher than are currently reported.

2.0 Need

Presently, no stock assessment for sandbar sharks has been completed in Western Australia. New management arrangements have been proposed for the West Coast Demersal Gillnet and Demersal Longline Fishery, Western Australia's two Northern shark fisheries and the Commonwealth Tuna and Billfish Fisheries (which could lead to a dramatic increase in longline fishing effort in Western Australia). It is therefore necessary for fisheries managers to have a much better understanding of the catch of sandbar sharks, the status of their stocks and the catch of other long-lived carcharhinids, such as the dusky shark, as a basis for future management decisions.

There is also a need for a methodology to be established on which to base future stock assessments for sandbar sharks. The stock assessment process requires a better understanding of the species' biology in Western Australia than is currently available. With the northern and western fisheries for sandbar sharks separated by a large closed area, studies of stock discrimination and movement are necessary to determine the appropriate geographic scale for management of this species.

Information relevant to the ongoing sustainable management of the shark stocks is not only important to enable the continued viability of the commercial shark fisheries, but also for the conservation of sharks in recognition of their importance as apex predators in the marine ecosystem and their role in maintaining biodiversity.

The effects of sandbar and dusky shark bycatch in 'non-shark' fisheries also need to be quantified and considered in relation to Australia's national and international conservation responsibilities. If exploitation of these species by non-target fisheries is shown to be unsustainable, the future viability of valuable fisheries (eg. Pilbara Fish Trawl and Southern and Western Tuna and Billfish) may be threatened.

3.0 Objectives

1. Study the biology of sandbar sharks in Western Australian waters, including:
   - (i) Movement patterns
   - (ii) Age and growth
   - (iii) Reproductive biology
   - (iv) Diet
   - (v) Stock Discrimination
2. Determine the level of mortality and exploitation of sandbar, dusky and related oceanic shark species in Western Australian waters by all fishing methods
3. Conduct stock assessments, including risk assessment of management options or sandbar sharks and refine the assessment of the status of the dusky shark stock.

4.0 Methods

4.1 Biology of *Carcharhinus plumbeus*

4.1.1 Data collection and sampling

Sampling for this project was conducted from August 2000 to June 2003, in waters between Admiralty Gulf (14°S, 126°E) in the Kimberley and Albany (35°S, 118°E) on the south coast. During the project, staff observed 1,195 gillnet sets over 756 days and 540 longline sets over 348 days. The spatial distribution of sampling effort, by each fishing method, is summarised by one degree latitude by one degree longitude blocks in Figure 4.1.a.

In total, 7,387 *Carcharhinus plumbeus* were sampled during the current project, from a variety of commercial gillnet and longline fisheries and during a series of fishery-independent longline fishing surveys on board the WA Department of Fisheries' research vessels *Flinders* and *Naturaliste*. As the gear used during research surveys was effectively identical to that used by the commercial longline sector, data from these surveys have been combined with the commercially-derived data, unless specified otherwise. The majority of sampled sharks (n = 5,041) were caught by demersal gillnets deployed from vessels operating in the WCDGDLF and JASDGDLF and a smaller number (n = 2,346) were caught by demersal longlines deployed from WANCSF vessels and during research surveys. The spatial distribution of samples collected by each fishing method during this project is summarised by one degree latitude by one degree longitude blocks in Figure 4.1.b. In addition to data and samples collected during this project, biological information on *C. plumbeus* and *C. obscurus* that was collected by the WA Department of Fisheries' Shark Research Section during other projects (eg. FRDC projects 93/067, 96/130, 2001/077, 2002/064), has also been included in some of the following analyses. These additional data include 90 sandbar sharks that were either tagged or sampled during a Department of Environment and Heritage (DEH) funded survey of the Pilbara Fish Trawl Fishery (Stephenson and Chidlow, 2003) and 20 gravid females, caught during a WA Department of Fisheries (DOF) drum-line survey off NW Cape in May 2000 (McAuley, unpublished data; Figure 4.1.b). Data from 348 sandbar sharks that were tagged prior to commencement of the current study are also included in tag movement analyses.

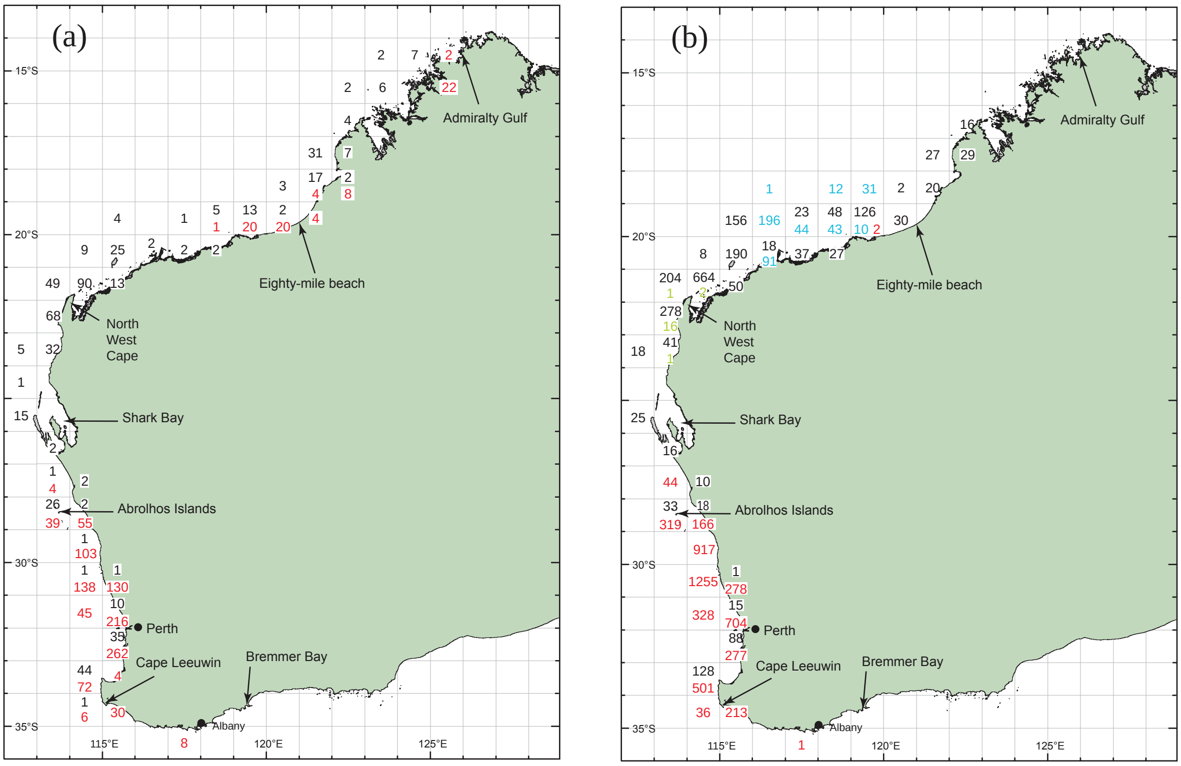


Figure 4.1. Spatial distribution, in one degree latitude by one degree longitude blocks, of (a) sampling effort and (b) specimen collection, between August 2000 and June 2003. Red numbers indicate (a) numbers of gillnet sets and (b) numbers of sharks caught by gillnets. Black numbers indicate (a) numbers of longline sets and (b) numbers of sharks caught by longlines. Blue numbers indicate sample sizes of sharks caught by fish trawling and green numbers indicate sample sizes of sharks caught by drum-lines.

Commercial gillnets were constructed of 0.9-1.0 mm diameter monofilament webbing, hung in a combination of 165 mm (6.5”) and 178 mm (7”) stretched mesh sizes with either a 15 or 20 mesh drop. Longlines (commercial and research) comprised size 12/0 J-shaped hooks, baited with mullet (*Mugil cephalus*) or mackerel (family Scombridae) and attached to their main lines via approximately 2m metal snoods. Gillnets and longlines were set demersally in depth ranges of 0-121 m (mean = 51 m) and 7.5-225 m (mean = 102 m), respectively. Details of trawl net and drumline configurations are given in Stephenson and Chidlow (2003) and Simpfendorfer et al (1999), respectively.

Whenever possible, sharks were sexed and fork length (FL) measured (to the nearest centimetre) as a straight line from the tip of the snout to the fork of the caudal fin. Total lengths (TL) of a subsample of sharks were also measured, as a straight line, along the same axis as fork length, from the tip of the snout to the tip of the caudal fin in its natural position.

4.1.2 Movement

An extensive tagging project, in which 1,759 sharks were tagged, was undertaken between August 2000 and June 2004 to study movements of *Carcharhinus plumbeus*. Additional data from 348 sandbar sharks, tagged during FRDC project nos. 93/067 and 96/130 between March 1994 and June 1999, were also included in these analyses. Sharks were tagged between Cape Leveque (16° 30’S, 123°E) and Hopetoun (34°S, 120°E, Figure 4.2). Release and capture data were stratified into 4 geographic regions to examine differences in the movements of sharks in different parts of the State. These were: north of 22ºS (North Coast), between 22°S and 29°S (Upper West Coast), between 29°S and 34°S (Lower West Coast) and south and east of 34°S 114°E (South Coast). Prior to release, sharks were sexed, measured and the date, location, and depth of each release were recorded. Sharks were tagged with Jumbo Rototags in the posterior half of their first dorsal fins, at approximately 30-50% of the height of the fin. A subsample of sharks were tagged with both Jumbo Rototags and nylon-headed dart tags, attached at the base of the first dorsal. A second subsample of tagged sharks were injected with either oxytetracyclene (OTC) or calcein, to aid in the validation of age and growth (see *4.1.3.4*).

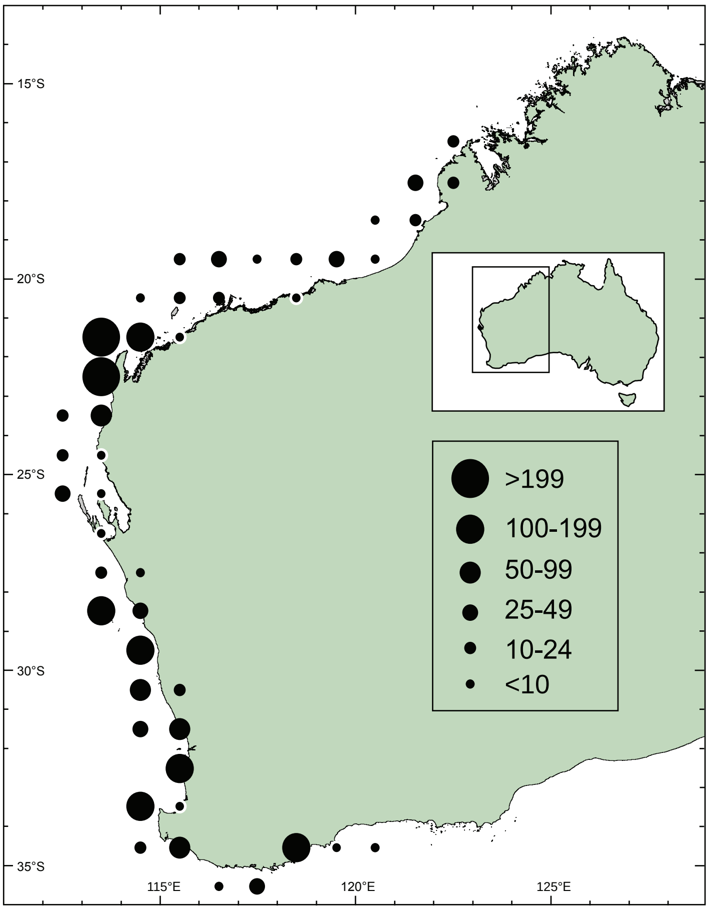


Figure 4.2. Release locations of 2,107 *Carcharhinus plumbeus*, tagged between 22/03/94 and 15/06/04.

Tag recapture information was received from commercial and recreational fishers, as well as from research staff during commercial and fishery-independent sampling. The return of tag recapture information was encouraged by a State-wide advertising campaign and by the offer of rewards, such as T-shirts and caps. The recapture information requested included the date and location of capture, length, tag number, species, sex, and condition of the shark and tag. To assist in the collection of comprehensive and accurate reporting, commercial fishers and observers were trained how to measure Fork Length, collect vertebral samples and provided with measuring tapes and standardised tag-recapture reporting forms.

4.1.3 Age and growth

4.1.3.1 Vertebral sample collection

Vertebral samples from 680 *Carcharhinus plumbeus*, ranging in size from 47 to 166cm FL, were collected from both commercial and fishery-independent sources between April 1999 and June 2002. Sharks obtained from commercial catches were caught by demersally-set gillnets (n=379) and longlines (n=263). A smaller number of sharks were caught using commercial-specification demersal longlines (n=20) and drum-lines (n=22, for details of drum-line specification see Simpfendorfer et al., 1999), deployed from Western Australian Department of Fisheries research vessels. Gillnets and longlines were fished in depth ranges of 9 m-121 m and 14m-157 m, respectively and drum-lines were fished in depths of between 54 and 100 m. Sampling was conducted between Eighty Mile Beach (20°S 120°E) on the north coast and Cape Leeuwin (35°S 115°E) in the south west of the State (Figure 4.1). A section of anterior vertebral column was removed from each specimen and stored frozen until being processed.

4.1.3.2 Vertebral processing and analysis

After defrosting vertebral samples, the neural arch, transverse processes (haemal arches) and excess tissue were excised from vertebral samples and the individual centra separated. Centra were soaked in a 5-10% sodium hypochlorite solution for up to sixty minutes, depending on their size, quantity and age of the solution, until all remaining tissue was removed. Clean centra were thoroughly rinsed in fresh water and dried in an oven at 50°C. Three centra from each shark were embedded in polyester casting resin and longitudinal cross-sections of 170 µm thickness were taken from as close to the focus of each centrum as possible, using an Buelher Isomet 5000 variable speed linear precision saw. Sections were mounted on microscope slides with casting resin and digitally photographed through a dissecting microscope under reflected light.

Images of centrum sections were viewed and brightness and contrast adjusted using Microsoft Photo Editor 3.01. Growth bands (defined as a narrow translucent band and adjacent wide opaque band) were independently counted by three readers, without knowledge of the size, sex or previous results for any shark. Two readers had experience in ageing sharks, while the third had no experience in ageing sharks but was experienced in ageing teleosts. Counts commenced after the birth mark, which was identified by a change of angle on the outer edge of the corpus calcareum and an associated translucent band. The readability of each section was scored according to the definitions in Table 4.1. Sections with a readability score of zero were excluded from further analysis.

Table 4.1. Definitions of vertebral section readability.

Readability	Definition
0	Unreadable.
1	Bands visible but difficult to interpret.
2	Bands visible but the majority difficult to interpret accurately.
3	Bands visible a minority difficult to interpret accurately.
4	All bands unambiguous.

A consensus for each reader's counts of the three centra from each shark was determined using the following criteria: (i) where at least two counts matched, the matching count was taken; (ii) where no counts matched but two counts varied by one, the count with the higher readability was taken; (iii) where no counts matched but two counts varied by one and readability was equal, the final reading, which was made with greater experience in the interpretation of band formation, was taken. Where a consensus could not be reached, that specimen was excluded from further analysis of that reader's results. A final consensus of the number of growth bands for each specimen was determined by taking the count that matched in at least two of the consensus counts from each reader.

The index of average percentage error (IAPE) was calculated for each reader's counts and for the consensus counts according to the method described by Beamish and Fournier (1981):

$$\mathrm{IAPE} = \frac{1}{N}\sum_{j=1}^{N}\left(\frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij} - X_j\right|}{X_j}\right)\times 100,$$

where N is the number of animals aged, R is the number of readings, X_{ij} is the count from the j^{th} animal at the i^{th} reading and X_j is the mean age of the j^{th} animal from i readings.

A form of the von Bertalanffy growth equation that fits the curve to a known size at birth (Simpfendorfer et al., 2000) was fitted to the resulting length at age data:

$$L_T = L_0 + (L_\infty - L_0)(1 - e^{-KT}),$$

where L_0 is the size at birth (42.5 cm FL for both sexes, see *5.1.4.2*), L_T is the length at time T, L_∞ is the asymptotic length and K is the Brody growth coefficient. Including the known size at birth, makes full use of all the empirical data and, to some extent, accounts for the inclusion of fast growing neonate and younger sharks in the length-at-age dataset. The equation was fitted using the non-linear regression function of Sigmaplot 9.0 (Systat, 2004).

Each reader characterised the outer edge of each section as either opaque or translucent, to assist in the determination of the seasonality of band formation (see *4.1.3.4*). Consensus on the outer edge condition for each specimen was decided for each reader by taking the condition that matched in at least two readings. A final consensus on outer edge condition was established by taking the condition that matched in at least two of the readers' consensus readings.

4.1.3.3 Growth rate estimation using tagging data

Release and recapture data from 104 tagged *C. plumbeus*, which were at liberty for between 1 and 2,723 days (7.5 years), were used to estimate growth rates for comparison with the rates calculated by vertebral analysis. Growth rates were calculated from growth-increment data using the Francis (1988) maximum likelihood method. This method estimates growth of tagged fish based on growth rates, g_α and g_β, at two arbitrary lengths, α (70 cm FL) and ß (110 cm FL), so that:

$$\Delta L_i = \left[\frac{\beta g_\alpha - \alpha g_\beta}{g_\alpha - g_\beta} - L_i\right]\left[1 - \left(1 + \frac{g_\alpha - g_\beta}{\alpha - \beta}\right)^{\Delta T_i}\right],$$

where L_1 = the length at release and ΔT_1 = the period at liberty.

The model also estimates variability in growth rates (v), measurement error and the probability of incorrectly recorded length data, referred to as the contamination probability p. It is assumed that ν is normally distributed with a mean of μ and a standard deviation σ and that σ is proportional to μ, such that $\sigma = v\mu$. Net measurement error at release and recapture is also assumed to be normally distributed with a mean of m and a standard deviation s.

The solver function of Excel (Microsoft, 2003) was used to estimate g_α, $g_ß$, v, μ, σ and p by maximising the likelihood function:

$$\lambda = \sum_i \log\left[(1-p)\lambda_i + p/R\right],$$

where, $$\lambda_i = \frac{\exp(-0.5(\Delta L_i - \mu_i - m)^2/(\sigma_i^2 + s^2)}{\left[2\pi(\sigma_i^2 + s^2)\right]^{0.5}},$$

R = the range of observed growth increments and subscript i refers to the i^{th} fish.

Confidence intervals of parameter estimates were calculated by refitting the model to 500 'bootstrapped' length increment data using the previously described methods. Bootstrapped length increments were generated by randomly selecting from a normal distribution with a mean equal to the predicted growth increment and a standard deviation of $v\mu$. Bootstrapped measurement error data were generated by randomly selecting from a normal distribution with a mean equal of m and a standard deviation of s.

4.1.3.4 *Validation of growth band periodicity and seasonality*

A subsample of 887 tagged sharks were injected with either oxytetracyclene (OTC, prior to December 2000) or calcein (post December 2000) to mark their vertebral centra for age validation. Both OTC and calcein were injected into the dorsal musculature, anterior to the first dorsal fin and adjacent to the vertebral column. OTC was administered in 25 mg kg^{-1} dosages and calcein was administered at dosages of 3-5 mg kg^{-1}.

Vertebral samples from injected sharks were either returned after capture by commercial fishers or collected by researchers during at sea sampling and prepared according to the previously described sectioning methods (see *4.1.3.2*). After mounting marked on microscope slides, they were digitally photographed via a dissecting microscope, firstly under normal reflected light and then under fluorescent light, through an ultra violet (UV) filter. Fluorescent images were then superimposed on their non-fluorescent counterparts using Adobe Illustrator 10.0. The transparency of the fluorescent layer of the composite image was then adjusted, so that the fluorescing mark was visible while banding patterns from the non-fluorescent layer could still be clearly distinguished. The number of complete growth bands after the fluorescing mark were then counted and plotted against time at liberty. The slope of the regression between post-injection band counts and time at liberty equates to the number of bands formed per year.

Sectioned OTC and calcein marked centrum sections were also used to examine the seasonality of growth band formation. Only those sections that exhibited complete opaque and translucent bands from the year in which the section was marked were used and it was assumed that a complete growth band took exactly one year to form. Widths of the opaque and translucent zone from the year in which the shark was tagged and the distance of the OTC/Calcein mark from the beginning of that year's growth increment (i.e. the start of the opaque band) were measured along the midline of the corpus calcareum. The times taken to form opaque and translucent bands and the year of tagging growth increment start date were estimated as:

$$\text{Opaque band formation time (days)} = 365 \text{ x } \frac{\text{Opaque band width}}{\text{Opaque band width} + \text{Translucent band width}}$$

$$\text{Translucent band formation time (days)} = 365 \text{ x } \frac{\text{Translucent band width}}{\text{Opaque band width} + \text{Translucent band width}}$$

$$\text{Increment start date} = \text{date tagged} - \left(365 \times \frac{\text{Growth increment start to mark distance}}{\text{Opaque band width} + \text{Translucent band width}} \right)$$

The estimated start dates and duration of growth increment formation were then graphed and compared to examine whether there was any commonality between individuals in seasonality of growth band formation.

4.1.4 Reproduction

Males were examined for clasper length, the degree of clasper calcification and the presence or absence of spermatozoa in the epididymis. Clasper length was measured as the distance from the distal tip of the clasper to the junction with the pelvic fin. Three stages of male maturity were defined, relative to the degree of clasper calcification: immature (uncalcified, where claspers were small and could be easily bent along their entire length), maturing (partially calcified, where claspers had begun to elongate and calcify but could still be bent along most or all of their length) and mature (calcified, where claspers were elongate and could not be bent at all). A subsample of male sharks was dissected to test for the presence or absence of spermatozoa by making a transverse incision across the kidney, thereby severing the epididymis, and running a thumb or finger along the epididymis towards the incision. If a large amount of milky-white fluid was expelled, then spermatozoa were judged to be present.

The length at which 50% of male sharks were mature ($L_{0.5}$) was calculated as $-a/b$ using the parameters a and b that were estimated by logistic regression analysis of the proportions of mature shark in 2 cm FL size classes. The proportion of mature individuals in each size class (P_L) was estimated as:

$$P_L = 1/(1 + e^{-(a + bx_L)}),$$

where x_L is the mean length of size class L and a and b are parameters that determine the location and shape of this curve. Values of a and b were estimated using the Solver routine in Microsoft Excel to maximise a modified form of the log-likelihood function given by White et al. (2002):

$$LL = \sum_L \left[\left(n_L - n_{m,L} \right) . \ln\left(1 - \hat{P}_L\right) + n_{m,L} . \ln\left(\hat{P}_L\right) \right]$$

where n_L is the number of sharks that were examined in size class L, $n_{m},_L$ is the number of mature sharks in size class L and is the $\hat{P}_L$ estimated proportion of mature sharks in size class L.

Ninety five percent confidence intervals were estimated for $L_{0.5}$ by randomly re-sampling (with replacement) the maturity-at-length data to create 1,000 new ‘bootstrapped’ datasets and then re-fitting the logistic maturity function to each.

Female maturity was defined by a combination of uterine and ovarian development (Table 4.2). Females were considered mature when they were classified as maturity stage of 3 or higher. The length at which 50% of female sharks were mature ($L_{0.5}$) and 95% confidence intervals were estimated by logistic regression analysis of the proportions of mature shark in 2 cm FL size classes, as described for males. Where present, the diameter of the largest yolky ovarian ovum was measured (Maximum Ovum Diameter, MOD). In pregnant individuals, the number of embryos in each litter was recorded and the total lengths of all embryos were measured. The sex ratios of embryos, expressed as the proportion of the litter that was female, were also recorded for a subsample of litters.

Table 4.2. Maturity stages of female *Carcharhinus plumbeus.*

Female maturity stage	Description
1	Uterus very thin along its entire length, empty. Ovary indistinguishable from epigonal organ. Immature.
2	Uterus very thin along most of its length but enlarged posteriorly, empty. Ovary difficult to distinguish from epigonal organ. Maturing.
3	Uterus enlarged along its entire length but empty. Ovary clearly distinguishable from epigonal organ and with differentiated ovarian follicles or developing yolky ova. Mature, not pregnant.
4	Uterus containing yolky eggs but no visible embryos on eggs. Ovulatory & post-ovulatory.
5	Uterus containing visible embryos. Pregnant.
6	Uterus enlarged and flaccid, appearing to have just given birth. Umbilical scars may be present. Post partum.

4.1.5 Diet

Dietary data were collected from 2,115 *Carcharhinus plumbeus,* caught by commercial gillnet and longline vessels and by drumlines and longlines during fishery independent research cruises in Western Australian waters, between December 1993 and November 2003. Sharks were sexed and measured as previously described and their stomachs examined. Stomach fullness was visually assessed according to a scale of 0 - 4, with 0 equating to completely empty, 1 being up to ¼ full; 2 being between ¼ and ½ full; 3 being between ½ and ¾ full and 4 being between ¾ and entirely full. Dietary items were identified to the lowest possible taxa and counted. If prey items could be identified but not accurately counted, they were assumed to be a single item. Consumed bait was excluded from analysis.

The occurrence method (Hyslop 1980) was used to analyse the stomach content data. Individual prey counts were also used to illustrate the actual numbers of prey items retrieved from individual specimens. Prey items were grouped into the following six categories for comparison of diets between sexes, sizes and regions: Cephalopods, Crustaceans, Sharks, Rays & skates, Teleosts and Others. Sharks were grouped into three size-classes : small (< 90 cm FL), medium (90-130 cm FL) and large (> 130 cm FL) for analysis of size related changes in diet. Data were further separated into three regions: north west (north of latitude 26°S), west coast (between latitudes 26°S and 33°S) and south west (south of latitude 33°S) to compare diets between regions.

Comparison of dietary overlap between sexes, size-classes and regions was performed using the Simplified Morisita Index (C_H, Krebs 1989) and Langton's scale of dietary overlap (Langton, 1982) of C_H: low overlap, 0-0.29; medium overlap, 0.30-0.59; and high overlap; > 0.60. Comparison of prey diversities between sexes, size-classes and regions was undertaken using the Shannon-Weiner Index (*H'*, Krebs 1989).

4.1.6 Stock discrimination

Blood samples were collected from a total of 102 *C. plumbeus*, caught in three locations between Broome and Cape Leeuwin (34.7°S, 115.3°E) during commercial and fishery independent sampling between March 2001 and May 2003 (Figure 4.3). Similar sample sizes were obtained from each region and sampling locations within each region were kept as discrete as possible. Each sample, consisted of between 1 and 2ml of blood, fixed with 3-4 ml of 100% EtOH.

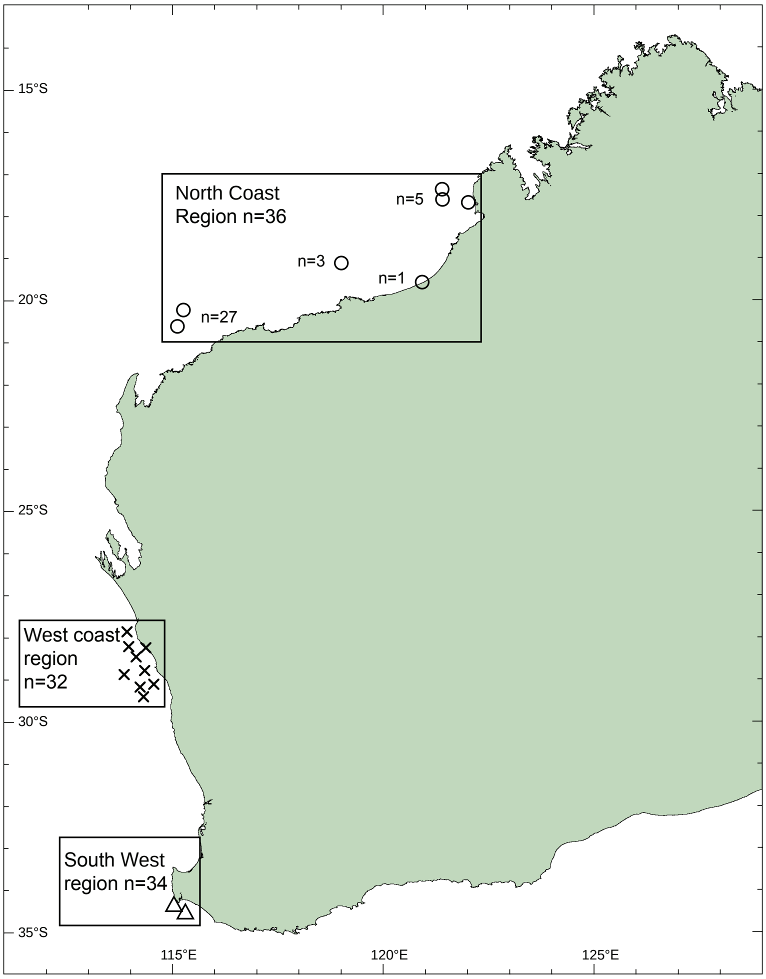


Figure 4.3. Capture locations of 102 *Carcharhinus plumbeus*, from which blood samples were collected for genetic stock discrimination analyses.

Samples are currently being analysed by Associate Professor Ed Heist (Fisheries and Illinois Aquaculture Center, Southern Illinois University), using microsatellite loci, which he has developed for north western Atlantic *C. plumbeus*. As results from this work were not complete when the draft of this report was submitted, they have instead been included in this report at Appendix V.

4.2 Mortality and exploitation of sandbar, dusky and related oceanic shark species

4.2.1 Determining valid catch and effort in the target fisheries

4.2.1.1 Temperate demersal gillnet and longline fisheries

Catch and effort data for the temperate demersal gillnet and longline fisheries were derived from monthly fishing returns, submitted to the Department of Fisheries by commercial fishers as a condition of their licenses. Monthly returns, which have been collected from the temperate gillnet and longline fisheries since 1975, are reported in 1° latitude by 1° longitude geographical blocks and are maintained by the Department's Catch and Effort Statistics Section (CAESS). These data have been validated and corrected as follows.

Definition of valid temperate 'shark' fishery data

As licensing information for the WA temperate 'shark' fisheries is only available from 1988 onwards, the Temperate Demersal Gillnet and Demersal Longline Fishery (TDGDLF) was instead defined according to fishing method and area of operation. Prior to 1993, the catch and effort dataset for the TDGDLF includes all gillnet and longline fishing records, excluding those from the estuaries, between the South Australian border and, North West Cape (22°S Latitude 114°E). From 1993 onwards, when the area between Steep Point (26° 45'S) and NW Cape was closed to targeted shark fishing, data have been taken from all gillnet and longline records outside estuaries, between the South Australian border and 26°S latitude (i.e. the nearest 1° line of latitude north of Steep Point). Nets with lengths of less than 100 m have been excluded from the dataset to remove misreported non-'shark fishery' netting methods (eg. haul nets, beach seines and throw nets), which were occasionally reported as gillnets, particularly in early records.

Correction of effort data

The accuracy of the CAESS data necessary for calculating gillnet and longline fishery effort, ie net length, days fished, hours fished per day and number of shots per day, were examined and in a relatively small number of records, were found to be incomplete or incorrect, particularly prior to 1989/90. Data validation and correction procedures were therefore developed using Microsoft Access software (Microsoft Corporation), to adjust invalid effort parameters. Wherever possible, missing or invalid data were replaced with the average value observed on that vessel during commercial sampling by Department of Fisheries Shark Research Section staff in that year. If no observer data were available for a vessel in the year in which the data was missing or deemed invalid, then the annual average value (excluding invalid records) from that vessel was used. If an average annual value was not available for a particular vessel, for example where the only available record was the one judged to be incorrect, the monthly average value (excluding invalid records) of the remainder of the fleet in that region was used. Invalid effort data were identified according to the following criteria. Where any data was missing it was replaced according to the procedures outlined above. Where net length was reported as less than 100 m or more than 12,000 m, or hours fished per day was equal to 24, the invalid value was replaced. One common problem, particularly in earlier years, was records in which the product of hours fished per shot and number of shots per day exceeded 24 hours. As fishing for more than 24 hours per day is impossible, it was taken that fishers were referring to undertaking multiple shots over the course of 24 hours. These records were therefore corrected by assuming the average monthly 'set time' per day, (excluding invalid records) of the remainder of the fleet in that region and replacing number of shots with a value of one.

Once effort parameters were corrected, monthly gillnet effort was calculated for each vessel in each block as the net length multiplied by the number of days fished, the number of hours fished per shot and the number of shots per day. Total gillnet effort was then calculated for each management zone of the TDGDLF, as the sum of monthly effort by all vessels within the zone. As the majority of operators in this fishery use demersal gillnets, longline fishing effort was standardised in terms of equivalent gillnet fishing effort by using the longline catch and gillnet catch rate of all sharks to back-calculate the amount of gillnet effort that would have been necessary to have caught that quantity of sharks (i.e. gillnet equivalent effort = longline catch divided by gillnet CPUE). As previous analysis of the accuracy of catch and effort data from the TDGDLF determined that due to missing returns, data prior to 1990 was incomplete, both gillnet and longline effort (and catch) were increased by 5% (Simpfendorfer and Donohue, 1998). Although this previous analysis estimated that greater levels of correction were necessary for returns data from the mid to late 1980s, it is now suspected that reported catch and effort during this period may have been overestimated by some fishers attempting to demonstrate their use of the shark resource ahead of proposed management of the fishery (see *1.1*). Additional correction to returns data from these years was therefore deemed unnecessary. Total fishing effort was calculated as the sum of the annual gillnet and longline effort and expressed in units of “kilometre gillnet hours” (km gn hr).

Correction of catch data

Problems were also found with gillnet and longline shark catches not attributed to the managed fishery’s catch due to discrepancies between catch and licensing data and in returns where shark catches were not properly separated (eg. records where all shark was reported as ‘shark, other’ or ‘bronze whaler’). The former problem was overcome by defining the fishery’s catch by method and area, rather than license information. The latter problem was overcome by assessing reported catches as either accurate or, where catches of key species (i.e. *C. obscurus*, *C. plumbeus*, *Mustelus antarcticus*, *Furgaleus macki*, *Galeorhinus galeus* and F. Squalidae) were not reported separately, inaccurate. Catch data were assessed regionally to account for differences in the composition of catches from different parts of the fishery and the criteria for determining accurate catches were adjusted through time to account for temporal changes in targeting practices, eg. less targeting of *G. galeus* since the late 1990s and the short-term fishery that developed for dogfish (F. Squalidae) out of Esperance in the mid 1990s. Catches were also judged to be inaccurate where the reported catch appeared to have been arbitrarily split (e.g. where catches were reported as 50% ‘gummy shark’ and 50% ‘bronze whaler’ or 33% ‘bronze whaler’, 33% ‘gummy shark’ and 33% ‘whiskery shark’, etc).

Catches of the fisheries’ traditional target species (i.e. *C. obscurus*, *F. macki*, *M. antarcticus*) in ‘inaccurate’ returns were re-estimated by reapportioning the total shark catch in those returns, based on the proportions of each species in returns from ‘accurately’ reporting vessels operating within the same block, in the same month or year. As *C. plumbeus* have historically been and remain a relatively minor component of the shark catch of some temperate demersal gillnet and longline vessels, some operators, particularly in the JASDGDLF, do not identify catches of this species separately. Therefore, catch records from TDGDLF vessels, operating between the northern limit of the WCDGDLF and a line of longitude at 118°E on the south coast, which did not separately report any *C. plumbeus* catch within a financial year were adjusted by reapportioning their monthly unidentified shark catch using the ratio of sandbar to unidentified shark catch from vessels operating in the same area in the same month or year, which did report *C. plumbeus* catches separately.

4.2.1.2 Northern shark fisheries

Due to the small number of vessels which operated in the WANCSF, their sporadic patterns of fishing effort and the geographic scale of the northern fishery, the procedures used to validate catch and effort data in the TDGDLF could not be applied to records from the WANCSF. Instead, the accuracy of reported *C. plumbeus* catches in the WANCSF were examined by comparing the fishery's monthly reported CPUE in the area west of 120°E (the area of the fishery that overlaps the primary range of *C. plumbeus*) with the monthly CPUE recorded in voluntary research log books from the same area. Log book data, comprising shot-by-shot catches (in numbers) and effort (number of hooks), were periodically kept by five vessels between July 1999 and June 2004. Log book catches were converted to live weight assuming a mean size of 156.1 cm TL, determined from commercial sampling on WANCSF vessels, and the length-weight relationship given by McAuley and Simpfendorfer (2003):

Live weight (kg) = $6.0 \times 10^{-6} \times TL^{2.9698}$

Monthly sandbar shark catch rates were calculated for both CAESS and log book datasets as the total monthly catch by all vessels operating in the area between NW Cape and longitude 120°E divided by total monthly effort (number of hooks) of those records.

Whilst reported CAESS effort (in terms of number of hooks and days fished per month) was consistent with both the log book data and the values observed during commercial sampling on board the majority of WANCSF vessels, there were significant differences between reported and log book catch rates. It was therefore deemed necessary to re-estimate the northern fishery's total *C. plumbeus* catches to provide a more accurate representation of the overall level of mortality. This was done by bootstrapping 1,000 sets of estimated annual catches in the WANCSF, using the reported effort from the area between NW Cape and longitude 120°E and randomly resampling catch rates from within the range of the mean annual log book CPUE ± the calculated level of precision (*PC*) of these rates. The precision of monthly log book and CAES reported catch rates, i.e. the level of change in CPUE that should be detectable in each dataset, was determined using the equation:

$$n = \frac{8CV^2}{PC^2}\left[1 + (1 - PC)^2\right]$$

where *n* is the sample size and *CV* is the coefficient of variation, calculated as the ratio of the standard deviation to average catch rate (van Belle, 2004), of each dataset.

4.2.2 Species composition of shark catches in non-target fisheries

4.2.2.1 Pilbara Fish Trawl

The Pilbara Fish Trawl Interim Managed Fishery (PFTF) is located between 114°10'E (North West Cape) and 120°E and consists of two zones: Zone 1 (in the west of the Pilbara fishery) and Zone 2 from 116°E to 120°E generally seaward of the 50 m isobath and landward of the 200 m isobath (Figure 4.4). The PFTF is a multi-species finfish fishery, which harvests over 100 species. Among the principal target species of this fishery are: blue-spot emperor (*Lethrinus hutchinsi*), threadfin bream (Family, Nemipteridae), red snapper (*Lutjanus erythopterus*) and flagfish (*Lutjanus vitta*). Reported shark catches in the PFTF were 43 tonnes in 2001/02, 56 tonnes in 2002/03 and 39 tonnes in 2003/04 (McAuley, unpublished data). However, as sharks are a relatively minor byproduct of this fishery, catches are not reported to species level and the species composition of PFTF catches was therefore estimated from observer data.

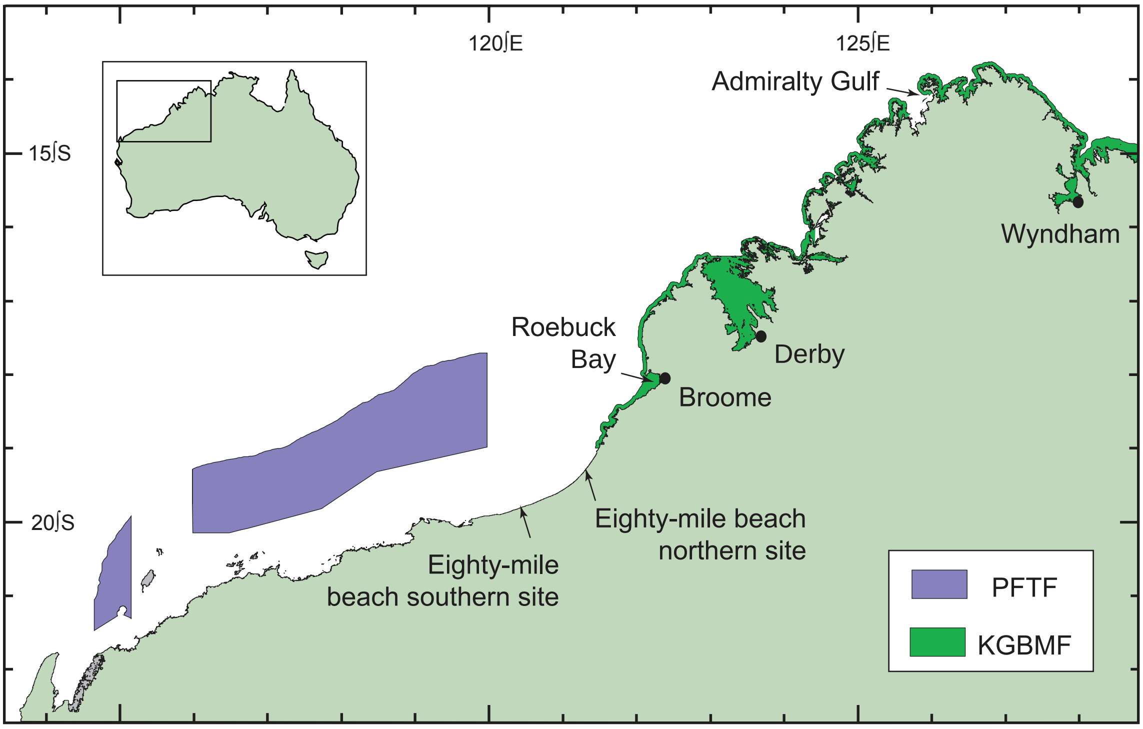


Figure 4.4. Boundaries of the Pilbara Fish Trawl managed Fishery (PFTF), Kimberly Gillnet and Barramundi Managed Fishery (KGBMF) and Eighty Mile Beach inshore gillnet sampling locations.

Elasmobranch catch/bycatch data were collected by an experienced shark biologist over 100 days between February and June 2002, from the 5 vessels licensed to operate in the PFTF (Stephenson and Chidlow, 2003). Sharks were identified, sexed, and their lengths (FL and/or TL) were measured to the nearest centimetre. The fate of sharks was also recorded as either retained or discarded. It was assumed that the 37 *C. plumbeus* that were tagged during this survey would have been retained had the observer not been on board and these were therefore included in the retained portion of the catch. The weight of *C. plumbeus* catches were estimated using the length weight relationship given in *4.2.1.2*, whilst catch weights of other species were estimated from published length weight relationships. Catches of individual elasmobranch species were then estimated by apportioning the annual reported shark catch by the PFTF according to the estimated proportions of each species in the observed catches.

4.2.2.2 *Northern inshore gillnet fisheries*

Elasmobranch catch composition data were collected by WA Department of Fisheries Shark Research Section staff from the two gillnet 'fisheries' that operate in northern Western Australia between the 19th of January 2003 and the 9th of June 2004. These are the Kimberley Gillnet and Barramundi Managed Fishery (KGBMF) and fishers operating on Eighty Mile Beach under exemptions to their fishing licences (Figure 4.4). In total, seven vessels are licensed to fish in the KGBMF, whilst two fishers are authorised to fish with gillnets on Eighty Mile Beach, under exemptions to commercial fishing licenses. With the exception of two additional bait-net endorsements, the commercial use of 'set' gillnets is otherwise prohibited in the Pilbara and Kimberley regions. Fishers in the KGBMF operate in the river and tidal creek systems of the Kimberley, whilst gillnet fishing on Eighty Mile Beach occurs in the intertidal zone. The primary target species of these fisheries are Barramundi (*Lates calcarifer*) and threadfin salmon (*Polydactylus macrochir* and *Eleutheronema tetradactylum*). Between 2000 and 2004, reported annual landings of elasmobranchs in the KGBMF were between 2.6 and 4.6 tonnes (live weight) and between 11.1 and 25.4 tonnes (live weight) from the Eighty Mile Beach gillnet sector (McAuley, unpublished data).

Table 4.3. Summary of northern inshore gillnet observer effort between 19/01/03 and 9/6/04.

Site	No. 'shots' observed	Obs. effort (km gn hr)	Mean soak time (hr)	Mean net length (m)	Mesh size (mm) min	Mesh size (mm) max	Mesh drop min	Mesh drop max
Roebuck Bay	33	8.5	1.0	325	140	140	33	33
Admiralty Gulf	24	17.1	4.4	176	178	178	?	?
Southern Eighty Mile Beach	62	95.2	9.9	168	140	178	16	33
Northern Eighty Mile Beach	41	46.3	11.6	119	140	178	16	16

Data were collected from five vessels at four locations (Table 4.3). These were the northern and southern ends of Eighty mile beach, Roebuck Bay and Admiralty Gulf (Figure 4.4). In total, 160 days of gillnet fishing were observed in depths of less than 10 m. Nets were constructed of between 0.8 and 0.9 mm diameter webbing, hung between a positively buoyant head-line and negatively buoyant ground-line, with a 'hanging coefficient' of approximately 0.67. Mesh sizes were between 140 and 178 mm (5½-7"), with drops (i.e. depths) of between 16 and 33 meshes. Elasmobranchs were identified, sexed, and their lengths (FL and/or TL) were measured to the nearest centimetre.

As the accuracy of fishing effort reported by the northern inshore gillnet sector has never been thoroughly assessed, CAESS data were examined to judge the reliability of the fisheries' reported effort, using similar methods to those used to validate effort in the TDGDLF. Returns from the KGBMF were defined according to the licences permitted in this fishery since 1980. As gillnet fishing on Eighty Mile beach has never been a licensed activity, data from this sector were instead defined according to method and area. Records from vessels targeting bait-fish (mullet and whiting) with small mesh-size gillnets were excluded from these datasets by identifying those returns in which only baitfish were reported. This assessment revealed several problems with the ways in which different fishers reported their fishing effort. In particular, reported net length, number of shots per day and hours fished per day were found to be confounded in records from a number of vessels. Specifically, some vessels had defined number of shots per day as the number of times their total net allocation had been fished within the daily fishing period (i.e. hours fished per day). However, other vessels had defined shots as the number of nets that their total net allocation had been separated into, whilst others had defined shots as the number of times they checked and/or moved their net(s) during the daily fishing period. A small number of vessels also reported periods of fishing for 24 hours per day, i.e. the amount of time that these vessels were at sea, rather than period for which the nets were actually fished.

It was therefore necessary to standardise reported effort parameters to obtain an accurate record of annual fishing effort in the northern inshore gillnet sector. This was done according to the following procedures. Returns in which 24 hours fishing per day was reported or where the product of the number of shots per day and hours fished per day was in excess of 24 hours were considered invalid. For invalid records from vessels for which observer data were available, the invalid parameter(s) were replaced with the observed value(s). Although this approach assumes that fishing behaviour did not change between the time of the invalid report and the collection of observer data, this seems to be a valid assumption as only one KGBMF skipper is known to have changed since the introduction of the fishery's management plan in 1989 and several fishers have indicated that their fishing practices have changed little since that time. Invalid records from vessels for which observer data were not available were corrected using the mean effort parameter value(s) of the 12 preceding and 12 subsequent valid records from those vessels. Annual effort in each region (see below) was then calculated as the sum of each vessel's standardised monthly effort.

As KGBMF fishers are not permitted to fillet shark catches at sea, the majority of the elasmobranchs caught in these fisheries are not retained and therefore, reported landings are thought to underestimate the fishery's actual catch. Also, due to problems with species identification and the relatively minor economic importance of elasmobranch catches, landings in the northern inshore gillnet sector are generally not reported to species level. Northern gillnet elasmobranch catches were therefore estimated from the observed catch rates of individual species and the validated annual effort in these 'fisheries'. Because observed species compositions in catches from northern and southern Eighty Mile Beach and Roebuck Bay (part of the KGBMF) were similar to each other but noticeably dissimilar to the observed composition in Admiralty Gulf, catches from Eighty Mile Beach and Roebuck Bay (Region 1) were estimated separately to those in the remainder of the KGBMF (Region 2).

4.2.3 *Gillnet mesh selectivity of sandbar sharks*

4.2.3.1 Data collection

To determine how the size composition of *Carcharhinus plumbeus* catches is related to the selectivity of the gillnets used in the TDGDLF and therefore, how catches might be affected by changes to the mesh sizes being used in the fishery, mesh selectivity data were collected from an experimental net, comprising six panels of different mesh sizes. The experimental net was deployed 83 times from commercial gillnet vessels during their normal fishing operations, in waters off the lower west coast of Western Australia between 01/03/01 and 24/04/03. The net was set demersally, adjacent to the vessels' other nets, in depth of 9-111 m, in the area between 26.2°S, 113.1°E and 30.9°S, 115.1°E (Figure 4.5). The net was constructed to commercial specifications, using commercially available nylon monofilament meshes and hung with a coefficient of 0.67 between a 20 mm diameter float-core head rope and a 11 mm diameter lead-core ground rope. The number of meshes between the top and bottom of each panel (i.e. the 'mesh drop') was varied so that all panels were approximately equal in depth (Table 4.4), and could be randomly ordered each time the net was deployed on a new vessel. Fork lengths (FL) of all *Carcharhinus plumbeus* captured in each panel of the experimental net, regardless of how they were captured, were recorded. As male and female sharks exhibited no discernible morphological differences in head-shape, it was assumed that their susceptibility to capture in the net was identical and data were not separated by sex for analysis.

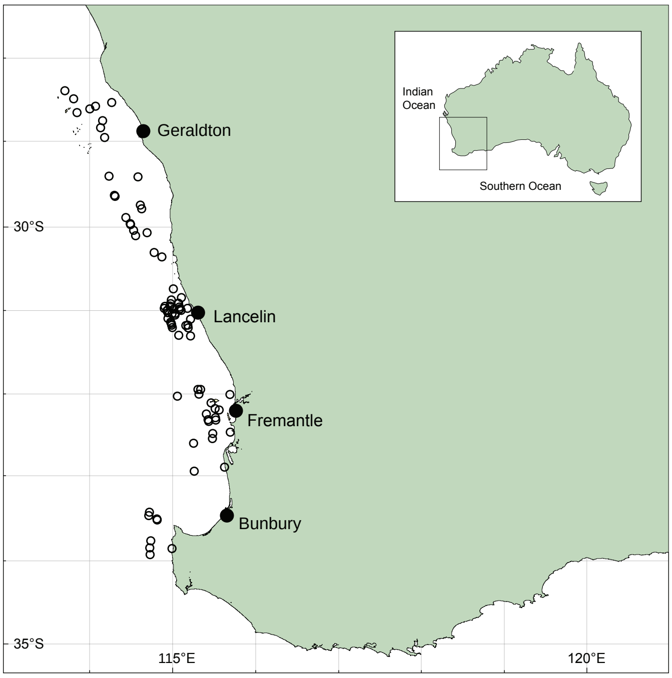


Figure 4.5. Locations of 83 experimental net deployments in SW Western Australia between March 2001 and April 2003.

Table 4.4. Experimental gillnet and individual net-panel specifications. Mesh sizes are the 'stretched' mesh size.

Mesh size (mm)	Mesh drop (n)	Depth (m)	Line diameter (mm)	Net length (m)
102 (4")	33	2.5	0.8	91
140 (5.5")	25	2.6	0.8	113
152 (6")	21	2.4	0.9	108
178 (7")	18	2.4	0.9	105
224 (8.8")	15	2.5	0.9	105
254 (10")	13	2.4	0.9	103

4.2.3.2 Data analysis

The weight of *C. plumbeus* catches from each panel of net was calculated using the relationship given in *4.2.1.2*. Fishing effort was calculated as the product of the length of each net panel and the amount of time for which it was fished and is expressed in units of kilometre gillnet hours (km gn hr). Catch rates were calculated, in terms of numbers of sharks and weight per km gn hr, for each panel and these log transformed catch rates compared by single factor analysis of variance (ANOVA).

Mesh selectivity parameters for *C. plumbeus* were calculated according to the method of Kirkwood and Walker (1986). This method assumes that: (i) the shape of the mesh selectivity curves are best described by a gamma distribution; (ii) each panel has equal fishing power; (iii) the length at maximum selectivity of each panel is proportional to mesh size; (iv) variance is constant for each panel; (v) catches within each length class are independent observations from a Poisson distribution and (vi) sampling occurs across the entire population (Kirkwood and Walker, 1986; McLoughlin and Stevens, 1994; Simpfendorfer and Unsworth, 1998). Gamma distributions were fitted to the length frequency data for each net panel, using the non-linear optimisation function in Microsoft Excel to maximise the log likelihood function:

$$L = \sum_{i=1}^{I}\sum_{j=1}^{J}\left[n_{ij}\ \ln(\mu_j S_{ij}) - \mu_j S_{ij}\right]$$

where n_{ij} is the number of fish from length class *j*, caught by net *i; μ_j is* the relative proportion of length class *j* in the population, given by:

$$\mu_j = \sum_{i=1}^{I} n_{ij} / \sum_{i=1}^{I} S_{ij}$$

and S_{ij} is the mean relative selectivity of mesh size *i* for fish from length class *j*,

$$S_{ij} = \left(l_j / \alpha_i \beta_i\right)^{\alpha_i} \exp\left(\alpha_i - l_j / \beta_i\right)$$

where α and β describe the probability density function of the gamma distribution for net *i*. Values of α and β were calculated from:

$$\alpha_i \beta_i = \theta_1 m_i$$

and

$$\beta_i = -0.5\left[\theta_1 m_i - \left(\theta_1^2 m_i^2 + 4\theta_2\right)^{0.5}\right]$$

where m_i is the mesh size of net *i*, θ_1 is a scaling parameter, which relates the mode of the gamma distribution (α,β) to mesh size and θ_2 is the variance of the distribution.

To estimate the level of uncertainty in parameter estimates, the original length frequency data were randomly re-sampled to generate 500 bootstrapped length frequency datasets for each mesh size. The mesh selectivity model was then refitted to the bootstrapped data to calculate the 95% confidence intervals.

4.2.4 Natural mortality

Natural mortality (*M*) was estimated for *Carcharhinus plumbeus* and *C. obscurus*, using a variety of indirect methods (Table 4.5) including, the age-independent methods of Pauly (1980), Hoenig (1983) and Jensen (1996) and the age-dependent methods of Petersen and Wroblewski (1984) and Chen and Watanabe (1989). These methods rely on values for a variety of biological parameters, which were derived from the empirical data collected during this and previous projects. Although the Petersen and Wroblewski (1984) method is based on a relationship between natural mortality and dry weight of an organism, when calculated with dry weight (using the conversion of dry weight = 0.2 x live weight, from Cortés, 2002), resulting estimates of *M* were inconsistently low relative to estimates from the other methods. Therefore, as suggested by Beerkircher et al. (2003), live weight was used instead for this method. To account for the uncertainty and variability in the empirically measured data, each method was calculated with 1,000 stochastically derived estimates of the required biological parameter(s) and the 95% confidence intervals of the results from each method were determined.

Table 4.5. Methods used to determine natural mortality rates (*M*) for *Carcharhinus plumbeus* and *C. obscurus*. *K* (yr^{-1}) and L_∞ (cm FL) are parameters of the von Bertalanffy growth curve; *T* = average water temperature (= 24°C, McAuley, unpublished data); t_{mat} = age at maturity (years); t_{max} = maximum age (years); *Z*, total mortality ($year^{-1}$); *wt* = live weight (kg).

Method	Relationship	Developed for
Age independent methods		
Pauly (1980)	$\ln(M) = -0.0066 - 0.297.\ln(L_\infty) + 0.6543.\ln(K) + 0.4627.\ln(T)$	175 fish stocks (including 2 shark species)
Hoenig (1983)	(i) $\ln(Z) = 1.46 - 1.01.\ln(t_{max})$	Teleosts
	(ii) $\ln(Z) = 0.941 - 0.873.\ln(t_{max})$	Cetaceans
	(iii) $\ln(Z) = 1.44 - 0.982.\ln(t_{max})$	Molluscs, teleosts and cetaceans
Jensen (1996)	(i) $M = 1.65/t_{mat}$	Theoretical
	(ii) $M = 1.5\,K$	Theoretical
Age independent methods		
Petersen and Wroblewski (1984)	$M_{wt} = 1.92wt^{-0.25}$	Particle-size theory and pelagic ecosystem data
Chen and Watanabe (1989)	$M(t)=\begin{cases}\dfrac{K}{1-e^{-K(t-t_0)}}, & t \le t_m \\ \dfrac{K}{a_0+a_1(t-t_m)+a_2(t-t_m)^2}, & t \ge t_m\end{cases}$	Theoretical
where:	$\begin{cases}a_0 = 1-e^{-K(t_M-t_0)} \\ a_1 = Ke^{-K(t_M-t_0)} \\ a_2 = -\frac{1}{2}K^2e^{-K(t_M-t_0)}\end{cases}$	
and:	$t_M = -\frac{1}{K}\ln\left(1-e^{Kt_0}\right)+t_0$	

Values of age at maturity t_{mat} (used in Jensen, 1996 and Chen and Watanabe, 1989) were derived from 1000 estimates of the lengths at which 50% of sharks were mature ($L_{0.5}$), stochastically estimated combinations of the von Bertalanffy growth parameters *K* and L_∞ and a known size at birth (L_0) of 42.5 cm. Estimates of $L_{0.5}$ were generated by randomly re-sampling (with replacement) the emprical maturity-at-length data to create 1000 new 'bootstrapped' datasets and then re-fitting the logistic maturity function (given in *4.1.4*) to each. Values for the von Bertalanffy parameters, *K* and L_∞ (also used in Pauly, 1980; Jensen, 1996 and Chen and Watanabe, 1989) were derived by re-sampling the empirical length-at-age data determined from vertebral analysis, to create 1000 new datasets and re-fitting the modified form of the growth curve (given in *4.1.3*) to each, through the known size at birth of 42.5 cm FL. Values of t_0 (used in Chen and Watanabe, 1989), were derived from each of the resulting estimates, using the standard definition of the von Bertalanffy curve:

$$L_t = L_\infty\left[1-e^{-K(t-t_0)}\right]$$

Based on the results of vertebral analysis and the maximum observed sizes of *C. plumbeus* during this and previous studies, maximum age, t_{max} (used in Hoenig, 1983), was determined to be between 30 and 40 years, i.e. the probability (*P*) of 30≤ t_{max}<40 = 1. The probability of maximum age being greater than 30 was assumed to decrease in a linear fashion by 10% yr^{-1}, until there was a zero probability that it was 40 years, i.e. $P(t_{max} = 31) = 0.9$, $P(t_{max} = 32) = 0.8$…. $P(t_{max} = 40) = 0.0$. Probabilities were scaled, so that their cumulative probability was 1 and values for t_{max} were inversely-selected at random from within the cumulative probability distribution. The same approach was taken in estimating maximum age of *C. obscurus*. Based on the results of vertebral analysis (Simpfendorfer et al. 2002), t_{max} was determined to be at least 40 years. Although Simpfendorfer et al (2002) and Natanson and Kohler (1996) have suggested that maximum age could be as high as 60 or 70 years, given the maximum observed size in Australia (365 cm TL, Last and Stevens, 1994), these estimates appear excessive. Therefore, maximum age was assumed to be less than 56 years, so that the probability (*P*) of 40≤ t_{max}<56 decreased by 6.25% yr^{-1}, until there was a zero probability that it was 56 years.

4.2.5 Fishing mortality

4.2.5.1 Sandbar sharks

Age specific rates of fishing mortality experienced by *Carcharhinus plumbeus* during the 2001/02, 2002/03 and 2003/04 fishing seasons (July-June) were derived from reported recapture rates of 1,759 tagged sharks. Tagged sharks were released in waters between Cape Leveque (16°S, 123°E) and Cape Leeuwin (34°S, 115°E, Figure 4.6) between August 2000 and June 2004 according to the methods given in *4.1.2*. In addition to recording the fork length, sex, date, location and depth of each release, the condition of tagged sharks was assessed on release as either: 1 (swam away strongly), 2 (swam away slowly) or 3 (sluggish or unable to swim away). Sharks with a release conditions of 3 or which exhibited other signs of being adversely affected by capture or tagging (such as bleeding from the gills) were excluded from the data used to determine recapture rates (n=88). To ensure tagged sharks had been allowed adequate time to mix into the population, recaptures of sharks that were at liberty for less than 90 days (n=9) were also excluded from determination of recapture rates. Recaptures reported by recreational fishers (n=3) were also excluded as these sharks were either reported or assumed to have been released alive, as was the single tag recapture during a fishery-independent research-cruise in August 2003. A total of 1,654 tagged *C. plumbeus* were therefore used for analysis of recapture rates.

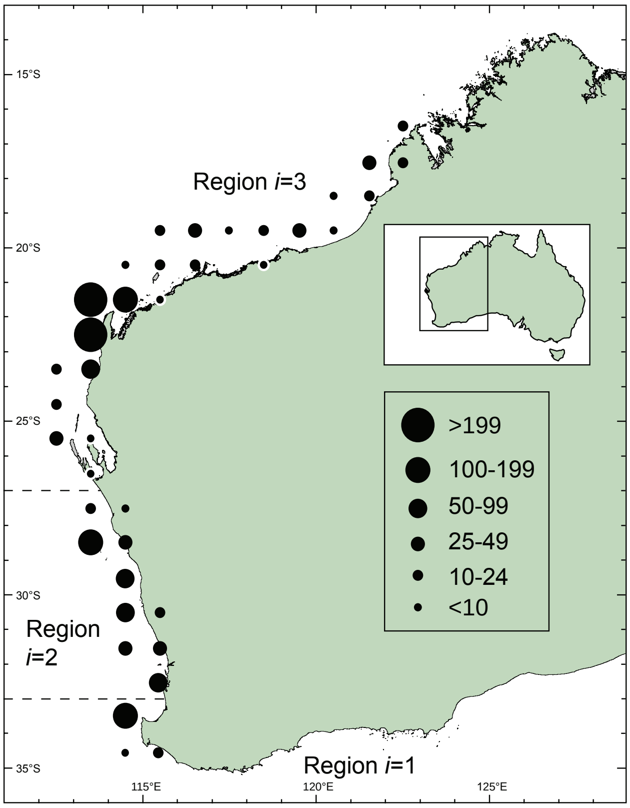


Figure 4.6 Release locations of 1,654 tagged *C. plumbeus*, used in determination of fishing mortality rates, showing the area closed to shark fishing between NW Cape (114º 06'E) and Steep Point (26º 30'S) and regions used for determining tag non-reporting rates.

Information on tag recaptures was received from commercial and recreational fishers and from research staff during collection of samples from commercial catches and during fishery-independent sampling. Recapture data included the date and location of recapture, length, sex, and condition of the shark and tag. The recapture rates of *C. plumbeus* tagged inside the area between Steep Point and NW Cape, which has been closed to targeted shark fishing since the 1970s, were compared with the recapture rates of sharks tagged in open areas to examine whether this closure afforded the stock any substantive protection.

To account for unreported tag recaptures, tag reporting behaviour was assessed separately for three regions (Figure 1), corresponding to the areas of the JASDGDLF (i=1), WCDGDLF (i=2) and the northern shark fisheries (i=3), using the method of Simpfendorfer (1999). Fishers were classified as either "reporters" or "non-reporters" depending on whether they returned any tag information within a year. Regional non-reporting rates were then estimated as the proportion of each region's annual *C. plumbeus* catch that was taken by "non-reporting" fishers. Catch figures were taken from compulsory monthly catch and effort returns supplied by all commercial fishers. The estimated number of recaptures of x year old tagged sharks during each month ($\hat{C}_{x,t}$) between July 2001 and June 2004, was calculated as:

$$\hat{C}_{x,t} = \sum_{i=1}^{i=3} \frac{C_{x,i,t}}{1 - D_{i,T}}$$

where $C_{x,i,t}$ is the number of reported recaptures of x year old sharks in region i during month t and $D_{i,T}$ is the non-reporting rate in region i during year T.

The number of tagged sharks of age *x* that were present in the population at the start of month $t+1$ ($n_{x,t+1}$) was calculated as:

$$n_{x,t+1} = \left(n_{x,t} - \hat{C}_{x,t}\right)e^{-(M_x+S)/12} + R_{x,t} \ ,$$

where $n_{x,t}$ is the number of tagged sharks present in the population at the start of month t, M_x is the instantaneous annual natural mortality rate of age-class x, S is the instantaneous annual tag shedding rate of 0.0358 yr^{-1} calculated for *C. obscurus* (Simpfendorfer, 1999) and $R_{x,t}$ is the number of sharks of age x tagged in month t. As results from reproductive sampling indicated that parturition in this population peaks between January and April, tagged sharks were assumed to move from age-class x into $x+1$ on the first of March each year.

The instantaneous annual rate of fishing mortality experienced by age class x during fishing season T, ($F_{x,T}$), was then derived from the Baranov catch equation (eg. Ricker, 1975; Quinn and Deriso, 1999):

$$\hat{C}_{x,T} = \frac{F_{x,T}}{Z_{x,T}}.n_{x,T}\left(1 - e^{-Z_{x,T}}\right),$$

where $Z_{x,T}$ is the instantaneous annual total mortality rate.

Since small numbers of recaptures from age classes in which the number of tagged sharks was low resulted in unrealistically high fishing mortality rates and because tag recaptures were not reported for all age classes in each year, it was necessary to modify the age-specific rates to provide a better representation of actual fishing mortality rates. This was achieved by pooling the tagging data from each 3-year age-class to 17+ years and from sharks aged between 18+ and 24+ years. As no sharks older than 24 years were tagged, fishing mortality of sharks older than this was assumed to decrease uniformly from the rate experienced by the 18-24+ year old age-class, in each subsequent year-class, until F was zero for sharks older than 30+ years of age. These multi-year age class rates, which are referred to as $\hat{F}_{2001/02}$, $\hat{F}_{2002/03}$ and $\hat{F}_{2003/04}$ respectively, are believed to provide the best representation of the actual levels of fishing mortality experienced by the *C. plumbeus* stock over the three years of the tagging project. These rates have therefore been used as the basis for providing formal advice on the status of the Western Australian sandbar shark stock.

4.2.5.2 Dusky sharks

The three schedules of exploitation tested in the previous dusky shark assessment, i.e. no fishing and the exploitation rates experienced by sharks released as neonates in 1994 and 1995 (Simpfendorfer et al., 1999; Simpfendorfer, 1999), were reassessed using updated empirical biological information in the new demographic model. In addition to the previously estimated exploitation rates, longer-term tagging data were used to re-estimate age-specific fishing mortality rates of the 1994 and 1995 tagged 'cohorts' using the Baranov catch equation. To do this, it was also necessary to re-estimate the non-reporting rates of tag recaptures using the new dataset of validated catches by the temperate demersal gillnet and demersal longline fisheries (see *4.2.1.1*). These were calculated for the same three regions as *C. plumbeus* used in the previous assessment (Figure 4.6). The previously estimated rate of tag-shedding was also used in determining fishing mortality rates of *C. obscurus*.

4.3 Stock assessment

4.3.1 Demographic analysis of *Carcharhinus plumbeus*

Demographic analysis was undertaken using standard life table techniques (e.g. Krebs, 1985) to test the effects of the estimated levels of fishing mortality on the Western Australian *C. plumbeus* stock. This technique is widely accepted as being the most appropriate method for assessing the status of long-lived elasmobranch species such as *C. plumbeus* (e.g. Hoenig and Gruber, 1990; Cailliet, 1992; Cortés, 1995; Cortés and Parsons, 1996; Smith et al., 1998; Simpfendorfer, 1999; Cortés, 1999; Brewster-Geisz and Miller, 2000; Cortés, 2002; Mollet and Cailliet, 2002; Simpfendorfer, 2004). Unlike other more sophisticated population-simulation models that rely on extensive and long-term information about catches, fishing effort, abundance, etc., demographic analysis is primarily based on biological parameters (particularly, age at maturity, maximum age and fecundity) and estimates of total mortality. In effect, demographic models calculate the survival of each age class in a population and the amount that each age class contributes to replenishment of the population.

The principal result from demographic analysis is generally referred to by ecologists as the rate, or current rate, of population increase (r). However, because this technique inherently assumes (unless specified otherwise) that all breeding-age females in a population contribute to its replenishment, r should more correctly be viewed as the maximum potential rate of population increase under the prescribed biological constraints. It has therefore become convention in demographic analysis of shark populations to describe r, as the intrinsic rate of population increase. Yet, this terminology can be easily confused with ecologists' interpretation of intrinsic rate of population increase, which is the maximum possible rate of population growth when population density is low and all other environmental conditions are optimal (often referred to as r_{max}). Whilst 'density-dependent' responses to population depletion, such as a reduction in age at maturity or increased survival are well recognised in other fish stocks (e.g. Jennings et al., 2001; Walters and Martell, 2004), there is little empirical evidence for such changes in shark populations. Also, given the highly conservative ('*k*-selected') demographic characteristics of the Western Australian *C. plumbeus* stock, it is likely that any density-dependent changes in its life history would take many decades to be detectable. Therefore, to avoid confusion, r is referred to here as the (current) capacity for population growth. Regardless of terminology, positive values of r indicate a population with the biological capacity to grow and negative values indicate population decline. The value of fishing mortality that would provide the maximum sustainable yield (F_{MSY}), when applied equally to all age classes, was calculated as $F_{MSY}=r/2$ (Ricker, 1975). In addition to estimating r, the demographic model was also used to calculate the net reproductive rate per generation (R_o), generation time (G), population doubling time (t_{x2}), proportion reaching maturity (PM) and the stable age distribution (C_x), for each schedule of mortality.

For each scenario of fishing mortality, the demographic model was calculated with 1000 sets of stochastically estimated biological parameters and natural mortality rates (derived by randomly re-sampling from the estimates obtained in 5.1 and 5.2, respectively), so that the mean and 95% confidence intervals of model results could be determined. The biological parameters used in the model were derived by re-sampling (with replacement) the empirical data collected during this project.

Life tables were based on the Euler-Lotka equation:

$$\sum_{x=\alpha}^{w} l_x e^{-rx} m_x = 1.0,$$

where l_x is the proportion of females surviving to age x, m_x is the fecundity (ie number of female offspring produced per female) at age x, α is the age at maturity and w is the maximum reproductive age.

Fecundity (m_x) was calculated by multiplying litter size by the proportion of female embryos and dividing by the number of years between litters. Values for litter size and the proportion of female embryos in each litter were randomly selected from normal distributions with means and standard deviations equal to the values of the empirical data (see *5.1.4.2*). The distribution for proportion of female embryos was truncated at zero and one to avoid negative values and values >1. As there was no indication from the analyses of reproductive data that breeding periodicity varied from 2 years, this value remained fixed. Values of female age at maturity (α) and maximum reproductive age (w) were derived according to the methods for t_{mat} and t_{max} in 4.2.4.

The proportion of the population surviving at the beginning of each age class was derived from the modified survival equation:

$$l_x = l_{x-1}(1 - F_{x-1})e^{-M_{x-1}},$$

where F_x is the instantaneous rate of fishing mortality of age-class x (see 4.2.5) and M_x is the instantaneous rate of natural mortality of age-class x (see 4.2.4).

Each schedule of annual age-specific ($F_{2001/02}$, $F_{2002/03}$ and $F_{2003/04}$, respectively) and multi-year age class fishing mortality ($\hat{F}_{2001/02}$, $\hat{F}_{2002/03}$ and $\hat{F}_{2003/04}$) was applied separately in the demographic model, with each of the rates of natural mortality calculated in 4.2.4., to assess how the Western Australian *C. plumbeus* population was affected by fishing over this three year period.

4.3.2 Refining the dusky shark, *Carcharhinus obscurus*, stock assessment

The status of the Western Australian dusky shark, *Carcharhinus obscurus*, stock was reassessed using the demographic model developed for sandbar sharks. Whilst the previous assessment has provided a sound basis for recent management of this stock, it primarily relied on biological information derived from *C. obscurus* populations in the western North Atlantic and western Indian Ocean. Also, the deterministic framework of the previous model was unable to fully explore the possible effects of uncertainty and variability in the stock's demographic rates. Additionally, longer-term tagging data is now available to estimate the fishing mortality rates of some older age classes. The new assessment therefore incorporates empirically measured data from the WA *C. obscurus* stock and updated exploitation rate data collected over the course of this project and during FRDC projects 93/067 and 96/130.

Litter size was randomly selected from within the range of the mean observed litter size ± its standard deviation. As there were no empirical data to suggest that embryonic sex ratio differed significantly from 1:1, the proportion of female embryos was selected from within a range with a mean of 0.5 and a standard deviation of 0.1. Values of female age at maturity (α) were determined by applying the same methods described for *C. plumbeus* (see 4.2.4.) to *C. obscurus* maturity at size data and stochastically estimated combinations of the von Bertalanffy growth parameters K and L_{∞}. Female length at age data were re-sampled from the data given by Simpfendorfer et al (1999) and Simpfendorfer et al (2002) and the von Bertalanffy curve was re-fitted, assuming a size at birth of 75.3cm FL (Simpfendorfer et al, 1999; Simpfendorfer et al, 2002). Based on the results of vertebral analysis (Simpfendorfer et al, 1999; Simpfendorfer et al, 2002) and using the same method as was used for *C. plumbeus* (4.2.4), the probabilities of maximum age being between 40 and 55 were scaled, so that their cumulative probability was 1 and values for w were inversely-selected at random from within the cumulative probability distribution. Breeding frequency could not be adequately estimated from the available empirical data. The previous assessment assumed that females produced a litter every three years, although tested the sensitivity of the stock's demographic rates for two and four year breeding periods. The current assessment was therefore conducted with five different scenarios of breeding frequency: two years, three years, four years, two or three years and two, three or four years. While two-year reproductive cycles are typical for the genus Carcharhinus, it has also been suggested that *C. obscurus* exhibits a two-year gestation and is therefore likely to have a three-year breeding cycle (GSAFDF, Simpfendorfer, 1999). Therefore, Scenario D (2-3 year periodicity) is thought most likely to encompass the actual breeding frequency of this stock. Rates of natural mortality were also estimated according to the methods described for *C. plumbeus* in 4.2.4.

5.0 Results

5.1 Biology of *Carcharhinus plumbeus*

5.1.1 Distribution and regional size structure

Data from 7,497 *Carcharhinus plumbeus* (7,387 from the current project, 90 from the Pilbara Trawl Fishery bycatch survey and 20 from the May 2000 drum-line survey), were examined to determine the species' distribution and regional differences in the size composition of the stock. The majority of specimens (n=6,478) were sampled from commercial catches, whilst 1,019 were derived from fishery-independent catches. Of the commercially-derived samples, 5,039 were caught by demersal gillnets between Shark Bay (26ºS) on the west coast and Point D'Entrecasteaux (116ºE) on the south coast, 54 were caught by demersal longlines between Shark Bay and a latitude of 32ºS on the west coast, 1,279 were caught by demersal longlines between North West Cape (22ºS 114ºE) and longitude 123ºE on the north coast and 90 were caught by fish trawl between 116ºE and 120ºE on the north coast. Of the 1,019 research-derived samples, 239 were caught by demersal longlines between Shark Bay and latitude 34ºS on the west coast, 758 by demersal longlines between Shark Bay and longitude 122ºE on the north coast, 20 by drumlines in the North West Cape region and two by demersal gillnets off Eighty-mile Beach during fishery-independent research cruises. The distribution and characteristics of sampling effort are summarised in Table 5.1. Capture locations are shown in Figure 4.1.

Table 5.1. Distribution and characteristics of *Carcharhinus plumbeus* sampling effort between July 2000 and June 2003.

Method	Region	No. shots	Depth range (m)	Mean net length (m)	Mean soak time (hr)	Mean No. hooks	No. caught
Gillnet	North of 26° S	81	4-101	290	8	-	2
	South of 26°S	730	9-121	1835	20	-	5,039
Longline	North of 26°S	413	8-225	-	5	128	2,053
	South of 26°S	126	35-142	-	12	79	293
Trawl	North of 26°S	426	47-112	-	3	-	90
Total		1,776	4-225				7,497

The smallest free-swimming male and female sharks (which were both caught by gillnets in the temperate fishery, i.e. south of 26°S) were 40 cm FL and 44.5 cm FL, respectively. The largest observed male and female sharks measured 165 cm FL and 166 cm FL, respectively. The 166 cm female was caught by gillnet south of 26°S, whilst 165 cm males were caught south of 26°S by gillnet (n=1) and by longline (n=1). The relationships between FL and TL for post-natal sharks are described by the equations: TL=1.1175.(FL)+6.3017 (n=878, r^2=0.9844) for males, TL=1.11262.(FL)+5.8188 (n=895, r^2=0.9858) for females and TL=1.1224.(FL)+6.0037 (n=1773, r^2=0.9852) for both sexes combined. Male and female FL to TL regressions were significantly different (ANCOVA, F=5.53; df=2, 1769; P=0.041).

Smaller sharks were prevalent in longline and gillnet catches from south of 26°S and larger sharks were more common in northern longline and trawl catches (Figure 5.1). The size distribution of sharks caught by longline in the southern region was unimodal for males, with a peak at 70-75 cm and weakly bimodal for females with the major peak at 75-80 cm and a minor peak at 140-150 cm (Figure 5.1a). The size distribution of *C. plumbeus* caught in commercial gillnets in the south was weakly bimodal for both sexes, with the major peak at 75-90 cm and a minor peak at 130-135 cm for males and at 80-85 cm and 140-145 cm for females (Figure 5.1b). Larger sharks (>120 cm FL) were more dominant in longline and trawl catches in the northern region (Figures 5.1c and 5.1d, respectively). The size distribution of sharks in the northern longline and trawl samples were both unimodal, with peaks of 135-140 cm for males and 145-150 cm for females and 130-140 cm for males and 140-150 cm for females, respectively.

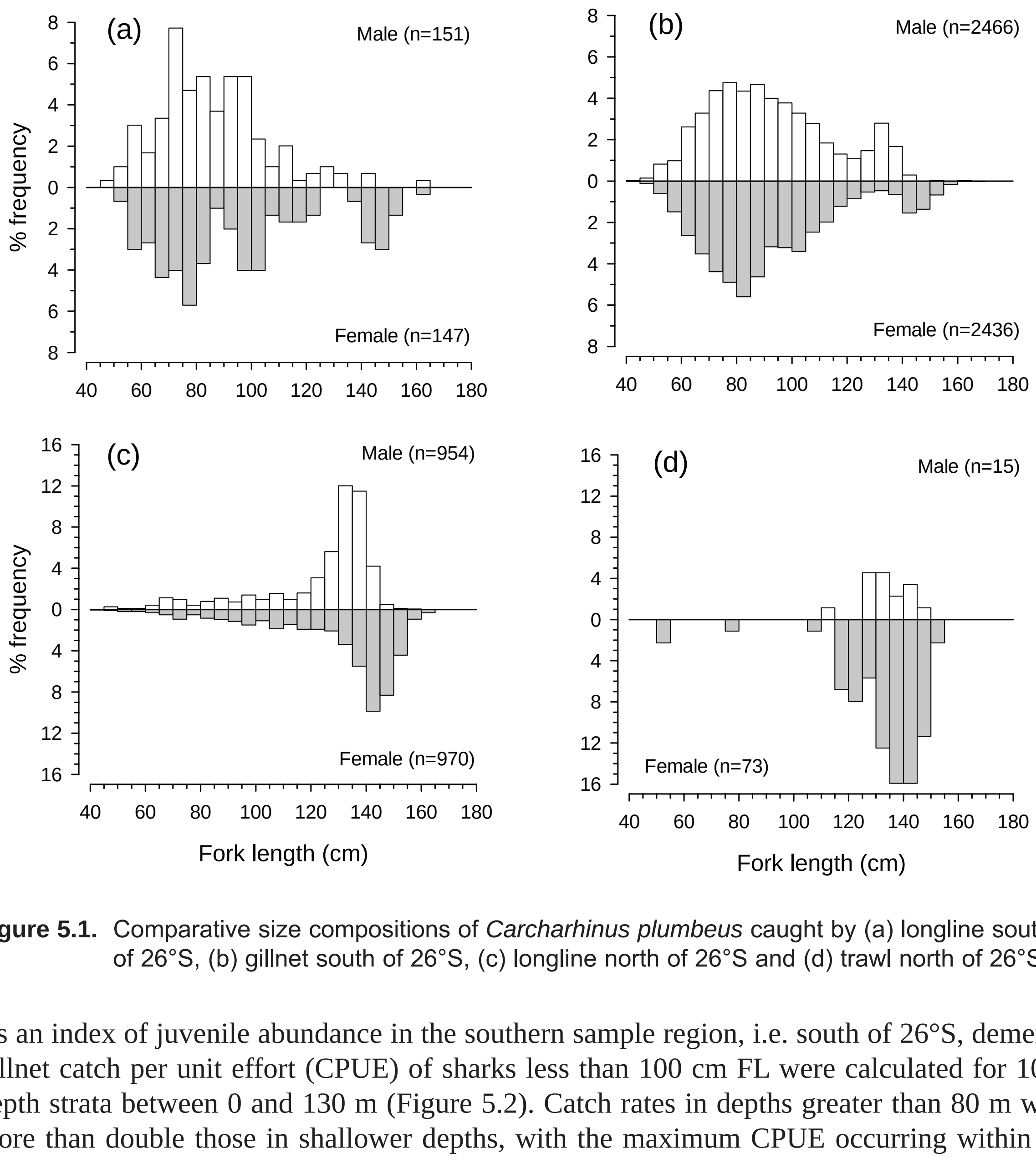


Figure 5.1. Comparative size compositions of *Carcharhinus plumbeus* caught by (a) longline south of 26°S, (b) gillnet south of 26°S, (c) longline north of 26°S and (d) trawl north of 26°S.

As an index of juvenile abundance in the southern sample region, i.e. south of 26°S, demersal gillnet catch per unit effort (CPUE) of sharks less than 100 cm FL were calculated for 10 m depth strata between 0 and 130 m (Figure 5.2). Catch rates in depths greater than 80 m were more than double those in shallower depths, with the maximum CPUE occurring within the 120-130 m stratum, although there was only a small amount of observed effort in depths greater than 120 m. After excluding data from the 0-10 m, 110-120 m and 120-130 m strata due to the low levels of observed effort, there was a statistically significant (ANOVA, r^2=0.90, F=102.34, P<0.0001) increase in CPUE with mean stratum depth between 10 m and 110 m.

The majority of neonate sharks (n=34), which were identified by the presence of a visible umbilical scar, were caught south of 28°S (Figure 5.3), in depths of 28-119 m. However, two neonates were caught as far north as Broome (17°S 121°E) in 84 m depth and small numbers were also caught at North West Cape (21°S 114°E, n=2) in depths of 100-197 m and off Ningaloo Reef (23°S 112°E, n=2) in a depth of 145 m.

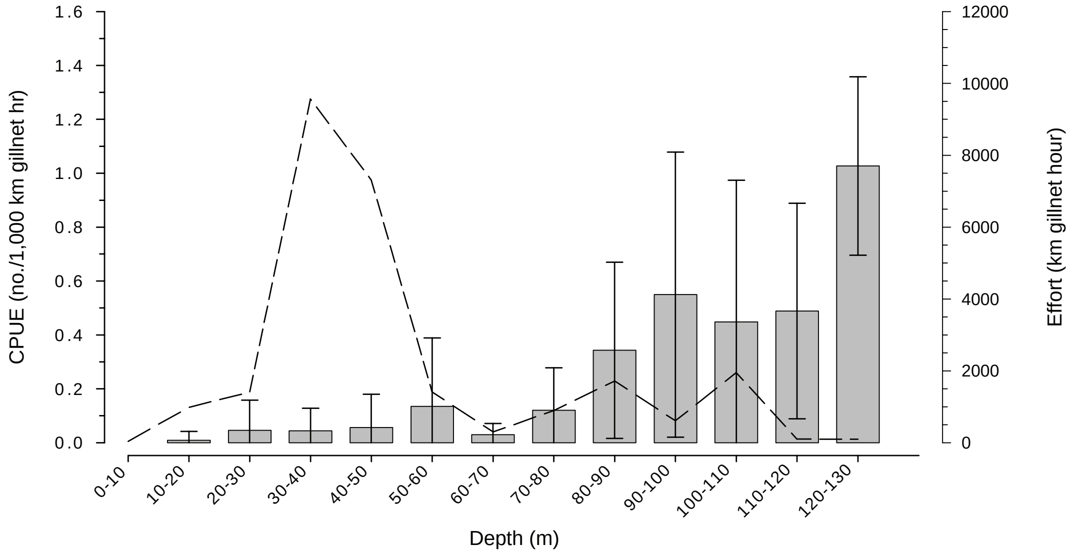


Figure 5.2. Mean Catch Per Unit Effort of *Carcharhinus plumbeus* with FL<100 cm in waters south of latitude 26°S, by 10 m depth stratum, between May 2000 and June 2003. Error bars indicate one standard deviation. Broken line shows observed effort.

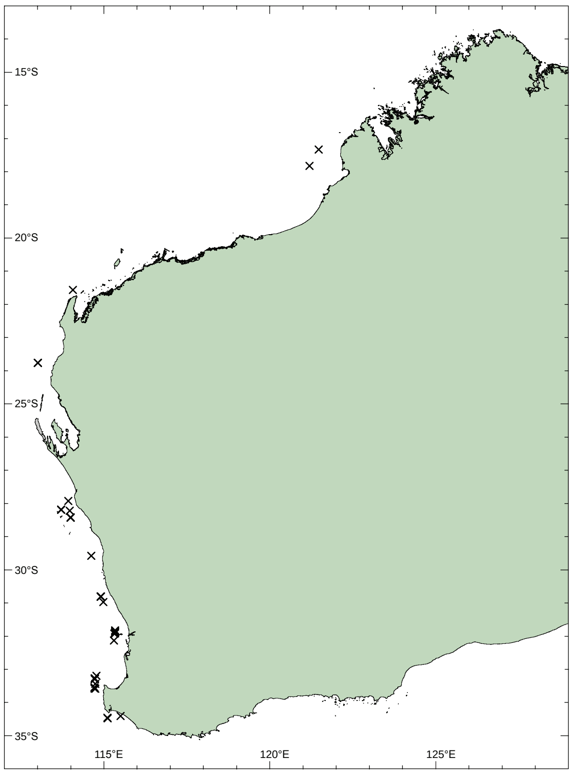


Figure 5.3. Capture locations of 40 neonate *Carcharhinus plumbeus*.

5.1.2 Movement

Recapture data were obtained for 154 tagged *Carcharhinus plumbeus*, equating to 7.2% of the sharks tagged since March 1994. Sharks for which data were returned were caught between 20/3/95 and 3/9/04 in waters between 19°S, 118°E on the north coast and 35°S, 119°E on the south coast (Figure 5.4a). Tagged sharks were recaptured between 0 and 2,963 days after their release, with a mean time at liberty of 493 days (Figure 5.5a). The majority of recaptures occurred at displacement distances, measured as straight lines between release and recapture locations, of less than 250 km (mean displacement of 213 km), although four tags were returned from distances of over 1,000 km from their release locations (Figure 5.5b). The largest displacement was by a male shark, which measured 75 cm FL at its release on 25/3/96 near Hopetoun on the south coast, which was recaptured on 5/5/04, 1,582 km away on the north coast (Figure 5.4b). There was no significant difference in the proportions of males and females recaptured (0.0702 and 0.0745, respectively, $\chi2$=0.0809, *df*=1, *P*=0.7761).

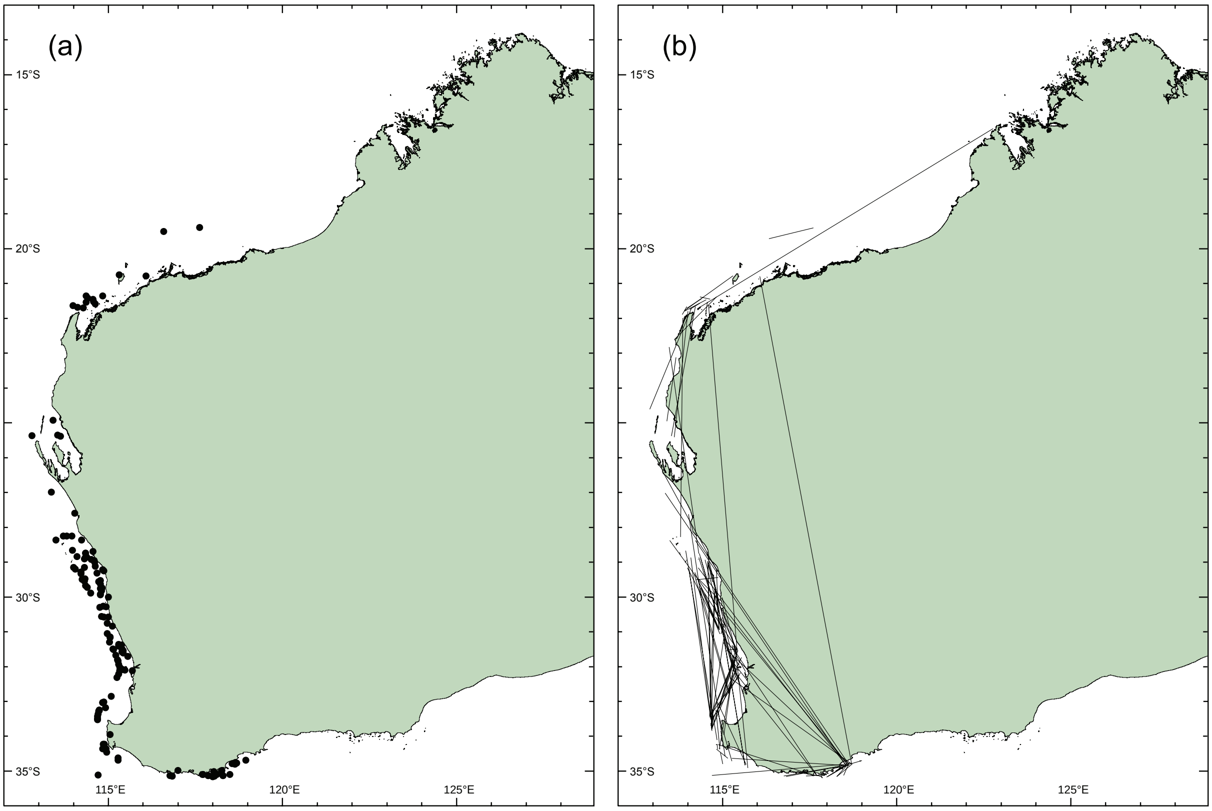


Figure 5.4. (a) Recapture locations and (b) displacement vectors of 141 *Carcharhinus plumbeus* tagged between March 1994 and June 2004.

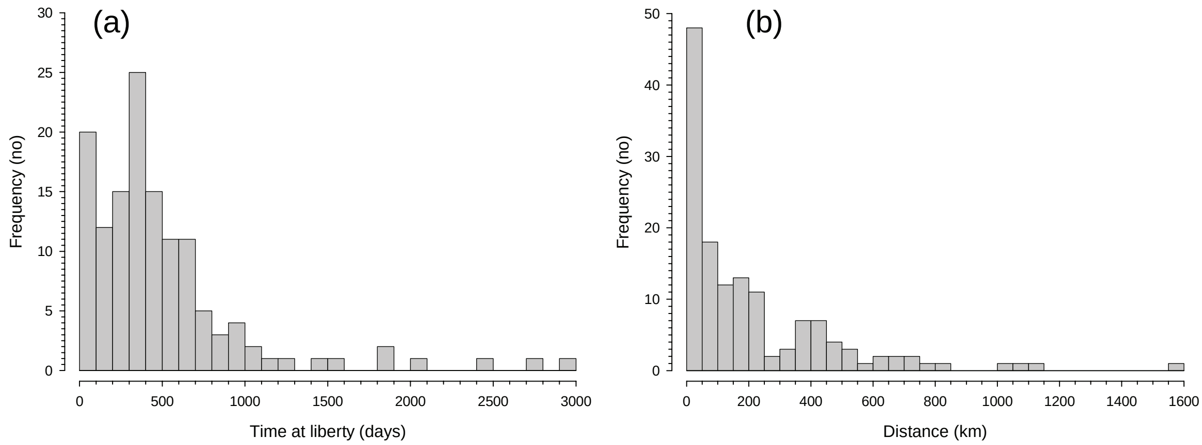


Figure 5.5. (a) Time at liberty and (b) displacement distance histograms of *Carcharhinus plumbeus* tag recaptures, for which (a) recapture dates were recorded (n=133) and (b) recapture locations were (n=141).

Although there was a significant linear increase in displacement distance with increased time at liberty (r^2=0.6802; ANOVA, *df*=133, *P*<0.0001), data from several tagged sharks differed substantially from this trend (Figure 5.6). Notable exceptions included a 141 cm FL at release male shark that was recaptured at North West Cape, 1,065 km from its release location (Cape Leveque), less than one year after his release and a 79 cm FL female shark that was recaptured 25 km from where she was tagged after nearly four years (1,445 days) at liberty. The slope of the regression between displacement distance and time at liberty (i.e. the expected dispersal rate of tagged sharks) was 2.8 km day^{-1}.

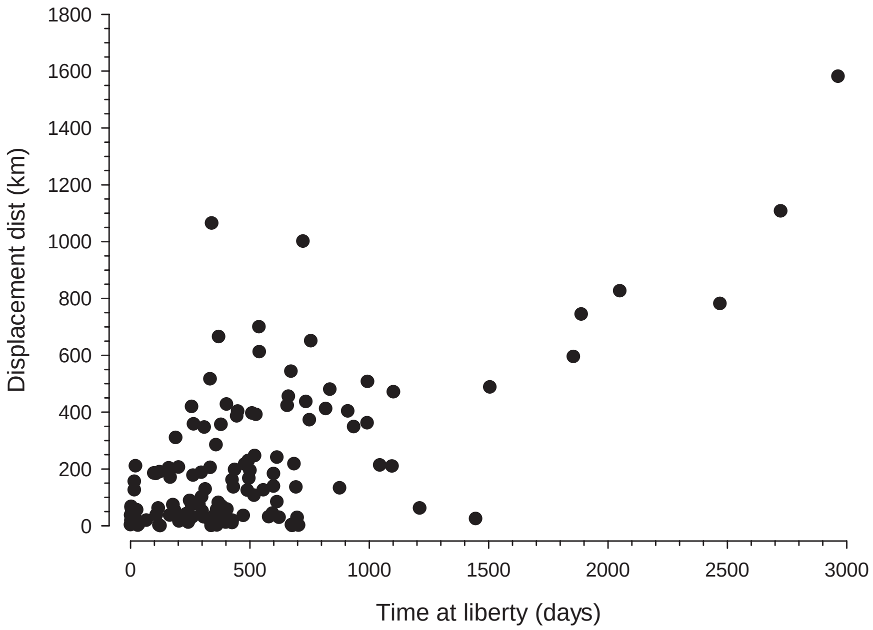


Figure 5.6. Time distance plot of 133 *Carcharhinus plumbeus* tag recaptures for which both recapture dates and locations were returned.

Between 63% (South Coast) and 81% (Lower West Coast) of tag recaptures occurred within the same region as sharks were released (Table 5.2). However, sharks that were tagged on the south and lower west coasts, were also recaptured in all other regions, whilst (with one exception) sharks tagged in the upper west coast and north coast regions were only recaptured within those regions. Although the mean time at liberty and displacement distance were highest for sharks tagged in the South Coast region (Table 5.3), there were no significant differences in either time at liberty (ANOVA, *F*=1.959, *df*=3, *P*=0.123) or displacement distances (ANOVA, *df*=3, *P*=0.182) between regions.

Table 5.2. Release and recapture regions of 141 tagged *Carcharhinus plumbeus* for which recapture locations were returned.

Release Region	Recapture Region South Coast	Lower WC	Upper WC	North Coast	Total
North Coast	-	-	3(23%)	**10(77%)**	13
Upper WC	-	1(10%)	**7(70%)**	2(20%)	10
Lower WC	3(4%)	**61(81%)**	10(13%)	1(1%)	75
South Coast	**27(63%)**	11(26%)	4(9%)	1(2%)	43
Total	30	73	24	14	141

Table 5.3. Regional summary of time at liberty and displacement statistics.

Release Region	Release (n)	Time at Liberty (days) (n)	Mean (min-max)	Displacement (km) (n)	Mean (min-max)
North Coast	633	13	460(178-910)	13	246(11-1065)
Upper WC	575	10	234(31-369)	10	195(0-666)
Lower WC	656	70	466(2-2723)	75	172(1-1108)
South Coast	243	40	639(0-2963)	43	278(2-1582)
Total	2107	133	500(0-2963)	141	213(0-1582)

Tag dispersal rates within each region were also similar (Figure 5.7). The only significant difference in regional dispersal rates was that of sharks tagged in the Lower West Coast region, which, at 3.5 km day^{-1}, dispersed faster than the overall rate (ANCOVA, *df*=2, *P*=0.0379). Sharks tagged in the Upper West Coast region dispersed least rapidly at 1.4 km day^{-1}.

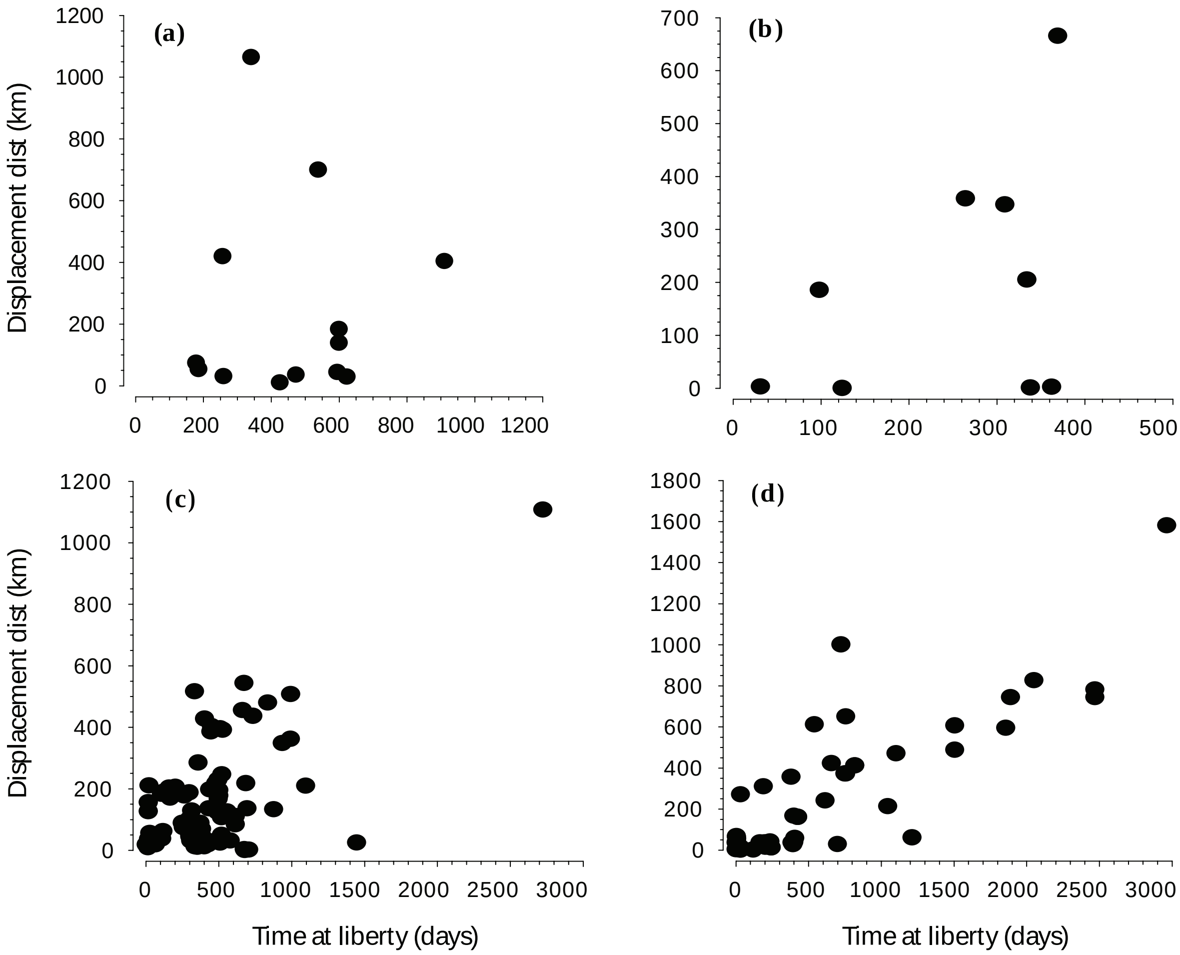


Figure 5.7. Time distance plots of *Carcharhinus plumbeus* tag recaptures for which both capture date and locations were returned of (a) sharks tagged in the North Coast region, (b) sharks tagged in the Upper West Coast region, (c) sharks tagged in the Lower West Coast region and (d) the South Coast region.

Sharks tagged in the South and Lower West Coast regions were mainly caught to the north or north-west of their release locations (Figure 5.8c and 5.8d, respectively). The mean displacement vector bearings (i.e. directions between release and capture locations) of sharks tagged in these regions were 302° (n=43, circular standard deviation=77.2°) and 345° (n=75, circular standard deviation=76.9°), respectively. Sharks tagged in the Upper West and North Coast regions, on the other hand exhibited a greater degree of easterly movement and less uniform directionality. Mean displacement vector bearings from these regions were 101.7° (n=10, circular standard deviation=125.7°, Figure 5.8c) and 60.9° (n=13, circular standard deviation=76.9°, Figure 5.8d), respectively.

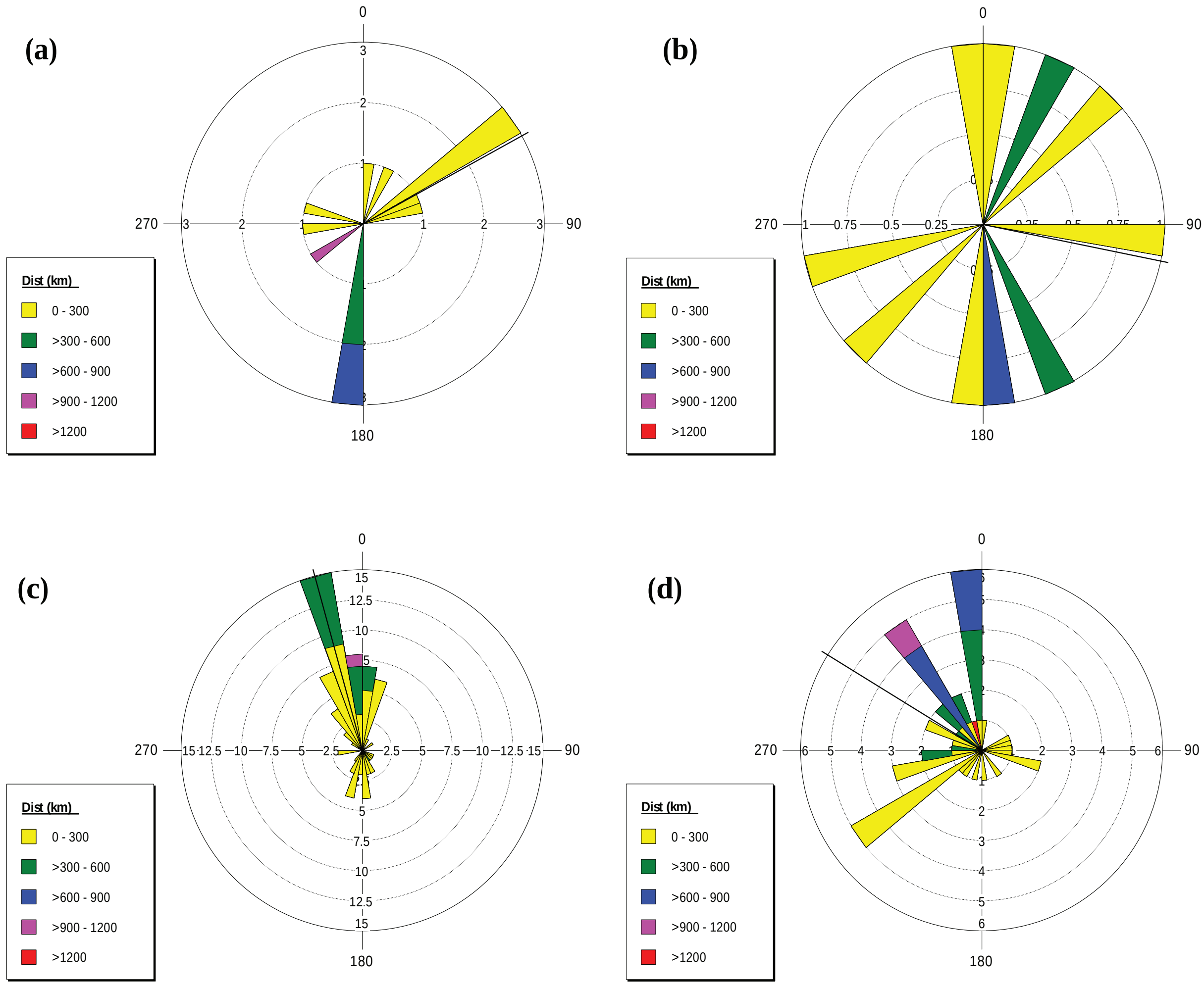


Figure 5.8. Frequency distributions of recapture displacement distance (km) and displacement vector bearing, by 10° increments, of 141 *Carcharhinus plumbeus* tagged in the (a) North Coast region, (b) Upper West Coast region, (c) Lower West Coast region and (d) South Coast region.

5.1.3 *Age and growth*

5.1.3.1 *Validation of growth band periodicity and seasonality*

Capture details and centrum sections were obtained were received from 29 injected sharks, which were at liberty for between 16 and 2,963 days. Of these, 22 were marked with calcein and 7 with OTC. Fluorescing marks were visible in all sections from calcein-marked sharks, however, could not be detected in sections from two OTC-injected sharks, which had been at liberty for 31 and 2723 days. There was a highly significant linear relationship between the number of complete growth bands counted after the injection marks and times at liberty (ANOVA, r^2=0.972, F=945, P<0.0001, Figure 5.9). The slope of this regression was 1.02 (SE=0.033), demonstrating that growth bands were formed annually.

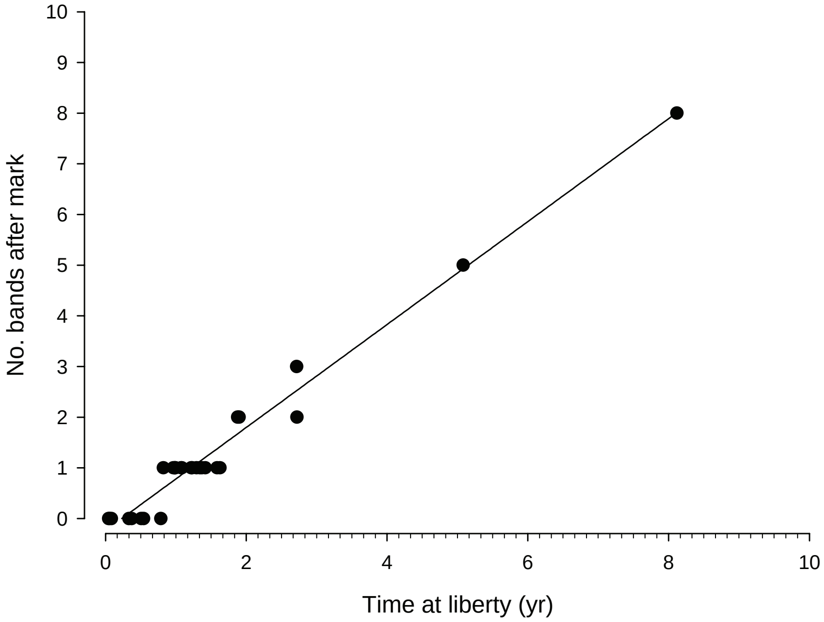


Figure 5.9. Number of growth bands counted after OTC or calcein mark in 29 sectioned *Carcharhinus plumbeus* centra.

Opaque band formation was estimated to take between 175 and 336 days (median=259 days), whilst translucent bands were formed over periods of 29-190 days (median=106). There appeared to be some degree of seasonality in growth band formation. Estimates of increment start dates were reasonably consistent with the formation of a new opaque zone in spring or summer (Figure 5.10). Growth increment start dates in the year(s) of tagging were estimated to be between April and February, however most (76%) began forming between August and January. Translucent band formation was also calculated to have occurred throughout the year, however, in 76% of examined sections, translucent bands were estimated to have started forming between April and September.

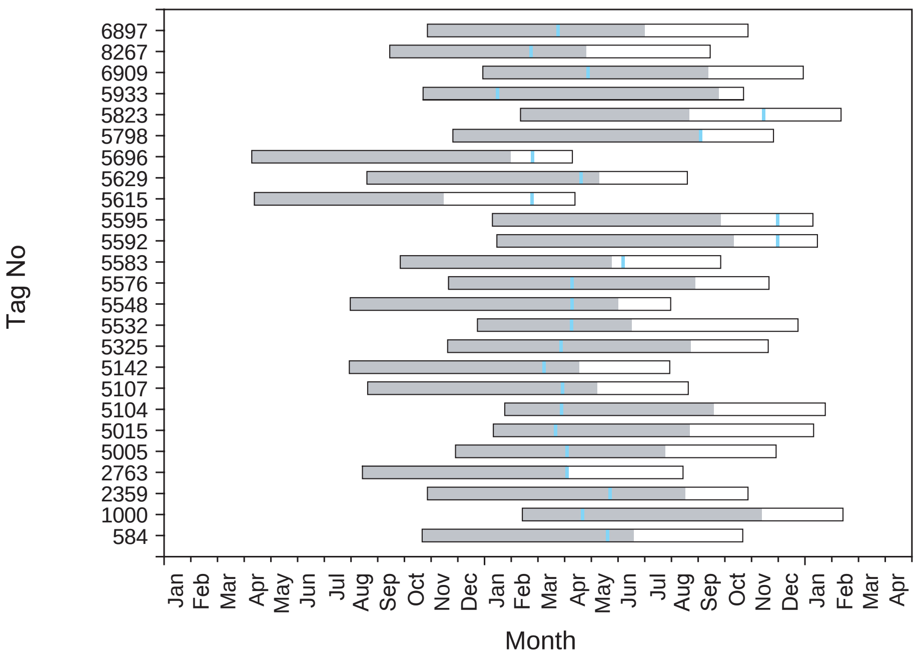


Figure 5.10. Diagrammatic representation of the estimated annual timing of vertebral growth band formation.

5.1.3.2 Vertebral analysis

Mean band counts, mean readability, IAPE and the percentage of readings that were in agreement with the final consensus counts were similar for all three readers (Table 5.3), although more consensus readings were obtained for readers A and B than reader C. Reader C provided both the highest individual reading (27 years) and highest consensus age (26 years). Final consensus counts between readers were reached for 238 specimens, ranging in size between 47 and 154 cm FL. The oldest male shark for which a consensus age was agreed was 19 years and the oldest agreed female age was 25 years. The oldest immature male and female sharks were both 12 years. Maturing females were aged at between 12 and 16 years and a single maturing male was aged at 15 years. The youngest mature sharks were aged at 14 (female) and 13 (male) years.

Table 5.3. Summary of vertebral band counts of Western Australian *Carcharhinus plumbeus*, for 3 readers and for final consensus counts.

Reader	Mean readability	Mean band count	IAPE	No consensus counts	Agreement with final band count (%)
A	1.8	10.9	10.0	528	49.8
B	2.1	10.2	14.0	522	44.8
C	1.9	10.6	12.6	482	47.3
Final	-	8.7	11.7	238	-

As suggested by the standard errors of parameter estimates (Table 5.4), there was no difference between male and female von Bertalanffy growth curves (Kimura, 1980, Likelihood Ratio test, χ^2=0.350, *df*=2, *P*=0.839; Figure 5.11). Using the known size at which 50% of sharks are mature ($L_{0.5}$, Section *5.1.4*), age at maturity was calculated as 14.0 years for males and 15.9 years for females. As determined from vertebral analysis, annual growth rates declined gradually with age, from 7.8 cm FL yr^{-1} in the first year to 2.3 cm FL yr^{-1} by 30 years of age.

Table 5.4. Summary of von Bertalanffy parameters, estimated from vertebral analysis of Western Australian *Carcharhinus plumbeus*. Values in parentheses are standard errors of parameter estimates.

Parameter	Male	Female	Combined
n	105	10.0	528
K (yr^{-1})	0.0440 (0.0078)	0.0386 (0.0052)	0.0402 (0.0042)
L_{∞} (cm FL)	226.3 (24.7)	245.8 (20.5)	239.6 (15.3)
t_0			-4.8588
r_2	0.9253	0.9396	0.9344

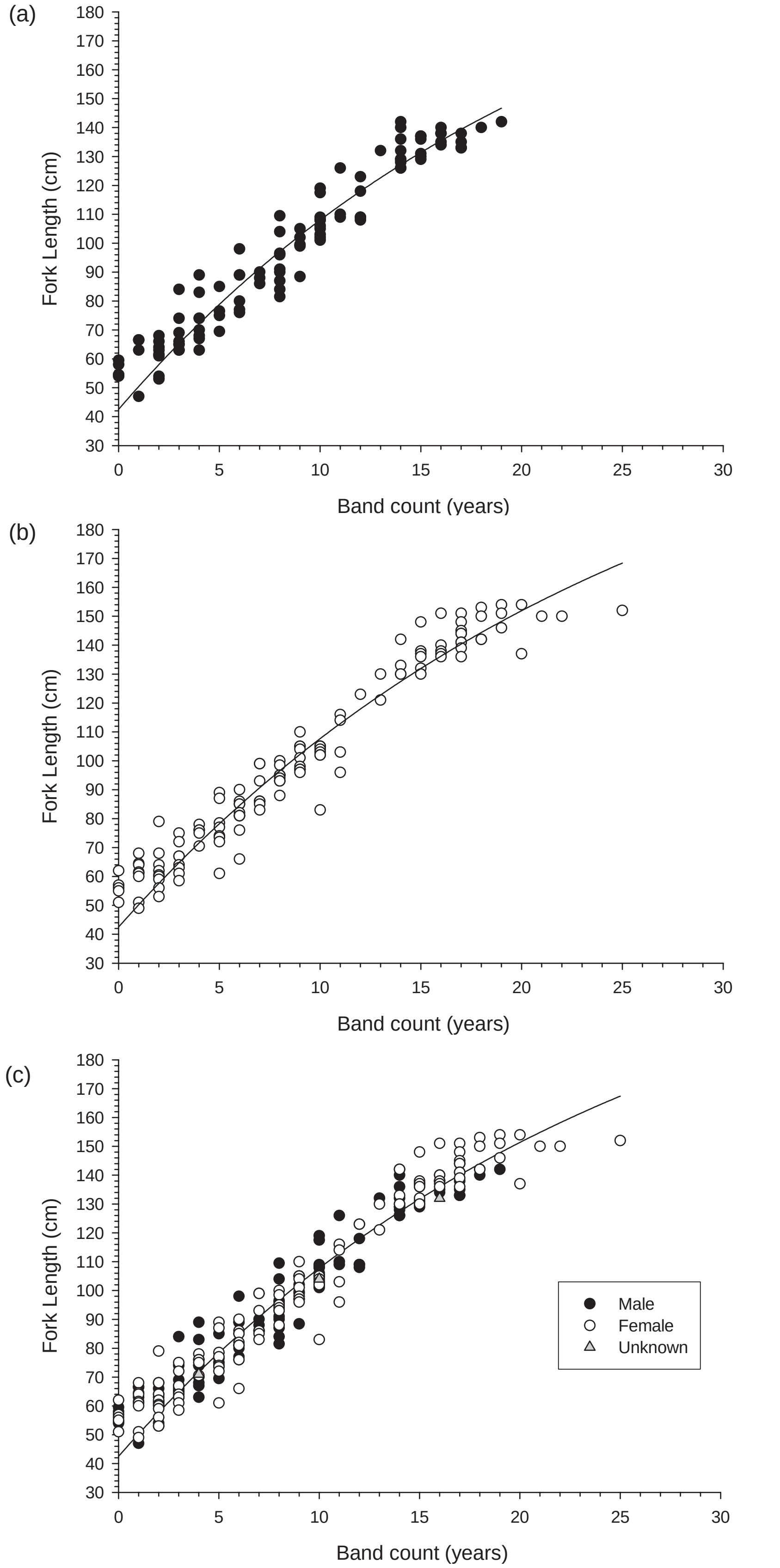


Figure 5.11. Length at age estimates and associated von Bertalanffy growth curves for Western Australian *Carcharhinus plumbeus* from vertebral analysis of (a) male (n=105), (b) female (n=130) and (c) combined sexes (n=238).

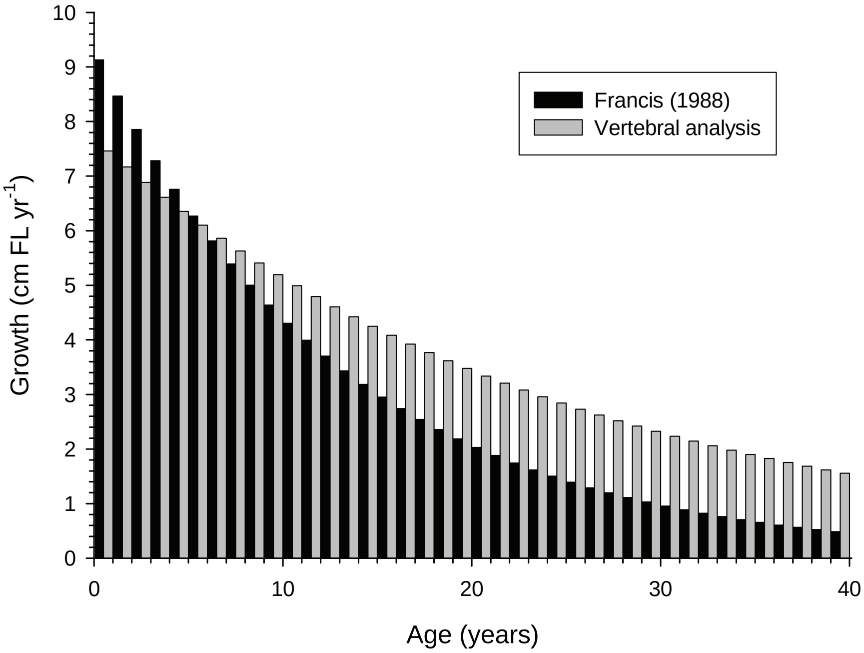


Figure 5.12. Comparison of annual growth rates in Western Australian *Carcharhinus plumbeus*, calculated from tagging data (Francis, 1988) and length at age data derived from vertebral analysis.

5.1.3.3 Estimation of growth rates from tagging data

The von Bertalanffy parameter estimates from the Francis (1988) model, were both noticeably different to and less precise than those calculated from vertebral analysis (Table 5.5). However, the confidence intervals associated with these estimates, suggest that the parameter estimates from the tagging data are unlikely to be statistically different to those obtained from vertebral analysis. The model indicated that growth variability in tagged sharks was substantial (v=0.37, i.e. growth rates varied by 37% of predicted growth). Whilst measurement error was estimated to be relatively small (m=0.03 cm, s=0.54 cm), there was a high probability of data contamination (p=0.52) from other sources. This suggests that outliers in the dataset might be exerting an undue influence on the model's ability to accurately estimate growth parameters and that these results should be treated with some caution.

Table 5.5. Growth and growth variability parameter estimates, with 95% confidence (CI), calculated from the Francis (1988) method for determining growth from tagging data.

	g_{α} (cm yr^{-1})	g_{β}(cm yr^{-1})	v	m (cm)	s (cm)	p	L_{∞} (cm FL)	K (yr^{-1})
Median	7.50	4.54	4.54	4.54	4.54	4.54	4.54	4.54
95% CI	0.7-15.8	0.3-11.7	0.3-11.7	0.3-11.7	0.3-11.7	0.3-11.7	0.3-11.7	0.3-11.7

Growth rates, calculated from the tagging data were initially higher than those calculated by vertebral analysis, however they declined more rapidly and begin to asymptote at an earlier age. Growth rates, as described by the von Bertalanffy parameters estimated by the two methods, are compared in Figure 5.12.

5.1.4 Reproductive biology

5.1.4.1 Male Reproductive Biology

The smallest male with fully calcified claspers was 117 cm FL and the largest with entirely uncalcified claspers was 125 cm FL (Figure 5.13). Partial clasper calcification was observed in sharks of between 111cm FL and 138 cm FL. The size at which 50% of males were mature ($L_{0.5}$) was 126.9 cm FL (with 95% confidence that $L_{0.5}$ was between 121 cm and 128 cm FL, Figure 5.14), which corresponds to 76% of the maximum observed size of males. The proportion of mature male sharks with running spermatozoa was highest between January (79%) and March (80%), after which the proportions progressively decreased to June and August when no running spermatozoa was detected (Figure 5.15). The proportion of mature males with running spermatozoa increased from 7.1% in October to 58% in December. These data suggest that mating activity peaks between January and March.

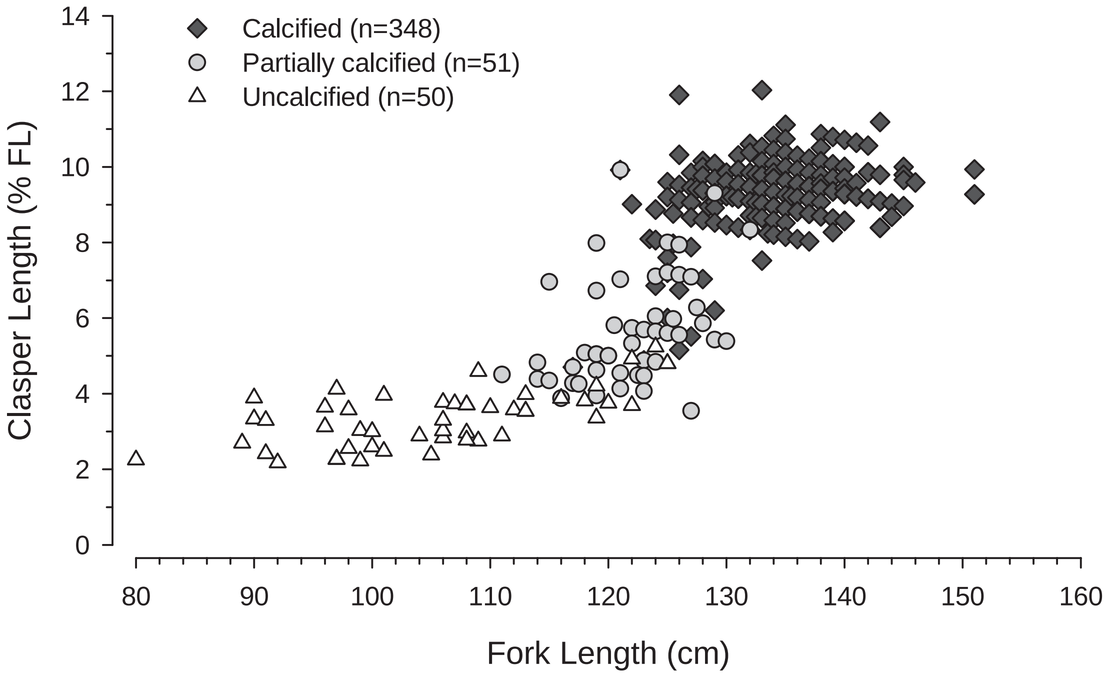


Figure 5.13. Clasper length and degree of clasper calcification as a function of fork length of 449 male *Carcharhinus plumbeus* sampled between May 2000 and June 2003.

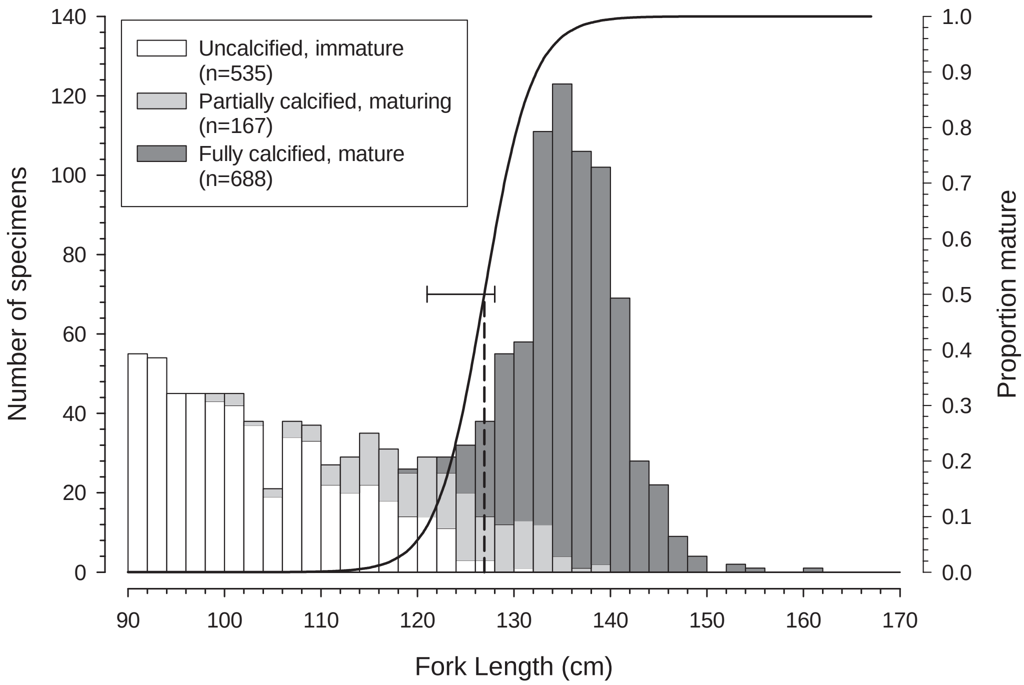


Figure 5.14. Degree of clasper calcification in 1,390 male *Carcharhinus plumbeus*, measuring between 90 cm and 160 cm FL, sampled between May 2000 and June 2003. Curve is the proportion of mature sharks by 2 cm FL size classes, as determined by logistic regression analysis; dashed vertical line indicates the estimated size at 50% maturity ($L_{0.5}$); error bars are 95% confidence intervals of the estimated $L_{0.5}$.

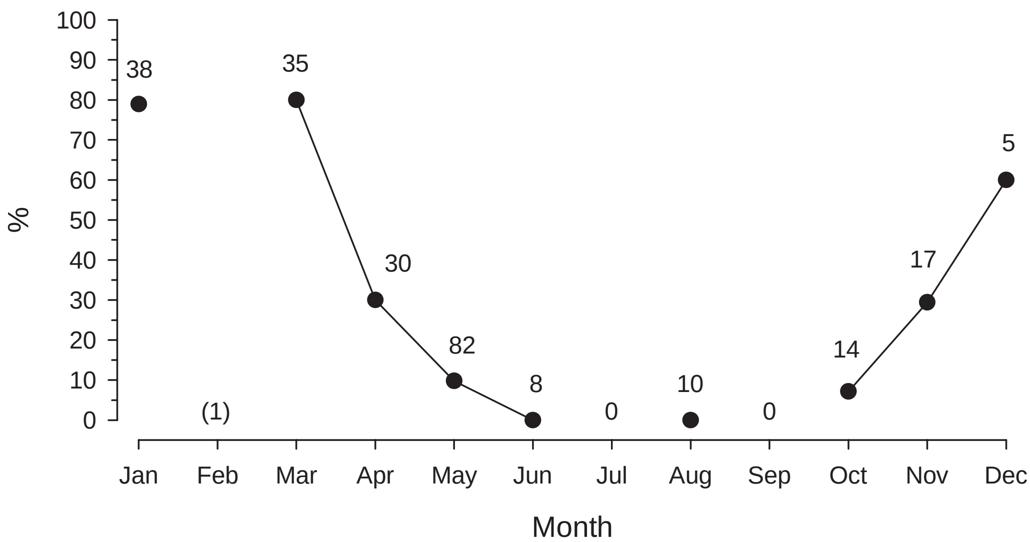


Figure 5.15. Monthly percentage of 239 mature male *Carcharhinus plumbeus*, sampled between May 2000 and June 2003, with running spermatozoa present in the epididymis. Numbers above points indicate sample sizes. Months in which sample sizes were less than five have been excluded and are shown in parentheses.

5.1.4.2 Female Reproductive Biology

The smallest mature (reproductive stage ≥ 3) female was 125 cm FL and the largest immature (stage 2) female was 143 cm FL (Figure 5.16). All observed females were mature by 146 cm FL. The size at which 50% of females were mature ($L_{0.5}$) was estimated by logistic regression analysis to be 135.9 cm FL (with 95% confidence that the value was between 134.7 cm and 136.8 cm FL), which corresponds to 83% of the maximum observed size of females.

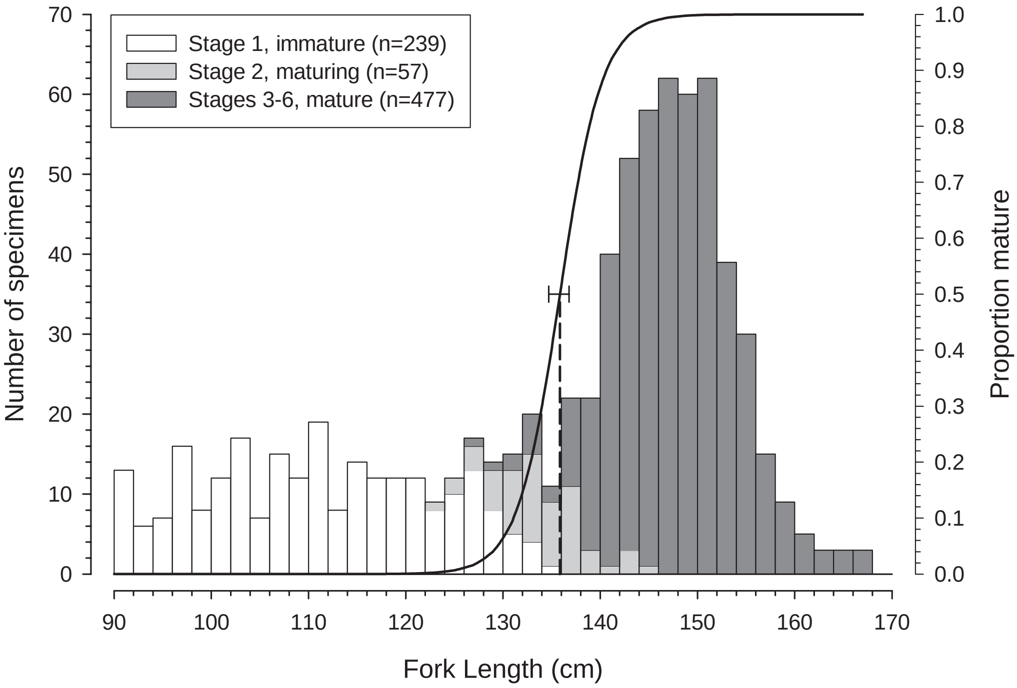


Figure 5.16. Maturity (uterine) stages of 773 female *Carcharhinus plumbeus*, measuring between 90 cm and 160 cm FL, sampled between May 2000 and June 2003. Curve is the proportion of mature sharks by 2 cm FL size classes, as determined by logistic regression analysis; dashed vertical line indicates the estimated size at 50% maturity ($L_{0.5}$); error bars are 95% confidence intervals of the estimated $L_{0.5}$.

All mature females that were examined (n=481) either had developing yolky ova, recently ovulated ova, embryos in-utero or showed evidence of recent parturition. Mature, non-pregnant females (i.e. stage 3 reproductive condition, n=182) were caught in all months except February, July and September, when sample sizes were small (Figure 5.17). However, they were most prevalent between April and November, when they contributed between 40% and 100% of the catch.

Ovulating and post-ovulatory females (i.e. stage 4 reproductive condition, n=40) were observed in January to April and again in November, however, the proportion of these was small (<5%) in all months except March, when they accounted for 34.7% of the mature females that were examined. Gravid females (i.e. stage 5 reproductive condition, n=171) were caught throughout the year, except in June and July, when limited sampling occurred (Figure 5.17). Only 15 gravid female sharks were observed with 'yolky' ova. However, the majority of these had a single (n=9) or pair (n=3) of large attritic ova, accompanied by numerous small previtellogenic follicles, suggesting that the larger ova, for which MOD was recorded, were the unovulated remnants of the previous ovarian cycle. Only one shark had more than four yolky ova concurrently with embryos in-utero. The proportion of post-partum female (i.e. stage 6 reproductive condition, n=88) in the catch of mature sharks decreased from 53% in January to 12% in May (Figure 5.17). Post-partum females were absent from catches between June and November and were only a low proportion (1.8%) of the December catch.

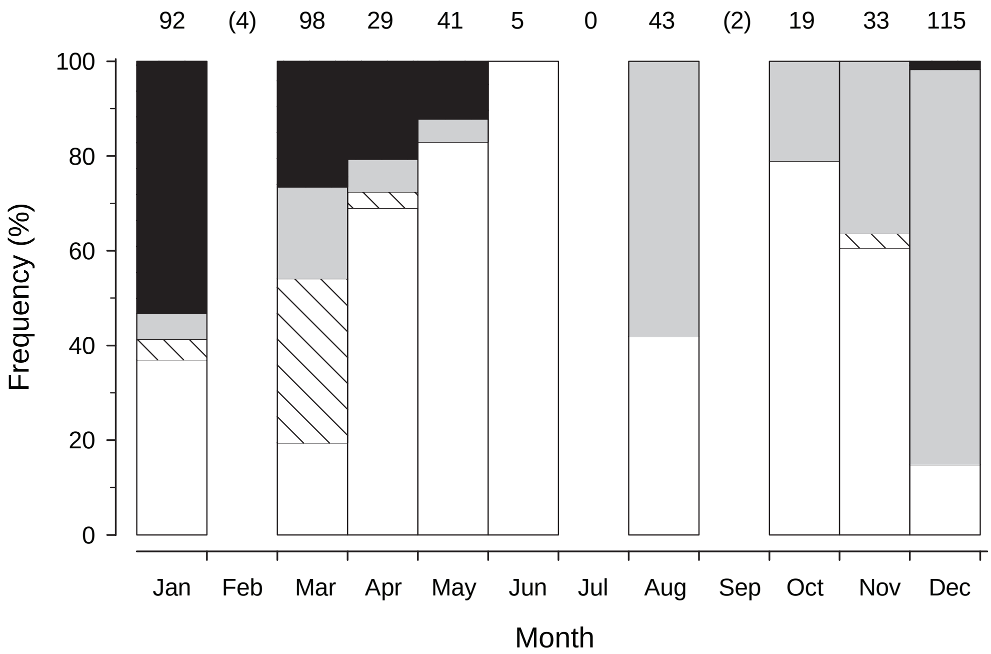


Figure 5.17. Monthly proportions of uterine conditions in 481 examined mature female *Carcharhinus plumbeus*, sampled between May 2000 and June 2003. White bars= stage 3, hatched bars=stage 4, grey bars=stage 5 and black bars=stage 6. Numbers above columns indicate sample sizes. Months in which sample sizes were less than five have been excluded and are shown in parentheses.

The mean Maximum Ovum Diameter (MOD) of non-pregnant females decreased from 25-29 mm in January and March to approximately 10 mm between April and October (Figure 5.18). All sharks with MOD of less than 5 mm were observed between April and August. Mean MOD subsequently increased to approximately 20 mm in November and December. Ova development therefore appears to take approximately 12 months.

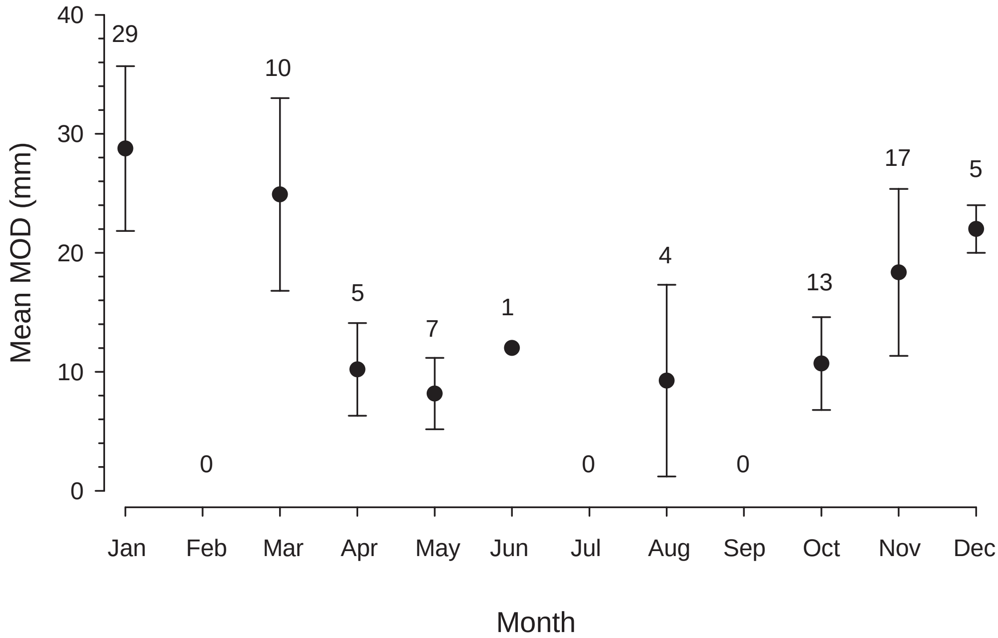


Figure 5.18. Monthly mean maximum ovum diameter from 91 stage 3 *Carcharhinus plumbeus* sampled between May 2000 and June 2003. Error bars indicate one standard deviation from the mean. Numbers above data points indicate sample sizes.

Litters from a subsample of 166 gravid female sharks, in addition to the 20 sharks caught during the drumline survey in May 2000, were examined for embryonic development. However, data from five near-term litters were excluded from the dataset, as there was evidence that embryos had been aborted prior to landing. Litter sizes ranged from four to 10 embryos, with a mean of 6.5. There was a weak but statistically significant correlation between litter size and maternal length (r^2=0.034, P=0.021). Sex ratios were recorded for 20 litters and the proportion of females ranged from 0.3 to 1.0, with a mean of 0.6 (std. dev. = 0.2), which significantly deviated from a 1:1 sex ratio (χ^2=4.13, df=1, P=0.04).

The monthly mean embryo length was high (42-48 cm TL) between January and April, after which it decreased to its minimum in May at 13 cm TL and then increased steadily between August and December, when it reached 43 cm TL (σ=3 cm, Figure 5.19). Attainment of maximum embryo lengths coincides with the peak in occurrence of post partum females in January (Figures 5.17 and 5.19).

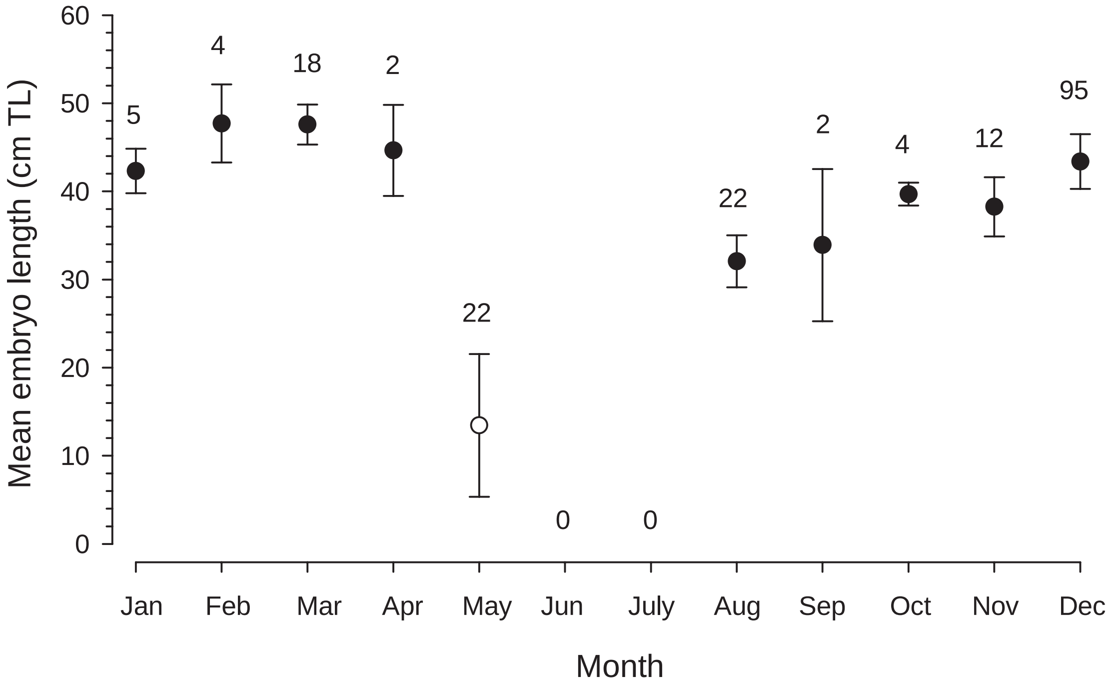


Figure 5.19. Monthly mean embryo lengths of 186 *Carcharhinus plumbeus* litters, sampled between May 2000 and June 2003. May data, represented by an unfilled circle, include data from 20 litters examined during the May 2000 drumline survey. Error bars indicate one standard deviation from the mean. Numbers above data points indicate sample sizes.

The largest recorded mean embryo length was 54 cm TL (which corresponds to 43 cm FL, using the post-natal FL-TL relationship) and the smallest free-swimming shark, which was caught by gillnet on the mid-west coast, was measured at 40 cm FL. Neonate sharks (n=40), which were identified by the presence of open umbilical scars, ranged in size from 40-66 cm FL. Embryos from three litters, ranging in size from 38-49 cm TL (29-39 cm FL), were observed swimming freely following removal from the uterus between November and May. However, based on the size of the largest embryos examined in-utero and the size of the smallest free-swimming neonates, all but the largest of these were unlikely to have been fully developed when released. Based on a combination of these data, size at birth is estimated to be approximately 40-45 cm FL.

5.1.5 Diet

Table 5.6. Occurrence of prey in the stomachs of 1241 *Carcharhinus plumbeus***.** Values in bold italics indicate totals for prey categories.

Prey category		Prey item	n	% occurence
Teleosts	***Family***		***724***	***34.2%***
	Clupeidae	Pilchard	38	1.8%
		Sprat	1	<0.1%
	Scombridae	Mackerel	32	1.5%
		Bonito	1	<0.1%
		Tuna	1	<0.1%
		Unidentified scombrid	4	0.2%
	Muraenidae	Eel, moray	4	0.2%
	Ophichthidae	Eel, snake	1	<0.1%
		Eel, unidentified	15	0.7%
	Labridae	Wrasse	11	0.5%
		Baldchin groper	4	0.2%
	Carangidae	Scad	5	0.2%
		Trevally	5	0.2%
		Samsonfish	1	<0.1%
	Monacanthidae	Leatherjacket	11	0.5%
	Platycephalidae	Flathead	10	0.5%
	Cheilodactylidae	Queen snapper	9	0.4%
		Dusky morwong	1	<0.1%
	Mullidae	Goatfish	6	0.3%
	Plotosidae	Cobbler	6	0.3%
	Pleuronectidae/ Bothidae	Flounder	5	0.2%
	Uranoscopidae	Stargazer	5	0.2%
	Ballistidae	Triggerfish	3	0.1%
	Triglidae	Gurnard	3	0.1%
	Chaetodontidae	Butterflyfish	2	<0.1%
	Engraulididae	Anchovy	2	<0.1%
	Hemiramphidae	Garfish	2	<0.1%
	Pomacanthidae	Angelfish	2	<0.1%
	Scaridae	Parrotfish	2	<0.1%
	Sillaginidae	King George whiting	1	<0.1%
		Whiting	1	<0.1%
	Sparidae	Pink snapper	2	<0.1%
	Acanthuridae	Surgeonfish	1	<0.1%
	Ariidae	Catfish	1	<0.1%
	Belonidae	Longtom	1	<0.1%
	Berycidae	Swallowtail	1	<0.1%
	Glaucosomidae	Dhufish	1	<0.1%
	Lethrinidae	Spangled emperor	1	<0.1%
	Ostraciidae	Cowfish	1	<0.1%
	Scorpaenidae	Scorpionfish	1	<0.1%
	Scorpididae	Footballer	1	<0.1%
	Serranidae	Cod	1	<0.1%
	Unidentified teleost		518	24.5%
Cephalopods			***433***	***20.5%***
	Octopus		218	10.3%
	Unidentified cephapopod		113	5.3%
	Squid		75	3.5%
	Cuttlefish		27	1.3%

Sharks		***34***	***1.6%***
	Gummy shark	3	0.1%
	Milk shark	3	0.1%
	Spottail shark	3	0.1%
	Catshark	2	<0.1%
	Angel shark	1	<0.1%
	Dusky shark	1	<0.1%
	Spurdog	1	<0.1%
	Wobbegong	1	<0.1%
	Unidentified shark	19	0.9%
Rays & skates		***33***	***1.6%***
	Stingray	15	0.7%
	Southern eagle ray	10	0.5%
	Shovelnose ray	3	0.1%
	Skate	1	<0.1%
	Stingray, blue spotted	1	<0.1%
	Unidentified ray	3	0.1%
Crustaceans		***11***	***0.5%***
	Western rocklobster	6	0.3%
	Bug	3	0.1%
	Crab	1	<0.1%
	Prawn	1	<0.1%
Other		***6***	***0.3%***
	Gastropod	2	<0.1%
	Plastic	1	<0.1%
	Scallop(s)	1	<0.1%
	Turtle	1	<0.1%
	Unidentified	1	<0.1%
	Total	1241	58.7%

Of the 2,115 *C. plumbeus* examined for dietary analysis, just over 52% (1,104) had empty stomachs. Teleosts were the most commonly observed prey category in the remaining specimens, occurring in 34.2% of examined stomachs (Table 5.6). Cephalopods (mainly octopus) were the only other major prey category, occurring in 20.5% of specimens, followed by other elasmobranchs (sharks, rays and skates, 3.2%), crustaceans (0.5%) and ‘other’ prey items (0.3%). Although the majority of teleosts could not be accurately identified due to their advanced state of digestion, a wide variety of both demersal and pelagic fish were described from the stomach contents of *C. plumbeus*. Whilst clupeids, scombrids, eels, wrasses and carangids were the most commonly identified groups, in total 33 families of teleosts were identified.

The diets of male and female sandbar sharks were similar, with a Morisita Index value (C_H) of 0.87, indicating a high degree of dietary overlap. Prey diversity (*H’*) for females was 2.18, and 2.20 for males. Similarly high levels of dietary overlap were found between size classes, with Morisita Indices of between 0.80 (between the small and medium classes) and 1.00 (between medium and large classes). Prey diversity was lowest in the smallest size class (*H’*=1.87), followed by the large size class (*H’*=2.09) and highest in medium sized sharks (*H’*=2.45). Dietary overlap between sharks from the three different regions was also high, with C_H values of between 0.80 (between sharks from the north-west and south-west) and 0.94 (between the south west and west coast regions). Prey diversity was highest in the north-west and west coast regions at 2.20 and 2.11, respectively and lowest in the south west at 1.60.

5.2 Mortality and exploitation of sandbar, dusky and related oceanic shark species

5.2.1 Catch and effort in the target fisheries

5.2.1.1 Temperate demersal gillnet and longline fisheries

Effort

Levels of validated effort in all areas corresponding to the current zones of the temperate demersal gillnet and demersal longline fisheries, were largely consistent with effort levels calculated directly from CAESS data in years for which license data were available (Figure 5.20). Effort peaked in 1985/86 in the area that became Zone 1 of the JASDGDLF (Figure 5.20a), in 1992/93 in Zone 2 of the southern fishery (Figure 5.20b) and in 1988/89 in the area now known as the WCDGDLF (Figure 5.20c). The rapid increase in predominantly gillnet effort in Zone 1 during the mid 1980s is believed to have arisen from increased fishing activity as operators attempted to establish catch history in the fishery before entry was limited by the introduction of the JASDGDLF management plan. The dramatic spike in fishing in the area north of Zone 1, in the area that was later (1997) to become the WCDGDLF, is believed to have been caused by a combination of displacement of effort from Zone 1 and increased fishing activity in anticipation of this area also becoming a fully managed limited entry fishery. Interestingly, there was no such surge in fishing activity in the area that was to become Zone 2 of the southern fishery, prior to the implementation of entry restrictions. Rather the peak in fishing activity there occurred some years after the introduction of the management plan.

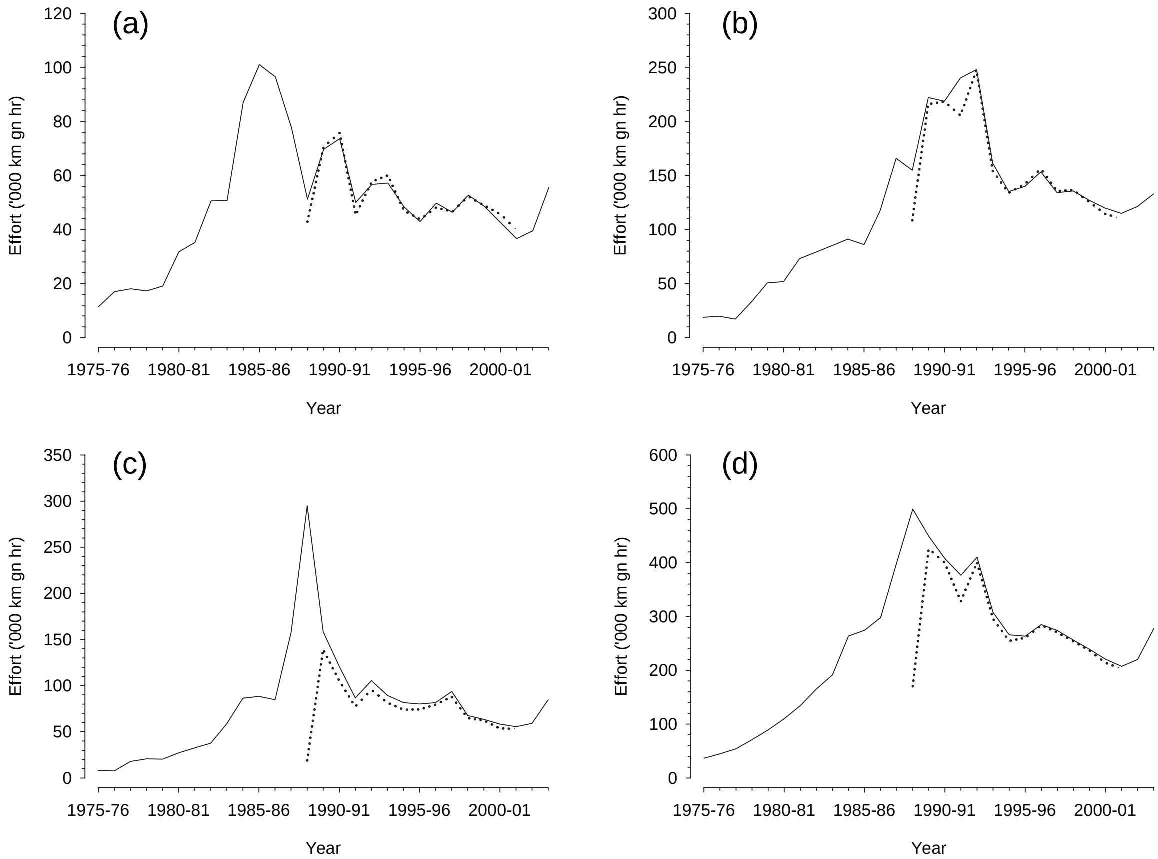


Figure 5.20. Reported (CAESS, dotted lines) and validated annual effort (solid lines) in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

Catch

Validated catches of all shark (and ray) species also generally matched CAESS reported catches in years where licensing data could be used to identify data from the fisheries (Figure 5.21). The biggest discrepancies between reported and validated catches were in the first year of management of the JASDGDLF. Trends in total shark catches generally matched the effort trends described above.

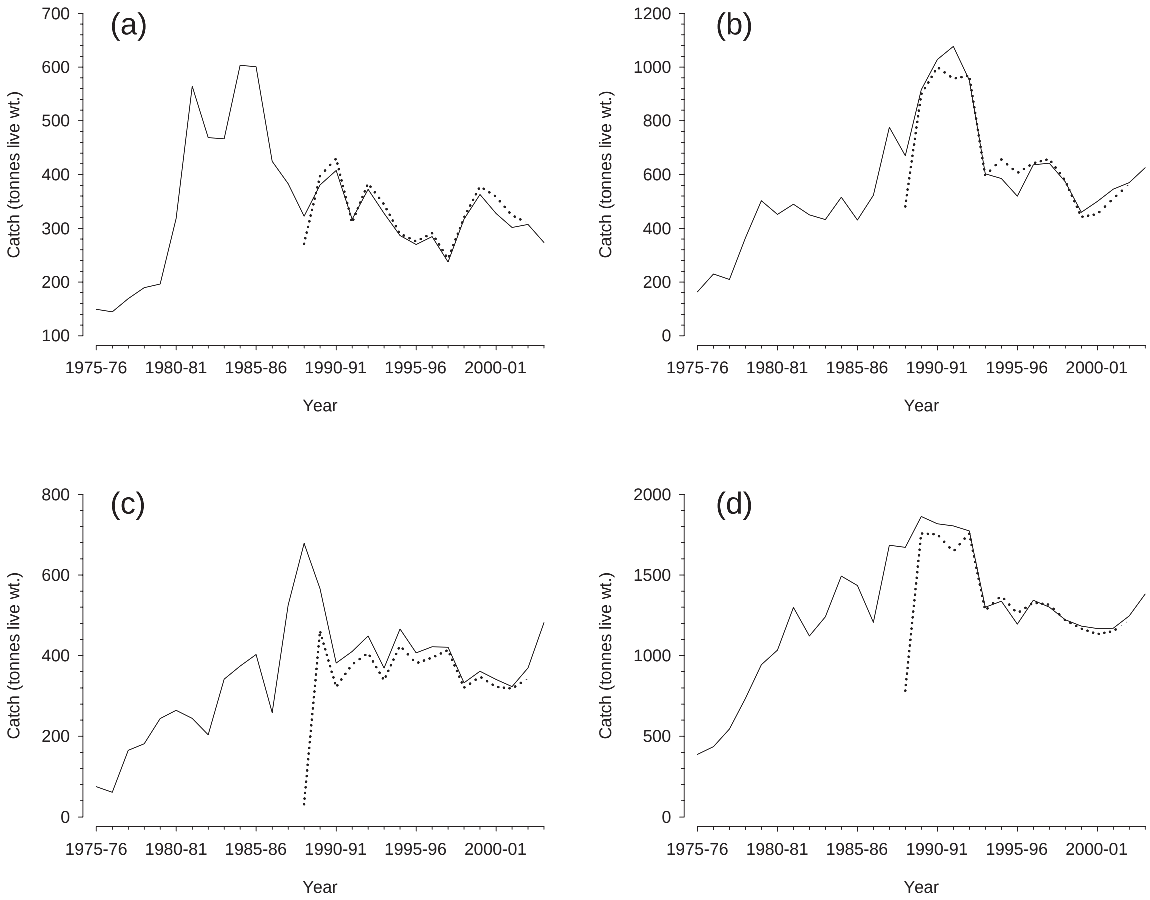


Figure 5.21. Reported (CAESS, dotted lines) and validated annual catch of all shark and ray species (solid lines) in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

Validated catches of the four temperate demersal gillnet and demersal longline fisheries key target species also closely match the CAESS reported catches since 1988 (Figures 5.22, 5.23, 5.24 and 5.25).

Total catches of 'bronze whalers' (i.e. primarily dusky sharks, Figure 5.22) have declined steadily since 1992/93. Until the late 1990s, the decline in dusky shark catches is believed to have been a direct result of the reduction in fishing effort, particularly in Zone 1 of the JASDGDLF and in the WCDGDLF. However, despite effort increases since 2001/02, 'bronze whaler' catches in Zone 1, have failed to rebound in the centre of the species' Western Australian range. Further, the CPUE of bronze whalers has reached historically low levels in all management zones of the TDGDLF (McAuley, 2004). Whilst low catch rates in Zone 2 of the JASDGDLF and in the WCDGDLF can be explained by less targeting of this species, it is believed that changing targeting practices have, at least partly, been in response to declining abundance of juvenile dusky sharks at the northern and eastern edges of their distribution. Further, through sampling of commercial gillnet catches during this project a statistically significant decline in the proportion of neonate dusky sharks has been detected in the fishery's catch over recent years, from 51% in 1994-96 to 38% in 2001-02. This suggests that the fishery's reported 'bronze whaler' catch has been increasingly comprised of larger individuals over recent years and catch rates might therefore be masking a possible decline in the abundance of this stock.

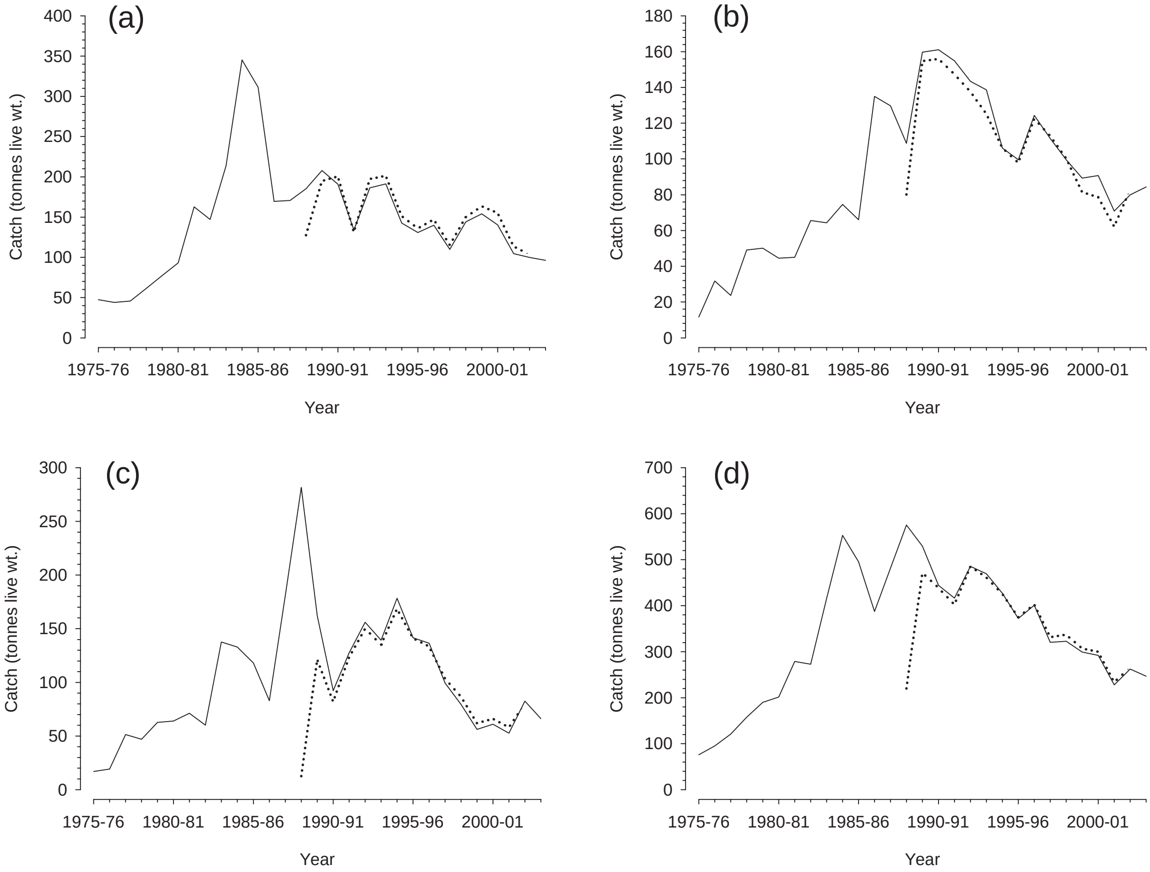


Figure 5.22. Reported (CAESS, dotted lines) and validated (solid lines) annual catches of 'bronze whaler' sharks in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

Trends in sandbar catches in the JASDGDLF have been flat since this species was reported separately in 1985 at between *ca.* 20-40 tonnes per year (Figure 5.23). The validated data indicate that since the mid 1990s, catches of this species have been relatively well reported and little adjustment to the CAESS data was required. Despite the nearly 200 tonne catch in 1989-90, sandbar catches have increased steadily in the WCDGDLF and, consequently in the TDGDLF as a whole, since reporting began. Increased targeting of this species is believed to have largely been a consequence of the declining abundance of the fishery's other traditional target species, dusky and whiskery sharks. Although dropping by 6.6% in 2003/04, sandbar shark catch rates in the WCDGDLF have been steady since 1999/2000.

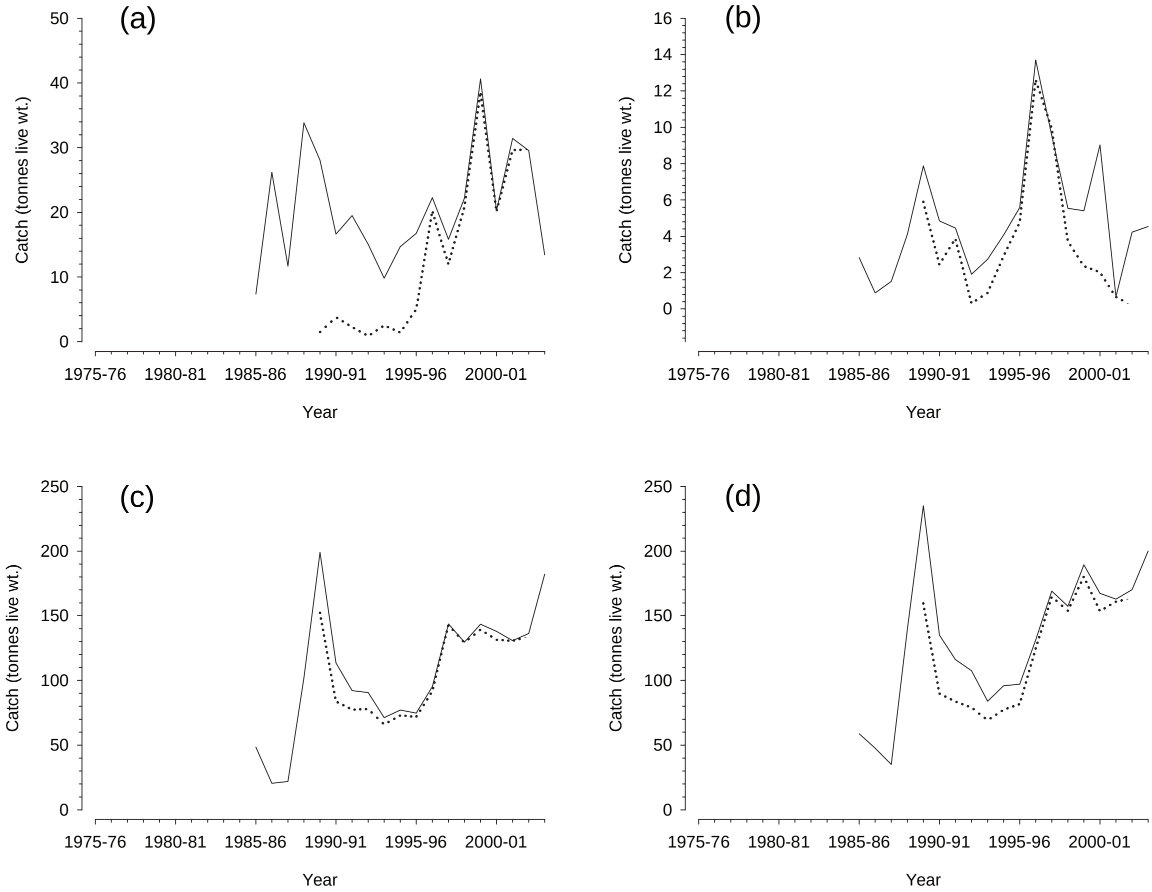


Figure 5.23. Reported (CAESS, dotted lines) and validated (solid lines) annual catches of sandbar sharks in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

Gummy shark, *Mustelus antarcticus*, catches have increased rapidly in the JASDGDLF since 2000/01 (Figure 5.24). Although these increases correspond to increased levels of targeting, particularly in Zone 2, in response to declining availability of dusky sharks and the fishery's other traditional target of school shark (*Galeorhinus galeus*), the steady upwards trend in CPUE is believed to indicate an increasing abundance since the fishery became managed in 1988 (McAuley, 2004). In addition, the effort reductions that were implemented in the JASDGDLF throughout the 1990s to address the depletion of the whiskery shark stock, are thought to have had a direct benefit in allowing the Western Australian component of the gummy shark stock to rebuild.

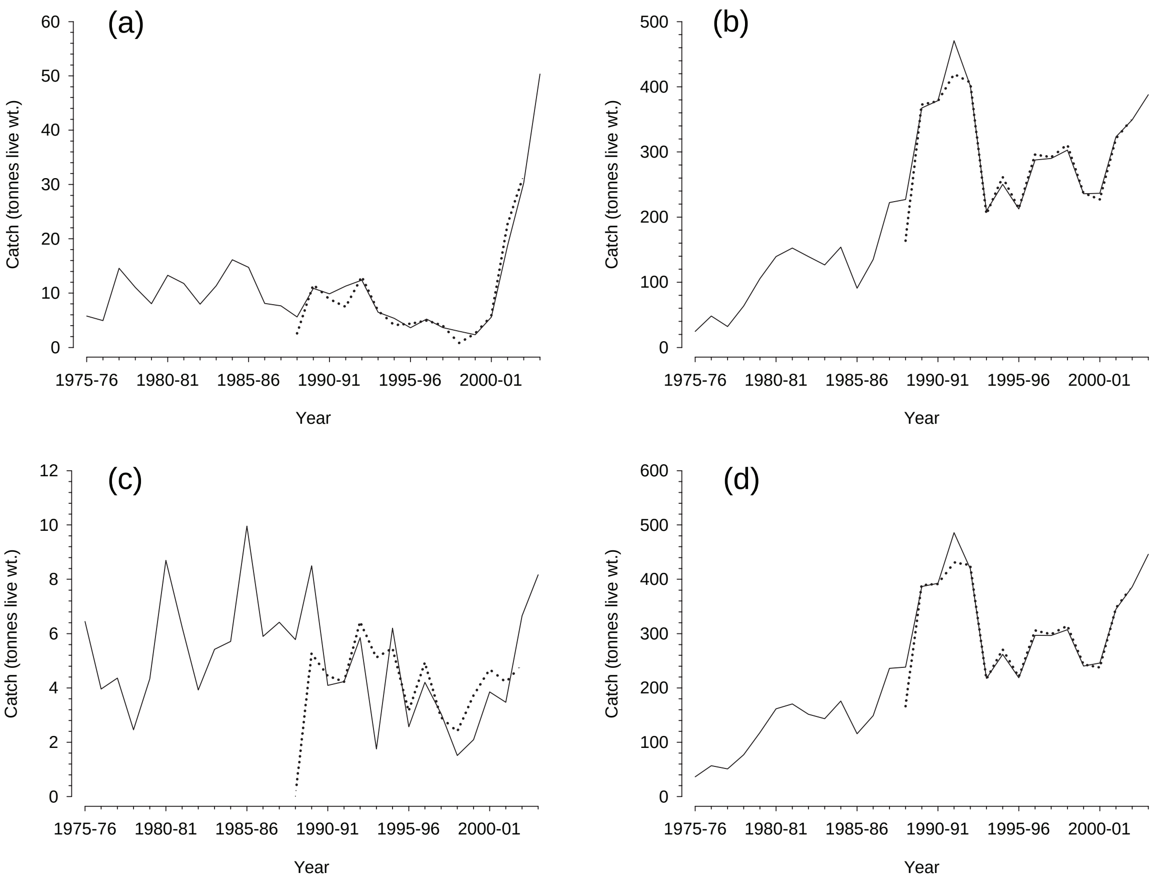


Figure 5.24. Reported (CAESS, dotted lines) and validated (solid lines) annual catches of gummy sharks in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

Whiskery shark catches have generally declined throughout the TDGDLGF since the mid to late 1980s (Figure 5.25), although overall, the catch rate of this species has remained relatively steady since 1988/89 (McAuley, 2004). The validated catch for years prior to 1988 indicate that historical catches of this stock were not as high as had previously been estimated (Simpfendorfer and Donohue, 1998). These new catch (and effort) data have been used to update the stock assessment for whiskery sharks, developed by Simpfendorfer et al. (2000). With the new catch and effort dataset, the model predicted that whilst the stock was depleted by historical levels of fishing, its estimated total biomass had stabilised at between 33.7% and 36.3% of its virgin level (B_0), with a best estimate that it was 35.1% of B_0 in 2002/03 (McAuley, 2004). The model also predicted that, although total biomass was still declining very slowly, mature female biomass had begun to increase.

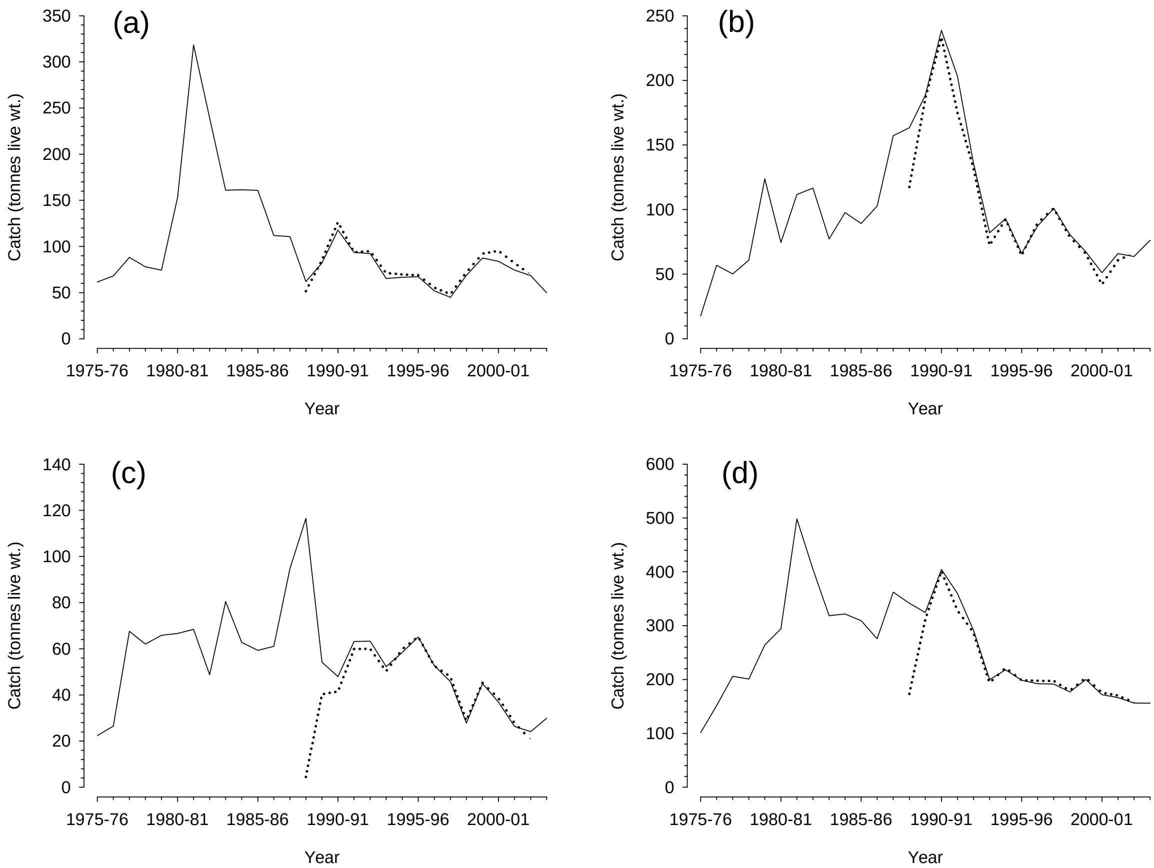


Figure 5.25. Reported (CAESS, dotted lines) and validated (solid lines) annual catches of whiskery sharks in (a) JASDGDLF Zone 1, (b) JASDGDLF Zone 2, (c) WCDGDLF and (d) total temperate demersal gillnet and longline fishery.

5.2.1.2 *Northern shark fisheries*

Monthly *C. plumbeus* catch rates calculated from log book data were consistently higher than those reported in statutory catch and effort returns (Figure 5.26). CAESS catch rates were also noticeably lower than the rates observed during commercial on board WANCSF vessels and fishery-independent sampling in the WANCSF area in all but one month (April 2004), when research sampling was being conducted at depths >300m. There were no distinct trends in either CAESS or log book CPUE data over this period and there was a high degree of variability in both datasets. The level of log book reporting was also highly variable. Between zero and 39 shots were recorded per month, with a mean of 11.3 shots recorded in all months, or 16.7 shots for months in which log book data were available.

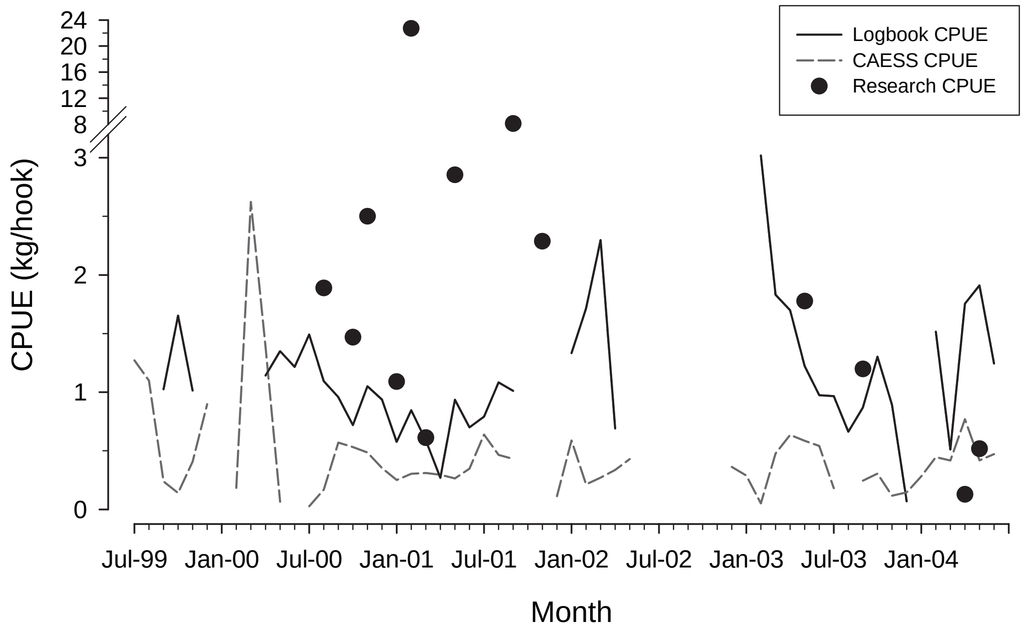


Figure 5.26. Monthly WANCSF catch rates calculated from monthly fishing returns (CAESS), log book and (fishery-dependent and fishery-independent) research data.

Although *C. plumbeus* catch rates in daily log book data were generally more variable than the monthly CAESS catch rates, log book data were also more precise than the CAESS data due to the greater number of available records (Table 5.7). Mean monthly log book catch rates were considerably higher than CAESS monthly catch rates in all years between 2000/01 and 2003/04, with CAESS catch rates between 25% (2002/03) and 63% (1999/00) of the log book rates (Figure 5.27). As effort parameters (i.e. number of hooks, shots and days fished) in the CAESS data were consistent with log book data and the values observed during research sampling, these differences must therefore have been caused by lower than expected catches, hence the need to re-estimate the fishery's catches.

Table 5.7. Coefficient of variation and precision of monthly *C. plumbeus* catch rates in the WANCSF, calculated from CAESS and research data between July 1999 and June 2004.

Data source	Year	No of records	Mean CPUE	St. dev. CPUE	CV	PC
Logbook	1999/00	143	1.25	0.83	0.67	20.2
	2000/01	234	0.86	0.73	0.86	20.3
	2001/02	96	1.20	1.03	0.86	30.2
	2002/03	72	1.43	1.01	0.71	29.0
	2003/04	208	1.01	0.95	0.94	23.3
CAESS	1999/00	13	0.95	1.13	1.19	2065
	2000/01	14	0.56	0.37	0.67	650
	2001/02	17	0.43	0.24	0.58	479
	2002/03	12	0.38	0.24	0.63	569
	2003/04	19	0.43	0.29	0.66	640

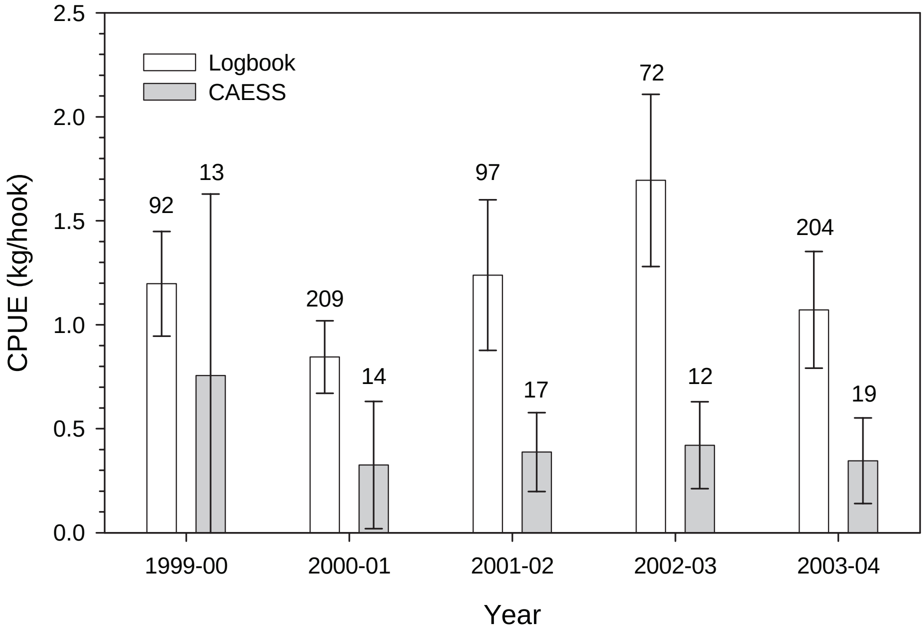


Figure 5.27. Mean monthly *C. plumbeus* catch rates of WANCSF vessels operating west of 120°E longitude, calculated from CAESS and log book data. Error bars indicate precision (PC) measured from coefficient of variation and numbers above columns are number of records.

Both CPUE datasets indicate a similar inter-annual trend over this period, although the magnitude of changes in CPUE is greater in the log book data. Both CAESS and log book data indicate that the fishery experienced relatively high catch rates in 1999/00 as the fishery began to develop, followed by a decline in 2000/01, steady increases for the next two years and another decline in 2003/04 (Figure 5.27).

Between 1999/00 and 2003/04, reported catches of *C. plumbeus* in the WANCSF were between 41% and 49% of the catches estimated from log book data and all were below the lower 95% confidence bounds of the estimated catches (Figure 5.28). Both reported and estimated catches increased between 1999/00 and 2000/01 and then stabilised for two years before increasing dramatically in 2003/04. The majority of fishing effort was expended in the area west of 120°E in all years except 2002/03, when 56% of fishing was to the east of *C. plumbeus*' principal range. Increasing CPUE between 2000 and 2003 caused stability in sandbar catches during this period, despite effort in the western area of the fishery declining in 2001/02 and 2002/03. Total effort in the fishery over this period increased each year, with the most substantial increase occurring in 2003/2004. Whilst total effort in the fishery increased by 40% in the most recent year, the amount of effort that was effectively targeted at *C. plumbeus* by being fished in the western area, more than trebled.

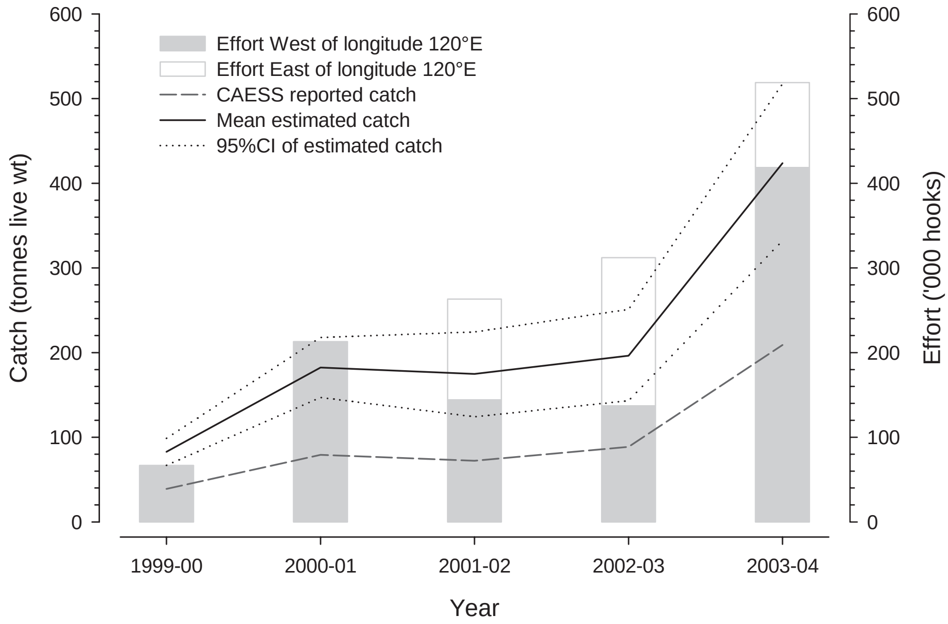


Figure 5.28. Reported (CAESS) and estimated annual catches of *C. plumbeus* in the WANCSF, showing reported effort east and west of longitude 120°E.

5.2.2 Non target fisheries elasmobranch catches

5.2.2.1 Pilbara Fish Trawl

In total 1,541 elasmobranchs were observed in catches by PFTF vessels. Of these, 193 (12.5%) were either retained or tagged (Table 5.8). Including tagged sharks in the retained portion of the elasmobranch catch, *Carcharhinus plumbeus* accounted for 55% of the retained shark catch by the PFTF. Five species (*C. plumbeus*, *Sphyrna mokarran*, *C. amboinensis*, *Hemipristis elongata* and *C. limbatus*/*C. tilstoni*) accounted for 95% of the observed retained catch and thirteen species (or groups) were discarded. Based on reported total shark catches of 42.7 tonnes, 56.4 tonnes and 39.3 tonnes (live wt), *C. plumbeus* catches were estimated to be 23.5 tonnes, 31.0 tonnes and 21.6 tonnes in 2001/02, 2002/03 and 2003/04, respectively. Observed size compositions of elasmobranch catches in the PFTF are given in Figure 5.29.

Table 5.8. Shark catch/bycatch observed during the Pilbara Fish Trawl Fishery survey, conducted between February and June 2002. Data have been re-estimated from those given in Stephenson and Chidlow, 2003.

Common name	Scientific name	Total	Est. weight (kg live wt)	Retained (no.)	Retained (kg live wt.)	Proportion of retained catch
Retained						
Sandbar	*Carcharhinus plumbeus*	90	2058.6	78	1784.1	0.55
Great hammerhead	*Sphyrna mokarran*	7	595.9	6	510.7	0.16
Pigeye	*Carcharhinus amboinensis*	3	295.1	3	295.1	0.09
Fossil	*Hemipristis elongata*	27	395.8	18	263.9	0.08
Blacktip	*Carcharhinus tilstoni & C. limbatus*	80	593.2	34	252.1	0.08
Tiger	*Galeocerdo cuvier*	5	168.3	2	67.3	0.02
Milk	*Rhizoprionodon acutus*	238	522.6	18	39.5	0.01
Weasel	*Hemigaleus microstoma*	559	772.7	18	24.9	0.01
Sharpnose	*Rhizoprionodon taylori*	114	210.5	9	16.6	0.01
Whitecheek	*Carcharhinus dussumieri*	102	214.2	7	14.7	0.00
Discarded						
Leopard	*Stegastoma fasciatum*	101	1627.8		0.0	0.00
Tawny nurse	*Nebrius ferrugineus*	4	257.1		0.0	0.00
Scalloped hammerhead	*Sphyna lewini*	115	189.5		0.0	0.00
Spot tail	*Carcharhinus sorrah*	25	90.7		0.0	0.00
Smooth hammerhead	*Sphyrna zygaena*	1	39.4		0.0	0.00
Longtail carpet sharks	*F. Hemiscylliidae*	12	20.0		0.0	0.00
Banded catshark	*Chiloscylium punctatum*	43	15.6		0.0	0.00
Winghead	*Eusphyra blochii*	1	15.1		0.0	0.00
Tasseled wobbegong	*Eucrossorhinus dasypogon*	4	9.5		0.0	0.00
Bignose	*Carcharhinus altimus*	6	4.9		0.0	0.00
Longnose grey	*Carcharhinus brevipinna*	1	4.2		0.0	0.00
Siteye	*Loxodon macrorhinus*	1	2.0		0.0	0.00
Northern wobbegong	*Orectolobus wardi*	2	0.8		0.0	0.00
Total		1541	8103.3	193	3268.9	0.40

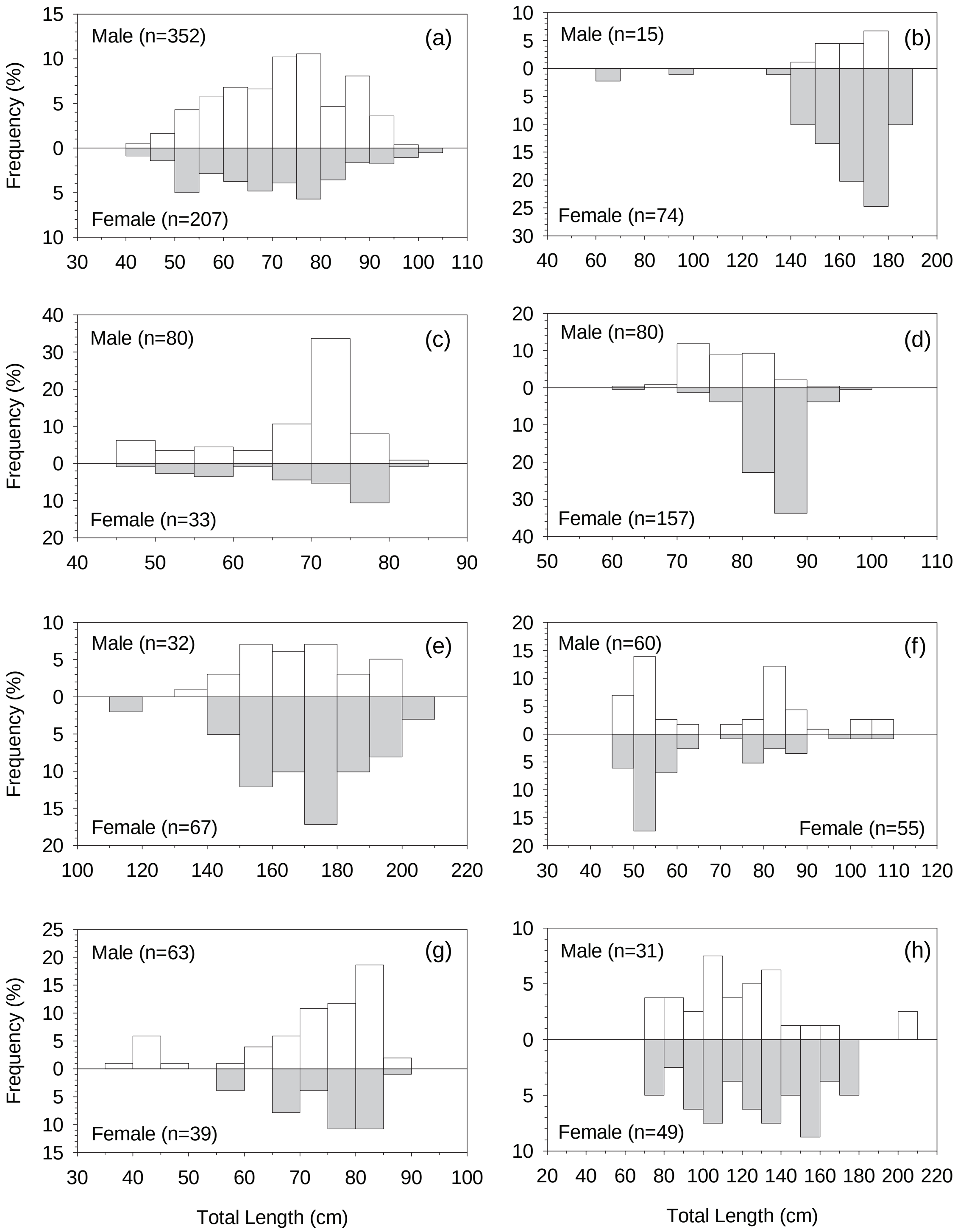


Figure 5.29. Sex and size compositions of frequently observed elasmobranch species in Pilbara Fish Trawl Fishery catches: (a) weasel shark, *Hemigaleus microstoma,* (b) sandbar shark, *Carcharhinus plumbeus,* (c) Australian sharpnose shark, *Rhizoprionodon taylori,* (d) milk shark, *R. acutus,* (e) leopard shark, *Stegastoma fasciatum,* (f) scalloped hammerhead shark, *Sphyrna lewini,* (g) whitecheek shark, *C. dussumieri,* (h) blacktip sharks, *C. limbatus* and *C. tilstoni.*

5.2.2.2 *Inshore gillnet fisheries*

Validated fishing effort in the KGBMF was far lower and less variable than the effort calculated directly from the reported data (Figure 5.30a). The relatively stable trend in the validated annual effort is believed to more accurately reflect the stability of license ownership and continuity of skippers and fishing behaviour in the fishery over the last 25 years. Validated annual effort from the Eighty Mile Beach area was also generally lower than directly estimated from CAESS (Figure 5.30b). The large spike in effort in 1988 resulted from the returns of a single vessel which reported fishing with a much larger amount of net (2,000 m) than has previously or since been reported by other vessels operating in this area. The decline in Eighty Mile Beach effort in 2005 is thought to be due, at least in part, to the omission of some overdue fishing returns.

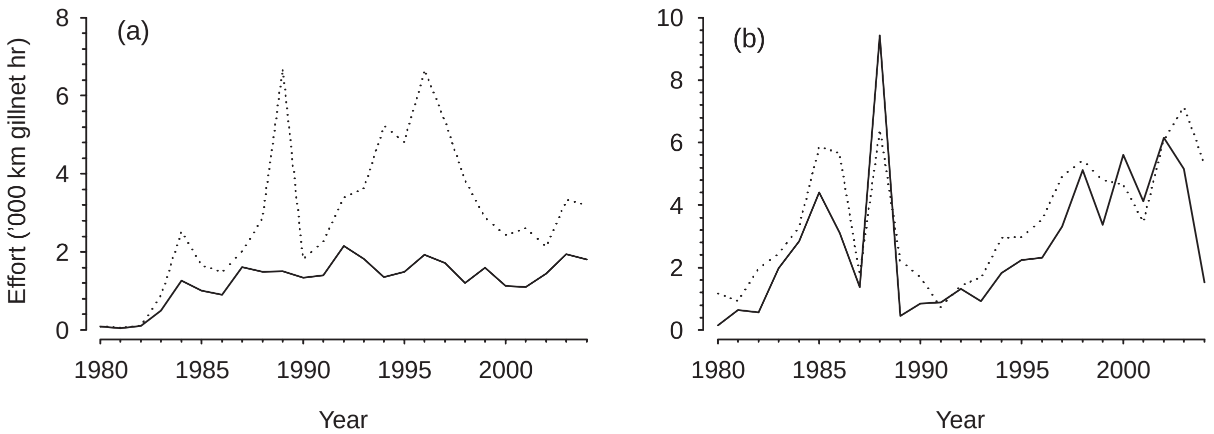


Figure 5.30. Reported (dotted lines) and validated (solid lines) annual effort in the (a) KGBMF and (b) Eighty Mile Beach gillnet sector.

In total, 23 elasmobranch species or species groups were recorded during northern inshore gillnet surveys (Table 5.9). Pigeye sharks (*Carcharhinus amboinensis*) were the most commonly recorded species in both regions. However, the five next most commonly recorded species in Region 1 (*Anoxypristis cuspidata*, *Carcharhinus limbatus*/*C. tilstoni*, *C. cautus*, *Eusphyra blochii* and *C. amblyrhynchoides*) were either absent or only recorded in small quantities in Region 2. By comparison, bull sharks (*C. leucas*), which were the second most common species in Region 2 were not observed in Region 1. The size compositions of the four most commonly caught species in the northern gillnet sector are shown in Figure 5.31. Based on validated effort and observed catch rates, annual northern gillnet catches of elasmobranchs were estimated to be between 190 tonnes live wt (2004) and 454 tonnes live wt (2002) between 2000 and 2004 (Tables 5.10 and 5.11). However, as retention of elasmobranch bycatch in the northern gillnet sector is thought to vary dramatically between vessels and operators, it was not possible to estimate what proportion of this catch was landed.

Table 5.9. Observed demersal gillnet catch composition from Eighty Mile Beach/Roebuck Bay (Region 1) and other KGBMF regions (Region 2).

Name	Species	Region 1 n	Region 1 Est weight (kg live wt)	Region 1 %	Region 2 n	Region 2 Est weight (kg live wt)	Region 2 %
Blacktip	*Carcharhinus limbatus/C. tilstoni*	75	487.1	5.3	12	91.0	10.3
Bull	*Carcharhinus leucas*	0	0.0	0.0	32	126.5	14.4
Graceful	*Carcharhinus amblyrhynchoides*	36	178.6	2.0	0	0.0	0.0
Hardnose	*Carcharhinus macloti*	3	12.5	0.1	0	0.0	0.0
Scalloped Hammerhead	*Sphyrna lewini*	1	109.1	1.2	0	0.0	0.0
Winghead	*Eusphyra blochii*	42	105.0	1.2	3	1.9	0.2
Lemon	*Negaprion acutidens*	19	113.0	1.2	8	52.1	5.9
Longnose grey	*Carcharhinus brevipinna*	3	3.4	0.0	0	0.0	0.0
Milk	*Rhizoprionodon acutus*	12	13.2	0.1	1	0.7	0.1
Nervous	*Carcharhinus cautus*	73	378.2	4.1	9	44.3	5.0
Narrow sawfish	*Anoxypristis cuspidata*	187	5156.4	56.5	3	82.7	9.4
Dwarf sawfish	*Pristis clavata*	14	135.0	1.5	17	235.1	26.7
Pigeye	*Carcharhinus amboinensis*	332	2066.0	22.6	66	218.5	24.8
Freshwater sawfish	*Pristis microdon*	0	0.0	0.0	1	23.7	2.7
Green sawfish	*Pristis zijsron*	17	161.6	1.8	0	0.0	0.0
Blacktip reef	*Carcharhinus melanopterus*	1	1.4	0.0	0	0.0	0.0
Sliteye	*Loxodon macrorhinus*	6	5.4	0.1	0	0.0	0.0
Shovelnose	*F. Rhynchobatidae/F Rhinobatidae*	22	63.5	0.7	0	0.0	0.0
Spottail	*Carcharhinus sorrah*	1	5.7	0.1	0	0.0	0.0
Stingray	*F. Dasyatididae*	4	20.0	0.2	1	0.0	0.0
Aus. sharpnose	*Rhizoprionodon taylori*	4	2.9	0.0	0	0.0	0.0
Tiger	*Galeocerdo cuvier*	1	57.2	0.6	0	0.0	0.0
Whitespot guitarfish	*Rhynchobatus australiae*	5	51.8	0.6	0	5.0	0.6
Total		858	9127.0		153	881.6	

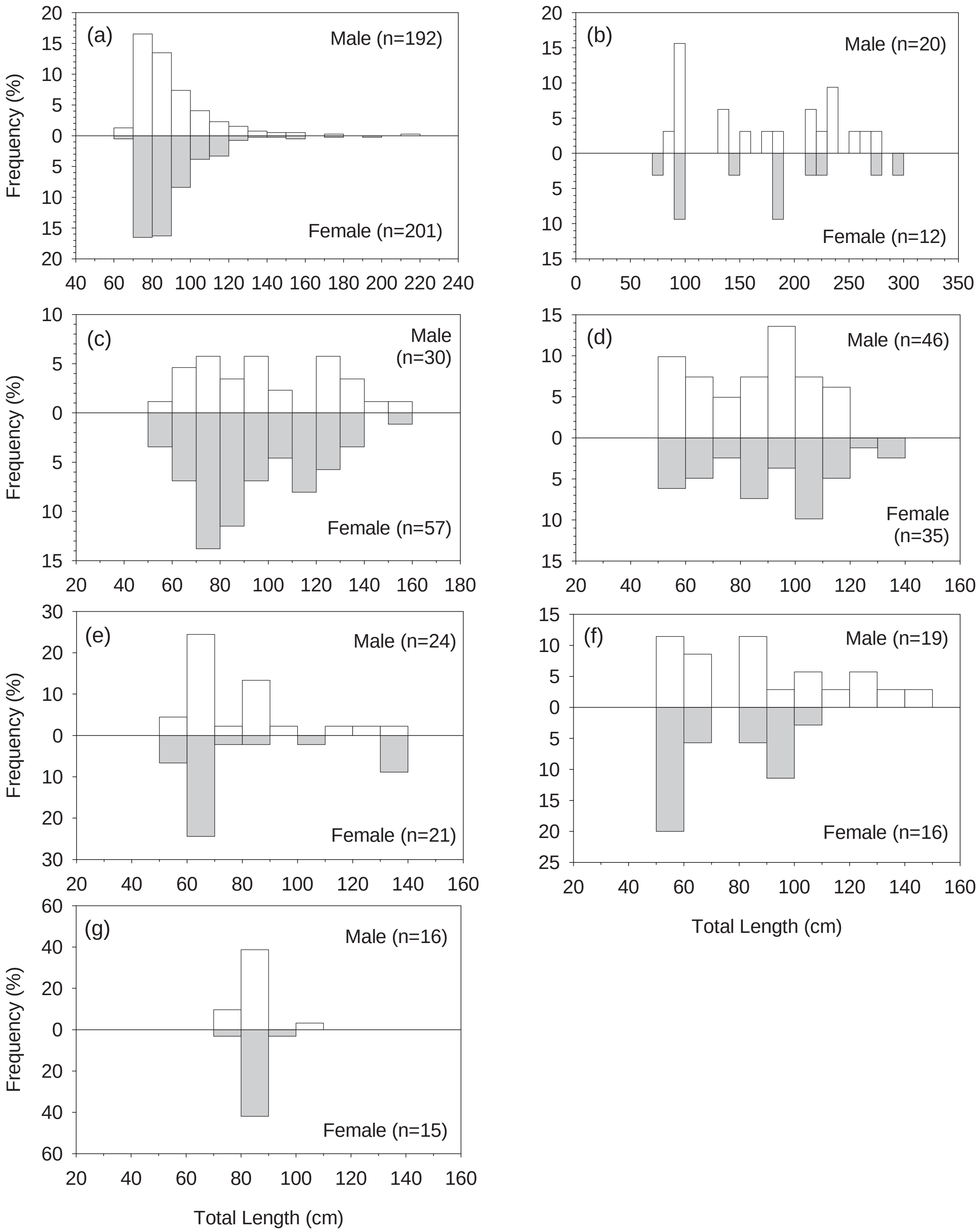


Figure 5.31. Sex and size compositions of frequently observed elasmobranch species in northern gillnet fisheries' catches: (a) Pigeye shark, *Carcharhinus amboinensis,* (b) narrow sawfish, *Anoxypristis cuspidata,* (c) blacktip sharks, *C. limbatus and C. tilstoni,* (d) nervous shark, *C. cautus,* (e) winghead shark, *Eusphyra blochii,* (f) graceful shark, *C. amblyrhynchoides* and (g) bull shark, *C. leucas.*

Table 5.10. Estimated gillnet catches of elasmobranchs in Region 1 of the northern inshore gillnet sector (Eighty Mile Beach and Roebuck Bay).

		Estimated catch (t live wt)				
Name	**Species**	**2000**	**2001**	**2002**	**2003**	**2004**
Narrow sawfish	*Anoxypristis cuspidata*	204.4	154.2	241.5	214.6	85.4
Pigeye	*Carcharhinus amboinensis*	82.0	60.4	91.1	77.4	24.5
Nervous	*Carcharhinus cautus*	14.9	12.5	22.6	23.2	14.8
Blacktip	*Carcharhinus limbatus/C. tilstoni*	19.3	14.4	22.3	19.5	7.2
Green sawfish	*Pristis zijsron*	6.4	5.3	9.5	9.6	6.0
Graceful	*Carcharhinus amblyrhynchoides*	7.1	5.5	8.8	8.1	3.8
Lemon	*Negaprion acutidens*	4.5	3.6	6.0	5.8	3.1
Winghead	*Eusphyra blochii*	4.2	3.3	5.5	5.3	2.8
Dwarf sawfish	*Pristis clavata*	5.3	4.1	6.5	5.9	2.6
Scalloped Hammerhead	*Sphyrna lewini*	4.3	3.2	4.7	4.0	1.2
Whitespot guitarfish	*Rhyncobatus australiae*	2.1	1.6	2.5	2.3	1.0
Shovelnose	*F. Rhynchobatidae/F Rhinobatidae*	2.5	1.8	2.8	2.3	0.7
Tiger	*Galeocerdo cuvier*	2.3	1.7	2.5	2.1	0.6
Stingray	*F. Dasyatididae*	0.8	0.6	0.9	0.7	0.2
Blacktip reef	*Carcharhinus melanopterus*	0.1	0.1	0.2	0.2	0.2
Milk	*Rhizoprionodon acutus*	0.5	0.4	0.6	0.5	0.1
Hardnose	*Carcharhinus maccloti*	0.5	0.4	0.5	0.5	0.1
Spottail	*Carcharhinus sorrah*	0.2	0.2	0.2	0.2	0.1
Sliteye	*Loxodon macrorhinus*	0.2	0.2	0.2	0.2	0.1
Grand Total		361.5	273.2	429.0	382.5	154.4

Table 5.11. Estimated gillnet catches of elasmobranchs in Region 2 of the northern inshore gillnet sector (areas other than Eighty Mile Beach and Roebuck Bay).

		Estimated catch (t live wt)				
Name	**Species**	**2000**	**2001**	**2002**	**2003**	**2004**
Dwarf sawfish	*Pristis clavata*	11.1	9.7	6.6	9.8	9.4
Pigeye	*Carcharhinus amboinensis*	10.3	9.1	6.2	9.1	8.7
Bull	*Carcharhinus leucas*	6.0	5.2	3.6	5.3	5.1
Blacktip	*Carcharhinus limbatus/C. tilstoni*	4.3	3.8	2.6	3.8	3.6
Narrow sawfish	*Anoxypristis cuspidata*	3.9	3.4	2.3	3.5	3.3
Lemon	*Negaprion acutidens*	2.5	2.2	1.5	2.2	2.1
Nervous	*Carcharhinus cautus*	2.1	1.8	1.2	1.9	1.8
Freshwater sawfish	*Pristis microdon*	1.1	1.0	0.7	1.0	0.9
Whitespot guitarfish	*Rhyncobatus australiae*	0.2	0.2	0.1	0.2	0.2
Winghead	*Eusphyra blochii*	0.1	0.1	0.1	0.1	0.1
Grand Total		41.7	36.5	24.8	36.9	35.3

5.2.3 Gillnet mesh selectivity of *Carcharhinus plumbeus*

The experimental net caught a total of 229 *Carcharhinus plumbeus*, of which, length measurements were obtained for 222. Length frequency (FL) data from both female and male sharks were pooled into 5 cm size classes for each mesh size (Figure 5.32). Although all panels caught a wide range of size classes, the mean length of catches generally increased with mesh size. The exception was the 10.2 cm mesh, which had a higher mean length (86.5 cm FL) than the larger 14.0 cm mesh (79.0 cm FL). Although adult-sized sharks (127-136 cm FL, see 5.1.4) were caught by all mesh sizes, sharks smaller than 75 cm FL were not present in catches by the 22.4 cm and 25.4 cm panels.

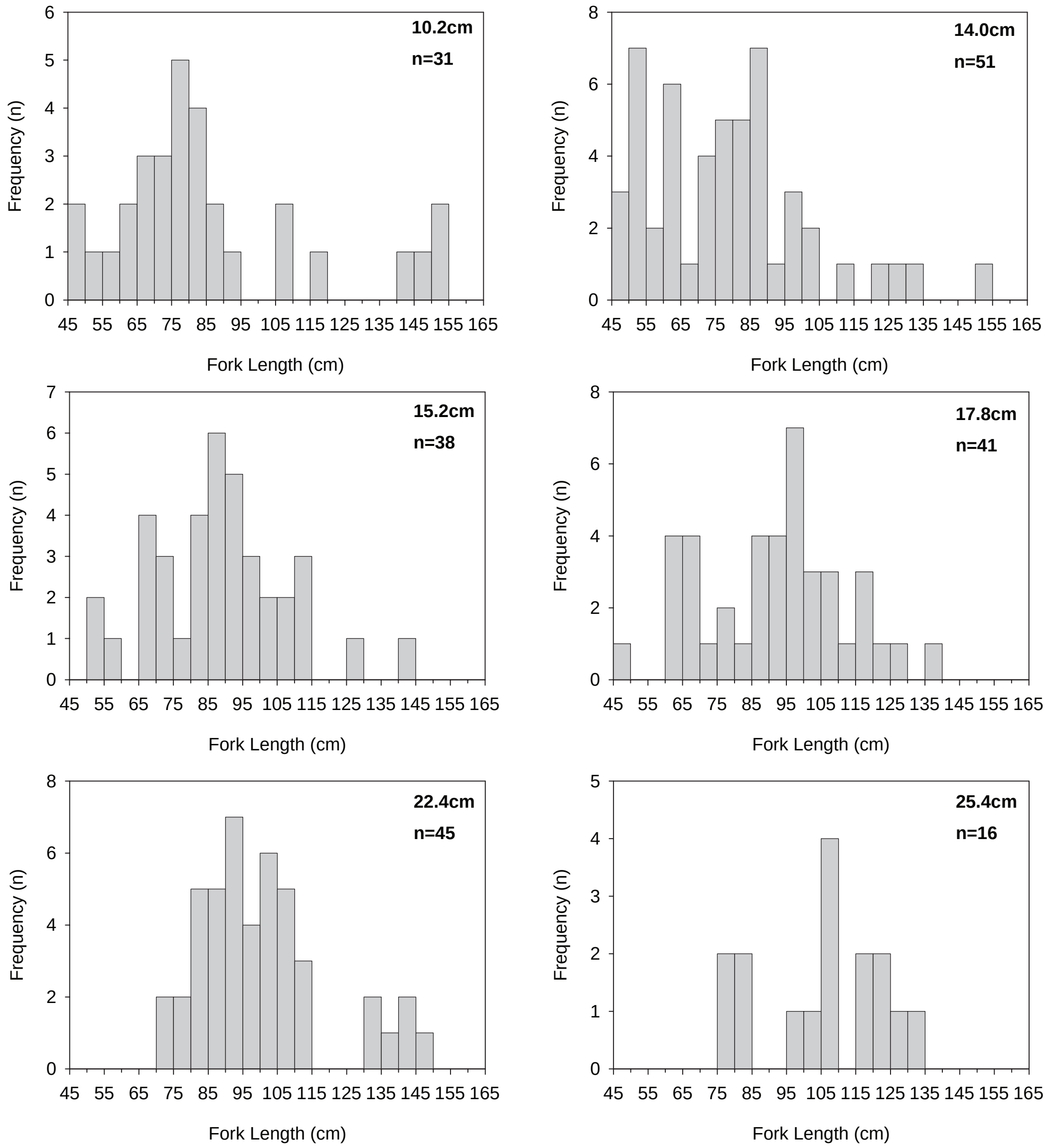


Figure 5.32. Size frequency distributions of 222 *Carcharhinus plumbeus* specimens caught in experimental gillnet panels. Mesh size and sample size are given in the upper right corner of each graph.

Catch rates by each mesh size were highly variable (Figure 5.33). Log transformed catch rates differed significantly between mesh sizes in terms of numbers of sharks caught (ANOVA, *df*=5, *P*=0.048), although not in terms of weight of catches (ANOVA, *df*=5, *P*=0.062). Mean catch rates (by number) were lowest for the 10.2 cm and 25.4 cm panels (0.2 and 0.1 sharks/

km gillnet hr, respectively) and approximately equal for the other 4 mesh sizes (0.3 sharks/km gillnet hr). Mean catch rates (by weight) increased steadily between the 10.2 cm and 22.4 cm mesh sizes (3.6-7.4 kg/km gillnet hr), while the 25.4 cm mesh size yielded the lowest catch rate (3.2 kg/km gillnet hr).

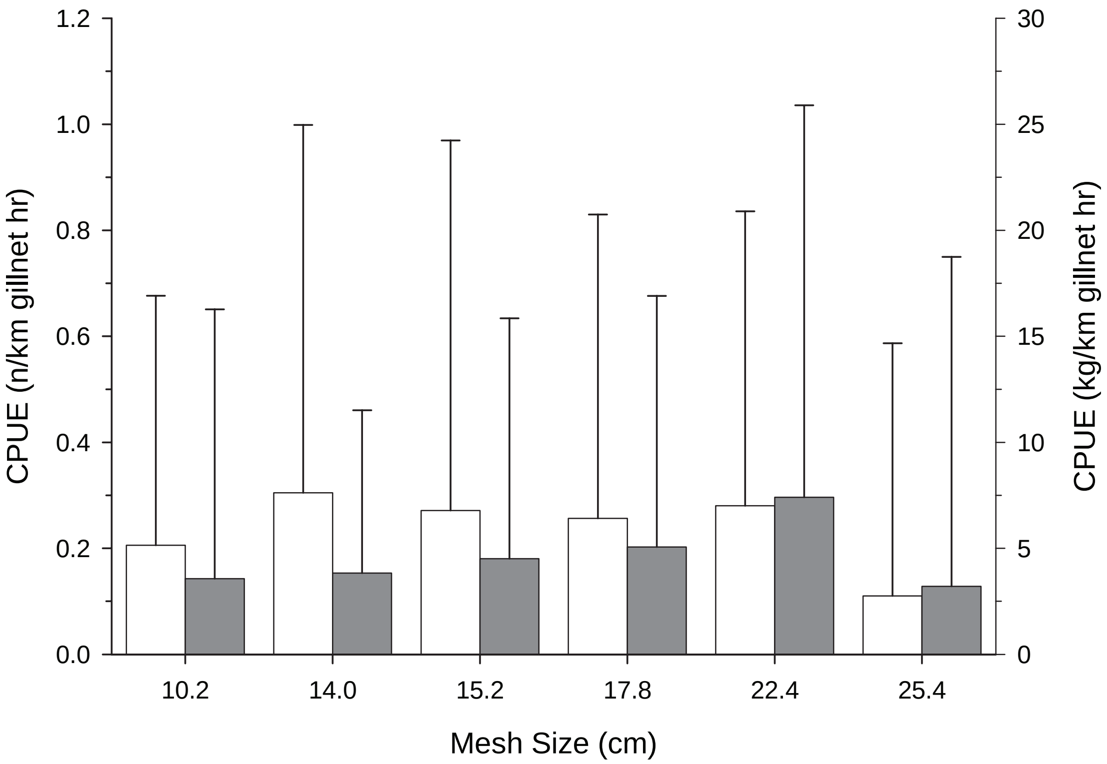


Figure 5.33. *Carcharhinus plumbeus* catch rates by number (open columns) and weight (filled columns) from each panel of the experimental net. Error bars indicate one standard deviation.

Estimates of θ_1 and θ_2 were 135.58 (with 95% confidence that the value was between 131.81 and 139.79) and 117,001 (with 95% confidence that the value was between 84,338 and 165,913), respectively. Relative selectivity plots of the six experimental mesh-sizes, show that the modal length of *C. plumbeus* catches increased with mesh size (Figure 5.34). The length of maximum selectivity of the commercially-important 17.8 cm (7") mesh-size was 94.7 cm. Although the other commercially utilised mesh size of 16.5 cm (6.5") was not empirically tested during this study, by substituting the estimate for θ_1 into equation (4), the length at maximum selectivity was calculated to be 87.9 cm.

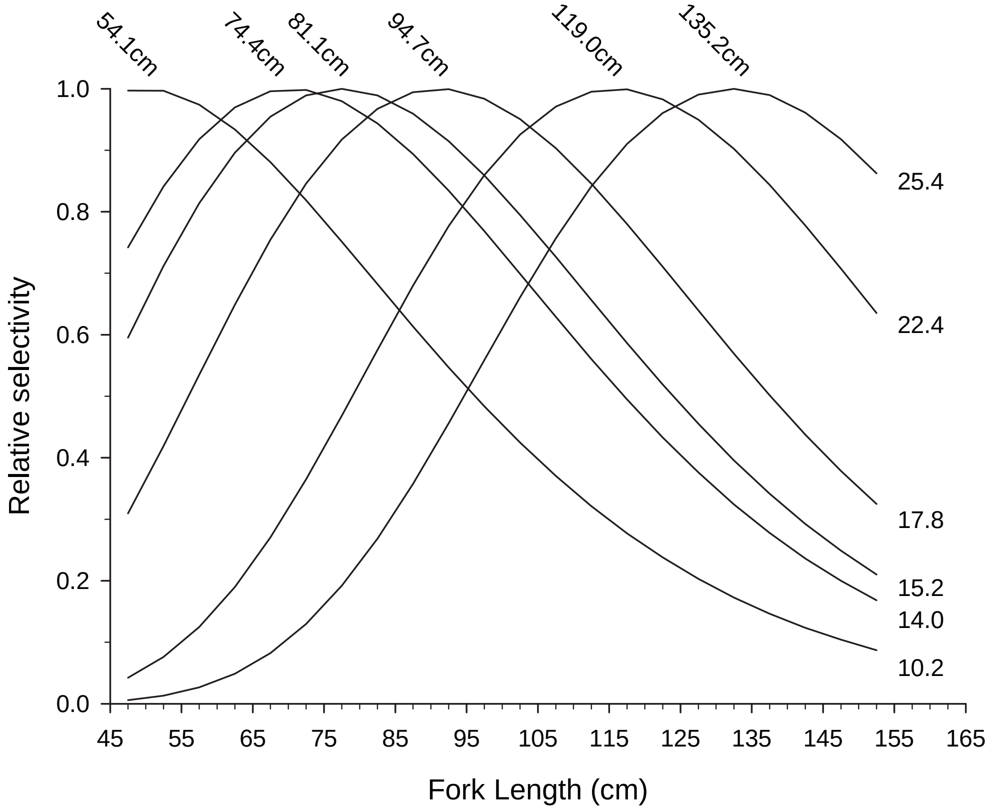


Figure 5.34. Relative gillnet mesh selectivities of the six panels of the experimental net. Mesh sizes are given at the right hand side of each curve. Lengths at maximum selectivity are given above each curve.

There were significant correlations between observed and predicted catches for all mesh sizes except 25.4 cm (Figure 5.35), indicating that the model provided an adequate fit to the data for all but the largest mesh size. However, the correlation coefficients in all but the 22.4cm panel ($r^2 = 0.800$), indicate that there was a considerable degree of variation in the length frequency data for most of the panels. Possible explanations for this are that the sample sizes might have been too small to accurately reflect the selectivity of each mesh size, particularly for the 25.4 cm dataset, or that sharks were not randomly distributed in relation to the nets.

As there were no obvious biases in the residual plots from the model (Figure 5.36), there was unlikely to have been any gross violation of the model's assumptions. The gamma distribution appears to provide a suitable representation of mesh selectivity for all datasets, except perhaps the 25.4 cm panel, as all size frequency plots exhibit a noticeable degree of right skew. Normal distributions were also fitted to these data but were found to provide a less satisfactory fit than gamma distributions.

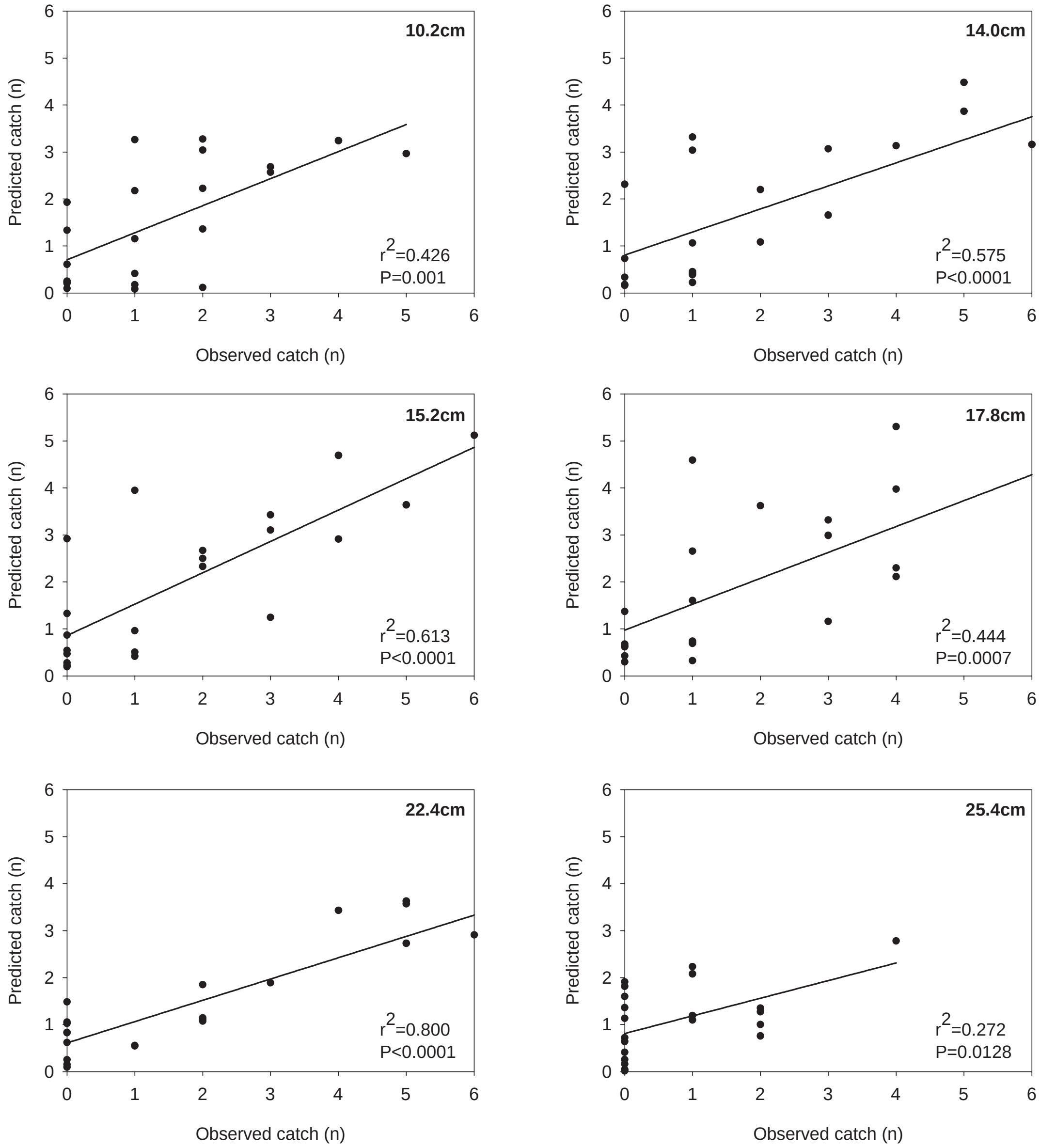


Figure 5.35. Observed versus predicted *Carcharhinus plumbeus* catches (number of fish) from the six panels of the experimental net. Mesh sizes are given in the upper right corner of each graph.

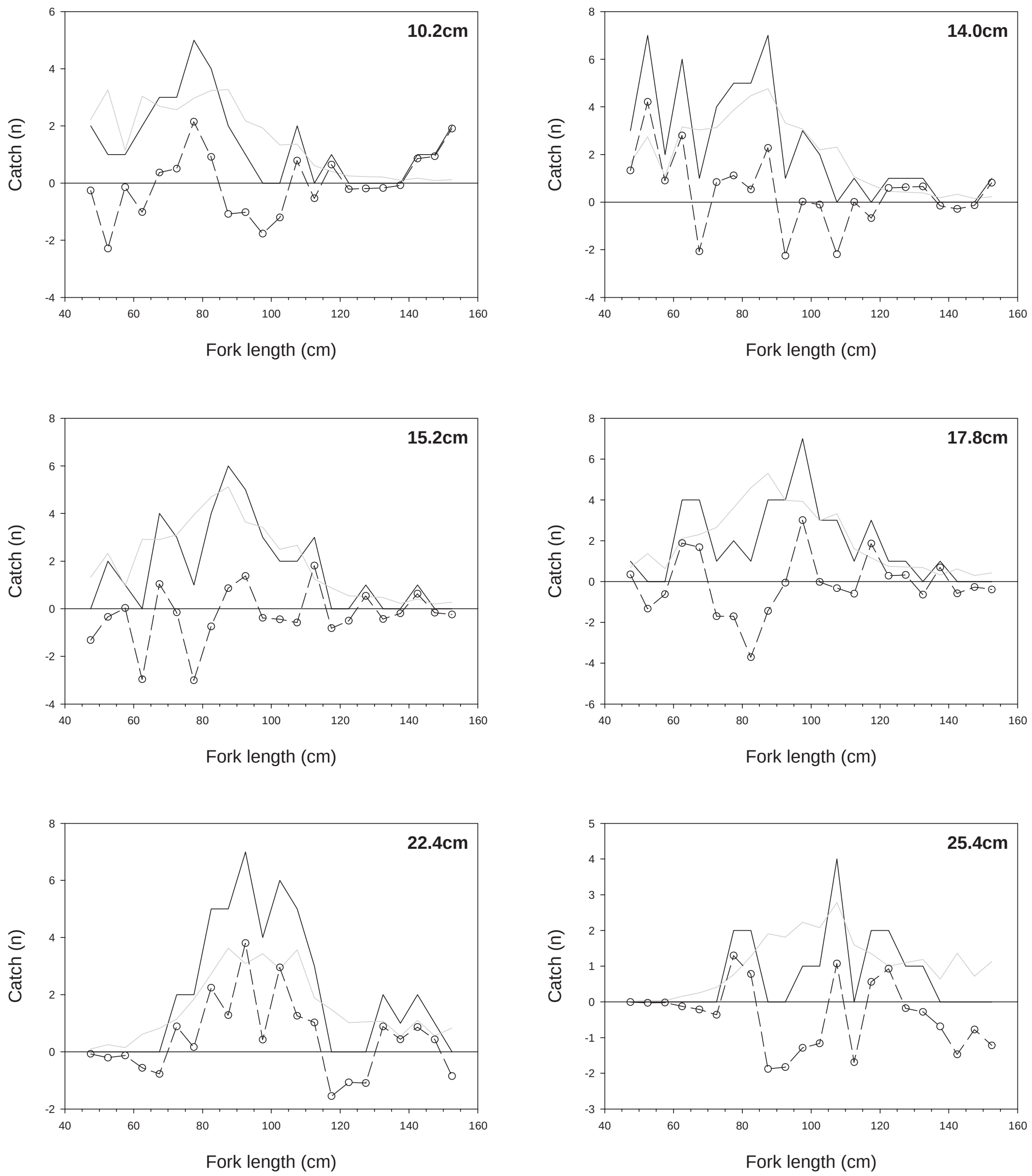


Figure 5.36. Observed and predicted catches and residual values of each size class from the six panels of the experimental net.

The size frequency distribution of the stock estimated from the mesh-selectivity parameters (Figure 5.37) is consistent with the observed size frequency in gillnet catches from the southern half of the State (see 5.1.1). These results further confirm that the *C. plumbeus* stock distributed south of Shark Bay is primarily comprised of juvenile sharks.

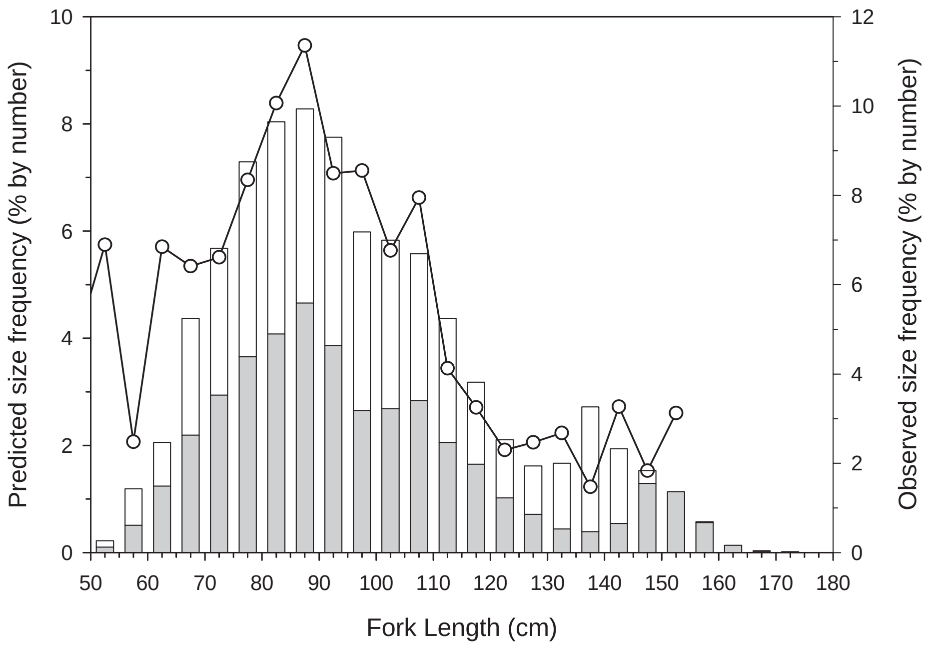


Figure 5.37. Size frequency of the Western Australian *Carcharhinus plumbeus* stock in waters off the lower west coast, as predicted by gillnet mesh selectivity parameters (line) and observed in commercial gillnet catches (vertical bars; grey=female, white=male; see 5.1.1).

5.2.4 Natural mortality

Estimates of instantaneous annual natural mortality rates (*M*) obtained from the Pauly (1980) and Hoenig (1983) methods were reasonably consistent (Table 5.1.2). The median rates calculated by each of these methods were within the 95% confidence limits of the other methods and all yielded realistic population growth rates when applied in the demographic model (see 5.3.1 and Appendix I). Estimates of *M* from the Jensen (1996) methods were generally lower than those calculated from the Pauly (1980) and Hoenig (1983) methods. In particular, Jensen's (1996) methods (ii) and (iii) gave inconsistently low estimates, with upper confidence intervals that were lower than the lower confidence intervals of all other age-independent estimates. These values of *M* were therefore omitted from the ranges from which the stochastically-estimated rates of natural mortality were calculated.

Table 5.12. Age independent estimates of instantaneous annual rate of natural mortality for *C. plumbeus. M* = median of 1000 estimates (units yr^{-1}); CI = confidence intervals.

Method	*M*	Min	Max	95% CI
Pauly (1980, mean water temp= 24°C)	0.113	0.081	0.139	(0.098 - 0.129)
Hoenig (1983), method i	0.126	0.106	0.139	(0.109 - 0.139)
Hoenig (1983), method ii	0.124	0.105	0.132	(0.107 - 0.132)
Hoenig (1983), method iii	0.136	0.116	0.150	(0.119 - 0.150)
Jensen (1996), method i	0.098	0.095	0.106	(0.096 - 0.099)
Jensen (1996), method ii	0.060	0.040	0.077	(0.050 - 0.071)
Jensen (1996), method iii	0.064	0.043	0.082	(0.054 - 0.075)

Whilst the age-independent methods of Petersen and Wroblewski (1984) and Chen and Watanabe (1989) yielded higher estimates of *M* for the youngest and oldest sharks, rates for those age-classes that are caught by the fisheries were generally lower than were estimated by age independent methods (Table 5.1.3). Substituting live weight for dry weight in the Petersen and Wroblewski (1984) method resulted in natural mortality rates that were consistent with estimates from the other methods and which, unlike the rates calculated using dry weight, gave positive population growth rates with zero fishing mortality in the demographic model (see 5.3.1 and Appendix I). The stochastically estimated rates of natural mortality used in the stock assessment retained some of the U-shaped characteristics of the Chen and Watanabe (1989) method, although the rates of the youngest and oldest age-classes were not as high as were estimated directly from this method.

Table 5.13. Age dependent estimates of natural mortality rates of *C. plumbeus*. $\overline{M}$ = mean of 1,000 estimates from bootstrapped biological parameter estimates (units yr^{-1}); CI = confidence interval.

Age class	Petersen & Wroblewski (1984) *M*	Chen & Watanabe (1989) *M*	Chen & Watanabe (1989) 95% CI	Stochastically estimated *M*	Stochastically estimated 95% CI
0+	0.216	0.228	(0.214 - 0.245)	0.160	(0.101 - 0.226)
1+	0.194	0.193	(0.182 - 0.205)	0.146	(0.100 - 0.192)
2+	0.177	0.168	(0.159 - 0.178)	0.136	(0.100 - 0.176)
3+	0.164	0.149	(0.141 - 0.158)	0.132	(0.100 - 0.163)
4+	0.153	0.135	(0.128 - 0.142)	0.126	(0.099 - 0.152)
5+	0.144	0.123	(0.117 - 0.130)	0.121	(0.099 - 0.144)
6+	0.137	0.114	(0.108 - 0.120)	0.119	(0.099 - 0.143)
7+	0.131	0.106	(0.101 - 0.112)	0.117	(0.098 - 0.143)
8+	0.125	0.100	(0.095 - 0.106)	0.116	(0.098 - 0.144)
9+	0.120	0.094	(0.089 - 0.100)	0.115	(0.094 - 0.143)
10+	0.116	0.090	(0.085 - 0.095)	0.112	(0.090 - 0.143)
11+	0.112	0.085	(0.081 - 0.091)	0.110	(0.086 - 0.143)
12+	0.109	0.082	(0.077 - 0.087)	0.108	(0.082 - 0.141)
13+	0.106	0.079	(0.074 - 0.084)	0.108	(0.079 - 0.143)
14+	0.103	0.076	(0.071 - 0.081)	0.106	(0.076 - 0.142)
15+	0.101	0.073	(0.069 - 0.078)	0.103	(0.074 - 0.142)
16+	0.099	0.071	(0.066 - 0.076)	0.103	(0.072 - 0.141)
17+	0.097	0.069	(0.064 - 0.074)	0.101	(0.069 - 0.141)
18+	0.095	0.067	(0.063 - 0.072)	0.101	(0.067 - 0.141)
19+	0.093	0.065	(0.061 - 0.070)	0.102	(0.066 - 0.143)
20+	0.091	0.064	(0.059 - 0.069)	0.099	(0.065 - 0.141)
21+	0.090	0.062	(0.058 - 0.067)	0.100	(0.063 - 0.140)
22+	0.089	0.061	(0.057 - 0.066)	0.099	(0.063 - 0.142)
23+	0.087	0.060	(0.055 - 0.065)	0.097	(0.061 - 0.140)
24+	0.086	0.059	(0.054 - 0.064)	0.096	(0.059 - 0.140)
25+	0.085	0.057	(0.053 - 0.063)	0.095	(0.058 - 0.142)
26+	0.084	0.057	(0.052 - 0.062)	0.096	(0.058 - 0.140)
27+	0.083	0.056	(0.051 - 0.061)	0.096	(0.057 - 0.140)
28+	0.082	0.055	(0.050 - 0.060)	0.094	(0.056 - 0.141)
29+	0.081	0.054	(0.050 - 0.059)	0.094	(0.055 - 0.142)
30+	0.081	0.053	(0.049 - 0.059)	0.093	(0.055 - 0.145)
31+	0.080	0.053	(0.048 - 0.644)	0.094	(0.053 - 0.149)
32+	0.079	0.052	(0.047 - 0.660)	0.095	(0.054 - 0.333)
33+	0.079	0.051	(0.047 - 0.675)	0.097	(0.052 - 0.428)
34+	0.078	0.051	(0.046 - 0.690)	0.098	(0.052 - 0.525)
35+	0.077	0.050	(0.046 - 0.704)	0.100	(0.052 - 0.562)
36+	0.077	0.050	(0.045 - 0.717)	0.103	(0.051 - 0.580)
37+	0.076	0.049	(0.045 - 0.730)	0.107	(0.051 - 0.587)
38+	0.076	0.049	(0.044 - 0.741)	0.119	(0.051 - 0.615)
39+	0.075	0.587	(0.044 - 0.752)	0.128	(0.050 - 0.628)
40+	0.075	0.603	(0.043 - 0.762)	0.162	(0.051 - 0.656)

5.2.5 *Age-specific rates of fishing mortality*

5.2.5.1 Sources of tag capture data

A total of 75 tagged *C. plumbeus* captures were reported between March 2001 and May 2004 (Table 5.14). More than 85% of these were reported from the target shark fisheries, of which 44 were caught by gillnets in the WCDGDLF, 12 by gillnets in the JASDGDLF and eight by longlines in the WANCSF. Of these, nine sharks were at liberty for less than 90 days, three were captured by recreational fishers and one was caught during a fishery independent survey and were excluded from analysis of capture rates.

Table 5.14. Sources of tagged *C. plumbeus* captures between August 2000 and May 2004 by fishery and method. Managed fisheries are abbreviated as follows: WCDGDLF= West Coast Demersal Gillnet and Demersal Longline Fishery; JASDGDLF= Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery; WANCSF=WA North Coast Shark Fishery; PFTF=Pilbara Fish Trawl fishery; SBPTF=Shark Bay Prawn Trawl Fishery.

Fishery	n	Method	n
WCDGDLF	44	Demersal gillnet	53
JASDGDLF	12	Demersal longline	8
WANCSF	8	Unspecified hook methods	5
Wetline Fishery	4	Handline	3
Recreational	3	Dropline	3
SBPTF	2	Trawl	3
PFTF	1		
Research	1		

A total of 664 sharks were tagged in the closed area between August 2000 and June 2004, compared to 1,080 tagged in open areas (Figure 4.6) over the same period. Thirteen of the sharks tagged in the closed area were captured before the end of 2003/04, compared to 63 captures of sharks tagged in open areas. Seven of the sharks tagged in the closed area were captured in the area of the WANCSF (five by WANCSF vessels, one by a ‘wetline’ vessel and one by a recreational fisher); three occurred inside the closed area (one by a recreational fisher, one during a fishery-independent research survey and one in the bycatch of a Shark Bay prawn trawler) and three were caught by WCDGDLF vessels.

The capture rate of sharks tagged in the closed area (n=13, 2.0%) was marginally higher but not significantly different to that of sharks that were tagged in the area of WANCSF (n=6, 1.7%; χ^2 = 0.007, *df*=1, *P*=0.931), indicating that sharks occurring in the closed area were no less likely to be caught than those in the adjacent area of the WANCSF. Although, overall the sharks tagged in the area of the TDGDLF were caught at a significantly higher rate (n=57, 7.9%) than those tagged in the closed area (χ^2 = 23.087, *df*=1, *P*=1.548 x10^{-6}) and in the WANCSF (χ^2 = 15.018, *df*=1, *P*=1.065 x10^{-4}), most of the sharks tagged in the TDGDLF were juveniles, whilst most of those tagged in the area north of Steep Point were sub-adults and adults. However, when capture rates only for sharks older than seven years were compared between areas, there was found to be no significant difference between the capture rate of sharks tagged in the closed area (n=10, 1.9%) and that of sharks tagged in open areas (n=20, 2.8%; χ^2 = 0.765, *df*=1, *P*=0.382). These results strongly suggest that the closed area in the centre of this stock’s range provides no significant protection to the sub-adult and adult age classes that primarily reside in the area north of Steep Point.

In addition, longer-term tag recapture data from two sharks, which were released as juveniles (71 cm FL and 75 cm FL, respectively) in the south-west of the State (between 32°S and 34°S) and caught in the WANCSF 7½ - 8 years later, suggest that as *C. plumbeus* reach maturity, they migrate northwards up the West Coast and across the closed area to join the bulk of the adult stock residing in waters off the north coast.

5.2.5.2 *Tag captures and fishing mortality rates*

Estimated annual non-reporting rates (D_{iT}) of tag captures were lowest in Region 1, generally higher in region 2 and highest in region 3 (Table 5.15). Non-reporting rates increased sharply in regions 2 and 3 during 2003/04 as a result of substantial increases in *C. plumbeus* catches by vessels that did not report any tag captures. It was estimated that a total of 29 tags were captured in 2001/02, 42 in 2002/03 and 80 in 2003/04. The majority of tags were captured in Region 2 in all years, although the number of estimated captures in region 3 increased by more than 300% between 2002/03 and 2003/04.

Table 5.15. Estimated annual tag non-reporting rates during the 2001/02, 2002/03 and 2003/04 fishing seasons and numbers of reported and estimated *C. plumbeus* tag captures by region (denoted by *i*).

	Non-reporting rates ($D_{i,t}$)			**Reported captures ($C_{i,T}$)**			**Estimated captures $_{i,T}$**		
Year	*i =1*	*i =2*	*i =3*	*i =1*	*i =2*	*i =3*	*i =1*	*i =2*	*i = 3*
2001-02	0.23	0.50	0.39	3	11	2	4	22	3
2002-03	0.13	0.47	0.55	8	13	4	9	24	9
2003-04	0.09	0.67	0.84	0	16	5	0	48	31

Age specific rates of instantaneous annual fishing mortality (F_x) were similar for 0+ to 10+ age-classes during 2001/02 and 2002/03 (Figure 5.38). Fishing mortality rates of adult sharks during these years were generally lower than those experienced by juveniles and were limited to a few age-classes. While fishing mortality increased in most age-classes during 2003/04, rates were still highest for sharks younger than 14 years. With the exception of the unrealistically high fishing mortality rate experienced by the 24+ age-class in 2002/03 (which was based on the capture of 2 sharks), the highest levels of fishing mortality in all years were experienced by 6+ to 8+ age-classes. These ages correspond closely to the ages at which the mesh sizes used in the TDGDLF (16.5 - 17.8 cm) attain their maximum selectivity (7.5 – 8.7 yrs). As evidenced by the 95% confidence intervals around the median estimates, variations in fishing mortality due to stochastic estimation of natural mortality rates were negligible.

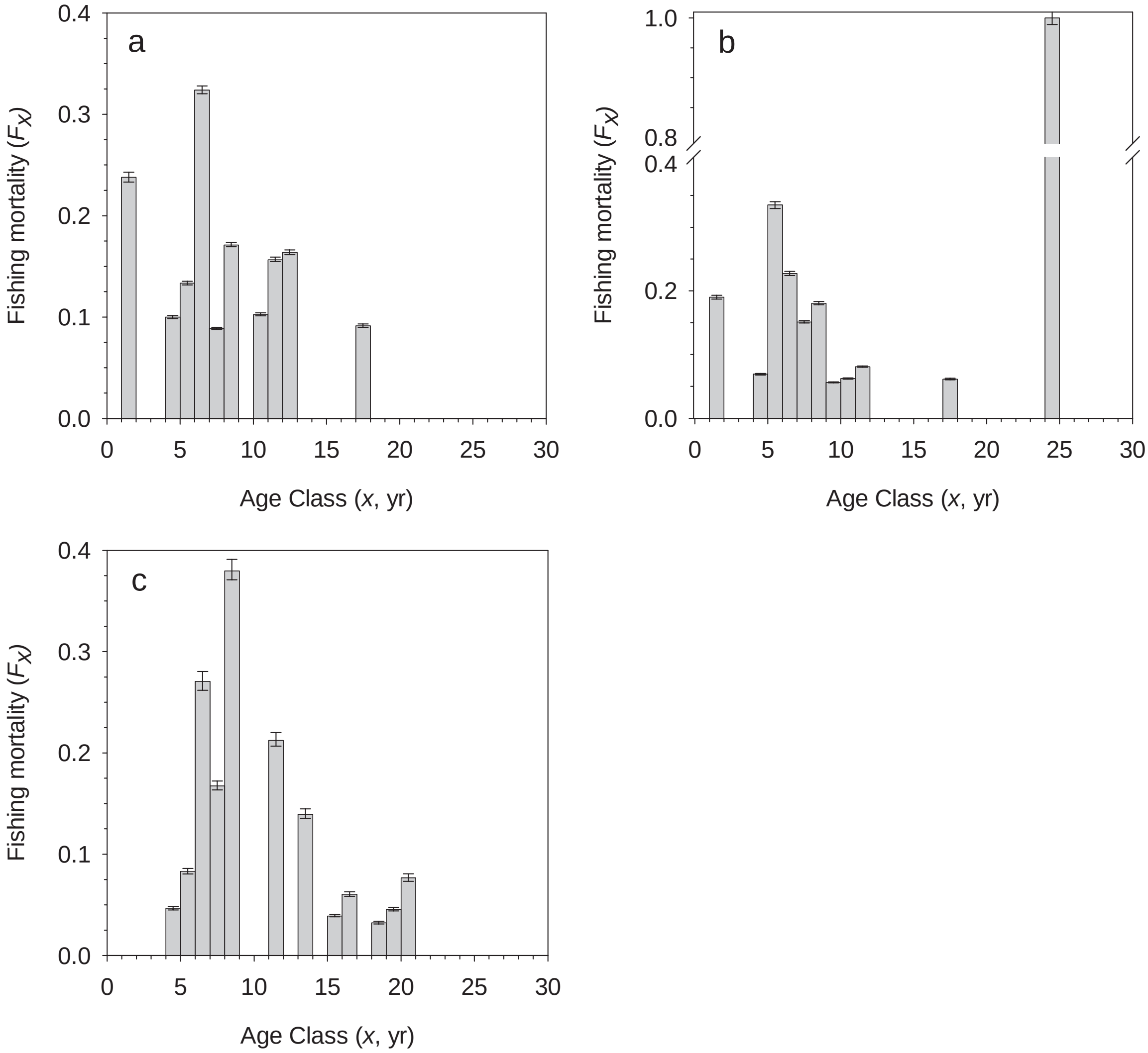


Figure 5.38. Age specific rates of instantaneous annual fishing mortality experienced by individual year classes of *C. plumbeus,* determined from capture rates of tagged sharks in (a) 2001/02, (b) 2002/03, (c) 2003/04. Bars are the median rates of 1000 estimates calculated with stochastic biological parameter values. Error bars indicate 95% confidence intervals.

The highest rates of fishing mortality determined for multi-year age classes ($\hat{F}_{x,2001/02}$ $\hat{F}_{x,2002/03}$ and $\hat{F}_{x,2003/04}$) were experienced by the 6-9 year age class in 2001/02 and 2003/04 and by the 3-6 year age class in 2002/03 (Figure 5.39). Rates of juvenile fishing mortality increased between 2001/02 and 2003/04, by between 11% in the 12-15 year age-class and 48% in the 6-9 year age-class. As no tag captures of sharks older than 17 years were reported during 2001/02, no estimates of fishing mortality could be made for the older age classes in the first year. Fishing mortality of the adult age-classes was estimated to have increased by between 108% (15-18 years) and 172% (18-24 years) between 2002/03 and 2003/04.

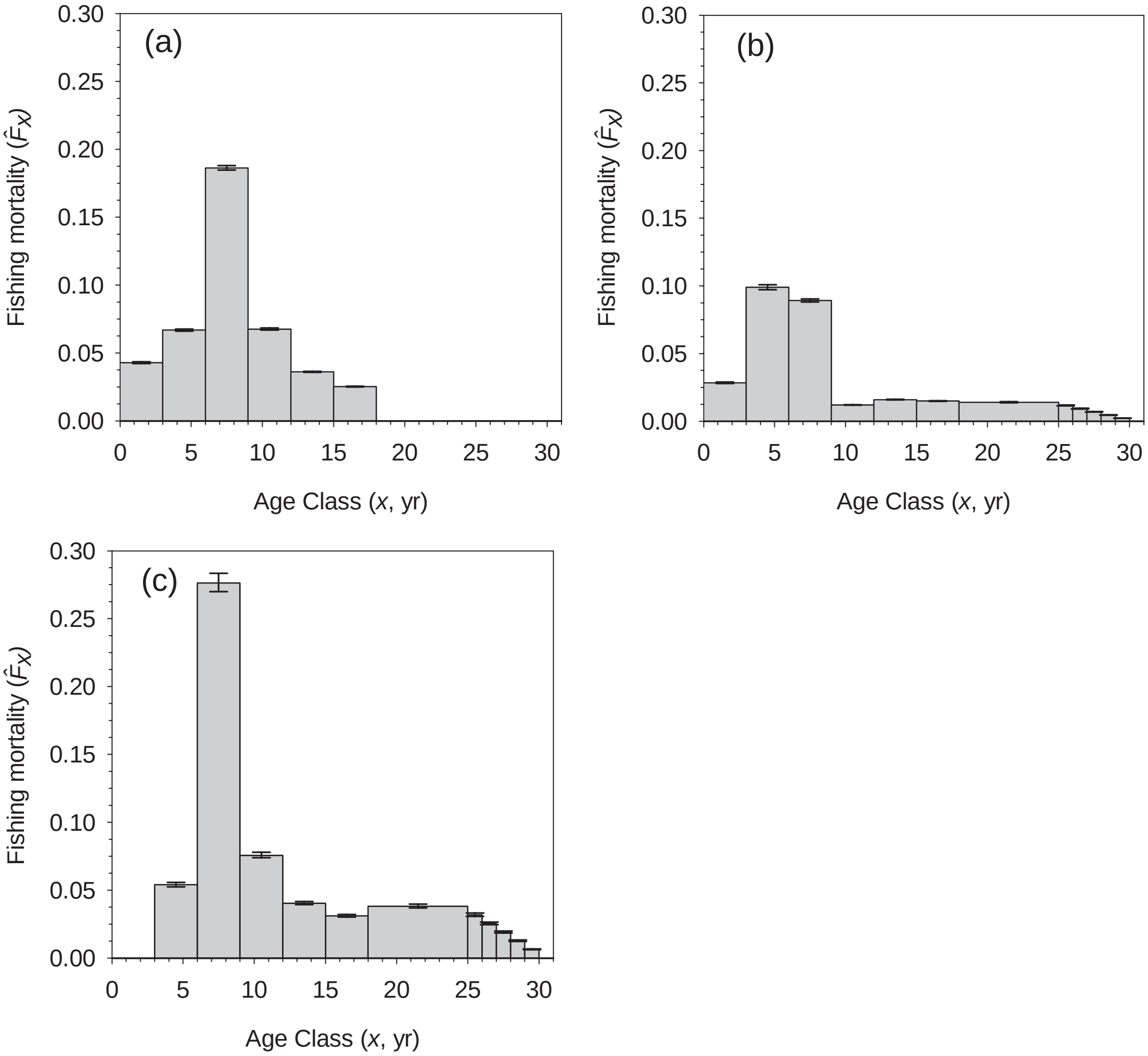


Figure 5.39. Rates of instantaneous annual fishing mortality, experienced by multi-year age classes of *C. plumbeus,* determined from capture rates of tagged sharks in (a) 2001/02, (b) 2002/03, (c) 2003/04. Bars are the median rates of 1000 estimates calculated with stochastic biological parameter values. Error bars indicate 95% confidence intervals.

5.3 Stock Assessment

5.3.1 Demographic analysis of the WA sandbar stock

Using stochastically estimated biological parameters and rates of natural mortality, the Western Australian *C. plumbeus* population was estimated to have an intrinsic rate of population growth of 0.025 (2.5% per year) with zero fishing mortality, with 95% confidence that *r* was between -0.018 and 0.055 yr^{-1} (Table 5.16; Appendix I, table i). Rates of natural mortality calculated from the Hoenig (1983) methods resulted in the lowest median population growth rates (r=0.007 to 0.023 yr^{-1}) with no fishing, whilst *M* calculated by Jensen's (1996) methods yielded the highest median values of *r* (0.046 to 0.086 yr^{-1}). The level of fishing mortality that would deliver Maximum Sustainable Yield, when applied evenly across all age classes, was calculated from the median estimate of *r*, using the stochastically estimated *M*, to be 0.017 $year^{-1}$. When tested in the demographic model, this rate resulted in a population growth rate of r= 0.013.

The age specific fishing mortality rates, $F_{2001/02}$, $F_{2002/03}$ and $F_{2003/04}$, all resulted in negative rates of population growth (*r*), under all but the most optimistic rates of natural mortality (Jensen, 1996, methods i and ii; Appendix I, tables ii-iv). Using stochastically estimated rates of natural mortality, median estimates of the rates at which the stock was declining under these levels of fishing mortality were: 4.9% per year in 2001/02 (with 95% confidence that *r* was between -0.092 and -0.019% yr^{-1}), 5.9% per year in 2002/03 (95% confidence intervals of r = -0.110 to -0.026% yr^{-1}) and 4.8% per year in 2003/04 (95% confidence intervals of r = -0.089 and -0.017% yr^{-1}; Table 5.16; Appendix I, table ii-iv). The most severe rates of natural mortality (Hoenig, 1983, method iii), gave median rates of population decline of 7.4% yr^{-1}, 8.5% yr^{-1} and 7.6% yr^{-1} in 2001/02, 2002/03 and 2003/04, respectively.

The adjusted multi-year age class rates of fishing mortality, $\hat{F}_{2001/02}$, $\hat{F}_{2002/03}$ and $\hat{F}_{2003/04}$, provided slightly more optimistic estimates of *r* than the age specific rates (Appendix I, tables v-vii). However, when combined in the demographic model with all but a few rates of natural mortality, *r* was nonetheless negative for all years of the study. Using stochastically estimated rates of natural mortality, median estimates of the rates at which the stock was declining under these levels of fishing mortality were: 3.2% per year in 2001/02 (with 95% confidence intervals of r = -0.075 and -0.001% yr^{-1}), 0.9% per year in 2002/03 (with 95% confidence of r = -0.054% yr^{-1} and +0.022% yr^{-1}) and 4.9% per year in 2003/04 (95% confidence intervals of r = -0.093 and -0.018% yr^{-1}; Table 5.16.; Appendix 1, tables v-vii). Estimates of natural mortality from Hoenig (1983, method iii), gave median rates of population decline of 5.6% yr^{-1}, 3.4% yr^{-1} and 7.8% yr^{-1} in 2001/02, 2002/03 and 2003/04, respectively.

Table 5.16. Summary of demographic analysis results for *Carcharhinus plumbeus* under stochastically estimated rates of natural mortality (*M*) and various schedules of fishing mortality.

Fishing mortality schedule	Proportion reaching maturity (P_M)	Net reprod. rate R_0 (no yr^{-1})	Generation time G (yr)	Doubling time $tx2$ (yr)	Potential pop. growth rate (r yr^{-1})
No fishing	0.134 (0.12, 0.13)	2.0 (0.8, 3.6)	22.7 (21.9, 24.2)	23.1 (-263.5, 193.0)	0.025 (-0.018, 0.055)
Age specific fishing mortality					
2001/02 ($F_{2001/02}$)	0.028 (0.02, 0.03)	0.4 (0.1, 0.7)	22.7 (21.7, 24.4)	-14.0 (-34.9, -7.5)	-0.049 (-0.092, -0.019)
2002/03 ($F_{2002/03}$)	0.033 (0.03, 0.04)	0.3 (0.1, 0.6)	20.0 (19.8, 20.6)	-11.7 (-26.5, -6.3)	-0.059 (-0.110, -0.026)
2003/04 ($F_{2003/04}$)	0.031 (0.02, 0.04)	0.4 (0.2, 0.8)	22.5 (21.6, 24.0)	-14.6 (-40.6, -7.8)	-0.048 (-0.089, -0.017)
Multi-year age class fishing mortality					
2001/02 ($\hat{F}_{2001/02}$)	0.040 (0.03, 0.05)	0.6 (0.2, 1.1)	22.8 (21.8, 24.2)	-21.1 (-158.4, -6.4)	-0.032 (-0.075, -0.001)
2002/03 ($\hat{F}_{2002/03}$)	0.068 (0.05, 0.08)	0.9 (0.3, 1.8)	22.6 (21.6, 24.1)	-25.1 (-460.5, 609.1)	-0.009 (-0.054, 0.022)
2003/04 ($\hat{F}_{2003/04}$)	0.032 (0.03, 0.04)	0.4 (0.1, 0.8)	22.1 (21.3, 23.5)	-14.2 (-39.6, -7.5)	-0.049 (-0.093, -0.018)

5.3.2 Alternative management options for the WA sandbar fishery

The relative contribution of each fishery that was identified as having a catch or bycatch of *C. plumbeus* was derived from the catches estimated in 5.2.1 and 5.2.2. Validated gillnet catches in the temperate demersal gillnet and longline fishery were 162.0 tonnes, 170.1 tonnes and 144.2 tonnes; temperate longline catches were 0.9 tonnes, 0.0 tonnes and 55.9 tonnes; Pilbara Fish Trawl fishery catches were 13.1 tonnes, 17.3 tonnes and 12.1 tonnes and in the WANCSF were 174.6 tonnes, 196.3 tonnes and 423.9 tonnes in 2001/02, 2002/03 and 2003/04, respectively. The proportion of the total *C. plumbeus* catch taken by the WANCSF increased from 48% in 2001/02, to 50% in 2002/03 and to 66% in 2003/04 (Figure 5.40). The proportion caught by temperate demersal gillneters dropped from 45% in 2001/02 to 22% in 2003/04, whilst the proportion taken by temperate longliners increased from less than 1% to nearly 9% over the same period. The combined take by the Pilbara Fish Trawl fishery, other trawlers and by the wetine sector accounted for between 3% (2003/04) and 7% (2002/03) of the total *C. plumbeus* catch.

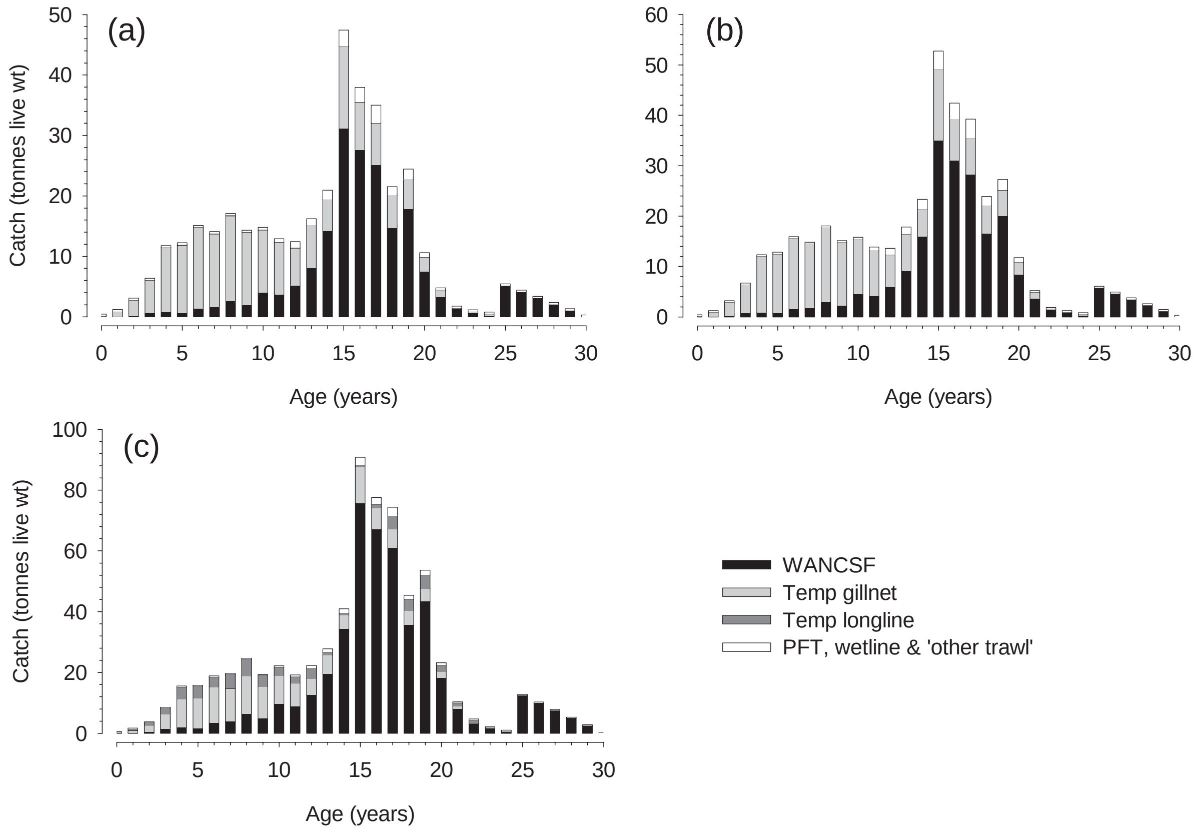


Figure 5.40. Estimated catches at-age of *C. plumbeus* in the temperate demersal gillnet and longline fishery (dark grey bars) the Pilbara Fish Trawl fishery (white bars) and the WA north coast shark (dark grey bars) during (a) 2001/02, (b) 2002/03 and (c) 2003/04.

Table 5.17. Fishery management options for obtaining neutral or positive intrinsic population growth rates (r) in the Western Australian Carcharhinus plumbeus stock, determined from demographic analysis. $\hat{F}_{2003/04}$ is the proportion of the 2003/04 level of fishing mortality determined for each of the target fisheries and, for reference, is shown relative to the fisheries' proportional 2003/04 levels of catch and effort. The options are ranked by r. The letters in brackets refer to the summary options A-G in the text.

WANCSF			Temperate Gillnet			Temperate Longline			Population growth rate (*r*)	
$\hat{F}_{2003/04}$	Catch*	Effort†	$\hat{F}_{2003/04}$	Catch*	Effort††	$\hat{F}_{2003/04}$	Catch*	Effort†	Median	95% confidence intervals
0.25	106	130	0.00	0	0	0.00	0	0	0.024	(-0.021, 0.055)
0.00	0	0	0.25	36	60	0.00	0	0	0.022	(-0.023, 0.055)
0.00	0	0	0.25	36	60	0.25	14	69	0.018	(-0.030, 0.049)
0.50 (C)	212	259	0.00	0	0	0.00	0	0	0.017	(-0.028, 0.049)
0.00	0	0	0.50 (F)	72	120	0.00	0	0	0.014	(-0.031, 0.044)
0.25 (D)	106	130	0.25 (G)	36	60	0.00	0	0	0.012	(-0.032, 0.043)
0.25 (D)	106	130	0.25	36	60	0.25	14	69	0.012	(-0.033, 0.043)
0.70 (B)	297	363	0.00	0	0	0.00	0	0	0.011	(-0.033, 0.043)
0.85 (A)	360	441	0.00	0	0	0.00	0	0	0.008	(-0.036, 0.040)
0.50 (B)	212	259	0.25 (G)	36	60	0.00	0	0	0.007	(-0.042, 0.036)
0.00	0	0	0.50 (F)	72	120	0.50	28	138	0.006	(-0.040, 0.038)
0.00	0	0	0.70 (E)	101	168	0.00	0	0	0.006	(-0.043, 0.038)
0.50 (C)	212	259	0.25	36	60	0.25	14	69	0.005	(-0.040, 0.037)
1.00 (A)	424	519	0.00	0	0	0.00	0	0	0.005	(-0.042, 0.036)
0.00	0	0	0.85	123	204	0.00	0	0	0.001	(-0.042, 0.034)
0.70 (B)	297	363	0.25	36	60	0.00	0	0	0.000	(-0.045, 0.032)
0.25 (D)	106	130	0.50 (F)	72	120	0.00	0	0	0.000	(-0.046, 0.032)

To test the outcomes of potential fishery management strategies, 65 hypothetical scenarios of fishing mortality in the various fishing sectors that catch *C. plumbeus* were tested in the model (Appendix II). A range of potential fishing mortality combinations, that would deliver neutral or positive population growth rates, were identified. Seventeen hypothetical combinations of fishing mortality that delivered neutral or positive intrinsic population growth rates were identified in the model (Table 5.17, Appendix II). Fifteen of these required zero fishing mortality in one or other of the target fisheries. The remaining two options required substantial reductions in both the WANCSF and the TDGDLF. These results are summarised as follows (unless otherwise stated, each case assumes zero fishing mortality in all other WA fishing sectors except the PFTF):

A. Maintaining the WANCSF at between 85 and 100% of its 2003/04 level of fishing mortality, requires closure of the temperate demersal gillnet and demersal longline fishery.

B. Reducing the WANCSF to 70% of its 2003/04 level of fishing mortality, would permit 25% of the 2003/04 level of exploitation by the temperate demersal gillnet fishery but would require closure of the temperate demersal longline fishery.

C. Reducing fishing mortality in the WANCSF to 50% of its 2003/04 level, would permit approximately 25% of the 2003/04 level of exploitation in the temperate demersal gillnet and demersal longline fishery.

D. Reducing fishing mortality in the WANCSF to 25% of its 2003/04 level, would permit either 25% of the 2003/04 level of exploitation in each of the temperate fisheries or 50% of the 2003/04 level of fishing in the temperate demersal gillnet fishery and no exploitation in the demersal longline fishery.

E. Maintaining the temperate gillnet fishery at between 70 and 85% of its 2003/04 level of exploitation, would permit 0% of the 2003/04 level of exploitation by the temperate longline fishery and the WANCSF.

F. Reducing the temperate gillnet fishery to 50% of its 2003/04 level of exploitation, would permit either 25% of the 2003/04 level of exploitation by the WANCSF and no exploitation by the temperate longline fishery (i.e. D above) or 50% of the 2003/04 level of exploitation by the temperate longline fishery and no exploitation by the WANCSF.

G. Reducing the temperate gillnet fishery to 25% of its 2003/04 level of exploitation, would permit either 70% of the 2003/04 level of exploitation by the WANCSF and no exploitation by the temperate longline fishery (i.e. B above) or 25% of the 2003/04 level of exploitation by the temperate longline fishery and no exploitation by the WANCSF. Other combinations are covered by the above points.

5.3.3 Refining the dusky shark, *Carcharhinus obscurus*, stock assessment

5.3.3.1 Biological parameters

Table 5.18. Summary of reproductive and von Bertalanffy data, from which *C. obscurus* demographic analysis parameters were sampled. CI=confidence interval.

	Litter size	Proportion female embryos	Breeding freq. (yr)	$L_{0.5}$ (cm FL)	b	Age at maturity (α, yr)	K (yr^{-1})	L_{∞} (cm FL)	t_0 (yr)	Max age (w, yr)
Mean	9.9	0.50	3	254.1	0.439	30	0.0367	374.4	-3.3	45
Std. Dev.	2.7	0.1								
min	2.1	0.10	2	245.4	0.210	27	0.0191	302.6	-4.0	40
max	17.8	0.85	4	261.1	0.808	35	0.0519	573.2	-2.9	55
Lower 95% CI	4.7	0.29	2	247.5	0.227	27	0.0262	317.7	-3.7	40
Upper 95% CI	15.1	0.70	4	259.5	0.769	32	0.0476	460.8	-3.0	53

Reproductive parameters were sampled from data collected (according to the criteria given in 4.1.4) from 460 female *C. obscurus*, ranging in size from 64 cm FL to 289 cm FL. Specimens were collected between the 12th of June 1993 and the 4th of June 2004, from waters west of the Lacepede Islands (17°S, 121°E) on the north coast to the east of Esperance (34°S, 123°E) on the south coast. Of these, 45 were mature (stages 3-6, inclusive) and 21 were maturing (stage 2). The smallest mature shark measured 250 cm FL and the largest immature shark was 255 cm. By fitting the logistic maturity function to the proportion of mature sharks by 5 cm FL size classes, the length at which 50% of female *C. obscurus* were mature was estimated to be 251.3 cm FL (Figure 5.41), with 95% confidence that $L_{0.5}$ was between 247.5cm FL and 25.4 cm FL (Table 5.18). Litters from eleven pregnant females contained between six and 13 embryos. Mean litter size was 9.9 with a standard deviation of 2.7.

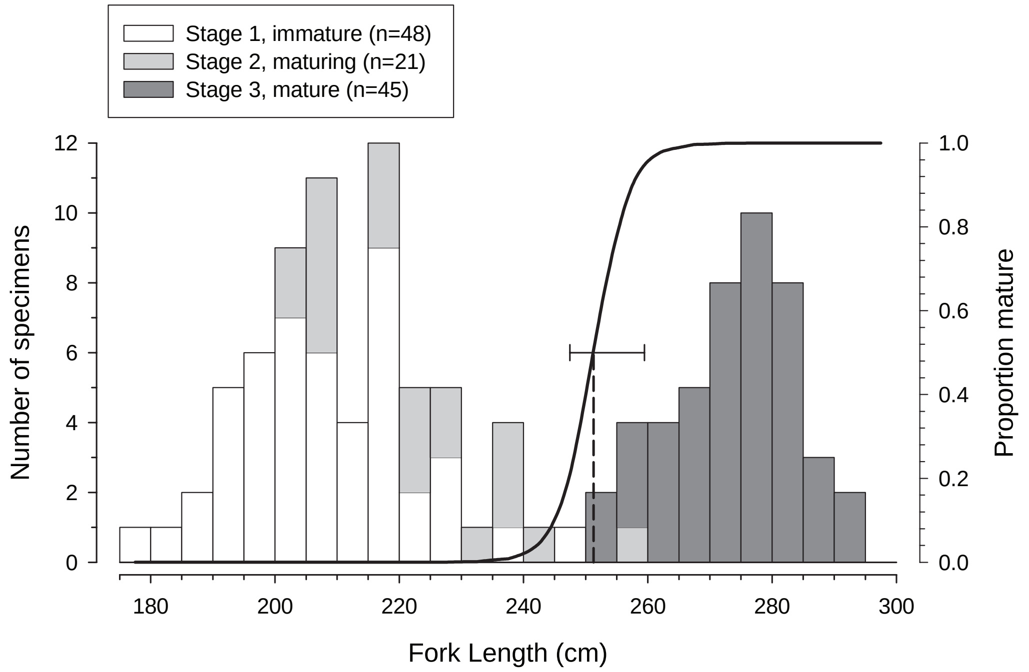


Figure 5.41. Maturity (uterine) stages of 114 female *Carcharhinus obscurus,* measuring between 175cm and 300cm FL, sampled between June 1993 and June 2004. Curve is the proportion of mature sharks by 5cm FL size classes, as determined by logistic regression analysis; dashed vertical line indicates the estimated size at 50% maturity ($L_{0.5}$); error bars are 95% confidence intervals of the estimated $L_{0.5}$.

Length at age data were estimated from vertebral samples of 127 female *C. obscurus* collected in waters between the Montebello Islands (20°S 115°E) on the north coast and east of Esperance (33°S 124°E) on the south coast between the 10th of June 1993 and the 4th of October 1998. Sharks ranged in size from 69 cm FL to 282 cm FL, with estimated ages between 0 and 32 years (Figure 5.42). When fitted to the assumed size at birth (L_0) of 75.3 cm FL, the fitted von Bertalanffy growth curve yielded parameter values of k=0.043 yr^{-1}, L_∞=354.4 cm FL and t_0= -3.0 years. The 95% confidence intervals of bootstrapped von Bertalanffy parameter estimates were k=0.026 and 0.048 yr^{-1}, L_∞=317.7 and 460.8 cm FL and t_0= -3.0 and -3.7 years. Age at 50% maturity was thereby estimated with 95% confidence to be between 27 and 32 years of age (Table 5.18), far higher than the 14-24 years tested in the previous assessment.

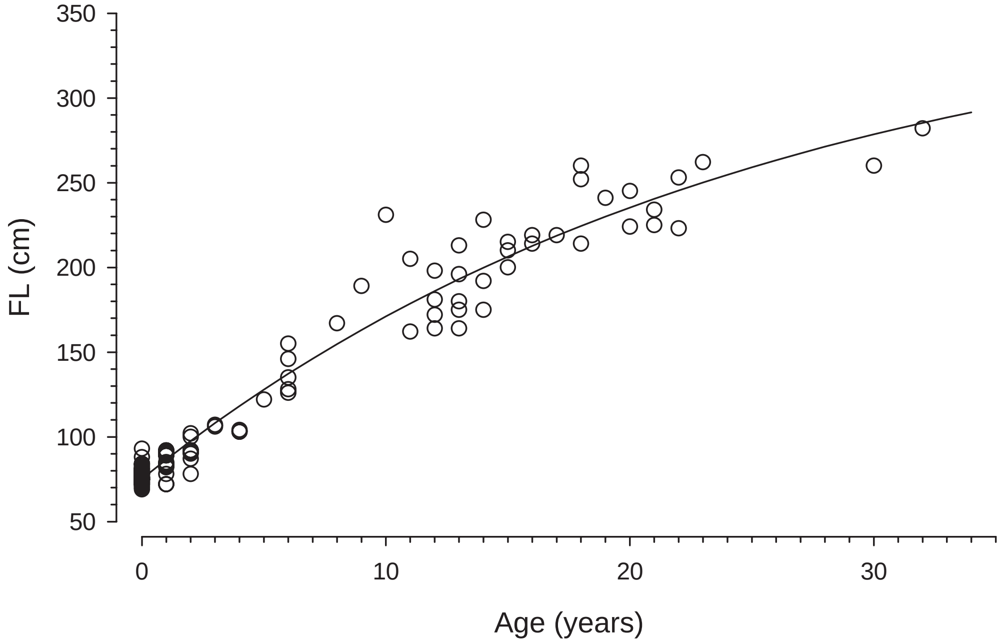


Figure 5.42. von Bertalanffy growth curve fitted to length at age estimates of 127 female *Carcharhinus obscurus* from Western Australia (from Simpfendorfer et al 2002).

5.3.3.2 Natural mortality rates

Table 5.19. Age independent estimates of instantaneous annual rates of natural mortality used in the current and previous demographic analyses of *C. obscurus. M* = median of 1,000 estimates (units yr^{-1}); CI = confidence intervals.

Method	*M*	Min	Max	95% CI	Previous assessment
Pauly (1980, mean water temp= 20°C)	0.088	0.050	0.115	(0.064-0.107)	0.110
Hoenig (1983), method i	0.094	0.075	0.104	(0.078-0.104)	0.083
Hoenig (1983), method ii	0.094	0.078	0.102	(0.080-0.102)	
Hoenig (1983), method iii	0.103	0.082	0.113	(0.084-0.113)	
Jensen (1996), method i	0.056	0.049	0.062	(0.051-0.061)	0.082
Jensen (1996), method ii	0.055	0.029	0.078	(0.039-0.071)	0.081
Jensen (1996), method iii	0.059	0.035	0.083	(0.042-0.076)	0.086

Based on the von Bertalanffy parameters derived from the empirical length at age data, rates of natural mortality estimated by the Pauly (1980) and Jensen (1996) methods were lower than those used in the previous assessment (Table 5.19). The rates estimated by the methods of Hoenig (1983), however, gave higher values than was previously estimated from method i (for teleosts). All of the age-independent methods resulted in lower rates of natural mortality than were estimated for *C. plumbeus*.

Table 5.20. Age dependent estimates of natural mortality rates of *C. obscurus*. $\overline{M}$ = mean of 1,000 estimates from bootstrapped biological parameter estimates (units yr-1); CI = confidence interval.

Age class	Petersen & Wroblewski (1984)	Chen & Watanabe (1989)		Stochastically estimated	
	M	*M*	95% CI	*M*	95% CI
0+	0.131	0.319	(0.280-0.354)	0.176	(0.061-0.311)
1+	0.119	0.250	(0.224-0.273)	0.159	(0.060-0.243)
2+	0.109	0.207	(0.187-0.223)	0.133	(0.058-0.203)
3+	0.102	0.177	(0.161-0.191)	0.118	(0.057-0.173)
4+	0.095	0.156	(0.142-0.167)	0.104	(0.058-0.152)
5+	0.090	0.139	(0.128-0.150)	0.098	(0.057-0.137)
6+	0.086	0.127	(0.116-0.136)	0.087	(0.057-0.124)
7+	0.082	0.116	(0.106-0.125)	0.087	(0.056-0.114)
8+	0.079	0.108	(0.098-0.117)	0.081	(0.056-0.106)
9+	0.076	0.101	(0.092-0.109)	0.079	(0.056-0.102)
10+	0.073	0.095	(0.086-0.103)	0.078	(0.056-0.101)
11+	0.071	0.090	(0.081-0.098)	0.079	(0.056-0.101)
12+	0.069	0.085	(0.077-0.093)	0.078	(0.056-0.101)
13+	0.067	0.082	(0.073-0.089)	0.079	(0.056-0.101)
14+	0.065	0.078	(0.070-0.086)	0.080	(0.056-0.101)
15+	0.064	0.075	(0.067-0.083)	0.078	(0.056-0.101)
16+	0.062	0.072	(0.064-0.080)	0.078	(0.056-0.101)
17+	0.061	0.070	(0.062-0.077)	0.079	(0.056-0.102)
18+	0.060	0.068	(0.060-0.075)	0.079	(0.056-0.102)
19+	0.059	0.066	(0.058-0.073)	0.077	(0.055-0.102)
20+	0.058	0.064	(0.056-0.071)	0.078	(0.056-0.102)
21+	0.057	0.062	(0.054-0.070)	0.080	(0.056-0.101)
22+	0.056	0.061	(0.053-0.068)	0.081	(0.057-0.102)
23+	0.055	0.059	(0.051-0.067)	0.079	(0.056-0.101)
24+	0.054	0.058	(0.050-0.066)	0.080	(0.056-0.101)
25+	0.054	0.057	(0.049-0.065)	0.079	(0.055-0.101)
26+	0.053	0.056	(0.048-0.064)	0.079	(0.054-0.101)
27+	0.052	0.055	(0.047-0.063)	0.078	(0.054-0.102)
28+	0.052	0.054	(0.046-0.062)	0.077	(0.053-0.101)
29+	0.051	0.053	(0.045-0.061)	0.078	(0.053-0.101)
30+	0.051	0.052	(0.044-0.060)	0.077	(0.052-0.101)
31+	0.050	0.051	(0.043-0.059)	0.077	(0.051-0.101)
32+	0.050	0.051	(0.042-0.059)	0.077	(0.051-0.102)
33+	0.050	0.050	(0.042-0.058)	0.074	(0.051-0.101)
34+	0.049	0.049	(0.041-0.057)	0.076	(0.050-0.101)
35+	0.049	0.049	(0.040-0.057)	0.075	(0.049-0.101)
36+	0.048	0.049	(0.040-0.056)	0.075	(0.050-0.102)
37+	0.048	0.050	(0.039-0.056)	0.075	(0.048-0.101)
38+	0.048	0.050	(0.039-0.055)	0.075	(0.048-0.101)
39+	0.048	0.060	(0.038-0.055)	0.074	(0.048-0.102)
40+	0.047	0.074	(0.038-0.818)	0.076	(0.047-0.102)
41+	0.047	0.087	(0.037-0.827)	0.074	(0.047-0.101)
42+	0.047	0.102	(0.037-0.835)	0.075	(0.047-0.101)
43+	0.046	0.106	(0.036-0.842)	0.073	(0.046-0.101)
44+	0.046	0.130	(0.036-0.849)	0.075	(0.046-0.101)
45+	0.046	0.155	(0.036-0.856)	0.073	(0.045-0.101)
46+	0.046	0.176	(0.035-0.862)	0.073	(0.045-0.102)
47+	0.046	0.198	(0.035-0.868)	0.073	(0.044-0.101)
48+	0.045	0.216	(0.035-0.874)	0.072	(0.044-0.101)
49+	0.045	0.242	(0.034-0.879)	0.074	(0.044-0.101)
50+	0.045	0.266	(0.034-0.883)	0.073	(0.043-0.102)
51+	0.045	0.294	(0.034-0.888)	0.073	(0.044-0.102)
52+	0.045	0.314	(0.033-0.891)	0.073	(0.043-0.101)
53+	0.045	0.343	(0.033-0.894)	0.073	(0.043-0.101)
54+	0.045	0.376	(0.033-0.897)	0.070	(0.042-0.101)
55+	0.044	0.411	(0.033-0.899)	0.072	(0.043-0.101)

Due to the relatively higher weight at age of *C. obscurus*, the age-dependent rates of natural mortality estimated by the Petersen and Wroblewski (1984) method were consistently lower than those for *C. plumbeus* (Table 5.20). The Chen and Watanabe (1989) method, however yielded slightly higher rates of M for the youngest age classes of *C. obscurus* than *C. plumbeus*. Also unlike *C. plumbeus*, where natural mortality was estimated to increase rapidly in the oldest age classes, mortality of older *C. obscurus* increased slowly and steadily after 39 years of age.

5.3.3.3 Tag non-reporting rates

Table 5.21. Annual tag non-reporting rates estimated from validated *C. obscurus* catches, reported and estimated tag captures in the three management zones (denoted by i) of the WA temperate demersal gillnet and demersal longline fisheries.

	Valid C. obscurus catch (t live wt)			Annual non-reporting Rates ($D_{i,t}$)			Reported tag captures ($C_{i,T}$)			Estimated tag Captures ($\hat{C}_{i,T}$)		
Year	*i=1*	*i=2*	*i=3*	*i=1*	*i=2*	*i=3*	*i=1*	*i=2*	*i=3*	*i=1*	*i=2*	*i=3*
1994	181	134	172	0.19	0.20	0.30	34	3	28	42	4	40
1995	126	87	133	0.09	0.09	0.36	68	10	37	75	11	58
1996	144	101	166	0.26	0.30	0.31	50	12	22	68	17	32
1997	142	116	113	0.34	0.30	0.18	10	12	7	15	17	9
1998	96	113	69	0.31	0.23	0.14	4	4	6	6	5	7
1999	193	90	75	0.13	0.31	0.08	2		1	2	0	1
2000	143	83	57	0.30	0.17	0.15			1	0	0	1
2001	111	75	54	0.17	0.00	0.15		1	2	0	1	2
2002	112	67	73	0.21	0.16	0.21		1		0	1	0
2003	97	83	78	0.23	0.15	0.14	2			3	0	0

Annual non-reporting rates of tag captures, estimated from validated catches in all three regions of the temperate demersal gil lnet and demersal longline fisheries varied between 0.00 (region 2, 2001) and 0.36 (region 3, 1995) (Table 5.21). Whilst the magnitude of these rates are similar to the monthly rates estimated for the previous assessment (Simpfendorfer et al., 1999; Simpfendorfer, 1999), there were noticeable differences between the monthly data from which the annual rates were estimated for this study and those calculated in the previous study (Figure 5.43).

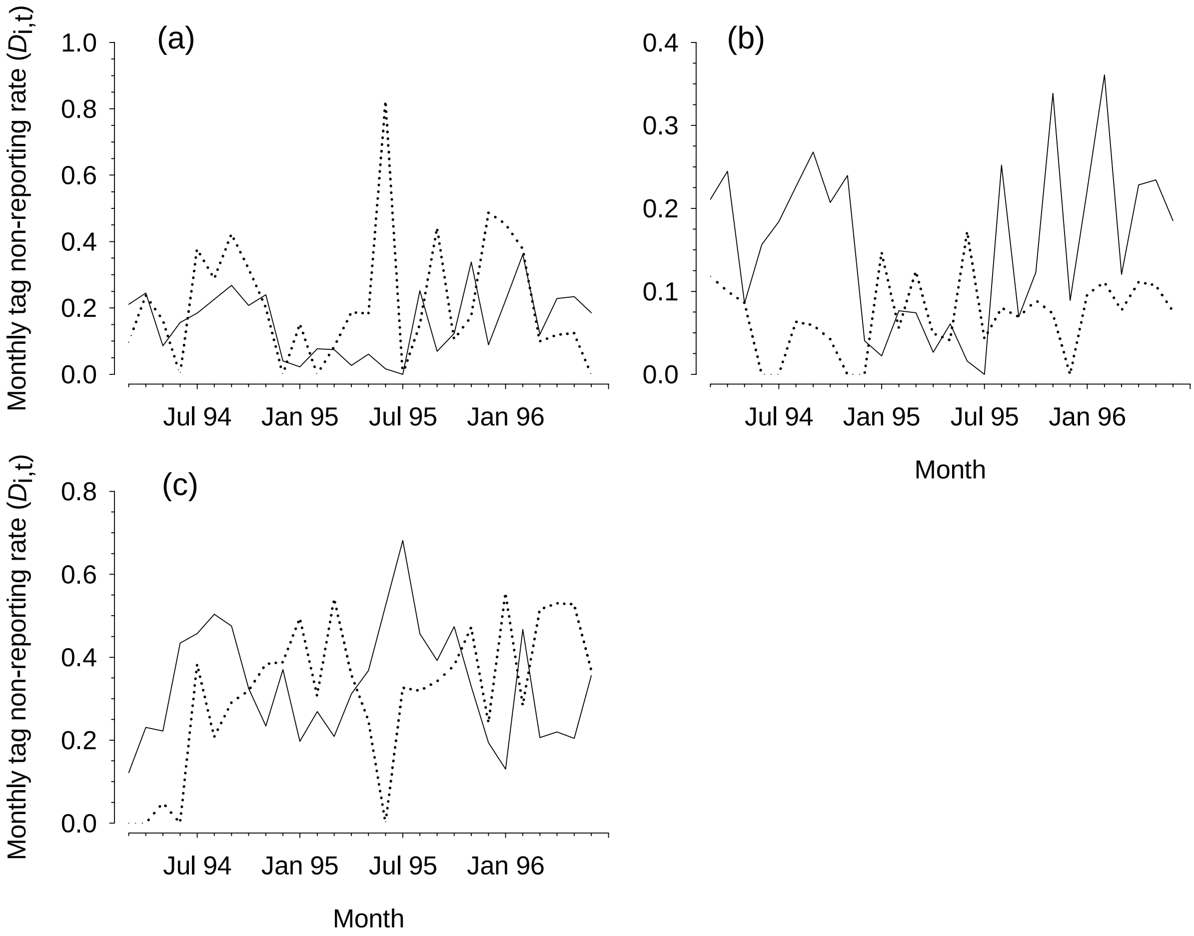


Figure 5.43. Comparison between regional monthly tag non-reporting rates estimated from data used in this study (solid lines) and those from previous assessment (dotted lines, Simpfendorfer et al., 1999; Simpfendorfer, 1999).

5.3.3.4 *Fishing mortality*

As in the previous study (Simpfendorfer et al., 1999; Simpfendorfer, 1999), age-specific fishing mortality rates experienced by the 1994 and 1995 cohorts were estimated to be highest for 0+ age classes and to subsequently decline at older ages (Figure 5.44). Exploitation was determined to be slightly lower than previously estimated for the 0+ age-class and slightly higher for the 1+ age class of both the 1994 and 1995 cohorts. Both studies estimated similar exploitation rates of sharks aged between two and five years, however the present study estimated lower fishing mortality rates for these age classes in the 1995 cohort. Whilst the previous assessment assumed that exploitation of sharks older than 6 years was zero, it was possible to estimate rates of fishing mortality for age-classes up to 9+ years from longer-term tag capture data. Although these rates were low at between 0.5% yr^{-1} and 1.2% yr^{-1}, their inclusion in the current assessment is important, given the very low levels of mortality that the previous assessment concluded were sustainable.

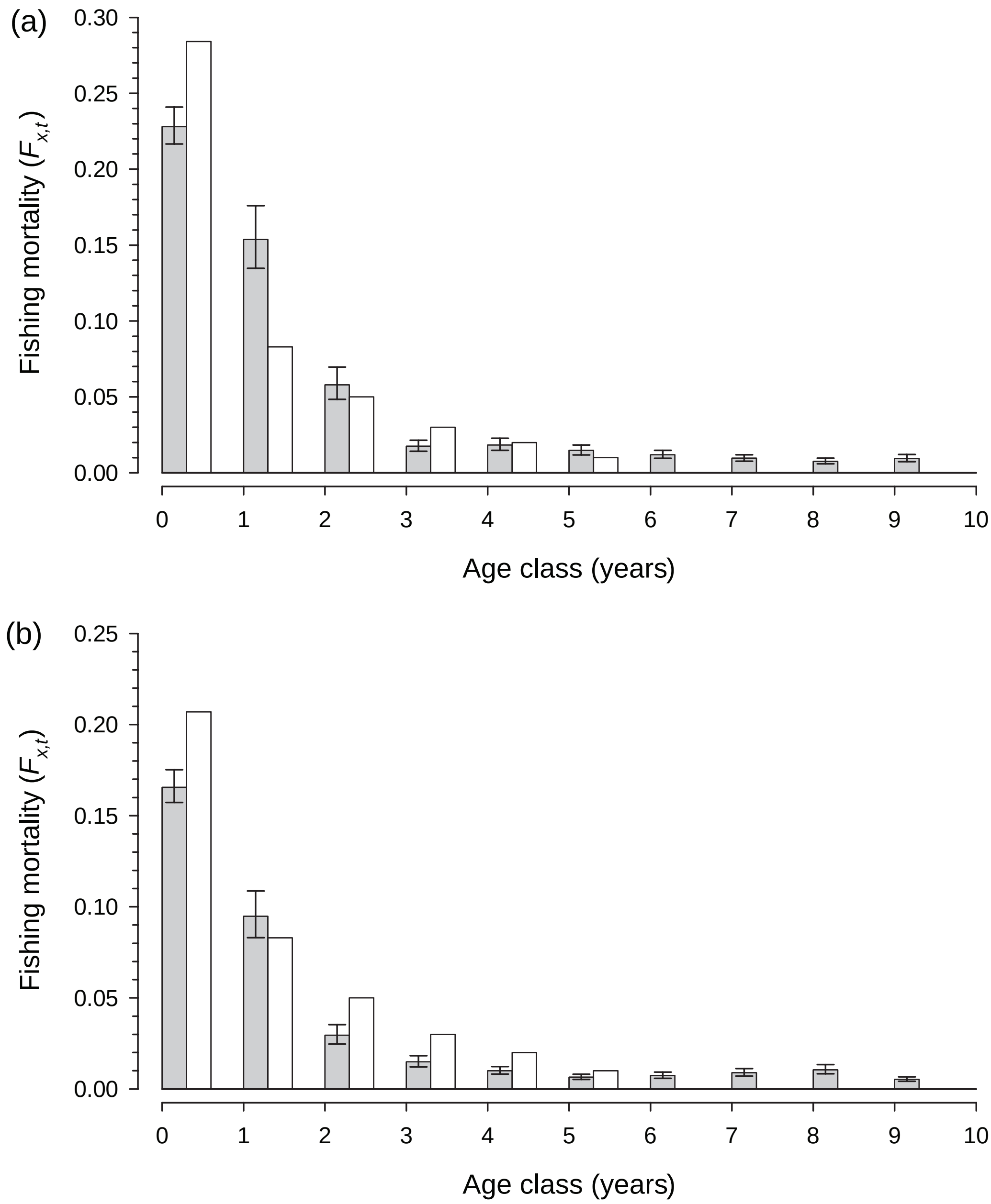


Figure 5.44. Fishing mortality rates estimated for (a) 1994 and (b) 1995 *Carcharhinus obscurus* cohorts in the current study (grey bars) and in the previous study (white bars). Error bars indicate 95% confidence intervals of estimates.

5.3.3.5 Demographic analysis

Based on a reproductive periodicity of two-years, in the absence of fishing mortality the Western Australian *C. obscurus* population was estimated to be potentially able to increase at rates of between 0.018 yr^{-1} (according to Hoenig, 1983, method iii) and 0.064 yr^{-1} (according to Jensen, 1996, methods i and ii, Appendix III, table i). Using stochastically derived rates of natural mortality, the median rate of potential population growth (*r*) was 3.3% per year, with 95% confidence that under these conditions, *r* was between 0.004 and 0.055 yr^{-1} (Table 5.22; Appendix III, table i). With a three-year breeding frequency and zero fishing mortality, rates of potential population growth were between 0.004 yr^{-1} (Hoenig, 1983, method iii) and 0.051 yr^{-1} (Jensen, 1996, method ii, Appendix III, table ii). With stochastically estimated natural mortality, *r* was estimated to be 0.020 yr^{-1}, with 95% confidence intervals of –0.008 yr^{-1} and 0.041 yr^{-1} (Table 5.22; Appendix III, table ii). With a four year breeding periodicity, *r* was estimated to be between –0.004 yr^{-1} (Hoenig, 1983, method iii) and 0.041 yr^{-1} (Jensen, 1996, method I, Appendix III, table iii) and with stochastically estimated natural mortality was 0.010 yr^{-1} (95% confidence intervals between –0.018 yr^{-1} and 0.032 yr^{-1}; Appendix III, table iii). By randomly sampling breeding frequency from values of two, three and four years, *r* was estimated to vary between –0.008 yr^{-1} (Hoenig, 1983, method iii) and 0.037 yr^{-1} (Jensen, 1996, methods i and ii, Appendix III, table iv) and with stochastically estimated natural mortality was 0.008 yr^{-1} (95% confidence intervals between –0.027 yr^{-1} and 0.035 yr^{-1}, Table 5.22; Appendix III, table iii). The best estimate of breeding frequency (i.e. randomly sampling between two and three years) resulted in median values of *r* that ranged between 0.013 yr^{-1} (Hoenig, 1983, method iv) and 0.057 yr^{-1} (Jensen, 1996, methods i and ii, Appendix III, table v) and with stochastically estimated natural mortality, of 0.025 yr^{-1} (95% confidence intervals between –0.007 yr^{-1} and 0.052 yr^{-1}, Table 5.22; Appendix III, table v). These potential rates of population growth are far lower than the previous assessment's best estimate of 0.042 yr^{-1}, indicating that this stock is able to withstand lower levels of fishing mortality than were previously believed to be sustainable.

The age-specific exploitation rates previously estimated for the 1994 and 1995 cohorts (Simpfendorfer et al., 1999; Simpfendorfer, 1999), yielded similar potential population growth rates as the fishing mortality rates estimated for those cohorts in the current assessment (Table 5.22; Appendix III, tables vi-xxv). With the best estimate of breeding frequency (2-3 years), the previously estimated exploitation rates yielded *r* estimates of 0.00 (95% confidence intervals between –0.038 and 0.034) and 0.003 (95% confidence intervals between –0.036 and 0.037) for the 1994 and 1995 cohorts, respectively. The fishing mortalities calculated in the current study estimated *r* as 0.00 (95% confidence intervals between –0.036 and 0.035) and 0.008 (95% confidence intervals between –0.031 and 0.040) for the 1994 and 1995 cohorts, respectively. With a breeding period of 2 years these rates increased to 0.007 (95% confidence intervals between –0.026 and 0.038) and 0.013 (95% confidence intervals between –0.022 and 0.044) for the two cohorts. At these marginal levels of potential population growth, the impacts of additional external fishing mortality (i.e. outside that inflicted by the temperate demersal gillnet and demersal longline fisheries) would be more severe than the previous assessment indicated.

Table 5.22. Summary of demographic analysis results for *Carcharhinus obscurus* under stochastically estimated rates of natural mortality (*M*) and various schedules of fishing mortality.

Fishing mortality schedule	Cohort	Reproductive frequency (yr)	Proportion reaching maturity (P_M)	Net reprod. rate R_0 (no yr^{-1})	Generation time *G* (yr)	Doubling time *tx2* (yr)	Potential pop. growth rate (r yr^{-1})
No fishing	n/a	2	0.066 (0.023, 0.149)	2.1 (0.7, 6.2)	31.4 (29.7, 33.5)	25.1 (-171.9, 230.6)	0.024 (-0.010, 0.058)
		3	0.063 (0.023, 0.135)	1.4 (0.5, 3.5)	31.4 (29.8, 33.5)	31.2 (-536.1, 484.0)	0.011 (-0.022, 0.040)
		4	0.065 (0.025, 0.150)	1.0 (0.4, 2.8)	31.4 (29.7, 33.7)	22.2 (-675.5, 689.7)	0.001 (-0.032, 0.033)
		2-3	**0.063 (0.023, 0.139)**	**1.7 (0.5, 4.9)**	**31.4 (29.8, 33.4)**	**27.3 (-324.7, 332.9)**	**0.016 (-0.020, 0.052)**
		2-4	0.063 (0.024, 0.147)	1.4 (0.4, 4.9)	31.5 (29.7, 33.6)	27.2 (-441.1, 475.0)	0.012 (-0.026, 0.051)
Simpfendorfer et al.,1999; Simpfendorfer, 1999	1994	2	0.036 (0.013, 0.086)	1.2 (0.4, 3.4)	31.4 (29.7, 33.7)	29.5 (-414.9, 602.7)	0.006 (-0.030, 0.039)
		3	0.038 (0.014, 0.084)	0.8 (0.3, 2.4)	31.4 (29.7, 33.6)	-27.8 (-635.9, 642.6)	-0.007 (-0.044, 0.028)
		4	0.043 (0.016, 0.095)	0.7 (0.2, 1.9)	31.4 (29.6, 33.6)	-29.5 (-426.3, 336.0)	-0.012 (-0.051, 0.021)
		2-3	**0.037 (0.014, 0.082)**	**1.0 (0.3, 2.9)**	**31.4 (29.7, 33.8)**	**-13.3 (-586.6, 693.0)**	**0.000 (-0.038, 0.034)**
		2-4	0.038 (0.014, 0.086)	0.9 (0.2, 2.9)	31.4 (29.7, 33.7)	-23.8 (-540.7, 416.7)	-0.005 (-0.044, 0.033)
	1995	2	0.042 (0.016, 0.093)	1.4 (0.5, 3.6)	31.5 (29.8, 33.6)	34.0 (-565.7, 524.7)	0.010 (-0.022, 0.040)
		3	0.041 (0.015, 0.093)	0.9 (0.3, 2.7)	31.4 (29.7, 33.6)	-24.0 (-439.9, 578.6)	-0.003 (-0.039, 0.031)
		4	0.043 (0.016, 0.095)	0.7 (0.2, 1.9)	31.4 (29.6, 33.6)	-29.5 (-426.3, 336.0)	-0.012 (-0.051, 0.021)
		2-3	**0.04 (0.015, 0.091)**	**1.1 (0.3, 3.2)**	**31.4 (29.8, 33.4)**	**23.8 (-678.2, 522.3)**	**0.003 (-0.036, 0.037)**
		2-4	0.041 (0.015, 0.092)	0.9 (0.3, 3.0)	31.4 (29.8, 33.7)	-19.2 (-445.2, 572.8)	-0.002 (-0.041, 0.035)
This study	1994	2	0.038 (0.014, 0.087)	1.2 (0.4, 3.3)	31.4 (29.8, 33.6)	29.8 (-617.0, 599.9)	0.007 (-0.026, 0.038)
		3	0.038 (0.014, 0.087)	0.8 (0.3, 2.3)	31.4 (29.8, 33.5)	-28.2 (-528.1, 586.3)	-0.006 (-0.043, 0.026)
		4	0.036 (0.014, 0.084)	0.6 (0.2, 1.7)	31.3 (29.7, 33.7)	-28.2 (-402.2, 393.3)	-0.016 (-0.052, 0.016)
		2-3	**0.038 (0.014, 0.089)**	**1.0 (0.3, 3.0)**	**31.4 (29.8, 33.6)**	**17.1 (-953.8, 798.5)**	**0.000 (-0.036, 0.035)**
		2-4	0.037 (0.014, 0.080)	0.9 (0.3, 2.5)	31.4 (29.8, 33.6)	-23.0 (-561.5, 486.1)	-0.004 (-0.043, 0.029)
	1995	2	0.045 (0.016, 0.103)	1.5 (0.5, 4.1)	31.3 (29.7, 33.6)	31.7 (-399.7, 472.7)	0.013 (-0.022, 0.044)
		3	0.046 (0.017, 0.100)	1.0 (0.3, 2.8)	31.3 (29.7, 33.5)	15.4 (-563.4, 847.2)	0.000 (-0.040, 0.033)
		4	0.045 (0.016, 0.103)	0.7 (0.3, 2.0)	31.4 (29.7, 33.5)	-31.4 (-592.8, 740.5)	-0.009 (-0.044, 0.022)
		2-3	**0.047 (0.017, 0.104)**	**1.3 (0.4, 3.6)**	**31.4 (29.7, 33.7)**	**28.9 (-514.2, 652.0)**	**0.008 (-0.031, 0.040)**
		2-4	0.044 (0.016, 0.103)	1.0 (0.3, 3.2)	31.3 (29.6, 33.5)	-11.2 (-463.3, 542.9)	-0.001 (-0.042, 0.037)

The previous assessment predicted that even low levels of exploitation of older age classes would be likely to result in the WA *C. obscurus* population declining. The levels of fishing mortality of sharks older than 10 years that would lead to such a decline were therefore re-estimated, assuming a 2-3 year breeding period, in the new demographic model. Under the schedule of age-specific fishing mortality calculated for the 1994 cohort, the model predicted with 55% certainty that if sharks older than 10 years of age were subject to a fishing mortality rate greater than 0.01 yr^{-1} (i.e. 1.0% yr^{-1}), the population was likely to decline (with 95% confidence that the rate could be no higher than 4.4% yr^{-1}). For the 1995 cohort, this rate was estimated with to be 2.0% yr^{-1} (with 95% confidence that the rate could be no higher than 5.2% yr^{-1}).

On the basis of these results it now appears far more likely that any additional mortality of older *C. obscurus* in catches and bycatch of other fisheries operating in Western Australian waters have lead to, at least temporarily, unsustainable levels of *C. obscurus* fishing mortality. However, given that catches of this species by the WA temperate demersal gillnet and longline fisheries have declined substantially since the tagging project was conducted (see 5.2.1.1), it is also possible that rates of juvenile fishing mortality have also decreased over the last decade.

6.0 Conclusions

This FRDC-funded project has provided critical information, which has enabled the Western Australian Department of Fisheries to develop robust management strategies to deal with the rapidly escalating catches from the State's *Carcharhinus plumbeus* population. Results from this project have already been used as the basis for developing an entirely new package of management arrangements for the WA North Coast Shark Fishery (Appendix IV) to ensure its long-term viability. These measures, together with some planned additional refinement of the West Coast Demersal Gillnet and Demersal Longline Fishery's management plan, will also ensure the sustainability of two of the State's temperate demersal gillnet and demersal longline fisheries' primary target species. It is hoped that the improved assessment of Western Australia's commercial shark stocks, which has been made possible by this and previous FRDC grants, will assist the State's shark fisheries to meet the Australian government's criteria for Ecologically Sustainable Management of Fisheries under Part 13 and 13A of the Environment Protection and Biodiversity Act (1999). The major conclusions of this project include:

- The Western Australian range of the sandbar shark, *Carcharhinus plumbeus*, is between at least Cape Leveque (16° 30'S, 123°E) in the north and Point D'Entrecasteaux (116°E) on the south coast. The species' apparent absence in the northern Kimberley and in south eastern waters, suggests that the Western Australian *C. plumbeus* stock is separate from that on the east coast of Australia.
- This stock exhibits a considerable degree of segregation between juvenile sharks, which are prevalent in deeper continental-shelf waters south of 26°S latitude and adults, which are more abundant in more northerly waters. Neonate sharks, which are rarely caught in the target temperate demersal gillnet and demersal longline fisheries, primarily occur in waters south of the Houtman Abrolhos Islands. However, as small numbers of neonates were also observed as far north as Broome, parturition apparently occurs throughout the species Western Australian range.
- Tagging data supports the hypothesis that juveniles born in the south west of the State remain in temperate waters for several years and slowly migrate northwards to join the breeding stock in the north-west as sub-adults or adults.

- To support the above conclusions adults must migrate into temperate waters to give birth. Whilst direct evidence of such migration was limited, several tag recaptures do support this hypothesis. These include two sub-adult and adult-sized tagged sharks, which travelled from NW Cape to the Abrolhos, two from NW Cape to Shark Bay and one from Cape Leveque to NW Cape. Most of these movements, including the latter, took less than 12 months to complete. Further, the dispersal rates of several tagged sharks demonstrated that sandbar sharks are probably capable of migrating distances of over 1,000 km in less than 1 year.

- Western Australian sandbar sharks are generally smaller at birth (40-45 cm FL) and attain a smaller maximum size (172 cm FL and 166 cm FL, observed in this study for males and females, respectively) than other populations for which data are available. Based on the results of vertebral analysis and maximum observed and reported sizes, maximum age was estimated to be at least 30 years and possibly as high as 40.

- The Western Australian sandbar shark population also attains sexual maturity at smaller sizes (127 cm FL and 136 cm FL for males and females, respectively) than populations elsewhere, notably those in the western North Atlantic and western Indian Ocean. However age at maturity (14 years and 16 years, for males and females, respectively) was found not to differ markedly from other populations.

- The von Bertalanffy growth curves derived from the tag-return data in the present study bore little resemblance to those estimated from the larger vertebral analysis dataset. The estimated level of natural variability in the growth of individual sharks suggests that in some situations, tagging data provide an unreliable basis for either determining or verifying growth rates of the population (as has been attempted in some previous studies). These situations include when most of the data come from short-term recaptures (when growth-increments are most variable) and when sample sizes are small relative to the amount of variation as were both the case in this study. These tagging data were therefore concluded to be a less reliable descriptor of age and growth than the length at age data derived from vertebral analysis and were therefore not included in the current stock assessment.

- In conjunction with the relatively small litters (mean of 6.5), 12-month gestation period and two-year breeding frequency, determined for this population, this combination of life-history parameters gives the WA sandbar shark stock a lower than expected capacity to withstand fishing pressure.

- In addition to this stock's inherently low productivity, the results from gillnet mesh-selectivity trials demonstrated that the gillnets used in the temperate WA demersal gillnet fishery are much less size-selective for sandbar sharks than they are for the related and co-occurring dusky shark, *Carcharhinus obscurus*. The consequence of this, as well as the relatively high abundance of juvenile sandbar sharks within the temperate demersal gillnet fishery (particularly the WCDGDLF) is that most juvenile age-classes are vulnerable to capture in the temperate gillnet fisheries.

- Fishing mortality rates, determined from tag captures, also indicated that exploitation of juvenile sandbar sharks was relatively high across multiple age-classes.

- In addition to the relatively high levels of gillnet fishing mortality, longline catches of larger sandbar sharks in the WANCSF and, in the most recent years, in the WCDGDLF escalated rapidly over the course of this project.

- Through demographic analysis, the combined levels of *C. plumbeus* fishing mortality were found to have become increasingly unsustainable over the course of the project. The best estimates of the potential rates of population growth, given the empirically measured biological constraints and estimated rates of fishing mortality, were –3.2% yr^{-1} in 2001/02, -0.9% yr^{-1} in 2002/03, -4.9% yr^{-1} in 2003/04 and projected to be –7.8% yr^{-1} in the current year (2004/05).

- Several potential combinations of fishing mortality that would deliver neutral or positive population growth rates were identified from the demographic model. As both of the target fisheries contribute to the exploitation of this stock, appropriate levels of exploitation in the WANCSF could not be determined independently of exploitation by the TDGDLF (mainly in the WCDGDLF) and *vice versa*. The model indicated that to achieve the capacity for positive growth in the population, and thus reverse the current declining trend in this stock, major reductions in fishing mortality are necessary in both the WANCSF and in the TDGDLF, unless the fishing mortality in one or other fishery is reduced to zero

- Re-assessment of the status of the dusky shark, *Carcharhinus obscurus*, using the new demographic analysis techniques developed for sandbar sharks, empirically measured biological data and longer-term tag-capture data, also indicate that this species is less resilient to fishing than was previously estimated.

- However, the model also indicated that the rates of age-specific fishing mortality experienced by sharks released as neonates in 1994 and 1995 were probably sustainable, as long as there was negligible additional fishing mortality (less than 1-2% yr^{-1}) outside the demersal gillnet and longline fisheries. The lower estimate of the sustainable level of external fishing mortality is in keeping with recent analyses of dusky shark CPUE data from the demersal gillnet and longline fisheries, which indicate that the breeding stock of dusky sharks has been in decline for some years and is leading to a reduction in recruitment.

- The stochastic demographic analysis framework developed during this project is a significant improvement on previous deterministic approaches to demographic assessment of shark populations. It is thought that these techniques, which account for the uncertainty and variability in the life-history characteristics of the Western Australian sandbar and dusky shark stocks, will benefit other researchers and fishery management agencies in the assessing shark stocks for which available time-series of catch and effort data are insufficient for construction of other types of model.

7.0 Benefits

The Western Australian shark fisheries, Department of Fisheries and the broader community have already received considerable benefit from identification of the unsustainable levels of fishing being experienced by the sandbar shark stock, before irreparable depletion had occurred. This research has enabled sustainable management arrangements to be developed for the Western Australian northern shark fisheries. The temperate demersal Gillnet and demersal longline fisheries, in which sandbar sharks have become a major component of the catch, will also benefit from the identification of the risk to this commercially important stock. Together with new management arrangements for the northern shark fisheries and imminent adjustments of the WCDGDLF management plan will not only ensure the continuing viability of these fisheries but will also greatly assist in their assessment under the Australian Government's Ecologically Sustainable Management of Fisheries criteria. The techniques and expertise developed in assessing the sandbar stock and reassessing the dusky shark stock will also improve the WA Department of Fisheries' ability to evaluate harvest strategies for key shark species, enabling more effective decision making processes for the management of the stocks.

8.0 Acknowledgements

The completion of this project would not have been possible without the considerable assistance of the Western Australian shark fishing industry and their contribution is very gratefully acknowledged. The authors also wish to thank all the WA Department of Fisheries' staff who contributed to the collection of data, especially Ryan Ashworth, Dennyse Newbound, Ben Sale and the skipper and crew of the Research Vessels Flinders and Naturaliste. Many thanks are due to all of the staff at the WA Marine Research Laboratory who provided invaluable advice throughout the project and during the analysis of data and drafting of this report. Particular thanks are due to Dr. Mike Moran who was instrumental in initiating this project, Dr Colin Simpfendorfer (Mote Marine Laboratory, Florida), who provided considerable advice on most of these analyses and Dr. Glenn Hyndes (Edith Cowan University), for his advice and support over the last four years. The detailed reviews of the stock assessment undertaken by Associate Professor Norm Hall (Centre for Fish and Fisheries, Murdoch University) and Professor Carl Walters (University of British Columbia, Fisheries Centre) have also greatly improved this report and they are also gratefully acknowledged.

9.0 References

Beamish, R.J. and Fournier, D.A. 1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38: 982-983

van Belle, G. 2004. Statistical rules of thumb. http://www.seattlecrc.org/vbelle

Beerkircher, L., Shivji, M. and Cortés, E. 2003. A Monte Carlo demographic analysis of the silky shark (*Carcharhinus falciformis*): implications of gear selectivity. Fish Bull. 101: 168-174

Brewster-Geisz, K. K., and T. J. Miller. 2000. Management of the sandbar shark, *Carcharhinnus plumbeus*: implications of a stage-based model. Fish. Bull. 98: 236-249.

Cailliet, G. M. 1992. Demography of the central Californian population of the leopard shark (*Triakis semifasciata*). Australian Journal of Marine and Freshwater Research 43: 183-193.

Chen, S., and S. Watanabe. 1989. Age dependence of natural mortality coefficient in fish populations dynamics. Nippon Suisan Gakkaishi 55: 205-208.

Cortés, E. 1995. Demographic analysis of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, in the Gulf of Mexico. Fishery Bulletin 93: 57-66.

Cortés, E. 1999. A stochastic stage-based population model of the sandbar shark in the Western North Atlantic. p. 115-136. *In*, Life in the slow lane. Ecology and conservation of long-lived marine animals. J. A. Musick (ed.). American Fisheries Society Symposium 23, Bethesda, Maryland.

Cortés, E. 2002. Incorporating uncertainty into demographic modeling: application to shark populations and their conservation. Conservation Biology 16: 1048-1062.

Cortés, E., And G. R. Parsons. 1996. Comparative demography of two populations of the bonnethead shark (*Sphyrna tiburo*). Canadian Journal of Fisheries and Aquatic Sciences 53: 709-718.

Francis, M.P., Griggs, L. H., Baird, S.J., Murray, T.E. & Dean, H. A. 2000. Fish bycatch in New Zealand tuna longline fisheries, 1988–89 to 1997–98. NIWA Technical Report 76.

Gaughan and Chidlow, 2005a. Demersal Gillnet and Demersal Longline Fisheries status report. In: *State of the Fisheries Report* 2003/04, eds, J.W. Penn, W.J. Fletcher and F. Head, Department of Fisheries, Western Australia, pp. 186-191

Gaughan and Chidlow, 2005b. Northern Shark Fisheries status report. In: *State of the Fisheries Report* 2003/04, eds, J.W. Penn, W.J. Fletcher and F. Head, Department of Fisheries, Western Australia, pp. 146-150

Hancock, D. A. and Edmonds, J.S. 1977. Mercury in shark in Western Australia. A preliminary report. Fish. Res. Bull. Dep. Fish. Wildl. (West. Aust.); no. 18, 22 pp.

Heald, D. I. 1987. The commercial shark fishery in temperate waters of Western Australia. Fisheries Department of Western Australia Research Report No. 75, 71pp.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82: 898-903.

Hoenig, J. M., And S. H. Gruber. 1990. Life history patterns in the elasmobranches: implications for fisheries management. p. 1 – 16. *In*, Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries. H. L. Pratt Jr, S. H. Gruber, and T. Taniuchi (eds.). NOAA Technical Report NMFS 90.

Hyslop, .E. J. 1980. Stomach content analysis – review of methods used in studies of the food of fishes. J. Fish Biol. 17: 411-429.

Jennings, S., Kaiser, M. J., Reynolds, J. D. 2001. Marine Fisheries Ecology. Blackwell Science Ltd.

Jensen, A. L. 1996. Beverton and holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53: 820-822.

Kirkwood, G. P. and Walker, T. I., 1986. Gill net selectivities for gummy shark, *Mustelus antarcticus* Günther, taken in south-eastern Australian waters. Aust. J. Mar. Fresh. Res., 37: 689-97.

Krebs, C. J. 1985. Ecology: the experimental analysis of distribution and abundance, 3rd ed. Harper and row, New York.

Krebs, C.J. 1989. Ecological Methods. Harper and Rowe, New York.

Langton, R.S. 1982. Diet overlap between the Atlantic cod, *Gadus morhua*, silver hake, *Merluccius bilinearis* and fifteen other Atlantic finfish. Fish. Bull. 80:745-759

Last, P. R and Stevens, J. D. 1994. Sharks and Rays of Australia. CSIRO, Melbourne, Australia, 513pp.

McAuley, R. 2004. Status Report for the Southern and West Coast Demersal Gillnet and Demersal Longline Fisheries and Northern Shark Fisheries. Number 11. April 2004. Unpublished report. Dept of Fisheries Government of Western Australia. Perth.

McAuley, R. and Simpfendorfer, C. 2003. Catch Composition of the Western Australian Temperate Demersal Gillnet and Demersal Longline Fisheries, 1994-1999. Fisheries Research Report No. 146, Department of Fisheries, Western Australia, 78 pp.

McLoughlin, K. J. and Stevens, J. D., 1994. Gill-net mesh selectivities for two species of commercial Carcharhinid sharks taken in northern Australia. Aust. J. Mar. Fresh. Res., 45: 521-34.

Mollet, H. F., And G. M. Cailliet. 2002. Comparative population demography of elasmobranches using life history tables, Leslie matrices and stage-based matrix models. Marine and Freshwater Research 53: 503-516.

Natanson, L. J., and Kohler, N.E. 1996. A preliminary estimate of age and growth of the dusky shark *Carcharhinus obscurus* from the south-west Indian Ocean, with comparisons to the western North Atlantic population. S. Afr. J. mar. Sci. 17:217-224.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer. 39: 175-192.

Peterson, I., And J. S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 41: 1117-1120.

Quinn, T. J. II and Deriso, R. B. 1999. Quantitative Fish Dynamics. Oxford University Press, New York. 542pp.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Board Can. 191: 1-382

Simpfendorfer, C. A. 1999. Demographic analysis of the dusky shark fishery in southwestern Australia. P. 149-160. *In*, Life in the slow lane. Ecology and conservation of long-lived marine animals. J. A. Musick (ed.). American Fisheries Society Symposium 23, Bethesda, Maryland.

Simpfendorfer, C. A. 2004. Demographic models: life tables, matrix models and rebound potential. *In*, Elasmobranch fisheries management techniques. Musick, J. A. and Bonfil, R. (eds.), pp. 187-203. APEC Secretariat, Singapore.

Simpfendorfer, C. A. and Unsworth, P., 1998. Gillnet mesh selectivity of dusky (*Carcharhinus obscurus*) and whiskery, (*Furgaleus macki*) sharks from south-western Australia. Aust. J. Marine Freshwater Res. 49: 713-718.

Simpfendorfer, C. A., McAuley, R.., Chidlow, J., Lenanton, R., Hall, N. and Bastow, T. 1999. Biology and stock assessment of Western Australia's commercially important shark species. Final report to the Fisheries Research and Development Corporation for project 96/130, 99 pp. December 1999. ISBN 0 7309 8448 6.

Simpfendorfer, C. A., Donohue, K. and Hall, N.G. 2000. Stock assessment for the whiskery shark (*Furgaleus macki* (Whitely)) in south-western Australia. Fish. Res. 47: 1-17.

Simpfendorfer, C.A., McAuley, R. Chidlow, J. and Unsworth. P. 2002. Validated Age and Growth of the Dusky Shark, *Carcharhinus obscurus*, from Western Australian Waters. Mar. Freshwater Res., 2002, **53**, 567-573

Smith, S. E., D. W. Au, And C. Snow. 1998. Intrinsic rebound potential of 26 species of Pacific sharks. Marine and Freshwater Research 48:663-678.

Stephenson, P. and Chidlow, J.C. 2003. Bycatch in the Pilbara Fish Trawl Fishery. Final Report to National Heritage Trust. Western Australian Department of Fisheries, Perth.

Stevens, J. D. and Wayte, S. E., 1999. A review of Australia's pelagic shark resources. Final Report to the Fisheries Research and Development Corporation for Project 98/107, 64pp.

Walters, C. J. and Martell, S. J. D. 2004. Fisheries Ecology and Management. Princeton University Press.

White, W. T. Hall, N. G and Potter, I. C. 2002. Size and age compositions and reproductive biology of the nervous shark, *Carcharhinus cautus* in a large subtropical embayment, including an analysis of growth during pre- and postnatal life. Marine Biology, 141: 1153-1164.

Whitely, G. P., 1943. Preliminary report on the long line fishery at Bunbury WA. Department of Fisheries, unpublished report, 9 pp (available from Western Australian Marine Research Laboratories: North Beach, WA).

10.0 APPENDICES

APPENDIX I

Table i. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population under zero fishing mortality. Definitions of demographic parameter symbols are given in Table 5.16.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.16	(0.12, 0.21)	2.1	(0.8, 4.2)	22.5	(21.6, 24.0)	20.0	(-138.3, 194.0)	0.030	(-0.018, 0.063)
Hoenig (1983), i	0.13	(0.09, 0.17)	1.6	(0.6, 3.7)	22.2	(21.4, 24.0)	24.3	(-310.0, 351.7)	0.017	(-0.028, 0.054)
Hoenig (1983), ii	0.14	(0.11, 0.18)	1.8	(0.6, 3.9)	22.3	(21.5, 23.9)	22.2	(-307.2, 196.4)	0.023	(-0.027, 0.057)
Hoenig (1983), iii	0.11	(0.08, 0.15)	1.3	(0.5, 2.7)	22.0	(21.2, 23.8)	24.9	(-362.2, 473.6)	0.007	(-0.040, 0.041)
Jensen (1996), i	0.21	(0.19, 0.21)	3.0	(1.1, 5.7)	22.8	(21.9, 24.3)	14.6	(-6.0, 70.5)	0.046	(-0.002, 0.077)
Jensen (1996), ii	0.38	(0.32, 0.45)	7.6	(2.7, 15.7)	23.5	(22.5, 25.5)	8.1	(5.9, 18.3)	0.086	(0.036, 0.117)
Jensen (1996), iii	0.36	(0.30, 0.42)	6.6	(2.2, 14.0)	23.5	(22.4, 25.3)	8.7	(6.0, 21.3)	0.079	(0.029, 0.114)
Petersen & Wroblewski (1984)	0.12	(0.11, 0.12)	1.9	(0.7, 3.6)	23.0	(22.1, 24.8)	24.8	(-166.0, 338.9)	0.023	(-0.019, 0.053)
Chen & Watanabe (1989)	0.17	(0.15, 0.19)	3.3	(1.3, 6.6)	23.6	(22.5, 25.5)	14.7	(8.0, 63.8)	0.046	(0.004, 0.077)
Stochastic *M*	0.13	(0.12, 0.13)	2.0	(0.8, 3.6)	22.7	(21.9, 24.2)	23.1	(-263.5, 193.0)	0.025	(-0.018, 0.055)

Table ii. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **age specific** estimates of 2001/02 fishing mortality ($F_{2001/02}$).

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.03	(0.02, 0.04)	0.4	(0.1, 0.8)	22.4	(21.5, 23.9)	-14.3	(-49.6, -7.3)	-0.049	(-0.095, -0.014)
Hoenig (1983), i	0.02	(0.02, 0.03)	0.3	(0.1, 0.7)	22.1	(21.3, 24.0)	-10.6	(-25.3, -6.3)	-0.065	(-0.110, -0.027)
Hoenig (1983), ii	0.03	(0.02, 0.04)	0.3	(0.1, 0.7)	22.2	(21.4, 23.9)	-12.1	(-28.1, -6.9)	-0.057	(-0.101, -0.025)
Hoenig (1983), iii	0.02	(0.01, 0.03)	0.2	(0.1, 0.5)	22.0	(21.2, 23.6)	-9.4	(-17.8, -5.8)	-0.074	(-0.119, -0.039)
Jensen (1996), i	0.04	(0.04, 0.04)	0.6	(0.2, 1.0)	22.7	(21.9, 24.5)	-21.4	(-106.4, -7.9)	-0.032	(-0.077, -0.003)
Jensen (1996), ii	0.08	(0.06, 0.09)	1.4	(0.5, 2.8)	23.5	(22.4, 25.5)	28.8	(-424.7, 417.9)	0.008	(-0.044, 0.039)
Jensen (1996), iii	0.07	(0.06, 0.09)	1.2	(0.4, 2.5)	23.4	(22.3, 25.3)	22.4	(-535.8, 498.0)	0.002	(-0.043, 0.034)
Petersen & Wroblewski (1984)	0.02	(0.02, 0.02)	0.3	(0.1, 0.6)	22.9	(22.1, 24.6)	-12.5	(-23.9, -7.2)	-0.056	(-0.096, -0.029)
Chen & Watanabe (1989)	0.03	(0.03, 0.04)	0.6	(0.2, 1.1)	23.5	(22.4, 25.4)	-22.5	(-138.4, -8.0)	-0.030	(-0.074, -0.002)
Stochastic *M*	0.03	(0.02, 0.03)	0.4	(0.1, 0.7)	22.7	(21.7, 24.4)	-14.0	(-34.9, -7.5)	-0.049	(-0.092, -0.019)

Table iii. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **age specific** estimates of 2002/03 fishing mortality ($F_{2002/03}$).

	PM		***R₀***		***G***		***t***		***r***	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.04	(0.03, 0.05)	0.3	(0.1, 0.7)	19.9	(19.8, 20.6)	-12.2	(-33.0, -6.3)	-0.057	(-0.109, -0.021)
Hoenig (1983), i	0.03	(0.02, 0.04)	0.2	(0.1, 0.5)	19.8	(19.8, 20.5)	-9.5	(-20.0, -5.7)	-0.073	(-0.122, -0.035)
Hoenig (1983), ii	0.03	(0.02, 0.04)	0.3	(0.1, 0.6)	19.8	(19.8, 20.6)	-10.6	(-22.8, -5.7)	-0.065	(-0.122, -0.030)
Hoenig (1983), iii	0.02	(0.02, 0.03)	0.2	(0.1, 0.4)	19.8	(19.7, 20.5)	-8.1	(-14.9, -5.1)	-0.085	(-0.135, -0.047)
Jensen (1996), i	0.05	(0.04, 0.05)	0.4	(0.2, 0.8)	20.0	(20.0, 20.6)	-16.9	(-71.0, -7.9)	-0.041	(-0.087, -0.009)
Jensen (1996), ii	0.09	(0.08, 0.11)	1.0	(0.3, 1.9)	20.2	(20.1, 20.8)	-12.6	(-445.3, 841.2)	-0.002	(-0.055, 0.031)
Jensen (1996), iii	0.08	(0.07, 0.10)	0.9	(0.4, 1.8)	20.1	(20.0, 20.8)	-20.3	(-494.8, 491.6)	-0.005	(-0.051, 0.028)
Petersen & Wroblewski (1984)	0.03	(0.02, 0.03)	0.2	(0.1, 0.5)	20.0	(20.0, 20.6)	-10.1	(-17.8, -5.9)	-0.069	(-0.118, -0.039)
Chen & Watanabe (1989)	0.04	(0.03, 0.04)	0.4	(0.1, 0.8)	20.1	(20.1, 20.8)	-15.5	(-53.7, -7.1)	-0.045	(-0.093, -0.012)
Stochastic *M*	0.03	(0.03, 0.04)	0.3	(0.1, 0.6)	20.0	(19.8, 20.6)	-11.7	(-26.5, -6.3)	-0.059	(-0.110, -0.026)

Table iv. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **age specific** estimates of 2003/04 fishing mortality ($F_{2003/04}$).

	PM		***R₀***		***G***		***t***		***r***	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.03	(0.03, 0.05)	0.4	(0.1, 0.8)	22.3	(21.4, 23.9)	-14.9	(-53.2, -7.5)	-0.047	(-0.092, -0.012)
Hoenig (1983), i	0.03	(0.02, 0.04)	0.3	(0.1, 0.6)	22.0	(21.1, 23.8)	-10.9	(-24.8, -6.6)	-0.064	(-0.106, -0.028)
Hoenig (1983), ii	0.03	(0.02, 0.04)	0.3	(0.1, 0.7)	22.1	(21.2, 23.6)	-12.2	(-31.1, -7.1)	-0.057	(-0.098, -0.022)
Hoenig (1983), iii	0.02	(0.01, 0.03)	0.2	(0.1, 0.5)	21.8	(21.0, 23.6)	-9.1	(-18.0, -5.8)	-0.076	(-0.119, -0.038)
Jensen (1996), i	0.05	(0.04, 0.05)	0.6	(0.2, 1.1)	22.5	(21.7, 24.1)	-22.2	(-154.7, 61.3)	-0.029	(-0.073, 0.001)
Jensen (1996), ii	0.10	(0.08, 0.12)	1.6	(0.6, 3.3)	23.4	(22.2, 25.4)	28.7	(-301.2, 320.2)	0.015	(-0.028, 0.044)
Jensen (1996), iii	0.09	(0.07, 0.11)	1.4	(0.6, 3.0)	23.3	(22.2, 25.2)	26.4	(-520.1, 509.4)	0.010	(-0.034, 0.044)
Petersen & Wroblewski (1984)	0.03	(0.02, 0.03)	0.3	(0.1, 0.6)	22.8	(21.9, 24.4)	-12.3	(-24.1, -7.1)	-0.057	(-0.098, -0.029)
Chen & Watanabe (1989)	0.04	(0.03, 0.04)	0.6	(0.2, 1.2)	23.4	(22.3, 25.4)	-23.4	(-165.5, -6.4)	-0.028	(-0.073, -0.001)
Stochastic *M*	0.03	(0.02, 0.04)	0.4	(0.2, 0.8)	22.5	(21.6, 24.0)	-14.6	(-40.6, -7.8)	-0.048	(-0.089, -0.017)

Table v. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **adjusted age-class** estimates of 2001/02 fishing mortality ($\hat{F}_{2001/02}$).

	PM		R_0		*G*		t_{x2}		*r*	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.04	(0.03, 0.06)	0.6	(0.2, 1.2)	22.4	(21.5, 23.8)	-21.0	(-145.1, 81.0)	-0.031	(-0.079, 0.002)
Hoenig (1983), i	0.03	(0.02, 0.05)	0.4	(0.1, 1.0)	22.2	(21.4, 23.8)	-15.4	(-65.7, -6.9)	-0.045	(-0.096, -0.009)
Hoenig (1983), ii	0.04	(0.03, 0.05)	0.4	(0.2, 1.0)	22.5	(21.5, 23.9)	-16.8	(-78.7, -8.0)	-0.041	(-0.082, -0.008)
Hoenig (1983), iii	0.03	(0.02, 0.04)	0.3	(0.1, 0.7)	22.0	(21.2, 23.6)	-12.4	(-35.3, -6.8)	-0.056	(-0.101, -0.020)
Jensen (1996), i	0.06	(0.05, 0.06)	0.8	(0.3, 1.5)	22.7	(21.9, 24.5)	-30.5	(-525.2, 580.6)	-0.014	(-0.056, 0.012)
Jensen (1996), ii	0.11	(0.09, 0.13)	2.0	(0.7, 4.0)	23.5	(22.4, 25.6)	23.1	(-159.2, 312.8)	0.024	(-0.023, 0.055)
Jensen (1996), iii	0.10	(0.08, 0.12)	1.7	(0.7, 3.6)	23.5	(22.4, 25.3)	26.2	(-376.0, 332.2)	0.018	(-0.024, 0.051)
Petersen & Wroblewski (1984)	0.03	(0.03, 0.03)	0.5	(0.2, 0.9)	23.0	(22.1, 24.6)	-17.3	(-55.8, -8.3)	-0.040	(-0.082, -0.012)
Chen & Watanabe (1989)	0.05	(0.04, 0.05)	0.9	(0.3, 1.7)	23.6	(22.5, 25.5)	-29.5	(-450.1, 465.1)	-0.014	(-0.057, 0.015)
Stochastic *M*	0.04	(0.03, 0.05)	0.6	(0.2, 1.1)	22.8	(21.8, 24.2)	-21.1	(-158.4, -6.4)	-0.032	(-0.075, -0.001)

Table vi. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **adjusted age-class** estimates of 2002/03 fishing mortality ($\hat{F}_{2002/03}$).

	PM		R_0		*G*		t_{x2}		*r*	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.07	(0.06, 0.10)	0.9	(0.3, 1.9)	22.3	(21.4, 23.8)	-24.5	(-382.6, 661.7)	-0.009	(-0.056, 0.025)
Hoenig (1983), i	0.06	(0.04, 0.08)	0.7	(0.2, 1.6)	22.0	(21.2, 23.6)	-23.9	(-410.4, 365.0)	-0.022	(-0.068, 0.015)
Hoenig (1983), ii	0.06	(0.05, 0.08)	0.8	(0.3, 1.6)	22.1	(21.3, 23.6)	-27.0	(-397.1, 366.5)	-0.017	(-0.061, 0.017)
Hoenig (1983), iii	0.05	(0.03, 0.07)	0.5	(0.2, 1.2)	21.8	(21.1, 23.3)	-19.0	(-145.4, 85.9)	-0.034	(-0.086, 0.004)
Jensen (1996), i	0.10	(0.09, 0.10)	1.3	(0.5, 2.6)	22.5	(21.8, 24.0)	29.0	(-532.4, 548.4)	0.007	(-0.040, 0.038)
Jensen (1996), ii	0.18	(0.15, 0.22)	3.1	(1.1, 6.2)	23.4	(22.3, 25.3)	14.7	(-28.8, 69.6)	0.046	(0.000, 0.075)
Jensen (1996), iii	0.17	(0.14, 0.21)	2.9	(0.9, 6.0)	23.3	(22.2, 25.1)	15.5	(-54.8, 97.0)	0.042	(-0.009, 0.076)
Petersen & Wroblewski (1984)	0.06	(0.05, 0.06)	0.8	(0.3, 1.4)	22.8	(21.9, 24.3)	-30.1	(-509.0, 340.5)	-0.017	(-0.059, 0.011)
Chen & Watanabe (1989)	0.08	(0.07, 0.09)	1.4	(0.5, 2.8)	23.4	(22.3, 25.4)	27.2	(-349.4, 427.5)	0.008	(-0.034, 0.038)
Stochastic *M*	0.07	(0.05, 0.08)	0.9	(0.3, 1.8)	22.6	(21.6, 24.1)	-25.1	(-460.5, 609.1)	-0.009	(-0.054, 0.022)

Table vii. Results of demographic analysis of the Western Australian *Carcharhinus plumbeus* population using **adjusted age-class** estimates of 2003/04 fishing mortality ($\hat{F}_{2003/04}$).

	PM		R_0		*G*		t_{x2}		*r*	
M	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Pauly (1980)	0.04	(0.03, 0.05)	0.4	(0.1, 0.9)	21.9	(21.1, 23.3)	-14.5	(-61.5, -7.2)	-0.047	(-0.092, -0.010)
Hoenig (1983), i	0.03	(0.02, 0.04)	0.3	(0.1, 0.6)	21.6	(20.9, 23.2)	-10.7	(-24.9, -6.1)	-0.065	(-0.114, -0.028)
Hoenig (1983), ii	0.03	(0.02, 0.04)	0.3	(0.1, 0.7)	21.8	(21.0, 23.2)	-11.9	(-29.1, -6.6)	-0.058	(-0.105, -0.024)
Hoenig (1983), iii	0.02	(0.01, 0.03)	0.2	(0.1, 0.5)	21.6	(20.7, 22.9)	-8.9	(-18.0, -5.5)	-0.078	(-0.127, -0.039)
Jensen (1996), i	0.05	(0.04, 0.05)	0.6	(0.2, 1.1)	22.2	(21.5, 23.6)	-22.5	(-122.9, -6.7)	-0.030	(-0.078, -0.001)
Jensen (1996), ii	0.10	(0.08, 0.12)	1.5	(0.5, 3.1)	23.0	(22.0, 24.7)	26.4	(-382.2, 336.9)	0.013	(-0.034, 0.047)
Jensen (1996), iii	0.09	(0.07, 0.11)	1.3	(0.5, 2.7)	22.9	(21.9, 24.7)	27.9	(-492.2, 508.9)	0.008	(-0.038, 0.041)
Petersen & Wroblewski (1984)	0.03	(0.02, 0.03)	0.3	(0.1, 0.6)	22.4	(21.6, 24.2)	-12.1	(-23.1, -6.8)	-0.057	(-0.101, -0.030)
Chen & Watanabe (1989)	0.04	(0.03, 0.04)	0.6	(0.2, 1.1)	23.0	(22.0, 24.8)	-22.3	(-167.4, -7.0)	-0.030	(-0.074, -0.001)
Stochastic *M*	0.03	(0.03, 0.04)	0.4	(0.1, 0.8)	22.1	(21.3, 23.5)	-14.2	(-39.6, -7.5)	-0.049	(-0.093, -0.018)

APPENDIX II

Population growth rates (r) in the WA *Carcharhinus plumbeus* stock, estimated by demographic analysis of 65 hypothetical rates of fishing mortality relative to the best estimates of fishing mortality in 2003/04 ($\hat{F}_{2003/04}$).

Proportion of $\hat{F}_{2003/04}$					Equivalent catch (tonnes live weight)					Equivalent Effort						
WANC SF	Temp GN	Temp LL	PFT	Others	WANCSF*	Temp GN**	Temp LL**	PFT***	Others ***	WANCSF†	Western WANCSF††	Temp GN†††	Temp LL†	PFT††††	Others	Median *r* (lower 95% CI, upper 95% CI)
0.25	0.00	0.00	1.00	0.00	106	0	0	12	0	130	105	0	0	663	n/a	0.024 (-0.021, 0.055)
0.00	0.25	0.25	1.00	0.00	0	36	14	12	0	0	0	60	69	663	n/a	0.018 (-0.03, 0.049)
0.50	0.00	0.00	1.00	0.00	212	0	0	12	0	259	210	0	0	663	n/a	0.017 (-0.028, 0.049)
0.00	0.50	0.00	1.00	0.00	0	72	0	12	0	0	0	120	0	663	n/a	0.014 (-0.031, 0.044)
0.25	0.25	0.00	1.00	0.00	106	36	0	12	0	130	105	60	0	663	n/a	0.012 (-0.032, 0.043)
0.25	0.25	0.25	1.00	0.00	106	36	14	12	0	130	105	60	69	663	n/a	0.012 (-0.033, 0.043)
0.70	0.00	0.00	1.00	0.00	297	0	0	12	0	363	294	0	0	663	n/a	0.011 (-0.033, 0.043)
0.85	0.00	0.00	1.00	0.00	360	0	0	12	0	441	357	0	0	663	n/a	0.008 (-0.036, 0.04)
0.50	0.25	0.00	1.00	0.00	212	36	0	12	0	259	210	60	0	663	n/a	0.007 (-0.042, 0.036)
0.00	0.50	0.50	1.00	0.00	0	72	28	12	0	0	0	120	138	663	n/a	0.006 (-0.04, 0.038)
0.00	0.70	0.00	1.00	0.00	0	101	0	12	0	0	0	168	0	663	n/a	0.006 (-0.043, 0.038)
0.50	0.25	0.25	1.00	0.00	212	36	14	12	0	259	210	60	69	663	n/a	0.005 (-0.04, 0.037)
1.00	0.00	0.00	1.00	0.00	424	0	0	12	0	519	420	0	0	663	n/a	0.005 (-0.042, 0.036)
0.00	0.85	0.00	1.00	0.00	0	123	0	12	0	0	0	204	0	663	n/a	0.001 (-0.042, 0.034)
0.70	0.25	0.00	1.00	0.00	297	36	0	12	0	363	294	60	0	663	n/a	0.000 (-0.045, 0.032)
0.25	0.50	0.00	1.00	0.00	106	72	0	12	0	130	105	120	0	663	n/a	0.000 (-0.046, 0.032)
0.70	0.25	0.25	1.00	0.00	297	36	14	12	0	363	294	60	69	663	n/a	-0.001 (-0.046, 0.032)
0.25	0.50	0.50	1.00	0.00	106	72	28	12	0	130	105	120	138	663	n/a	-0.002 (-0.049, 0.032)
0.00	0.70	0.70	1.00	0.00	0	101	39	12	0	0	0	168	193	663	n/a	-0.003 (-0.045, 0.027)
0.85	0.25	0.00	1.00	0.00	360	36	0	12	0	441	357	60	0	663	n/a	-0.003 (-0.052, 0.028)
0.00	1.00	0.00	1.00	0.00	0	144	0	12	0	0	0	240	0	663	n/a	-0.004 (-0.05, 0.025)
0.85	0.25	0.25	1.00	0.00	360	36	14	12	0	441	357	60	69	663	n/a	-0.004 (-0.05, 0.027)
0.00	1.00	0.00	1.00	0.00	0	144	0	12	0	0	0	240	0	663	n/a	-0.005 (-0.049, 0.025)
0.50	0.50	0.00	1.00	0.00	212	72	0	12	0	259	210	120	0	663	n/a	-0.005 (-0.053, 0.025)
0.50	0.50	0.50	1.00	0.00	212	72	28	12	0	259	210	120	138	663	n/a	-0.007 (-0.052, 0.021)
1.00	0.25	0.00	1.00	0.00	424	36	0	12	0	519	420	60	0	663	n/a	-0.008 (-0.056, 0.024)
1.00	0.25	0.25	1.00	0.00	424	36	14	12	0	519	420	60	69	663	n/a	-0.008 (-0.053, 0.021)
0.25	0.70	0.70	1.00	0.00	106	101	39	12	0	130	105	168	193	663	n/a	-0.009 (-0.056, 0.022)
0.25	0.70	0.00	1.00	0.00	106	101	0	12	0	130	105	168	0	663	n/a	-0.01 (-0.053, 0.022)
0.00	0.85	0.85	1.00	0.00	0	123	48	12	0	0	0	204	235	663	n/a	-0.011 (-0.054, 0.02)
0.25	1.00	0.00	1.00	0.00	106	144	0	12	0	130	105	240	0	663	n/a	-0.012 (-0.06, 0.02)
0.70	0.50	0.50	1.00	0.00	297	72	28	12	0	363	294	120	138	663	n/a	-0.013 (-0.053, 0.018)

Proportion of $\hat{F}_{2003/04}$					Equivalent catch (tonnes live weight)					Equivalent Effort						
WANC SF	Temp GN	Temp LL	PFT	Others	WANCSF*	Temp GN**	Temp LL**	PFT***	Others ***	WANCSF†	Western WANCSF††	Temp GN†††	Temp LL†	PFT††††	Others	Median *r* (lower 95% CI, upper 95% CI)
0.70	0.50	0.00	1.00	0.00	297	72	0	12	0	363	294	120	0	663	n/a	-0.013 (-0.059, 0.02)
0.85	0.50	0.00	1.00	0.00	360	72	0	12	0	441	357	120	0	663	n/a	-0.016 (-0.061, 0.013)
0.85	0.50	0.50	1.00	0.00	360	72	28	12	0	441	357	120	138	663	n/a	-0.017 (-0.062, 0.013)
0.50	0.70	0.70	1.00	0.00	212	101	39	12	0	259	210	168	193	663	n/a	-0.017 (-0.061, 0.016)
0.50	1.00	0.00	1.00	0.00	212	144	0	12	0	259	210	240	0	663	n/a	-0.017 (-0.066, 0.011)
0.50	0.70	0.00	1.00	0.00	212	101	0	12	0	259	210	168	0	663	n/a	-0.018 (-0.068, 0.014)
0.25	0.85	0.85	1.00	0.00	106	123	48	12	0	130	105	204	235	663	n/a	-0.018 (-0.066, 0.01)
0.25	0.85	0.00	1.00	0.00	106	123	0	12	0	130	105	204	0	663	n/a	-0.019 (-0.064, 0.012)
0.00	1.00	1.00	1.00	0.00	0	144	56	12	0	0	0	240	276	663	n/a	-0.02 (-0.062, 0.012)
1.00	0.50	0.00	1.00	0.00	424	72	0	12	0	519	420	120	0	663	n/a	-0.02 (-0.065, 0.012)
1.00	0.50	0.50	1.00	0.00	424	72	28	12	0	519	420	120	138	663	n/a	-0.021 (-0.07, 0.011)
0.70	0.70	0.00	1.00	0.00	297	101	0	12	0	363	294	168	0	663	n/a	-0.023 (-0.07, 0.008)
0.70	0.70	0.70	1.00	0.00	297	101	39	12	0	363	294	168	193	663	n/a	-0.023 (-0.066, 0.01)
0.70	1.00	0.00	1.00	0.00	297	144	0	12	0	363	294	240	0	663	n/a	-0.023 (-0.069, 0.01)
0.50	0.85	0.85	1.00	0.00	212	123	48	12	0	259	210	204	235	663	n/a	-0.025 (-0.071, 0.006)
0.50	0.85	0.00	1.00	0.00	212	123	0	12	0	259	210	204	0	663	n/a	-0.026 (-0.072, 0.007)
0.25	1.00	1.00	1.00	0.00	106	144	56	12	0	130	105	240	276	663	n/a	-0.026 (-0.066, 0.003)
0.85	0.70	0.00	1.00	0.00	360	101	0	12	0	441	357	168	0	663	n/a	-0.027 (-0.071, 0.004)
0.85	0.70	0.70	1.00	0.00	360	101	39	12	0	441	357	168	193	663	n/a	-0.028 (-0.072, 0.003)
0.85	1.00	0.00	1.00	0.00	360	144	0	12	0	441	357	240	0	663	n/a	-0.028 (-0.075, 0.001)
0.70	0.85	0.00	1.00	0.00	297	123	0	12	0	363	294	204	0	663	n/a	-0.03 (-0.074, 0.001)
1.00	0.70	0.00	1.00	0.00	424	101	0	12	0	519	420	168	0	663	n/a	-0.031 (-0.079, -0.001)
0.70	0.85	0.85	1.00	0.00	297	123	48	12	0	363	294	204	235	663	n/a	-0.031 (-0.071, -0.002)
1.00	0.70	0.70	1.00	0.00	424	101	39	12	0	519	420	168	193	663	n/a	-0.032 (-0.076, -0.001)
0.50	1.00	1.00	1.00	0.00	212	144	56	12	0	259	210	240	276	663	n/a	-0.033 (-0.077, -0.003)
1.00	1.00	0.00	1.00	0.00	424	144	0	12	0	519	420	240	0	663	n/a	-0.034 (-0.077, -0.002)
0.85	0.85	0.85	1.00	0.00	360	123	48	12	0	441	357	204	235	663	n/a	-0.035 (-0.078, -0.005)
0.85	0.85	0.00	1.00	0.00	360	123	0	12	0	441	357	204	0	663	n/a	-0.036 (-0.084, -0.004)
0.70	1.00	1.00	1.00	0.00	297	144	56	12	0	363	294	240	276	663	n/a	-0.038 (-0.084, -0.008)
1.00	0.85	0.85	1.00	0.00	424	123	48	12	0	519	420	204	235	663	n/a	-0.039 (-0.082, -0.008)
1.00	0.85	0.00	1.00	0.00	424	123	0	12	0	519	420	204	0	663	n/a	-0.04 (-0.082, -0.009)
0.85	1.00	1.00	1.00	0.00	360	144	56	12	0	441	357	240	276	663	n/a	-0.044 (-0.088, -0.014)
2.00	1.00	1.00	1.00	0.00	848	144	56	12	0	1038	839	240	276	663	n/a	-0.079 (-0.124, -0.05)

* Reported catch; **Validated catch; ***Estimated catch
†Total reported effort (‘000 hooks); ††Reported effort (‘000 hooks) between North West Cape (longitude 114°E) and Cape Leveque (longitude 120°E); †††Validated effort (‘000 km gillnet hr); ††††Days. * CI = confidence intervals, (lower, upper)

APPENDIX III

Table i. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under zero fishing mortality, based on a reproductive periodicity of **2 years**. Definitions of demographic parameter symbols are given in Table 5.22.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.066	(0.023, 0.149)	2.1	(0.7, 6.2)	31.4	(29.7, 33.5)	25.1	(-171.9, 230.6)	0.024	(-0.010, 0.058)
Hoenig (1983), i	0.015	(0.040, 0.112)	2.3	(0.8, 5.3)	31.5	(29.7, 34.1)	24.3	(-102.8, 166.1)	0.027	(-0.005, 0.053)
Hoenig (1983), ii	0.067	(0.043, 0.102)	2.3	(0.9, 5.4)	31.4	(29.7, 34.0)	24.7	(-106.2, 194.9)	0.027	(-0.004, 0.053)
Hoenig (1983), iii	0.067	(0.032, 0.091)	1.7	(0.7, 4.4)	31.3	(29.4, 33.7)	29.1	(-402.8, 417.4)	0.018	(-0.010, 0.046)
Jensen (1996), i	0.197	(0.192, 0.203)	7.6	(3.2, 14.3)	32.7	(30.6, 35.5)	10.8	(8.2, 19.1)	0.064	(0.036, 0.084)
Jensen (1996), ii	0.206	(0.104, 0.346)	7.6	(2.8, 17.7)	32.6	(30.7, 35.7)	10.9	(7.7, 21.4)	0.064	(0.032, 0.090)
Jensen (1996), iii	0.184	(0.090, 0.324)	6.9	(2.5, 16.1)	32.5	(30.6, 35.3)	11.3	(7.8, 24.2)	0.061	(0.029, 0.089)
Petersen & Wroblewski (1984)	0.131	(0.113, 0.146)	5.1	(2.2, 9.5)	33.0	(30.9, 35.7)	13.7	(9.9, 27.8)	0.051	(0.025, 0.070)
Chen & Watanabe (1989)	0.064	(0.042, 0.091)	2.5	(1.0, 5.2)	32.7	(30.5, 35.7)	24.1	(-65.8, 140.0)	0.028	(-0.001, 0.050)
Stochastic *M*	0.080	(0.052, 0.110)	2.8	(1.1, 5.7)	31.9	(30.0, 34.4)	20.9	(11.4, 96.8)	0.033	(0.004, 0.055)

Table ii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under zero fishing mortality, based on a reproductive periodicity of **3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.063	(0.023, 0.135)	1.4	(0.5, 3.5)	31.4	(29.8, 33.5)	31.2	(-536.1, 484.0)	0.011	(-0.022, 0.040)
Hoenig (1983), i	0.014	(0.042, 0.108)	1.5	(0.6, 3.6)	31.5	(29.8, 34.3)	33.6	(-332.3, 661.1)	0.013	(-0.018, 0.039)
Hoenig (1983), ii	0.067	(0.042, 0.102)	1.5	(0.6, 3.4)	31.5	(29.7, 34.0)	35.4	(-523.8, 562.5)	0.013	(-0.017, 0.038)
Hoenig (1983), iii	0.066	(0.030, 0.088)	1.1	(0.4, 2.9)	31.2	(29.4, 33.7)	30.6	(-588.0, 555.0)	0.004	(-0.030, 0.033)
Jensen (1996), i	0.197	(0.192, 0.203)	5.0	(1.9, 9.6)	32.7	(30.7, 35.5)	13.7	(9.6, 31.3)	0.050	(0.020, 0.072)
Jensen (1996), ii	0.207	(0.102, 0.352)	5.2	(1.9, 11.8)	32.7	(30.8, 35.5)	13.4	(8.8, 32.8)	0.051	(0.020, 0.078)
Jensen (1996), iii	0.181	(0.087, 0.323)	4.4	(1.8, 11.0)	32.6	(30.6, 35.3)	15.0	(9.2, 37.8)	0.046	(0.018, 0.075)
Petersen & Wroblewski (1984)	0.131	(0.113, 0.146)	3.4	(1.4, 6.5)	32.9	(30.9, 35.9)	18.3	(11.6, 58.3)	0.038	(0.011, 0.058)
Chen & Watanabe (1989)	0.065	(0.042, 0.092)	1.6	(0.7, 3.3)	32.7	(30.5, 35.8)	36.9	(-355.7, 363.4)	0.015	(-0.013, 0.037)
Stochastic *M*	0.080	(0.052, 0.109)	1.9	(0.8, 3.7)	31.9	(30.1, 34.5)	30.8	(-235.9, 237.2)	0.020	(-0.008, 0.041)

Table iii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under zero fishing mortality, based on a reproductive periodicity of **4 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.065	(0.025, 0.150)	1.0	(0.4, 2.8)	31.4	(29.7, 33.7)	22.2	(-675.5, 689.7)	0.001	(-0.032, 0.033)
Hoenig (1983), i	0.014	(0.040, 0.108)	1.1	(0.4, 2.8)	31.4	(29.6, 34.2)	31.2	(-736.9, 584.1)	0.004	(-0.027, 0.032)
Hoenig (1983), ii	0.065	(0.042, 0.103)	1.1	(0.4, 2.6)	31.5	(29.6, 34.1)	36.1	(-726.3, 639.3)	0.004	(-0.027, 0.029)
Hoenig (1983), iii	0.068	(0.033, 0.088)	0.9	(0.3, 2.0)	31.3	(29.5, 33.8)	-26.5	(-745.1, 716.9)	-0.004	(-0.039, 0.023)
Jensen (1996), i	0.197	(0.192, 0.203)	3.7	(1.7, 7.5)	32.7	(30.8, 35.4)	16.9	(11.0, 42.6)	0.041	(0.016, 0.062)
Jensen (1996), ii	0.198	(0.103, 0.348)	3.7	(1.4, 8.9)	32.7	(30.8, 35.8)	17.0	(10.0, 60.6)	0.040	(0.010, 0.068)
Jensen (1996), iii	0.181	(0.095, 0.313)	3.3	(1.2, 7.2)	32.5	(30.6, 35.1)	18.4	(10.9, 80.1)	0.037	(0.007, 0.062)
Petersen & Wroblewski (1984)	0.131	(0.113, 0.146)	2.5	(1.1, 4.8)	32.9	(30.9, 35.9)	23.9	(13.0, 110.4)	0.028	(0.002, 0.048)
Chen & Watanabe (1989)	0.064	(0.041, 0.092)	1.2	(0.5, 2.5)	32.6	(30.4, 35.8)	42.8	(-487.9, 742.7)	0.006	(-0.022, 0.027)
Stochastic *M*	0.079	(0.053, 0.111)	1.4	(0.6, 2.8)	31.8	(30.0, 34.5)	41.5	(-369.6, 684.1)	0.010	(-0.018, 0.032)

Table iv. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under zero fishing mortality, based on a reproductive periodicity of **2-4 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.063	(0.024, 0.147)	1.4	(0.4, 4.9)	31.5	(29.7, 33.6)	27.2	(-441.1, 475.0)	0.012	(-0.026, 0.051)
Hoenig (1983), i	0.015	(0.041, 0.108)	1.5	(0.5, 4.5)	31.5	(29.6, 34.1)	27.3	(-461.2, 383.3)	0.014	(-0.022, 0.048)
Hoenig (1983), ii	0.065	(0.043, 0.103)	1.5	(0.5, 4.3)	31.4	(29.7, 33.9)	31.4	(-513.4, 407.9)	0.013	(-0.023, 0.046)
Hoenig (1983), iii	0.066	(0.020, 0.059)	0.8	(0.3, 2.2)	31.2	(29.4, 33.6)	-25.8	(-585.7, 511.8)	-0.008	(-0.044, 0.025)
Jensen (1996), i	0.128	(0.125, 0.132)	3.3	(1.1, 7.7)	32.5	(30.7, 35.3)	18.4	(10.1, 86.7)	0.037	(0.004, 0.064)
Jensen (1996), ii	0.132	(0.065, 0.226)	3.4	(1.0, 10.1)	32.8	(30.8, 35.7)	17.9	(7.8, 83.5)	0.037	(0.001, 0.071)
Jensen (1996), iii	0.117	(0.059, 0.209)	3.1	(0.9, 8.4)	32.6	(30.5, 35.3)	19.3	(-45.8, 126.7)	0.035	(-0.002, 0.067)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	2.2	(0.8, 5.4)	32.8	(30.9, 35.9)	26.6	(-132.4, 271.8)	0.024	(-0.005, 0.051)
Chen & Watanabe (1989)	0.042	(0.027, 0.059)	1.1	(0.4, 2.7)	32.6	(30.7, 36.0)	30.4	(-618.4, 610.0)	0.003	(-0.028, 0.030)
Stochastic *M*	0.052	(0.033, 0.071)	1.3	(0.4, 3.0)	31.8	(30.0, 34.2)	36.5	(-514.9, 737.7)	0.008	(-0.027, 0.035)

Table v. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under zero fishing mortality, based on a reproductive periodicity of **2-3 years**.

	PM		***R₀***		***G***		***t_x2***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.063	(0.023, 0.139)	1.7	(0.5, 4.9)	31.4	(29.8, 33.4)	27.3	(-324.7, 332.9)	0.016	(-0.020, 0.052)
Hoenig (1983), i	0.014	(0.040, 0.108)	1.8	(0.6, 4.8)	31.4	(29.7, 34.0)	27.4	(-282.6, 321.2)	0.020	(-0.016, 0.050)
Hoenig (1983), ii	0.067	(0.042, 0.103)	1.9	(0.6, 4.6)	31.4	(29.7, 34.1)	29.2	(-462.1, 342.4)	0.020	(-0.015, 0.048)
Hoenig (1983), iii	0.067	(0.033, 0.091)	1.5	(0.5, 4.0)	31.3	(29.5, 33.9)	28.7	(-660.6, 395.7)	0.013	(-0.023, 0.044)
Jensen (1996), i	0.197	(0.192, 0.203)	6.1	(2.2, 13.3)	32.7	(30.7, 35.6)	12.2	(8.6, 27.6)	0.057	(0.025, 0.081)
Jensen (1996), ii	0.199	(0.100, 0.352)	6.0	(2.1, 16.5)	32.7	(30.7, 35.6)	12.2	(7.8, 29.5)	0.057	(0.023, 0.088)
Jensen (1996), iii	0.183	(0.089, 0.320)	5.3	(1.7, 13.4)	32.5	(30.6, 35.3)	13.2	(8.2, 33.7)	0.052	(0.017, 0.083)
Petersen & Wroblewski (1984)	0.131	(0.113, 0.146)	4.3	(1.6, 8.7)	32.8	(30.9, 35.8)	15.4	(10.1, 43.3)	0.045	(0.013, 0.068)
Chen & Watanabe (1989)	0.064	(0.042, 0.092)	2.0	(0.7, 4.7)	32.7	(30.6, 36.0)	28.8	(-167.5, 294.5)	0.021	(-0.014, 0.046)
Stochastic *M*	0.079	(0.050, 0.110)	2.2	(0.8, 5.2)	31.9	(30.2, 34.6)	25.4	(-150.0, 244.2)	0.025	(-0.007, 0.052)

Table vi. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the 1994 cohort, based on a reproductive periodicity of **2 years**.

	PM		***R₀***		***G***		***t_x2***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.036	(0.013, 0.086)	1.2	(0.4, 3.4)	31.4	(29.7, 33.7)	29.5	(-414.9, 602.7)	0.006	(-0.030, 0.039)
Hoenig (1983), i	0.009	(0.026, 0.068)	1.4	(0.5, 3.5)	31.6	(29.7, 34.2)	33.4	(-446.9, 487.5)	0.012	(-0.022, 0.039)
Hoenig (1983), ii	0.042	(0.027, 0.067)	1.5	(0.6, 3.4)	31.5	(29.7, 34.0)	35.6	(-427.9, 663.6)	0.012	(-0.018, 0.038)
Hoenig (1983), iii	0.043	(0.021, 0.059)	1.1	(0.4, 2.8)	31.2	(29.5, 33.6)	30.2	(-657.4, 906.2)	0.004	(-0.027, 0.032)
Jensen (1996), i	0.128	(0.125, 0.132)	5.0	(2.0, 9.0)	32.7	(30.7, 35.4)	13.8	(10.0, 28.1)	0.050	(0.022, 0.069)
Jensen (1996), ii	0.132	(0.068, 0.228)	4.9	(1.9, 11.2)	32.7	(30.7, 35.7)	13.9	(9.1, 33.5)	0.050	(0.020, 0.076)
Jensen (1996), iii	0.119	(0.056, 0.206)	4.3	(1.7, 10.2)	32.5	(30.6, 35.5)	15.1	(9.4, 38.1)	0.046	(0.017, 0.073)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	3.4	(1.4, 6.5)	33.0	(30.9, 35.9)	18.5	(11.7, 55.2)	0.037	(0.010, 0.057)
Chen & Watanabe (1989)	0.042	(0.027, 0.060)	1.6	(0.6, 3.3)	32.7	(30.7, 35.9)	37.0	(-545.2, 649.8)	0.014	(-0.014, 0.035)
Stochastic *M*	0.052	(0.035, 0.072)	1.9	(0.8, 3.8)	31.9	(30.1, 34.5)	31.6	(-213.2, 274.6)	0.020	(-0.008, 0.042)

Table vii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the 1994 cohort, based on a reproductive periodicity of **3 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.084)	0.8	(0.3, 2.4)	31.4	(29.7, 33.6)	-27.8	(-635.9, 642.6)	-0.007	(-0.044, 0.028)
Hoenig (1983), i	0.009	(0.024, 0.064)	0.9	(0.3, 2.2)	31.4	(29.6, 34.2)	-31.3	(-711.4, 581.8)	-0.004	(-0.037, 0.025)
Hoenig (1983), ii	0.038	(0.025, 0.062)	0.9	(0.3, 2.1)	31.4	(29.6, 34.1)	-28.9	(-630.6, 675.9)	-0.003	(-0.036, 0.023)
Hoenig (1983), iii	0.039	(0.018, 0.053)	0.7	(0.2, 1.7)	31.2	(29.5, 33.7)	-32.1	(-567.9, 565.6)	-0.012	(-0.048, 0.016)
Jensen (1996), i	0.116	(0.113, 0.119)	3.0	(1.2, 5.6)	32.7	(30.7, 35.6)	20.2	(12.6, 80.8)	0.034	(0.006, 0.054)
Jensen (1996), ii	0.117	(0.062, 0.197)	2.9	(1.1, 6.5)	32.6	(30.8, 35.4)	20.7	(11.4, 106.5)	0.033	(0.004, 0.058)
Jensen (1996), iii	0.108	(0.052, 0.188)	2.6	(1.0, 6.0)	32.5	(30.6, 35.4)	22.4	(10.9, 133.4)	0.030	(0.001, 0.056)
Petersen & Wroblewski (1984)	0.077	(0.066, 0.085)	2.0	(0.8, 3.7)	32.7	(30.9, 35.7)	31.2	(-119.6, 230.3)	0.021	(-0.008, 0.039)
Chen & Watanabe (1989)	0.038	(0.024, 0.054)	1.0	(0.4, 2.0)	32.6	(30.6, 35.9)	-27.2	(-915.3, 910.9)	-0.001	(-0.027, 0.021)
Stochastic *M*	0.047	(0.031, 0.066)	1.1	(0.5, 2.4)	31.9	(30.1, 34.4)	35.7	(-1,059.6, 688.8)	0.003	(-0.025, 0.027)

Table viii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the 1994 cohort, based on a reproductive periodicity of **4 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.084)	0.6	(0.2, 1.7)	31.3	(29.6, 33.5)	-32.3	(-412.8, 402.9)	-0.015	(-0.047, 0.016)
Hoenig (1983), i	0.009	(0.025, 0.066)	0.7	(0.2, 1.6)	31.4	(29.6, 33.9)	-34.2	(-445.9, 472.7)	-0.014	(-0.045, 0.014)
Hoenig (1983), ii	0.038	(0.026, 0.060)	0.7	(0.3, 1.5)	31.4	(29.8, 34.0)	-35.7	(-794.2, 510.0)	-0.013	(-0.043, 0.014)
Hoenig (1983), iii	0.039	(0.019, 0.054)	0.5	(0.2, 1.3)	31.3	(29.5, 33.8)	-27.8	(-313.2, 272.3)	-0.021	(-0.053, 0.008)
Jensen (1996), i	0.116	(0.113, 0.119)	2.2	(0.9, 4.2)	32.7	(30.7, 35.6)	27.0	(-83.9, 132.3)	0.025	(-0.003, 0.045)
Jensen (1996), ii	0.118	(0.058, 0.206)	2.2	(0.8, 5.4)	32.6	(30.6, 35.5)	25.6	(-142.8, 208.7)	0.025	(-0.006, 0.052)
Jensen (1996), iii	0.106	(0.051, 0.181)	2.0	(0.8, 4.5)	32.6	(30.7, 35.3)	29.3	(-359.5, 273.3)	0.021	(-0.006, 0.047)
Petersen & Wroblewski (1984)	0.077	(0.066, 0.085)	1.5	(0.6, 2.7)	32.9	(30.9, 35.9)	40.7	(-358.8, 392.6)	0.013	(-0.014, 0.031)
Chen & Watanabe (1989)	0.039	(0.025, 0.054)	0.7	(0.3, 1.6)	32.7	(30.6, 35.9)	-39.5	(-565.0, 655.3)	-0.010	(-0.039, 0.013)
Stochastic *M*	0.047	(0.029, 0.066)	0.8	(0.4, 1.7)	31.8	(30.1, 34.5)	-38.8	(-745.6, 589.2)	-0.006	(-0.032, 0.017)

Table ix. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the 1994 cohort, based on a reproductive periodicity of **2-4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.086)	0.9	(0.2, 2.9)	31.4	(29.7, 33.7)	-23.8	(-540.7, 416.7)	-0.005	(-0.044, 0.033)
Hoenig (1983), i	0.008	(0.025, 0.064)	0.9	(0.3, 2.7)	31.5	(29.7, 34.2)	-20.4	(-515.4, 488.1)	-0.002	(-0.038, 0.031)
Hoenig (1983), ii	0.039	(0.025, 0.060)	0.9	(0.3, 2.5)	31.5	(29.8, 33.9)	-23.3	(-798.6, 559.9)	-0.003	(-0.039, 0.029)
Hoenig (1983), iii	0.038	(0.019, 0.051)	0.7	(0.2, 2.0)	31.2	(29.4, 33.6)	-27.4	(-610.0, 633.7)	-0.012	(-0.048, 0.022)
Jensen (1996), i	0.116	(0.113, 0.119)	3.0	(1.1, 7.4)	32.7	(30.7, 35.4)	19.7	(9.8, 85.3)	0.034	(0.002, 0.062)
Jensen (1996), ii	0.119	(0.061, 0.209)	3.0	(1.0, 9.5)	32.8	(30.8, 35.7)	19.6	(-35.6, 106.4)	0.034	(-0.001, 0.069)
Jensen (1996), iii	0.108	(0.051, 0.193)	2.7	(0.8, 7.5)	32.6	(30.5, 35.3)	21.1	(-94.0, 143.3)	0.031	(-0.007, 0.064)
Petersen & Wroblewski (1984)	0.077	(0.066, 0.085)	2.0	(0.8, 4.7)	32.9	(31.0, 35.8)	28.8	(-188.8, 301.2)	0.022	(-0.006, 0.047)
Chen & Watanabe (1989)	0.038	(0.024, 0.054)	1.0	(0.3, 2.4)	32.7	(30.6, 35.8)	20.4	(-1,358.9, 835.8)	0.000	(-0.035, 0.027)
Stochastic *M*	0.046	(0.029, 0.065)	1.1	(0.4, 2.8)	31.9	(30.0, 34.6)	30.0	(-529.7, 643.9)	0.004	(-0.027, 0.032)

Table x. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the 1994 cohort, based on a reproductive periodicity of **2-3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.037	(0.014, 0.082)	1.0	(0.3, 2.9)	31.4	(29.7, 33.8)	-13.3	(-586.6, 693.0)	0.000	(-0.038, 0.034)
Hoenig (1983), i	0.008	(0.024, 0.066)	1.1	(0.4, 2.9)	31.5	(29.6, 34.1)	26.4	(-476.1, 858.1)	0.003	(-0.031, 0.033)
Hoenig (1983), ii	0.039	(0.025, 0.060)	1.1	(0.4, 2.6)	31.4	(29.6, 33.8)	25.7	(-693.2, 525.6)	0.002	(-0.030, 0.030)
Hoenig (1983), iii	0.038	(0.019, 0.051)	0.8	(0.3, 2.3)	31.2	(29.6, 33.8)	-30.7	(-453.3, 529.7)	-0.006	(-0.039, 0.025)
Jensen (1996), i	0.116	(0.113, 0.119)	3.6	(1.4, 7.6)	32.7	(30.7, 35.6)	17.3	(10.8, 62.9)	0.040	(0.011, 0.063)
Jensen (1996), ii	0.119	(0.062, 0.203)	3.6	(1.3, 9.1)	32.6	(30.7, 35.6)	17.1	(9.6, 68.9)	0.040	(0.008, 0.069)
Jensen (1996), iii	0.105	(0.053, 0.183)	3.1	(1.0, 7.7)	32.6	(30.6, 35.5)	18.8	(8.8, 125.1)	0.036	(0.001, 0.065)
Petersen & Wroblewski (1984)	0.077	(0.066, 0.085)	2.4	(0.9, 4.8)	32.9	(30.9, 35.7)	24.7	(-37.8, 168.4)	0.027	(-0.003, 0.048)
Chen & Watanabe (1989)	0.038	(0.025, 0.054)	1.2	(0.4, 2.8)	32.7	(30.6, 35.9)	36.1	(-889.6, 651.7)	0.006	(-0.025, 0.031)
Stochastic *M*	0.047	(0.030, 0.065)	1.3	(0.5, 3.0)	31.9	(30.1, 34.4)	34.6	(-652.5, 688.5)	0.008	(-0.022, 0.035)

Table xi. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the **1995 cohort**, based on a reproductive periodicity of **2 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.042	(0.016, 0.093)	1.4	(0.5, 3.6)	31.5	(29.8, 33.6)	34.0	(-565.7, 524.7)	0.010	(-0.022, 0.040)
Hoenig (1983), i	0.009	(0.029, 0.104)	1.8	(0.6, 4.9)	31.4	(29.7, 34.0)	28.6	(-280.2, 318.6)	0.020	(-0.016, 0.050)
Hoenig (1983), ii	0.057	(0.045, 0.102)	2.3	(0.9, 5.2)	31.5	(29.7, 33.9)	24.4	(-95.1, 161.4)	0.027	(-0.005, 0.053)
Hoenig (1983), iii	0.067	(0.032, 0.091)	1.7	(0.6, 4.3)	31.3	(29.5, 33.7)	31.1	(-303.9, 447.7)	0.018	(-0.015, 0.046)
Jensen (1996), i	0.197	(0.192, 0.203)	7.8	(3.2, 14.3)	32.6	(30.7, 35.5)	10.7	(8.2, 19.1)	0.065	(0.036, 0.085)
Jensen (1996), ii	0.204	(0.100, 0.357)	7.5	(2.6, 17.7)	32.7	(30.8, 35.5)	10.9	(7.7, 23.1)	0.064	(0.030, 0.090)
Jensen (1996), iii	0.181	(0.083, 0.319)	6.5	(2.4, 16.3)	32.5	(30.6, 35.3)	11.7	(8.0, 24.9)	0.059	(0.028, 0.087)
Petersen & Wroblewski (1984)	0.131	(0.113, 0.146)	5.1	(2.1, 9.6)	32.9	(31.0, 35.8)	13.8	(9.7, 28.8)	0.050	(0.024, 0.071)
Chen & Watanabe (1989)	0.066	(0.041, 0.092)	2.5	(0.9, 5.3)	32.7	(30.6, 35.9)	23.4	(-38.6, 116.6)	0.028	(-0.003, 0.051)
Stochastic *M*	0.079	(0.052, 0.110)	2.8	(1.1, 5.5)	31.9	(30.0, 34.5)	21.2	(12.2, 94.3)	0.032	(0.004, 0.054)

Table xii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the **1995 cohort**, based on a reproductive periodicity of **3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.041	(0.015, 0.093)	0.9	(0.3, 2.7)	31.4	(29.7, 33.6)	-24.0	(-439.9, 578.6)	-0.003	(-0.039, 0.031)
Hoenig (1983), i	0.009	(0.026, 0.070)	1.0	(0.4, 2.4)	31.5	(29.7, 34.1)	20.0	(-537.8, 815.0)	0.000	(-0.031, 0.028)
Hoenig (1983), ii	0.044	(0.027, 0.067)	1.0	(0.4, 2.3)	31.5	(29.7, 33.9)	-20.0	(-989.3, 687.3)	-0.001	(-0.033, 0.025)
Hoenig (1983), iii	0.043	(0.021, 0.059)	0.8	(0.3, 1.8)	31.2	(29.4, 33.5)	-33.1	(-512.9, 483.8)	-0.009	(-0.039, 0.018)
Jensen (1996), i	0.128	(0.125, 0.132)	3.2	(1.4, 6.0)	32.6	(30.7, 35.4)	18.9	(12.0, 59.0)	0.036	(0.010, 0.056)
Jensen (1996), ii	0.131	(0.066, 0.224)	3.2	(1.1, 7.6)	32.6	(30.8, 35.5)	18.5	(10.4, 100.4)	0.037	(0.004, 0.063)
Jensen (1996), iii	0.118	(0.055, 0.208)	2.9	(1.0, 6.9)	32.5	(30.6, 35.5)	20.3	(-23.1, 94.9)	0.033	(-0.001, 0.061)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	2.2	(0.9, 4.2)	32.8	(30.9, 35.8)	26.8	(-64.0, 144.3)	0.025	(-0.003, 0.043)
Chen & Watanabe (1989)	0.042	(0.028, 0.059)	1.0	(0.4, 2.3)	32.6	(30.7, 35.9)	32.5	(-987.5, 877.3)	0.001	(-0.028, 0.024)
Stochastic *M*	0.052	(0.032, 0.073)	1.2	(0.4, 2.6)	31.9	(30.0, 34.4)	40.8	(-647.1, 678.9)	0.006	(-0.027, 0.029)

Table xiii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the **1995 cohort**, based on a reproductive periodicity of **4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.043	(0.016, 0.095)	0.7	(0.2, 1.9)	31.4	(29.6, 33.6)	-29.5	(-426.3, 336.0)	-0.012	(-0.051, 0.021)
Hoenig (1983), i	0.009	(0.028, 0.070)	0.7	(0.3, 1.8)	31.4	(29.7, 34.2)	-33.2	(-565.9, 540.0)	-0.010	(-0.042, 0.019)
Hoenig (1983), ii	0.042	(0.029, 0.069)	0.7	(0.3, 1.7)	31.4	(29.7, 34.1)	-33.5	(-527.5, 781.3)	-0.010	(-0.042, 0.016)
Hoenig (1983), iii	0.043	(0.020, 0.057)	0.6	(0.2, 1.4)	31.2	(29.5, 33.7)	-30.0	(-338.1, 370.0)	-0.018	(-0.048, 0.011)
Jensen (1996), i	0.128	(0.125, 0.132)	2.4	(1.0, 4.6)	32.7	(30.7, 35.5)	24.4	(-20.4, 119.5)	0.028	(-0.001, 0.047)
Jensen (1996), ii	0.131	(0.068, 0.232)	2.5	(0.9, 6.0)	32.7	(30.7, 35.6)	23.3	(-70.7, 178.6)	0.029	(-0.003, 0.055)
Jensen (1996), iii	0.118	(0.058, 0.201)	2.1	(0.8, 5.1)	32.6	(30.6, 35.4)	26.7	(-176.0, 299.1)	0.024	(-0.006, 0.049)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	1.7	(0.7, 3.2)	33.0	(30.9, 36.0)	36.5	(-292.7, 299.6)	0.016	(-0.011, 0.035)
Chen & Watanabe (1989)	0.042	(0.027, 0.060)	0.8	(0.3, 1.6)	32.6	(30.5, 35.9)	-41.1	(-879.1, 665.9)	-0.006	(-0.034, 0.015)
Stochastic *M*	0.051	(0.034, 0.071)	0.9	(0.3, 1.9)	31.9	(30.0, 34.5)	-32.2	(-706.5, 789.1)	-0.003	(-0.033, 0.019)

Table xiv. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the **1995 cohort**, based on a reproductive periodicity of **2-4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.041	(0.015, 0.092)	0.9	(0.3, 3.0)	31.4	(29.8, 33.7)	-19.2	(-445.2, 572.8)	-0.002	(-0.041, 0.035)
Hoenig (1983), i	0.010	(0.028, 0.071)	1.0	(0.3, 3.0)	31.4	(29.6, 34.0)	15.7	(-838.7, 534.9)	0.000	(-0.034, 0.034)
Hoenig (1983), ii	0.042	(0.029, 0.067)	1.0	(0.3, 2.7)	31.5	(29.7, 34.1)	-12.7	(-655.4, 501.0)	0.000	(-0.035, 0.032)
Hoenig (1983), iii	0.042	(0.021, 0.059)	0.8	(0.2, 2.3)	31.2	(29.5, 33.8)	-25.9	(-508.0, 440.4)	-0.008	(-0.049, 0.027)
Jensen (1996), i	0.128	(0.125, 0.132)	3.3	(1.4, 8.0)	32.6	(30.7, 35.7)	18.5	(10.5, 66.1)	0.037	(0.009, 0.065)
Jensen (1996), ii	0.135	(0.068, 0.226)	3.5	(1.1, 9.9)	32.6	(30.8, 35.7)	17.5	(8.5, 83.9)	0.039	(0.001, 0.072)
Jensen (1996), iii	0.115	(0.055, 0.210)	3.0	(1.0, 8.8)	32.5	(30.6, 35.2)	19.7	(-12.5, 117.3)	0.034	(0.000, 0.067)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	2.3	(0.9, 5.6)	33.0	(30.9, 36.0)	25.8	(-135.9, 189.1)	0.025	(-0.005, 0.052)
Chen & Watanabe (1989)	0.043	(0.027, 0.060)	1.1	(0.4, 2.8)	32.7	(30.7, 35.7)	30.0	(-679.1, 662.3)	0.003	(-0.031, 0.032)
Stochastic *M*	0.052	(0.033, 0.071)	1.2	(0.4, 3.3)	31.8	(30.1, 34.5)	31.4	(-626.1, 864.5)	0.006	(-0.025, 0.037)

Table xv. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated by Simpfendorfer et al (1999) and Simpfendorfer (1999) for the **1995 cohort**, based on a reproductive periodicity of **2-3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.040	(0.015, 0.091)	1.1	(0.3, 3.2)	31.4	(29.8, 33.4)	23.8	(-678.2, 522.3)	0.003	(-0.036, 0.037)
Hoenig (1983), i	0.009	(0.028, 0.073)	1.2	(0.4, 3.1)	31.5	(29.7, 34.1)	30.0	(-533.5, 858.1)	0.005	(-0.028, 0.036)
Hoenig (1983), ii	0.043	(0.029, 0.069)	1.2	(0.4, 3.0)	31.5	(29.7, 34.0)	32.4	(-597.7, 601.0)	0.006	(-0.027, 0.036)
Hoenig (1983), iii	0.043	(0.020, 0.057)	0.9	(0.3, 2.6)	31.1	(29.4, 33.7)	-22.3	(-498.2, 592.3)	-0.002	(-0.035, 0.030)
Jensen (1996), i	0.128	(0.125, 0.132)	3.9	(1.6, 8.1)	32.6	(30.7, 35.4)	16.2	(10.6, 44.7)	0.043	(0.016, 0.065)
Jensen (1996), ii	0.131	(0.066, 0.223)	3.9	(1.3, 10.0)	32.6	(30.7, 35.7)	15.9	(9.3, 64.7)	0.043	(0.008, 0.073)
Jensen (1996), iii	0.115	(0.056, 0.208)	3.5	(1.1, 9.2)	32.5	(30.6, 35.4)	17.5	(9.0, 89.0)	0.039	(0.003, 0.070)
Petersen & Wroblewski (1984)	0.085	(0.073, 0.095)	2.6	(1.0, 5.5)	32.9	(30.8, 36.0)	22.8	(0.3, 114.3)	0.030	(0.000, 0.053)
Chen & Watanabe (1989)	0.042	(0.027, 0.059)	1.3	(0.5, 3.0)	32.7	(30.7, 36.0)	37.8	(-863.6, 458.8)	0.008	(-0.021, 0.033)
Stochastic *M*	0.052	(0.032, 0.072)	1.5	(0.5, 3.4)	31.7	(30.1, 34.6)	36.0	(-416.0, 627.3)	0.013	(-0.019, 0.039)

Table xvi. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1994 cohort**, based on a reproductive periodicity of **2 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.087)	1.2	(0.4, 3.3)	31.4	(29.8, 33.6)	29.8	(-617.0, 599.9)	0.007	(-0.026, 0.038)
Hoenig (1983), i	0.008	(0.026, 0.065)	1.4	(0.5, 3.2)	31.5	(29.7, 34.2)	33.1	(-539.5, 546.7)	0.010	(-0.023, 0.036)
Hoenig (1983), ii	0.040	(0.026, 0.064)	1.3	(0.5, 3.1)	31.4	(29.7, 34.1)	36.5	(-701.9, 592.3)	0.009	(-0.024, 0.036)
Hoenig (1983), iii	0.039	(0.018, 0.053)	1.0	(0.4, 2.5)	31.2	(29.5, 33.8)	22.0	(-589.4, 637.5)	0.001	(-0.030, 0.028)
Jensen (1996), i	0.121	(0.118, 0.124)	4.6	(2.0, 8.7)	32.7	(30.7, 35.5)	14.4	(10.1, 33.4)	0.048	(0.021, 0.068)
Jensen (1996), ii	0.123	(0.063, 0.213)	4.4	(1.6, 10.5)	32.6	(30.6, 35.8)	14.8	(9.3, 47.1)	0.047	(0.013, 0.073)
Jensen (1996), iii	0.115	(0.054, 0.200)	4.2	(1.4, 10.1)	32.7	(30.6, 35.4)	15.1	(9.1, 47.8)	0.045	(0.010, 0.072)
Petersen & Wroblewski (1984)	0.076	(0.066, 0.085)	2.9	(1.3, 5.6)	32.8	(30.9, 35.9)	21.0	(12.5, 70.5)	0.033	(0.007, 0.053)
Chen & Watanabe (1989)	0.032	(0.021, 0.047)	1.2	(0.5, 2.5)	32.7	(30.5, 35.7)	39.5	(-943.7, 730.1)	0.006	(-0.021, 0.027)
Stochastic *M*	0.045	(0.029, 0.063)	1.6	(0.6, 3.2)	31.9	(30.1, 34.6)	35.6	(-420.9, 543.0)	0.014	(-0.014, 0.036)

Table xvii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1994 cohort**, based on a reproductive periodicity of **3 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.087)	0.8	(0.3, 2.3)	31.4	(29.8, 33.5)	-28.2	(-528.1, 586.3)	-0.006	(-0.043, 0.026)
Hoenig (1983), i	0.008	(0.026, 0.065)	0.9	(0.3, 2.2)	31.5	(29.8, 34.1)	-26.2	(-522.1, 788.5)	-0.004	(-0.038, 0.024)
Hoenig (1983), ii	0.040	(0.025, 0.062)	0.9	(0.3, 2.0)	31.5	(29.7, 34.1)	-29.5	(-843.5, 582.0)	-0.003	(-0.036, 0.022)
Hoenig (1983), iii	0.039	(0.019, 0.052)	0.7	(0.2, 1.6)	31.2	(29.5, 33.6)	-34.3	(-506.3, 527.3)	-0.013	(-0.046, 0.015)
Jensen (1996), i	0.121	(0.118, 0.124)	3.2	(1.3, 5.8)	32.6	(30.6, 35.3)	19.3	(12.3, 66.8)	0.036	(0.009, 0.056)
Jensen (1996), ii	0.122	(0.060, 0.213)	3.0	(1.0, 7.0)	32.6	(30.7, 35.5)	19.5	(9.9, 90.7)	0.035	(0.001, 0.061)
Jensen (1996), iii	0.113	(0.054, 0.196)	2.7	(1.0, 6.7)	32.5	(30.5, 35.4)	21.3	(-56.2, 183.9)	0.031	(-0.001, 0.060)
Petersen & Wroblewski (1984)	0.076	(0.066, 0.085)	2.0	(0.9, 3.8)	32.9	(30.9, 35.9)	30.4	(-119.9, 281.6)	0.022	(-0.003, 0.042)
Chen & Watanabe (1989)	0.032	(0.020, 0.047)	0.8	(0.3, 1.7)	32.7	(30.5, 35.8)	-38.1	(-640.6, 884.1)	-0.007	(-0.035, 0.016)
Stochastic *M*	0.044	(0.028, 0.063)	1.0	(0.4, 2.2)	31.8	(30.1, 34.5)	27.6	(-652.1, 676.3)	0.001	(-0.030, 0.025)

Table xviii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1994 cohort**, based on a reproductive periodicity of **4 years**.

	PM		R_0		***G***		t_{x2}		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.036	(0.014, 0.084)	0.6	(0.2, 1.7)	31.3	(29.7, 33.7)	-28.2	(-402.2, 393.3)	-0.016	(-0.052, 0.016)
Hoenig (1983), i	0.008	(0.025, 0.065)	0.7	(0.2, 1.7)	31.5	(29.6, 34.2)	-30.0	(-491.1, 622.1)	-0.012	(-0.045, 0.017)
Hoenig (1983), ii	0.040	(0.025, 0.062)	0.7	(0.2, 1.6)	31.5	(29.7, 34.0)	-36.1	(-513.7, 526.7)	-0.012	(-0.046, 0.015)
Hoenig (1983), iii	0.039	(0.019, 0.053)	0.5	(0.2, 1.3)	31.2	(29.5, 33.8)	-28.1	(-370.6, 212.5)	-0.022	(-0.056, 0.008)
Jensen (1996), i	0.121	(0.118, 0.124)	2.3	(0.9, 4.4)	32.7	(30.7, 35.5)	26.5	(-29.7, 138.5)	0.025	(-0.002, 0.045)
Jensen (1996), ii	0.123	(0.063, 0.213)	2.3	(0.8, 5.2)	32.8	(30.7, 35.6)	25.2	(-141.3, 191.0)	0.026	(-0.005, 0.051)
Jensen (1996), iii	0.109	(0.051, 0.196)	2.0	(0.7, 4.8)	32.5	(30.7, 35.3)	28.0	(-187.4, 293.2)	0.022	(-0.009, 0.049)
Petersen & Wroblewski (1984)	0.076	(0.066, 0.085)	1.5	(0.6, 3.0)	32.8	(30.9, 35.8)	43.0	(-527.5, 516.1)	0.011	(-0.015, 0.033)
Chen & Watanabe (1989)	0.032	(0.020, 0.048)	0.6	(0.2, 1.2)	32.7	(30.7, 35.6)	-37.0	(-396.6, 539.8)	-0.015	(-0.047, 0.006)
Stochastic *M*	0.044	(0.028, 0.065)	0.8	(0.3, 1.6)	31.8	(30.0, 34.6)	-40.0	(-715.2, 917.2)	-0.008	(-0.038, 0.014)

Table xix. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1994 cohort**, based on a reproductive periodicity of **2-4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.037	(0.014, 0.080)	0.9	(0.3, 2.5)	31.4	(29.8, 33.6)	-23.0	(-561.5, 486.1)	-0.004	(-0.043, 0.029)
Hoenig (1983), i	0.008	(0.024, 0.067)	0.9	(0.3, 2.5)	31.5	(29.6, 34.0)	-23.7	(-657.0, 415.5)	-0.003	(-0.035, 0.029)
Hoenig (1983), ii	0.040	(0.025, 0.064)	1.0	(0.3, 2.6)	31.5	(29.7, 34.1)	-16.6	(-463.9, 706.3)	-0.001	(-0.040, 0.030)
Hoenig (1983), iii	0.040	(0.018, 0.052)	0.7	(0.3, 2.1)	31.2	(29.5, 33.6)	-28.3	(-459.8, 365.2)	-0.011	(-0.045, 0.023)
Jensen (1996), i	0.121	(0.118, 0.124)	3.1	(1.2, 7.4)	32.7	(30.7, 35.5)	19.7	(10.7, 74.7)	0.035	(0.007, 0.063)
Jensen (1996), ii	0.124	(0.061, 0.218)	3.2	(1.0, 10.1)	32.7	(30.7, 35.5)	18.7	(-41.0, 110.2)	0.036	(-0.001, 0.072)
Jensen (1996), iii	0.108	(0.051, 0.196)	2.7	(0.9, 7.9)	32.6	(30.6, 35.3)	21.2	(-91.3, 143.2)	0.031	(-0.004, 0.065)
Petersen & Wroblewski (1984)	0.076	(0.066, 0.085)	2.0	(0.7, 4.8)	32.9	(30.9, 35.9)	28.3	(-226.5, 392.5)	0.021	(-0.011, 0.048)
Chen & Watanabe (1989)	0.032	(0.020, 0.047)	0.8	(0.3, 2.2)	32.7	(30.6, 35.8)	-32.8	(-667.4, 594.8)	-0.006	(-0.038, 0.024)
Stochastic *M*	0.045	(0.028, 0.063)	1.1	(0.4, 2.7)	31.9	(30.0, 34.6)	27.4	(-500.2, 777.3)	0.002	(-0.030, 0.031)

Table xx. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1994 cohort**, based on a reproductive periodicity of **2-3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.038	(0.014, 0.089)	1.0	(0.3, 3.0)	31.4	(29.8, 33.6)	17.1	(-953.8, 798.5)	0.000	(-0.036, 0.035)
Hoenig (1983), i	0.009	(0.026, 0.068)	1.1	(0.4, 2.9)	31.5	(29.6, 34.3)	26.2	(-687.7, 750.2)	0.004	(-0.032, 0.034)
Hoenig (1983), ii	0.040	(0.025, 0.064)	1.1	(0.4, 2.7)	31.4	(29.7, 34.0)	27.1	(-576.2, 792.8)	0.003	(-0.028, 0.031)
Hoenig (1983), iii	0.039	(0.019, 0.053)	0.8	(0.3, 2.2)	31.2	(29.5, 33.7)	-28.2	(-723.6, 694.5)	-0.006	(-0.043, 0.025)
Jensen (1996), i	0.121	(0.118, 0.124)	3.7	(1.4, 7.9)	32.6	(30.7, 35.4)	16.9	(10.6, 60.7)	0.041	(0.010, 0.064)
Jensen (1996), ii	0.123	(0.060, 0.214)	3.7	(1.3, 9.6)	32.6	(30.7, 35.5)	16.8	(9.5, 74.1)	0.041	(0.008, 0.070)
Jensen (1996), iii	0.111	(0.052, 0.198)	3.4	(1.0, 9.0)	32.5	(30.6, 35.6)	17.8	(-27.1, 81.1)	0.038	(0.000, 0.068)
Petersen & Wroblewski (1984)	0.076	(0.066, 0.085)	2.3	(0.9, 5.1)	32.8	(30.9, 35.9)	25.4	(-119.5, 179.3)	0.026	(-0.002, 0.050)
Chen & Watanabe (1989)	0.032	(0.020, 0.047)	1.0	(0.4, 2.3)	32.7	(30.5, 35.8)	-21.2	(-731.2, 762.0)	-0.001	(-0.032, 0.025)
Stochastic *M*	0.045	(0.029, 0.063)	1.2	(0.5, 2.9)	31.8	(30.1, 34.5)	32.0	(-549.8, 577.2)	0.007	(-0.023, 0.034)

Table xxi. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1995 cohort**, based on a reproductive periodicity of **2 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.045	(0.016, 0.103)	1.5	(0.5, 4.1)	31.3	(29.7, 33.6)	31.7	(-399.7, 472.7)	0.013	(-0.022, 0.044)
Hoenig (1983), i	0.010	(0.031, 0.077)	1.6	(0.6, 3.8)	31.5	(29.7, 34.0)	32.2	(-382.0, 364.5)	0.015	(-0.017, 0.042)
Hoenig (1983), ii	0.048	(0.030, 0.076)	1.6	(0.6, 3.8)	31.4	(29.7, 34.1)	33.4	(-421.6, 404.1)	0.015	(-0.015, 0.042)
Hoenig (1983), iii	0.046	(0.023, 0.062)	1.2	(0.4, 3.1)	31.2	(29.5, 33.8)	31.4	(-442.6, 544.8)	0.006	(-0.028, 0.035)
Jensen (1996), i	0.143	(0.140, 0.147)	5.5	(2.2, 10.4)	32.6	(30.7, 35.4)	13.0	(9.4, 27.9)	0.053	(0.025, 0.074)
Jensen (1996), ii	0.146	(0.073, 0.254)	5.5	(2.0, 11.9)	32.7	(30.8, 35.5)	13.0	(8.9, 31.7)	0.053	(0.021, 0.077)
Jensen (1996), iii	0.134	(0.066, 0.228)	5.1	(1.7, 11.7)	32.6	(30.6, 35.3)	13.5	(9.0, 39.9)	0.051	(0.017, 0.077)
Petersen & Wroblewski (1984)	0.092	(0.079, 0.102)	3.6	(1.5, 6.8)	32.8	(30.9, 35.9)	17.3	(11.4, 46.5)	0.040	(0.013, 0.060)
Chen & Watanabe (1989)	0.042	(0.026, 0.059)	1.6	(0.6, 3.2)	32.7	(30.6, 35.9)	38.8	(-270.7, 520.4)	0.014	(-0.015, 0.036)
Stochastic *M*	0.055	(0.034, 0.078)	1.9	(0.8, 4.0)	31.9	(30.1, 34.5)	31.1	(-206.9, 266.0)	0.020	(-0.008, 0.043)

Table xxii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1995 cohort**, based on a reproductive periodicity of **3 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.046	(0.017, 0.100)	1.0	(0.3, 2.8)	31.3	(29.7, 33.5)	15.4	(-563.4, 847.2)	0.000	(-0.040, 0.033)
Hoenig (1983), i	0.010	(0.031, 0.078)	1.1	(0.4, 2.6)	31.6	(29.6, 34.3)	33.1	(-654.3, 493.1)	0.004	(-0.028, 0.030)
Hoenig (1983), ii	0.048	(0.031, 0.074)	1.1	(0.4, 2.6)	31.5	(29.7, 34.1)	27.6	(-1,162.1, 676.3)	0.002	(-0.032, 0.029)
Hoenig (1983), iii	0.047	(0.021, 0.065)	0.8	(0.3, 1.9)	31.2	(29.5, 33.7)	-30.8	(-761.2, 679.2)	-0.006	(-0.039, 0.020)
Jensen (1996), i	0.143	(0.140, 0.147)	3.7	(1.6, 6.6)	32.6	(30.7, 35.4)	17.0	(11.4, 43.5)	0.041	(0.014, 0.060)
Jensen (1996), ii	0.148	(0.074, 0.244)	3.7	(1.3, 8.5)	32.7	(30.7, 35.7)	16.9	(10.2, 72.5)	0.040	(0.008, 0.066)
Jensen (1996), iii	0.131	(0.062, 0.228)	3.1	(1.2, 7.8)	32.6	(30.6, 35.3)	19.2	(10.2, 77.2)	0.036	(0.006, 0.064)
Petersen & Wroblewski (1984)	0.092	(0.079, 0.102)	2.4	(1.0, 4.4)	33.0	(30.9, 35.9)	24.7	(-42.4, 162.1)	0.027	(0.000, 0.046)
Chen & Watanabe (1989)	0.042	(0.026, 0.061)	1.0	(0.4, 2.3)	32.8	(30.6, 35.8)	31.1	(-759.1, 909.5)	0.001	(-0.027, 0.024)
Stochastic *M*	0.055	(0.034, 0.077)	1.3	(0.5, 2.7)	31.8	(30.1, 34.5)	42.1	(-618.9, 810.9)	0.008	(-0.021, 0.030)

Table xxiii. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1995 cohort**, based on a reproductive periodicity of **4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.045	(0.016, 0.103)	0.7	(0.3, 2.0)	31.4	(29.7, 33.5)	-31.4	(-592.8, 740.5)	-0.009	(-0.044, 0.022)
Hoenig (1983), i	0.010	(0.031, 0.077)	0.8	(0.3, 2.0)	31.4	(29.7, 34.3)	-32.8	(-637.5, 447.5)	-0.008	(-0.040, 0.022)
Hoenig (1983), ii	0.048	(0.032, 0.074)	0.8	(0.3, 2.0)	31.6	(29.7, 34.1)	-32.3	(-700.5, 589.1)	-0.007	(-0.037, 0.021)
Hoenig (1983), iii	0.048	(0.023, 0.063)	0.6	(0.2, 1.6)	31.2	(29.5, 33.7)	-31.5	(-446.0, 373.1)	-0.016	(-0.045, 0.014)
Jensen (1996), i	0.143	(0.140, 0.147)	2.8	(1.2, 5.2)	32.8	(30.8, 35.4)	21.7	(13.2, 88.5)	0.031	(0.007, 0.051)
Jensen (1996), ii	0.148	(0.076, 0.251)	2.8	(1.0, 6.6)	32.6	(30.7, 35.7)	21.1	(-24.4, 130.5)	0.032	(-0.001, 0.058)
Jensen (1996), iii	0.131	(0.062, 0.240)	2.4	(0.9, 5.8)	32.6	(30.6, 35.4)	24.6	(-97.4, 188.6)	0.027	(-0.004, 0.055)
Petersen & Wroblewski (1984)	0.092	(0.079, 0.102)	1.8	(0.7, 3.4)	32.8	(30.9, 35.7)	34.5	(-308.6, 321.1)	0.018	(-0.009, 0.038)
Chen & Watanabe (1989)	0.041	(0.026, 0.059)	0.8	(0.3, 1.7)	32.7	(30.7, 35.7)	-39.2	(-916.2, 755.3)	-0.007	(-0.036, 0.015)
Stochastic *M*	0.055	(0.036, 0.075)	1.0	(0.4, 1.9)	31.9	(30.1, 34.7)	-24.1	(-863.6, 956.6)	-0.001	(-0.030, 0.020)

Table xxiv. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the **1995 cohort**, based on a reproductive periodicity of **2-4 years**.

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.044	(0.016, 0.103)	1.0	(0.3, 3.2)	31.3	(29.6, 33.5)	-11.2	(-463.3, 542.9)	-0.001	(-0.042, 0.037)
Hoenig (1983), i	0.010	(0.028, 0.078)	1.1	(0.4, 3.2)	31.5	(29.6, 34.2)	21.9	(-595.2, 571.1)	0.003	(-0.031, 0.037)
Hoenig (1983), ii	0.048	(0.030, 0.076)	1.1	(0.4, 3.2)	31.6	(29.8, 34.1)	26.5	(-690.8, 663.5)	0.004	(-0.031, 0.037)
Hoenig (1983), iii	0.048	(0.023, 0.065)	0.9	(0.3, 2.7)	31.2	(29.4, 33.8)	-23.1	(-415.8, 471.8)	-0.005	(-0.043, 0.031)
Jensen (1996), i	0.143	(0.140, 0.147)	3.7	(1.4, 8.5)	32.7	(30.8, 35.5)	16.9	(10.0, 61.5)	0.041	(0.009, 0.068)
Jensen (1996), ii	0.147	(0.074, 0.254)	3.9	(1.2, 10.2)	32.7	(30.7, 35.5)	16.4	(9.2, 80.9)	0.042	(0.007, 0.073)
Jensen (1996), iii	0.128	(0.064, 0.232)	3.3	(1.1, 9.6)	32.6	(30.6, 35.3)	18.2	(8.8, 120.5)	0.037	(0.003, 0.071)
Petersen & Wroblewski (1984)	0.092	(0.079, 0.102)	2.5	(1.0, 5.8)	32.9	(30.9, 35.9)	23.9	(-50.4, 141.1)	0.028	(-0.001, 0.054)
Chen & Watanabe (1989)	0.041	(0.027, 0.059)	1.1	(0.4, 2.8)	32.7	(30.7, 35.8)	25.0	(-601.9, 655.6)	0.002	(-0.030, 0.032)
Stochastic *M*	0.054	(0.036, 0.077)	1.3	(0.4, 3.4)	31.9	(30.1, 34.7)	30.8	(-444.5, 599.5)	0.008	(-0.027, 0.038)

Table xxv. Results of demographic analysis of the Western Australian *Carcharhinus obscurus* population under the rates of age specific fishing mortality estimated in the current study for the 1995 cohort, based on a reproductive periodicity of **2-3 years.**

	PM		***R_0***		***G***		***t_{x2}***		***r***	
M	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pauly (1980)	0.047	(0.017, 0.104)	1.3	(0.4, 3.6)	31.4	(29.7, 33.7)	28.9	(-514.2, 652.0)	0.008	(-0.031, 0.040)
Hoenig (1983), i	0.010	(0.030, 0.077)	1.3	(0.5, 3.4)	31.4	(29.6, 33.9)	29.9	(-450.1, 481.8)	0.009	(-0.024, 0.039)
Hoenig (1983), ii	0.046	(0.032, 0.076)	1.3	(0.5, 3.3)	31.4	(29.7, 34.0)	34.6	(-829.6, 542.5)	0.009	(-0.023, 0.038)
Hoenig (1983), iii	0.047	(0.023, 0.065)	1.0	(0.3, 2.7)	31.3	(29.5, 33.8)	20.1	(-793.5, 1,010.8)	0.000	(-0.036, 0.031)
Jensen (1996), i	0.143	(0.140, 0.147)	4.5	(1.8, 9.4)	32.7	(30.7, 35.5)	14.6	(9.8, 36.4)	0.047	(0.018, 0.070)
Jensen (1996), ii	0.149	(0.075, 0.254)	4.5	(1.5, 12.3)	32.9	(30.7, 35.7)	14.7	(8.7, 48.6)	0.047	(0.014, 0.077)
Jensen (1996), iii	0.131	(0.062, 0.231)	3.9	(1.3, 10.1)	32.5	(30.5, 35.4)	16.0	(9.3, 55.9)	0.043	(0.007, 0.072)
Petersen & Wroblewski (1984)	0.092	(0.079, 0.102)	3.0	(1.2, 6.3)	32.9	(30.8, 36.0)	20.1	(11.6, 97.0)	0.034	(0.005, 0.057)
Chen & Watanabe (1989)	0.042	(0.026, 0.060)	1.3	(0.5, 3.0)	32.6	(30.5, 35.8)	36.4	(-519.7, 515.0)	0.008	(-0.024, 0.034)
Stochastic *M*	0.055	(0.035, 0.079)	1.5	(0.6, 3.6)	31.9	(30.1, 34.5)	35.2	(-570.7, 515.5)	0.013	(-0.018, 0.039)

APPENDIX IV

SUITABLE FOR PUBLIC RELEASE

SUMMARY OF NEW MANAGEMENT PACKAGE FOR THE NORTHERN SHARK FISHERIES

WA NORTH COAST SHARK FISHERY
AND
JOINT AUTHORITY NORTHERN SHARK FISHERY

June 2005

WA NORTH COAST SHARK FISHERY (WANCSF)

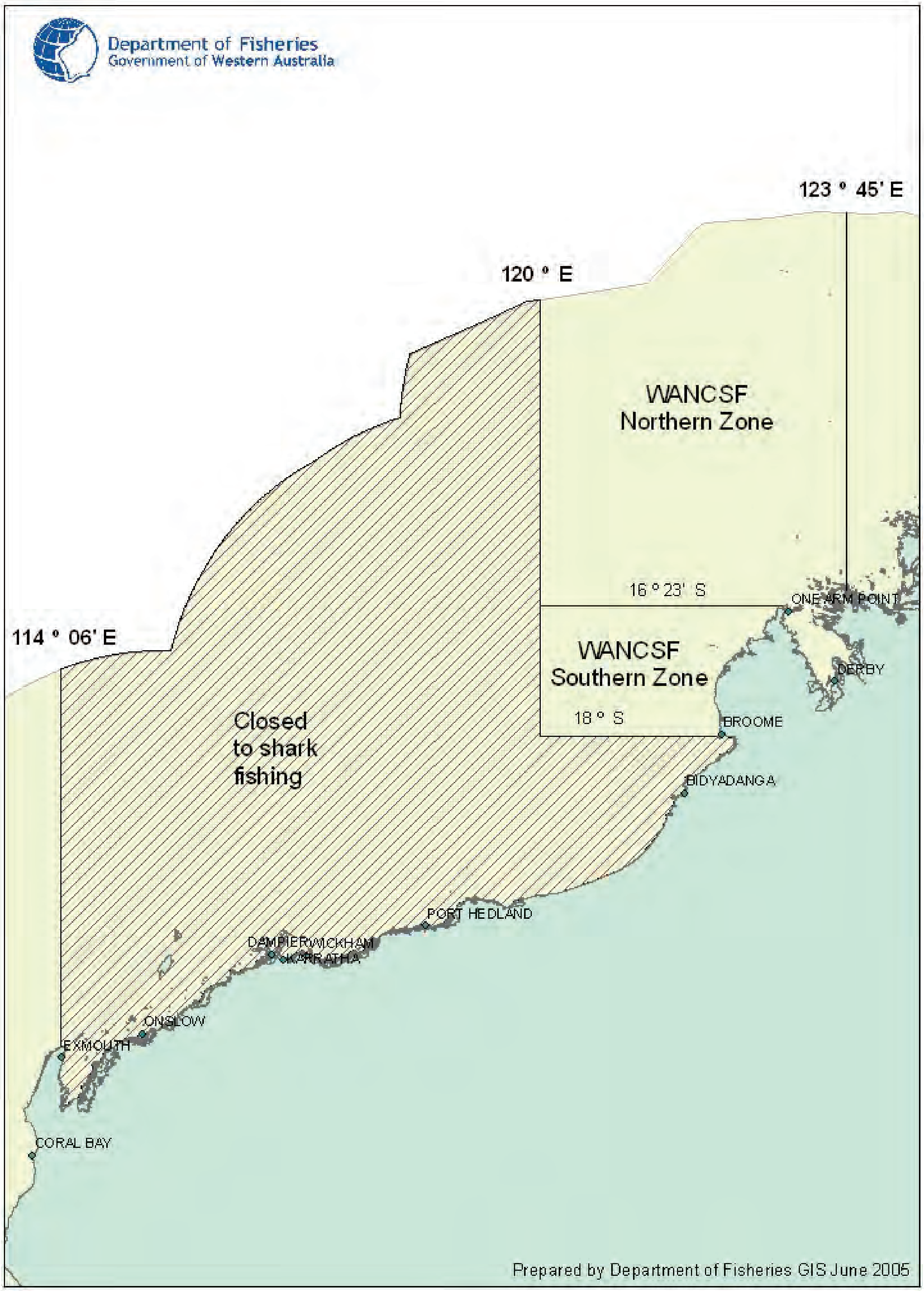
An indefinite (minimally 20-year) spatial closure to shark-fishing gear (shark longline and shark dropline) between North West Cape and Broome will come into effect on 1 July 2005. Industry has agreed to this timeframe and will cease fishing at this time in the closed area. The closure will be implemented by amending *North Coast Shark Fishing (Professional) Notice 1993* (Notice 602) by removing Schedule 1.

A Ministerial Exemption (i.e. subject to Ministerial approval) **will be drafted for the boats that will be fishing between Broome and Koolan Island, with conditions that implement the following management package (or similar) -**

- Area between Broome (not including Roebuck Bay) and Koolan Island to remain open. This area will be split into two zones (one southern and one northern zone) with the line (**latitudinal**) at Cape Leveque (16º 23’ S latitude).
- Open area will be set out as: from Broome, westerly along the latitude of 18º S to the intersection of 120º E longitude, then north to the intersection of the AFZ, then east to the intersection of 123º 45’ E longitude, then south to Koolan Island. See map.
- Fishing season to begin on 1 August 2005, all year round in the northern zone (Cape Leveque to Koolan Island) and between 1 October and 31 January in southern zone (Broome to Cape Leveque).
- Effort controls with maximum of 100 demersal longline days and 200 pelagic gillnet days between Broome and Koolan Island.
- Of the total 300 fishing days, a maximum of 100 fishing days with either gear type will only be permitted to be used in the southern zone (Broome and Cape Leveque) between 1 October and 31 January.
- Closure of King Sound to shark fishing using demersal longlines and pelagic gillnets.
- Implementation of VMS to monitor closed areas and fishing of effort days.
- Introduction of a fillet to fin ratio of 9.1kg of **shark** : 1 kg of fin and a trunk to fin ratio of 18.2kg of trunk : 1 kg of fin in the northern zone (Cape Leveque to Koolan Island).
- Maintain the existing finning and filleting prohibitions for sharks landed in the southern zone (Broome to Cape Leveque). Sharks will need to be landed in a whole, headed and/or gutted condition with the associated fins.

- Implementation of 10% at-sea observer coverage provided by Department Research staff. Initially, at sea observer focus will aim to verify shark catches (specifically sandbar sharks) in the southern zone (Broome to Cape Leveque) and will be complemented by 70% observer coverage of southern zone landings.
- A requirement for all catch within the southern zone (Broome to Cape Leveque) to be landed in Broome for observer purposes.
- Maximum length of pelagic gillnets of 2,000 metres with a mesh size of 6.3 – 7.3 inches (160 – 185 mm mesh) with a maximum drop of 100 meshes.
- Demersal longlines to have no more than 1,000 hooks attached. Use of wire traces will be permitted.
- Allow WANCSF operators to land mackerel with pelagic gillnets provided they hold mackerel quota in the Pilbara zone of the Mackerel Interim Managed Fishery. Need to distinguish grey and Spanish mackerel quota.
- Bycatch arrangements to be developed for those operators not holding mackerel quota.
- WANCSF operators fishing in the northern zone (north of Cape Leveque, 16° 23’ S latitude) may fish in the JANSF within the same trip, but may not fish in the NT fishery prior to unloading the JANSF/northern zone WANCSF trip catch.
- No hooks to be attached to gillnets or related fishing gear (i.e. hooks only be used on approved longline gear).
- No automated baiting devices to be used on demersal longlines.
- Pelagic gillnets not to be used within 3 nautical miles of the high water mark.
- Pelagic gillnets and demersal longlines cannot be carried on a fishing boat at the same time.

WANCSF SHARK GEAR SPATIAL CLOSURE 1 JULY 2005



JOINT AUTHORITY NORTHERN SHARK FISHERY (JANSF)

The package will be as follows-

- Effort controls with maximum of 200 demersal longline days and 400 pelagic gillnet days in the JANSF (i.e. east of Koolan Island).
- Implementation of VMS.
- Introduction of a fillet to fin ratio of 9.1kg flesh : 1 kg of fin and a trunk to fin ratio of 18.2kg of trunk : 1 kg of fin.
- Maximum length of pelagic gillnets of 2,000 metres with a mesh size of 6.3 to 7.3 inches (160mm-185mm) with a maximum drop of 100 meshes.
- Demersal longlines to have no more than 1000 hooks attached. Wire traces will be permitted.
- JANSF operators may fish in the northern zone of the WANCSF (north of Cape Leveque, 16° 23'S) within the same trip, but may not fish in the NT fishery prior to unloading the JANSF/northern zone WANCSF trip catch.
- Implementation of an observer program (but initially a lower priority than observer coverage in the southern zone (Broome to Cape Leveque) of the WANCSF.
- Allow JANSF operators to land mackerel with pelagic gillnets provided they hold mackerel quota in the Kimberley zone of the Mackerel Interim Managed Fishery. Need to distinguish grey and Spanish mackerel quota.
- Bycatch arrangements to be developed for those operators not holding mackerel quota.
- No hooks to be attached to gillnets or related fishing gear (i.e. hooks only be used on approved longline gear).
- No automated baiting devices to be used on demersal longlines.
- Pelagic gillnets not to be used within 3 nautical miles of the high water mark.
- Pelagic gillnets and demersal longlines cannot be carried on a fishing boat at the same time.

STATEWIDE SHARK MANAGEMENT ARRANGEMENTS WITH LEGISLATIVE IMPLICATIONS FOR COMMERCIAL SHARK FISHING IN NORTHERN WA

- The drafting of prohibition orders under section 43 of the *Fish Resources Management Act 1994* (FRMA) that would give effect to -

  (a) a prohibition on the use of wire traces in all WA commercial fisheries under State jurisdiction, with the exception of the Mackerel Interim Managed Fishery (and in the WANCSF and the JANSF under exemption);

  (b) a prohibition on the use of longlines in all commercial fisheries under State jurisdiction, excepting those fisheries where this is provided for by the management plan; and

  (c) a prohibition on the use of both hand hauled and power hauled pelagic or demersal gillnets, fishing net drums, Puretic power blocks and any similar device for hauling a fishing net in all commercial fisheries under State jurisdiction, excepting those fisheries where this is provided for by the management plan.

- sharks and rays becoming commercially protected fish, with the following exceptions-

  (i) sharks and rays (other than sawfish of the genus *Pristis* and dusky sharks with an interdorsal fin measurement of over 70 cm) taken under the authority of an authorisation that provides for the use of demersal gillnet, demersal longline or pelagic gillnet;

  (ii) sharks and rays (other than sawfish of the genus *Pristis* and dusky sharks) were taken under the authority of a managed fishery licence in the following managed fisheries-

    - the Marine Aquarium Fish Fishery (taken in accordance with the management plan);
    - the Kimberley Gillnet and Barramundi Managed Fishery; and
    - any other managed fishery where the take of sharks and rays is specifically provided for in the management plan (e.g. Northern Demersal Scalefish Managed Fishery); and

  (iii) Persons who possess sharks or rays taken in accordance with an authorisation as provided for under Commonwealth law;

- Shark fishers (only) permitted to possess dusky sharks with an interdorsal fin measurement of 70cm or less (1.5 metres fork length) and to be landed in a whole, headed and/or gutted condition with the dorsal fins intact.

- Both sharks and rays to be listed as Category 1 fish.

- Significantly increasing the penalties for illegal possession of sharks and rays, including increases to the prescribed value for sharks and rays as follows-

  (i) Fins-
  value per kg = $120
  value per fin = $24

  (ii) Whole shark or trunk (or part other than fins)-
  value per kg = $8
  value per fish = $120.

APPENDIX V

Genetic Population Structure of Western Australian sandbar shark (*Carcharhinus plumbeus*) based on nuclear DNA microsatellite loci.

Technical Report

To

WA Marine Research Laboratory
PO Box 20, North Beach
WA 6920
Australia

By
Edward J. Heist
Fisheries and Illinois Aquaculture Center
Southern Illinois University,
Carbondale, IL 62901-6511
USA

Sep 5, 2005

Introduction

Molecular markers including nuclear DNA microsatellite loci have been widely applied to study genetic stock structure of fishes, including sharks (Heist 2004). When a species is divided into multiple reproductively isolated demes, genetic drift within demes results in allele frequency differences among demes. Various estimators of Wright's (1969) F_{ST} can be used to quantify the variance in allele frequencies among populations and a wide variety of statistical tests can be employed to test the null hypothesis that $F_{ST} = 0$ (i.e. allele frequencies are identical across the sampled region). Fishes that exhibit allele frequency differences across their range are likely composed of distinct fishery stocks that may best be managed as multiple independent units provided the spatial (and perhaps temporal) boundaries of stocks can be identified. In coastal sharks that utilize inshore nursery areas, the best management may be the protection of nursery areas owing to the critical role these habitats play in recruitment (Hueter et al. 2004).

While freshwater fish populations tend to be highly structured because of barriers to movement, marine fishes exhibit far less genetic structure (Ward 2000) and may require large sample sizes and multiple marker types to adequately resolve stock structure. Several studies of shark population structure reveal little or no stocks structure across considerable geographic scales. Heist et al. (1995) found no significant differences in allozymes or mtDNA haplotype frequencies in sandbar sharks from the Gulf of Mexico and the Atlantic coast of the USA. Heist and Gold (1999) found no differences in microsatellite allele frequencies across in the same regions. Feldheim et al. (2001) found small but statistically significant FST values in lemon sharks (*Negaprion brevirostris*) from Florida, the Bahamas, and Brazil, but concluded that the magnitude of FST was so small that it was probably not "biologically significant". Keeney et al. (2005) found small but significant FST values for microsatellite loci between the US Atlantic, Gulf of Mexico, and Caribbean (Belize) and much larger F_{ST} values for mtDNA haplotypes across a similar range. Conversely, Gardner and Ward (1998) found significant heterogeneity in allele frequencies in gummy sharks (*Mustelus antarcticus*) from southern Australia.

The purpose of this study is to employ DNA microsatellite markers to determine whether sandbar sharks collected from three regions of western Australia possess different allele frequencies and hence comprise multiple fishery stocks. Microsatellite markers are highly polymorphic regions of nuclear DNA that are scored using the polymerase chain reaction (PCR) and polyacrylamide gel electrophoresis (O'Connell & Wright 1997). Microsatellites are comprised of very short repetitive elements that are non-coding and thus alleles, which differ by size due to variable numbers of copies of the repeat motif, are presumed to be selectively equivalent meaning that allele frequency differences reflect a lack of interbreeding among populations and not the effects of adaptation to local conditions. Sandbar sharks from the western North Atlantic exhibit low levels of allozyme and mtDNA variation (Heist et al. 1995) and thus microsatellites, which are typically very polymorphic, are likely to be efficient markers for investigating genetic stock structure of sandbar sharks in Australia.

MATERIALS AND METHODS

Fin clips of sandbar sharks stored in 95% ethanol were provided by Rory McCauley of the WA Marine Research Laboratory. Samples were collected from three regions: Cape Leeuwin ("Southwest", n=34), Abrolhos ("Midwest", n=32), and Port Hedlan ("North Coast", n=36). Genomic DNA was isolated from fin clips using the QIAGEN DNeasy tissue kit (Quiagen Inc.) and stored at –20°C. In each individual four microsatellite loci were amplified using primers described in Keeney and Heist (2003). PCR reactions contained approximately 1-10 ng genomic DNA, 0.1 units Taq DNA polymerase, 0.5 µM each primer, 200 µM each dNTP, 2 mM MgCl2, and 1X Taq buffer (50 mM KCl, 10 mM Tris, 0.1% Triton X-100, pH 9.0). One primer was radiolabeled with $\gamma^{32}P$ using T4 polynucleotide kinase prior to amplification. Amplification consisted of a two-minute denaturation step at 94°C, 35 cycles of 94°C for 30 s, 56-60°C for 30 s, and 72°C for 30 s, followed by a single five-minute extension step at 72°C. Alleles at individual loci were separated on denaturing polyacrylamide gels and visualized via autoradiography using a cloned *C. limbatus* allele of known length as a size standard.

Data were analyzed using the Genepop 3.3 software package (Raymond & Rousset 1995) and the Genetic Data Analysis (GDA) program of Lewis and Zaykin (2001). Each combination of locus and sample was tested for deviations from Hardy-Weinberg expectations using Genepop. This provides a useful check on the presence of artifacts (e.g. null alleles) that can lead to spurious conclusions. Samples were tested for significant genic (allelic) differentiation at each locus and across all loci using Genepop. Estimates of Weir and Cockerham's θ (1984), an unbiased estimator of Wright's (1969) FST were computed using Genepop. Summary statistics (numbers of alleles, expected and observed heterozygosity) were calculated using GDA

RESULTS AND DISCUSSION

All four microsatellite loci were highly polymorphic in western Australian sandbar shark producing between 9 and 17 alleles and observed heterozygosity ranging from 43 to 97% (Table 1). Two of twelve tests for deviations from Hardy Weinberg equilibrium, both involving locus Cli-106, were nominally significant for deviations from Hardy-Weinberg equilibrium but neither would be considered significant following Bonferroni correction for multiple testing (Rice 1989).

Estimates of F_{ST} across all loci were nonsignificant for comparisons between NC and MW and for comparisons between NC and SW (Table 2). Two of twelve single locus estimates of F_{ST} were nominally significant, one of which (locus Cli-12 between MW and SW) remained significant after correction for multiple testing (Table 2). The comparison between NC and SW across all loci was not significant (p = 0.054) but the comparison between MW and SW was significant (p = 0.018) largely due to the effects of locus Cli-12. Unbiased estimates of F_{ST} are small (and some even negative) for two loci (Cli-103 and Cli-106) while estimates for the other loci and for all loci combined tend to be positive (Table 3).

The results of this study indicate no evidence of stock structure in sandbar shark between NC and MW but perhaps the presence of stock structure between (NC + MW) and SW. While failure to reject the null hypothesis that allele frequencies are identical between NC and MW should not be taken as proof that no stock structure exists between these regions, the allele frequencies are so similar that much larger sample sizes and/or examination of mtDNA (see below) would be needed to detect genetic heterogeneity among these regions, if it exists.

It is difficult to ascertain whether the statistically significant results involving SW are valid given the relatively low sample sizes employed in the study and the fact that two of the four loci detected no significant results. Suggested improvements for future studies include increasing the sample sizes (both in terms of the numbers of individuals and the number of microsatellite loci), examination of mtDNA diversity, and nursery ground characterization and sampling. Larger numbers of individuals will permit more refined estimates of F_{ST} among regions and will allow smaller but statistically significant values of F_{ST} to be detected. Additional loci would refine the estimate of F_{ST} across loci and would allow for the detection of individual loci that gave outlying, and hence suspect, results. Recent studies (Pardini et al. 2001, Keeney et al. 2005) indicate that maternally-inherited mtDNA can indicate much higher levels of stock structure in sharks than nuclear markers such as microsatellites. The discrepancy is presumably due to a tendency for female sharks to be philopatric for parturition location, thus allowing mtDNA haplotype frequencies to drift among regions in the presence of higher levels of male-mediated gene flow in nuclear markers. Furthermore, sampling neonates in nursery areas may be useful to detect the presence of stocks that segregate for reproduction even when these stocks overlap at other time of the year (Keeney et al. 2005).

LITERATURE CITED

Feldheim, K.A., S.H. Gruber & M.V. Ashley. 2001. Population genetic structure of the lemon shark (*Negaprion brevirostris*) in the western Atlantic: DNA microsatellite variation. Molecular Ecology 10: 295-303.

Gardner, M.G. & R.D. Ward. 1998. Population structure of the Australian gummy shark (*Mustelus antarcticus* Gunther) inferred from allozymes, mitochondrial DNA and vertebrae counts. Marine and Freshwater Research 49: 733-745.

Heist, E.J. 2004. Genetics of Sharks, Skates, and Rays. *In:* J.C. Carrier, J.A. Musick & M.R. Heithaus (ed.) Biology of Sharks, Skates, and Rays, CRC Press, Boca Raton, FL. Heist, E.J. & J.R. Gold. 1999. Microsatellite DNA variation in sandbar sharks (*Carcharhinus plumbeus*) from the Gulf of Mexico and mid-Atlantic Bight. Copeia 5: 182-186.

Heist, E.J., J.E. Graves & J.A. Musick. 1995. Population genetics of the sandbar shark (*Carcharhinus plumbeus*) in the Gulf of Mexico and Mid-Atlantic Bight. Copeia 18: 555-562.

Hueter, R.E., M.R. Heupel, E.J. Heist & D.B. Keeney. 2004. The implications of philopatry in sharks for the management of shark fisheries. Journal of Northwest Atlantic Fishery Science in press.

Keeney, D.B. & E.J. Heist. 2003. Characterization of microsatellite loci isolated from the blacktip shark and their utility in requiem and hammerhead sharks. Molecular Ecology Notes 3: 501-504.

Keeney, D.B., M.R. Heupel, R.E. Hueter & E.J. Heist. 2005. The genetic structure of blacktip shark (*Carcharhinus limbatus*) nurseries in the western Atlantic, Gulf of Mexico, and Caribbean Sea inferred from control region sequences and microsatellites. Molecular Ecology 14: 1911-1923.

Lewis, P.O. & D. Zaykin. 2001. Genetic Data Analysis: Computer program for the analysis of allelic data. Version 1.0 (d16c). Free program distributed by the authors over the internet from http://lewis.eeb.uconn.edu/lewishome/software.html.

O'Connell, M. & J.M. Wright. 1997. Microsatellite DNA in fishes. Reviews in Fish Biology & Fisheries 7: 331-363.

Pardini, A.T., C.S. Jones, L.R. Noble, B. Kreiser, H. Malcolm, B.D. Bruce, J.D. Stevens, G. Cliff, M.C. Scholl, M. Francis, C.A.J. Duffy & A.P. Martin. 2001. Sex-biased dispersal of great white sharks - In some respects, these sharks behave more like whales and dolphins than other fish. Nature 412: 139-140.

Raymond, M. & F. Rousset. 1995. GENEPOP (version 1.2): population genetics software for exact tests and ecumenicism. Journal of Heredity 86: 248-249.

Rice, W.R. 1989. Analyzing tables of statistical tests. Evolution 43: 223-225.

Ward, R.D. 2000. Genetics in fisheries management. Hydrobiologia 420: 191-201.

Weir, B.S. & C.C. Cockerham. 1984. Estimating F-statistics for the analysis of population structure. Evolution 38: 1358-1370.

Wright, S. 1969. Evolution and the Genetics of Populations. Volume 2, The Theory of Gene Frequencies. University of Chicago Press, Chicago. 511 pp.

Table 1. Number of individuals surveyed (n), number of alleles (A), expected heterozygosity (He),observed heterozygosity (Ho), and p-values (p) for tests of deviations from Hardy-Weinberg equilibrium for four microsatellite loci in western Australia sandbar sharks. Deviations nominally significant at the p<0.05 level are in **bold**.

Locus	Population	n	A	He	Ho	p
Cli-12	NC	36	8	0.719092	0.694444	0.368
Cli-12	MW	32	9	0.512897	0.437500	0.528
Cli-12	SW	33	10	0.852214	0.878788	0.735
Cli-103	NC	33	16	0.917016	0.878788	0.259
Cli-103	MW	29	13	0.883243	0.965517	0.140
Cli-103	SW	28	15	0.892857	0.892857	0.149
Cli-106	NC	35	8	0.812836	0.742857	0.343
Cli-106	MW	32	8	0.815972	0.687500	**0.012**
Cli-106	SW	33	9	0.851748	0.727273	**0.012**
Cli-108	NC	35	10	0.536232	0.428571	0.155
Cli-108	MW	32	10	0.729663	0.687500	0.100
Cli-108	SW	32	10	0.758929	0.625000	0.071

Table 2. Significance values (and standard deviations) for tests of genic differentiation among sampled locations. Comparisons nominally significant at the p<0.05 level are in **bold.**

Locus	NC and MW	NC and SW	MW and SW
Cli-12	0.234 (0.008)	0.190 (0.007)	**0.001** (<0.001)
Cli-103	0.861 (0.006)	0.702 (0.010)	0.638 (0.009)
Cli-106	0.388 (0.008)	0.380 (0.010)	0.241 (0.007)
Cli-108	0.141 (0.008)	**0.009** (0.002)	0.739 (0.008)
Combined	0.341	0.054	**0.018**

Table 3. Weir and Cockerham's (1984) unbiased estimators of FST among sampled locations. Negative values are not significantly different fro zero. See Table 2 for tests of significance.

Locus	NC and MW	NC and SW	MW and SW
Cli-12	0.022	0.018	0.098
Cli-103	-0.005	-0.006	-0.006
Cli-106	-0.005	-0.001	0.004
Cli-108	0.021	0.035	-0.011
Combined	0.007	0.010	0.021

Appendix 1. Allele frequencies by locus and sample location.

Cli -12

Allele	NC	MW	SW
211	0.00	0.00	3.03
213	4.17	1.56	12.12
215	8.33	3.13	7.58
217	8.33	1.56	6.06
219	4.17	3.13	4.55
221	0.00	0.00	4.55
223	9.72	12.50	15.15
225	50.00	68.75	30.30
227	11.11	6.25	12.12
229	4.17	1.56	4.55
235	0.00	1.56	0.00

Cli-103	NC	MW	SW
108	0.00	0.00	1.79
112	3.03	1.72	1.79
116	9.09	8.62	7.14
118	12.12	10.34	14.29
120	6.06	10.34	3.57
122	3.03	0.00	3.57
124	7.58	3.45	1.79
126	18.18	25.86	21.43
128	13.64	12.07	16.07
130	4.55	5.17	1.79
132	4.55	12.07	12.50
134	3.03	0.00	5.36
136	6.06	3.45	0.00
138	3.03	1.72	1.79
140	1.52	3.45	1.79
142	3.03	1.72	5.36
144	1.52	0.00	0.00

Cli-106	NC	MW	SW
174	1.43	4.69	3.03
176	12.86	17.19	18.18
178	0.00	0.00	3.03
180	22.86	20.31	9.09
182	30.00	32.81	25[illegible]
184	7.14	4.69	9.09
186	17.14	6.25	18.18
188	7.14	7.81	9.09
190	1.43	6.25	4.55

Cli-108	NC	MW	SW
116	0.00	0.00	1.56
118	0.00	0.00	1.56
120	0.00	1.56	0.00
122	67.14	48.44	45.31
124	11.43	17.19	12.50
126	0.00	3.13	4.69
128	5.71	0.00	0.00
130	2.86	7.81	9.38
132	1.43	4.69	4.69
134	4.29	6.25	10.94
136	1.43	4.69	7.81
140	2.86	3.13	0.00
142	1.43	0.00	0.00
144	0.00	0.00	1.56
160	1.43	3.13	0.00

List of Fisheries Research Reports

Not all have been listed here, a complete list is available online at http://www.fish.wa.gov.au

83 The Western Rock Lobster fishery 1985/86. Brown, R.S. and Barker, E.H. (1990).

84 The Marine open shelf environment: review of human influences. Hancock, D.A. (1990).

85 A Description of the British United Trawlers / Southern Ocean Trawlers operation in the Great Australian Bight during the period 19.11.77 to 28.5.79. Walker, M.H., Blight, S.J. and Clarke, D.P. (1989).

86 The Demersal trawl resources of the Great Australian Bight as indicated by the fishing operations of the stern trawlers Othello, Orsino and Cassio in the period 19.11.77 to 28.5.79. Walker, M.H. and Clarke, D.P. (1990).

87 The recreational marron fishery in Western Australia summarised research statistics, 1971–1987. Morrissy, N.M. and Fellows, C.J. (1990).

88 A synopsis of the biology and the exploitation of the Australasian pilchard, *Sardinops neopilchardus* (Steindachner). Part 1: Biology. Fletcher, W.J. (1990).

89 Relationships among partial and whole lengths and weights for Western Australian pink snapper *Chrysophrys auratus* (Sparidae). Moran, M.J. and Burton, C. (1990).

90 Unpublished.

91 A synopsis of the biology and the exploitation of the Australasian pilchard, *Sardinops neopilchardus* (Steindachner) Part II : History of stock assessment and exploitation. Fletcher, W.J. (1991).

92 Spread of the introduced yabbie *Cherax albidus* Clark, 1936 in Western Australia. Morrissy, N.M. and Cassells, G. (1992).

93 Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munro) (Teleostei: Sparidae). Norriss, J.V., Tregonning, J.E., Lenanton, R.C.J. and Sarre, G.A. (2002).

94 to 98 No reports were published under these numbers.

99 An Investigation of weight loss of marron *(Cherax tenuimanus)* during live transport to market. Morrissy, N.; Walker, P.; Fellows, C.; Moore, W. (1993).

100 The Impact of trawling for saucer scallops and western king prawns on the benthic communities in coastal waters off south-western Australia. (FRDC final report 90/019) Laurenson, L.B.J., Unsworth, P., Penn, J.W. and Lenanton, R.C.J. (1993).

101 The Big Bank region of the limited entry fishery for the western rock lobster *Panulirus cygnus*. Chubb, C.F., Barker, E.H. and Dibden, C.J. (1994).

102 A Review of international aquaculture development and selected species in environments relevant to Western Australia. Lawrence, C.S. (1995).

103 Identifying the developmental stages for eggs of the Australian pilchard, *Sardinops sagax*. White, K.V. and Fletcher, W.J. (Warrick Jeffrey) (1998).

104 Assessment of the effects of a trial period of unattended recreational netting in selected estuaries of temperate Western Australia. Lenanton, R.C., Allison, R. and Ayvazian, S.G. (1996).

105 The western rock lobster fishery 1986/7 to 1990/91. Chubb, C.F., Barker, E.H.and Brown, R.S. (1996).

106 Environmental and biological aspects of the mass mortality of pilchards (Autumn 1995) in Western Australia. Fletcher, W.J., Jones, B., Pearce, A.F. and Hosja, W. (1997).

107 Chemical composition of yabbies, *Cherax albidus* Clark 1936 from Western Australian farm dams. Francesconi, K.A. and Morrissy, N.M. (1996).

108 Aspects of the biology and stock assessment of the whitebait, *Hyperlophus vittatus*, in south western Australia. Gaughan, D.J., Fletcher, W.J., Tregonning, R.J. and Goh, J. (1996).

109 The western rock lobster fishery 1991/92 to 1992/93. Chubb, C.F. and Barker, E.H. (1998).

110 A Research vessel survey of bottom types in the area of the Abrolhos Islands and mid-west trawl fishery. Dibden, C.J. and Joll, L.M. (1998).

111 Sea temperature variability off Western Australia 1990 to 1994. Pearce, A., Rossbach, M., Tait, M. and Brown, R. (1999).

112 Final report, FRDC project 94/075: enhancement of yabbie production from Western Australian farm dams. Lawrence, C., Morrissy, N., Bellanger, J. and Cheng, Y. W. (1998).

113 Catch, effort and the conversion from gill nets to traps in the Peel-Harvey and Cockburn Sound blue swimmer crab *(Portunus pelagicus)* fisheries. Melville-Smith, R., Cliff, M. and Anderton, S.M. (1999).

114 The Western Australian scallop industry. Harris, D.C., Joll, L.M. and Watson, R.A. (1999).

115 Statistical analysis of Gascoyne region recreational fishing study July 1996. Sumner, N.R. and Steckis, R.A. (1999).

116 The western rock lobster fishery 1993/94 to 1994/95 Chubb, C.F. and Barker, E.H. (2000).

117 A 12-month survey of coastal recreational boat fishing between Augusta and Kalbarri on the west coast of Western Australia during 1996-97. Sumner, N.R. and Williamson, P.C. (1999).

118 A study into Western Australia's open access and wetline fisheries. Crowe, F., Lehre, W. and Lenanton, R.J.C. (1999).

119 Final report : FRDC project 95/037 : The biology and stock assessment of the tropical sardine, *Sardinella lemuru*, off the mid-west coast of Western Australia. Gaughan, D.J. and Mitchell, R.W.D. (2000).

120 A 12 month survey of recreational fishing in the Leschenault Estuary of Western Australia during 1998. Malseed, B. E., Sumner, N.R. and Williamson, P.C. (2000).

121 Synopsis of the biology and exploitation of the blue swimmer crab, *Portunus pelagicus* Linnaeus, in Western Australia. Kangas, M.I. (2000).

122 Western rock lobster mail surveys of licensed recreational fishers 1986/87 to 1998/99. Melville-Smith, R. and Anderton, S.M. (2000).

123 Review of productivity levels of Western Australian coastal and estuarine waters for mariculture planning purposes. CDRom in back pocket has title "Chlorophyll-a concentration in Western Australian coastal waters - a source document. by S. Helleren and A. Pearce" (document in PDF format) Pearce, A., Helleren, S. and Marinelli, M. (2000).

124 The Evaluation of a recreational fishing stock enhancement trial of black bream *(Acanthopagrus butcheri)* in the Swan River, Western Australia. Dibden, C.J., Jenkins, G., Sarre, G.A., Lenanton, R.C.J. and Ayvazian, S.G. (2000).

125 A history of foreign fishing activities and fishery-independent surveys of the demersal finfish resources in the Kimberley region of Western Australia. [Part funded by Fisheries Research and Development Corporation Project 94/026] Nowara, G.B. and Newman, S.J. (2001).

126 A 12 month survey of recreational fishing in the Swan-Canning Estuary Basin of Western Australia during 1998-99. Malseed, B.E. and Sumner, N.R. (2001).

127 A 12 month survey of recreational fishing in the Peel-Harvey Estuary of Western Australia during 1998-99. Malseed, B.E. and Sumner, N.R. (2001).

128 Aquaculture and related biological attributes of abalone species in Australia - a review. Freeman, K.A. (2001).

129 Morpholgy and incidence of yabby *(Cherax albidus)* burrows in Western Australia. Lawrence, C.S., Brown, J.I. and Bellanger, J.E. (2001).

130 Environmental requirements and tolerences of rainbow trout *(Oncorhynchus mykiss)* and brown trout *(Salmo trutta)* with special reference to Western Australia : a review. Molony, B. (2001).

131 Pilchard *(Sardinops sagax)* nursery areas and recruitment process assessment between different regions in southern Western Australia. Gaughan, D.J., Baudains, G.A., Mitchell, R.W.D. and Leary, T.I. (2002).

132 A review of food availability, sea water characteristics and bivalve growth performance occuring at coastal culture sites in temperate and warm temperate regions of the world. Saxby, S.A. (2002).

133 Preliminary assessment and seasonal fluctuations in the fish biota inhabiting the concentrator ponds of Dampier Salt, Port Hedland, with options for the potential application of results. Molony, B. and Parry, G. (2002).

134 Towards an assessment of the natural and human use impacts on the marine environment of the Abrolhos Islands. Volume 1, Summary of existing information and current levels of human use. CDRom in back pocket has the title "Abrolhos Habitat Survey". Webster, F.J., Dibden, C.J., Weir, K.E. and Chubb, C.F. (2002). Volume 2, Strategic research and develoment plan. Chubb, C.F., Webster, F.J., Dibden, C.J. and Weir, K.E. (2002).

135 The western rock lobster fishery 1995/96 to 1996/97. Chubb, C.F. and Barker, E.H. (2002).

136 Assessment of gonad staging systems and other methods used in the study of the reproductive biology of narrow-barred Spanish mackerel , *Scomberomorus commerson*, in Western Australia. Mackie, M. and Lewis, P. (2001).

137 Annual report on the monitoring of the recreational marron fishery in 2000, with an analysis of long-term data and changes within this fishery. Molony, B. and Bird, C. (2002).

138 Historical diving profiles for pearl oyster divers in Western Australia. Lulofs, H.M.A. and Sumner, N.R. (2002).

139 A 12-month survey of recreational fishing in the Gascoyne bioregion of Western Australia during 1998-99. Sumner, N.R., Willimson, P.C. and Malseed, B.E. (2002).

140 The western rock lobster fishery 1997/98 to 1998/99. Chubb, C.F. and Barker, E.H. (2003).

141 A guide to good otolith cutting. Jenke, J. (2002).

142 Identifying the developmental stages of preserved eggs of snapper, Pagrus auratus, from Shark Bay, Western Australia. Norriss, J. V. and Jackson G. (2002).

143 Methods used in the collection, preparation and interpretation of narrow-barred Spanish mackerel (Scomberomorus commerson) otoliths for a study of age and growth in Western Australia. Lewis P. D. and Mackie, M. (2003).

144 FRDC Project 1998/302 – Rock Lobster Enhancement and Aquaculture Subprogram: Towards establishing techniques for large scale harvesting of pueruli and obtaining a better understanding of mortality rates. Phillips B. F. (2003).

145 The western rock lobster fishery 1999/2000 to 2000/01. Chubb, C.F. and Barker, E.H. (2004).

146 Catch composition of the Western Australian temperate demersal gillnet and demersal longline fisheries, 1994 to 1999. McAuley, R. and Simpfendorfer, C. (2003).

147 Quantification of changes in recreational catch and effort on blue swimmer crabs in Cockburn Sound and Geographe Bay, FRDC Project No 2001/067. Sumner, N.R. and Malseed, B.E. (2004).

148 Historical distribution and abundance of the Australian sea lion (Neophoca cinerea) on the west coast of Western Australia. Campbell, R. (2004).

149 The western rock lobster fishery 2001/02 to 2002/03. Chubb, C. F. and Barker, E. H. (2004).

150 Unpublished.

151 Biology and stock assessment of the thickskin (sandbar) shark, *Carcharhinus plumbeus*, in Western Australia and further refinement of the dusky shark, *Carcharhinus obscurus*, stock assessment, Final FRDC Report – Project 2000/134. McAuley, R., Lenanton, R. Chidlow, J., Allison, R. and Heist, E. (2005).

152 Development of a DNA Database for Compliance and Management of Western Australian Sharks, Final FRDC Report – Project 2003/067. McAuley, R., Ho, K. and Thomas, R. (2005).

The Western Australian Fisheries and Marine Research Laboratories
at Hillarys Boat Harbour, Perth, are the
centre for fisheries research in Western Australia