A Review of the Biology and Status of White Sharks in Australian Waters



H. Malcolm, B. D. Bruce and J. D. Stevens – September 2001

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Environment Australia
Department of the Environment

Natural Heritage Trust
Helping Communities Helping Australia

CONTENTS

Acronyms used in this report

AFMA	Australian Fisheries Management Authority
ASAF	Australian Shark Attack File
ASFB	Australian Society for Fish Biology
BRS	Bureau of Resource Sciences
CALM	Conservation and Land Management (Western Australia)
CITES	Convention on International Trade in Endangered Species
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CMR	CSIRO Marine Research
DEH	Department of Environment and Heritage (South Australia)
DNRE	Department of Natural Resources and Environment (Victoria)
DPIWE	Department of Primary Industries, Water & Environment (Tasmania)
EA	Environment Australia
EPBC Act	Environmental Protection and Biodiversity Conservation Act
GAB	Great Australian Bight
GFCSA	Game Fishing Club of South Australia
FWA	Fisheries Western Australia
IUCN	International Union for the Conservation of Nature
ITQ	Individual Transferable Quota
MAFRI	Marine and Freshwater Resources Institute (Victoria)
MSPP	Marine Species Protection Program (Environment Australia)
MSF	(South Australian) Marine Scale-fish Fishery
NHT	Natural Heritage Trust
NSW	New South Wales
NWSRWG	National White Shark Research Working Group
PIRSA	Primary Industries and Resources South Australia
Qld	Queensland
QDPI	Queensland Department of Primary Industries
SA	South Australia
SARDI	South Australian Research and Development Institute
SAMSFMC	South Australian Marine Scalefish Fishery Management Committee
SENT	South East Non-Trawl
SSF	Southern Shark Fishery
Tas	Tasmania
Vic	Victoria
WA	Western Australia
WAMRL	Western Australian Marine Research Laboratory
WSCDOA	White Shark Cage Dive Operators Association
WSF	Western Australian Shark Fishery

Executive Summary

The white shark (*Carcharodon carcharias*) is a wide-ranging species that occurs primarily in coastal, temperate waters. In Australia, it has been recorded from central Queensland, around the south coast, to North West Cape, Western Australia, but it is more common in the south. Sharks, in general, are known to be particularly susceptible to fishing pressure because of their specialised life history strategies with generally slow growth, late attainment of sexual maturity, low fecundity and close stock-recruitment relationship. White sharks are naturally low in abundance and are one of the less productive species of sharks, producing relatively few young during their life spans. This makes their populations particularly susceptible to over-fishing. Considerable recent debate has focused on possible regional and worldwide declines in white shark abundance and this has led to the species protection in South Africa, California, Florida, Namibia, Malta, and the Maldives. In Australia, white sharks are fully protected under State and Commonwealth legislation. They are listed as '*Vulnerable*' under the Commonwealth Environment Protection and Biodiversity Conservation Act (1999). However, despite these moves to conserve white sharks, threats to the species were (previously) poorly documented, commonly used indices of abundance were ambiguous, and basic biological details (in particular, patterns of movement) were poorly known.

In April 1999, CSIRO Marine Research began a project on white sharks in Australian waters. This project, funded under the Commonwealth Government's Natural Heritage Trust, was collaborative with a wide variety of Commonwealth, State, and non-government groups and agencies. The objectives of the project were to:

- Help clarify the current population status of white sharks in Australian waters
- Assess impacts on the species
- Create a regional network of observers to log sightings and collect vital biological data
- Monitor movement patterns using a variety of conventional tagging as well as sophisticated acoustic and satellite tracking systems, and
- Provide guidelines for the conservation and management of the species.

The project ran concurrently with the development of a National Recovery Plan for white sharks, by Environment Australia, and was structured to establish various reporting and base protocols to enable the effective implementation of the Recovery Plan. This report details the findings of this project.

Data on white shark captures and interactions were sourced from commercial and recreational fishers via telephone interviews, questionnaire, articles in magazines and via a regional network of over 40 researchers, fisheries compliance officers, National Parks and Wildlife officers and members of the general public throughout Australia. Biological details were summarised from existing published and unpublished data, archived samples as well as samples and data collected during the course of the study. A variety of reporting protocols were established with State agencies, tourism operators and in commercial fishery logbooks.

White sharks are caught as bycatch in a number of Australian fisheries including: the Southern Shark Fishery, Western Australian Shark Fishery, various demersal long-line and set or drum-line fisheries, tuna farm industry (SA) and the recreational gill-net fishery (Tas). They are also occasionally caught by recreational line fishers (all States), in crab trap and rock lobster pot ropes, in demersal trawls and by the ocean haul fishery (NSW). White sharks are also targeted (under permit) by shark control programs in NSW and Qld. Catch rate estimates are limited by a lack of standardised reporting or unrealistic reporting requirements, changes in effort and fisher behaviour and in some cases miss-identification. Estimates for some fisheries (e.g. the tuna farm industry in SA, the inshore scalefish fishery in Tas and the commercial line fishery in NSW) require further evaluation. On average, it is estimated that approximately 200 white sharks are caught in Australian waters each year. However, catch rates and interactions are highly variable between fishers, regions and years. Catches may exceed 360 in some years. About 40% of captured white sharks are released alive, although post-release survival rates are unknown. There is evidence that illegal targeting still occurs in Australian waters but its magnitude is unknown.

Most white sharks captured in fishing operations are either juveniles or sub-adults. Catches of white sharks are not evenly distributed across southern Australia and are not well correlated with effort. Fishing activities in the west coast zone of WA (Shark Bay to Bunbury) and Great Australian Bight appear to have significantly higher interactions with white sharks than other areas suggesting that they are more common in those areas.

Anecdotal reports suggest a long-term decline in white shark interactions and catches in Australian waters, although catch rates appear to have been relatively stable over the last decade. The extent of this decline is difficult to quantify due to poor records and marked inter-annual variability. Long-term data are available for shark control programs and game-fishing records. In all cases, significant declines in catches have been recorded. Catch rates declined by approximately 75% since the 1960s and by 50% since the 1950s in the Qld and the NSW shark control programs respectively. Mean size at capture has also declined in the NSW program, although this is not evident in the Qld data. Shark control programs take primarily juvenile white sharks. Game-fish captures of white sharks (prior to protection) declined by 86% in SA between the 1950s and the 1980s and by 97% in NSW. However, a substantial proportion of the decline in captures was most likely a result of changes in the areas fished and moves to tag-release in later years. Catch rates appear to have been reasonably stable over the last decade. Standardised reporting of white shark sightings at the Neptune Is. (SA), formalising reporting mechanisms in commercial logbooks and continued monitoring of white shark captures by shark control programs along the eastern seaboard offer some promise for monitoring white shark activity in Australian waters. However, newly established indices will require long-term datasets before they can be used to assess population trends. Untapped opportunities exist for establishing additional reporting of white shark sightings in several areas (e.g. sightings by the tuna industry in SA, abalone divers and by game-fishers throughout southern Australia).

White sharks of all sizes occur throughout their Australian range. However, there is a tendency for juveniles to occur in different areas to sub-adults and adults. Juveniles are most commonly encountered in inshore areas, often in the vicinity of open coast beaches. The GAB, Victor Harbour–Coorong region (SA), areas off Portland and Ninety Mile Beach (Vic), Garie Beach–Wattamolla and Port Stephens–Newcastle (NSW) and some areas of southern Queensland appear to be seasonally important for juvenile white sharks. White sharks also appear to segregate by sex.

Male and female white sharks reach sexual maturity at similar sizes in Australian waters to that reported elsewhere (3.6–3.8 m and approximately 5.0 m respectively). Age at maturity is estimated to be 10–13 years in males and 18–23 years in females. They are oophagous, the embryos being nourished by a supply of unfertilised eggs, which the female continues to ovulate during pregnancy. The gestation period is estimated to exceed 12 months (probably 18 mo) with females breeding only every 2–3 years. Litter sizes range from 2-10. Size at birth is 1.2–1.4 m and birth weight is up to 32 kg. Juveniles (estimated to be less than 1.5 m in length) are most commonly captured between December and June suggesting a summer–autumn pupping period.

White sharks eat a variety of prey including finfish, other sharks and rays, marine mammals (seal, sea lions, dolphins and whales), squid, crustaceans and sea birds. Diet changes with size. Juveniles less that 2.7 m feed primarily on fish and other sharks and rays. Marine mammals become important in the diet of sharks larger than 2.7 m.

Over 200 white sharks have been tagged in Australian waters. Most have been tagged free–swimming by researchers and cage-dive operators at North Neptune Is., South Australia. Tags include standard game–fish tags, visual identification tags and electronic tags (acoustic, archival and satellite). The overall recapture rate is comparable to some other tagged sharks (4.1%), however the low number tagged limits the benefit of using conventional tagging to examine–broad scale movement patterns. The resighting rate of tagged sharks at North Neptune Is. was high, averaging 59% for the period August 1999 to April 2001. Sharks tagged with archival and satellite tags were highly mobile, travelling distances up to 3000 km at speeds of 2.5–3.3 km per hour. Movements were restricted to shelf and coastal waters and sharks were recorded swimming to depths of up to 94 m.

Genetic data suggest that white sharks comprise a single population in Australian and New Zealand waters that is distinct from the South African population. Efforts to conserve white sharks in Australian waters would thus benefit by the introduction of similar protective legislation in New Zealand.

Neither a stock assessment nor an estimate of population size is yet possible for Australian waters. Future stock assessment work will require a longer time series of catches together with either a trend in relative abundance or at least one estimate of absolute abundance. Standardised reporting protocols established during this project will help assess status over time but considerably more data are required. However, a deterministic model, combining available data and current catch estimates, was used to estimate the *minimum* population size of female white sharks (age 1 and above) in Australian waters which could support current catches (assuming that these are sustainable). The minimum population size of females, given these parameters was estimated be within the range of 2,728–13,746.

The incidental capture of white sharks in Australian fisheries is likely to continue in the foreseeable future. However, widespread discussion about their vulnerable status and protection in Australian waters has had a tangible and positive benefit for the species in recent times. There is no evidence to suggest that white sharks should be upgraded from vulnerable to endangered under protective legislation. There are strong indications that the current protection is of benefit and should be maintained.

1. INTRODUCTION

1.1 Background

The white shark (*Carcharodon carcharias*) is a wide-ranging species that occurs in both the northern and southern hemispheres. It is most common in temperate waters but it is occasionally recorded from the tropics. In Australia, it has been recorded from central Queensland around the south coast to North West Cape, Western Australia, but is more common in the south (Last and Stevens 1994). It is usually found over the continental shelf, often close inshore, and has been recorded from the surface down to 1280 m. Its occasional presence at oceanic islands far from land suggests that, at times, it makes trans-oceanic movements (Compagno 1984). White sharks have a high profile and public attitudes to them have undergone a major change in the last 10 years from the irrational fear inspired by post 'JAWS' paranoia to an informed concern over their population status. Sharks generally are known to be particularly susceptible to fishing pressure because of their specialised life history strategies with generally slow growth, late attainment of sexual maturity, low fecundity and close stock-recruitment relationship. White sharks are one of the less productive species of sharks and produce relatively few young during their life spans. Considerable recent debate has focused on possible regional and worldwide declines in their abundance and this has led to the species protection in South Africa, California, Florida, Namibia, Malta, the Maldives and in Australia.

Several white shark expeditions by the Cousteau Society, other documentary makers and by cage dive operators in South Australia during the late 1980s experienced increasing difficulties in attracting white sharks. As a result, concerns were expressed that numbers of white sharks were declining in the area. In Australia, white sharks are taken as by-catch in various commercial fisheries as well as being captured in shark control programs and by recreational fishers. The IUCN Shark Specialist Group in its draft global action plan for sharks has 'Red Listed' white sharks in the *Vulnerable* category. In the light of this information, there was considerable pressure exerted by conservation groups and sectors of the general community to follow the lead of other countries in conferring national protection on white sharks in Australia.

In September 1996, a workshop was held in Sydney to discuss national protection for the species. While no consensus was reached at the meeting, white sharks have subsequently been protected in all Australian waters. A recommendation from the meeting, which was subsequently implemented, was the formation of a National White Shark Research Working Group (NWSRWG). A strategic research plan was drafted at the inaugural meeting of the NWSRWG in Adelaide in December 1996 and components from this plan are included in this project. However, despite these moves to conserve white sharks, threats to the species were poorly documented, commonly used indices of abundance were ambiguous, and basic biological details (in particular, patterns of movement) were poorly known. Although protected by legislation there were no guidelines to enable an assessment of either the appropriateness or the effectiveness of such conservation measures. Considerable, but uncollated, historical information sets existed regarding sightings, captures and distribution. Platforms of opportunity (e.g. cage-dive operations) existed that could facilitate the collection of vital biological data and which could be used to develop useful indices of abundance.

There was also the potential to identify sources and to quantify levels of threat through appropriate public and fishing industry liaison.

1.2 Need

White sharks are currently protected in all Australian State and Commonwealth waters. The biological argument for protection is primarily based on the characteristics of white sharks that suggest they are vulnerable to exploitation due to their 'K' selected life history strategy, and their position as an apex predator. White sharks are naturally relatively low in abundance, are long-lived and have relatively low natural mortality. Females do not reproduce until in excess of 4.5 – 5.0 m, produce few pups (7-11) and individuals may not reproduce every year (see various reviews in Klimley and Ainley 1996 for full biological details). These characteristics imply that white shark populations are poorly adapted to withstand increases in mortality from non-natural sources and, due to their low reproductive potential, would recover very slowly if reduced in abundance.

It is reasonable to assume that populations have undergone a decline over the last 50 years. However, there are currently few data on the size of white shark populations in either Australia or world-wide and available abundance indices, which have shown apparent declines, are open to interpretation. Long-term movement patterns and the linkages between Australian white shark populations are still poorly understood and it is not yet possible to assess the implication of any observed regional declines in abundance. This has led to protection based on the precautionary principle in several areas.

There is a clear need for better information on the level of threats to white sharks, and improved understanding of their biology and ecology, in order to assess and interpret the impact of these threats.

1.3 Objectives

In April 1999, CSIRO Marine Research began a project on white sharks in Australian waters. This project, funded under the Commonwealth Government's Natural Heritage Trust, was collaborative with a wide variety of Commonwealth, State, and non-government groups and agencies. The objectives of the project were to:

- Help clarify the current population status of white sharks in Australian waters.
- Assess impacts on the species.
- Create a regional network of observers to log sightings and collect vital biological data.
- Monitor movement patterns using a variety of conventional tagging as well as sophisticated acoustic and satellite tracking systems.
- Provide guidelines for the conservation and management of the species.

The project ran concurrently with the development of a National Recovery Plan for white sharks by Environment Australia (EA) and was structured to establish various reporting and base protocols to enable the effective implementation of the Recovery Plan.

This report provides a review of the biology and status of white sharks in Australia, based on historical data and the findings of this project.

1.4 Summary of current protective legislation

1.4.1 Australia

White sharks are currently protected in all State waters and Commonwealth waters under a variety of different Acts (Table 1). Protection of white sharks in Australia is complex due to differences between these various State and Commonwealth Acts. In NSW and Queensland, there are exemptions in place that enable white sharks to be caught and killed in shark control programs.

Table 1. Summary of protective legislation for white sharks in Australia

Primary Act	Jurisdiction	Summary of relevant section	Date regulation/declaration in force for white shark
Environmental Protection and Biodiversity Conservation Act 1999	Commonwealth.	Part 13, S 178 (1e) Listed as vulnerable	Initially declared on 17 December 1997 (ESP Act)
Fisheries Act 1982	SA	S.42 A person must not take a fish declared by regulation to be protected	January 1998
Fisheries Act 1995	Vic	S.69 Aquatic biota can be declared protected by the Governor in Council S.7. A person must not take, injure, damage, destroy, possess, keep, display for reward, release or sell any protected biota	Declared by the Governor in Council under Section 69(1) of the Fisheries Act (1995), August 1998
Living Marine Resources Management Act 1995	Tas	S.135 (1) The minister can declare any species of fish to be protected (2) A person must not take any protected fish	Initially declared under previous Act in 1995. Continued 1996 to new Act under Regulation 18(3) Fisheries General Fees and Regulations
Threatened Species Protection Act 1995	Tas	Vulnerable	
Fisheries Management Act 1994	NSW	S.8 Fisheries Closure Notification- taking of white sharks prohibited by all methods in all waters except approved shark meshing contractors for scientific purposes Part 7a Protected Species under Schedule 5 (Species vulnerable to extinction)	Gazetted January 1997 Section 8 Protected under Section 7a on 14 May 1999
Fisheries Resources Management Act 1994	WA	S.45 A class of fish may be prescribed to be totally protected fish S.46 A person must not take, possess, sell or purchase, consign, bring in to the State: any totally protected fish	November 1997
Fisheries Act 1994	Qld	S.78 (1) A person must not unlawfully take, possess or sell a regulated fish. Fisheries Amendment Regulation (No 6) 1997: Schedule 4, Pt 3 Div 5: white sharks regulated. S65: does not apply to shark control contractors.	July 1997

1.4.2 International Protection
White sharks are fully protected in South Africa, Namibia, California, Florida, Maldives, and Malta. Malta listed the white shark as protected under their Environment Protection Act in 1999. The IUCN lists white sharks as *Vulnerable*.

2. METHODS

Data collected during the course of this project are stored in a purpose designed Microsoft ACCESS database (subsequently referred to as the white shark database).

Place names referred to in the text are shown in Figure 1.

2.1 Catch estimates and threat assessment

An integral part of identifying threats to white sharks is estimating how many are caught within different sectors/fisheries by area and method. The impacts of different sectors can then be compared, and an overall assessment made. Catch and effort can be compared to determine if the two are linked within each sector (i.e. more effort, greater catch) or identify locations where sharks are more prevalent or more vulnerable to capture.

Catch information was primarily sought from three fisheries (Southern Shark Fishery, Western Australian Shark Fishery, and the SA Marine Scale-fish Fishery). Gill-net and long-line effort data (standardised as km-lifts) from the Southern Shark Fishery (SSF) were obtained by one degree block for the periods 1973-79, 1980-89 and 1990-99. Similar effort data (km net hours) for the Western Australian Shark Fishery (WSF) were obtained for the periods 1980-89 and 1990-99.

Catch information was also sought from a number of other fisheries on an ad-hoc basis. In some cases, detailed catch records were obtained and capture positions could be mapped, although generally catch information was anecdotal.

2.1.1 Formal reporting mechanisms and requirements
Information on white shark captures were obtained from sources where the reporting of these captures is required. However, there are few formal reporting arrangements in Australia.

GNO1 Logbook – SE Non-Trawl
The GNO1 is a compulsory logbook filled out by fishers operating in Commonwealth South East Non-Trawl (SENT) fisheries that are under the management of Australian Fisheries Management Authority (AFMA) and joint State jurisdiction. This includes the SSF. This logbook has been in operation since 1997. Some fishers previously recorded interactions with white sharks in either general comments or under the wildlife interaction section. The logbook was modified in July 1999 (GN01a) and now includes a specific section for interactions with wildlife and threatened sharks, including white sharks.

Note: Individual capture records are not presented in this report. GNO1 records are confidential under law and individual records cannot be published.

Place names mentioned in the text.

Western Australia

1	North West Cape
2	Shark Bay
3	Kalbarri
4	Perth
5	Bunbury
6	Cape Leeuwin
7	Augusta
8	Albany
9	Esperance
10	Israelite Bay
11	Eyre

South Australia

12	Head of the Bight
13	Fowlers Bay
14	Ceduna
15	Thevenard
16	Nuyts Archipelago
17	Streaky Bay
18	Coffin Bay
19	Port Lincoln
20	Sir Joseph Banks Group
21	Dangerous Reef
22	Little English Is.
23	North Neptune Is.
24	South Neptune Is.
25	Spencer Gulf
26	Wardang Is.
27	Point Turton
28	Kangaroo Is.
29	Seal Bay
30	Gulf St Vincent
31	Adelaide
32	Victor Harbour
33	The Coorong
34	The Pages
35	Robe

Victoria

36	Portland
37	Portland
38	Port Phillip Bay
39	San Remo
40	Phillip Is.
41	Wilson Promontory
42	Bass Strait
43	Corner Inlet
44	Port Albert
45	Ninety Mile Beach
46	Lakes Entrance
47	Oil Rigs
48	Everard Horseshoe

Tasmania

49	Reid Rocks
50	Moriarty Rocks
51	Bicheno
52	Hobart

New South Wales

53	Eden
54	Montague Is.
55	Tuross Inlet
56	Royal National Park
57	Wattamolla
58	Garie Beach
59	Sydney
60	Newcastle
61	Port Stephens
62	Forster

Queensland

63	Gold Coast
64	Point Lookout
65	Moreton Bay
66	Townsville

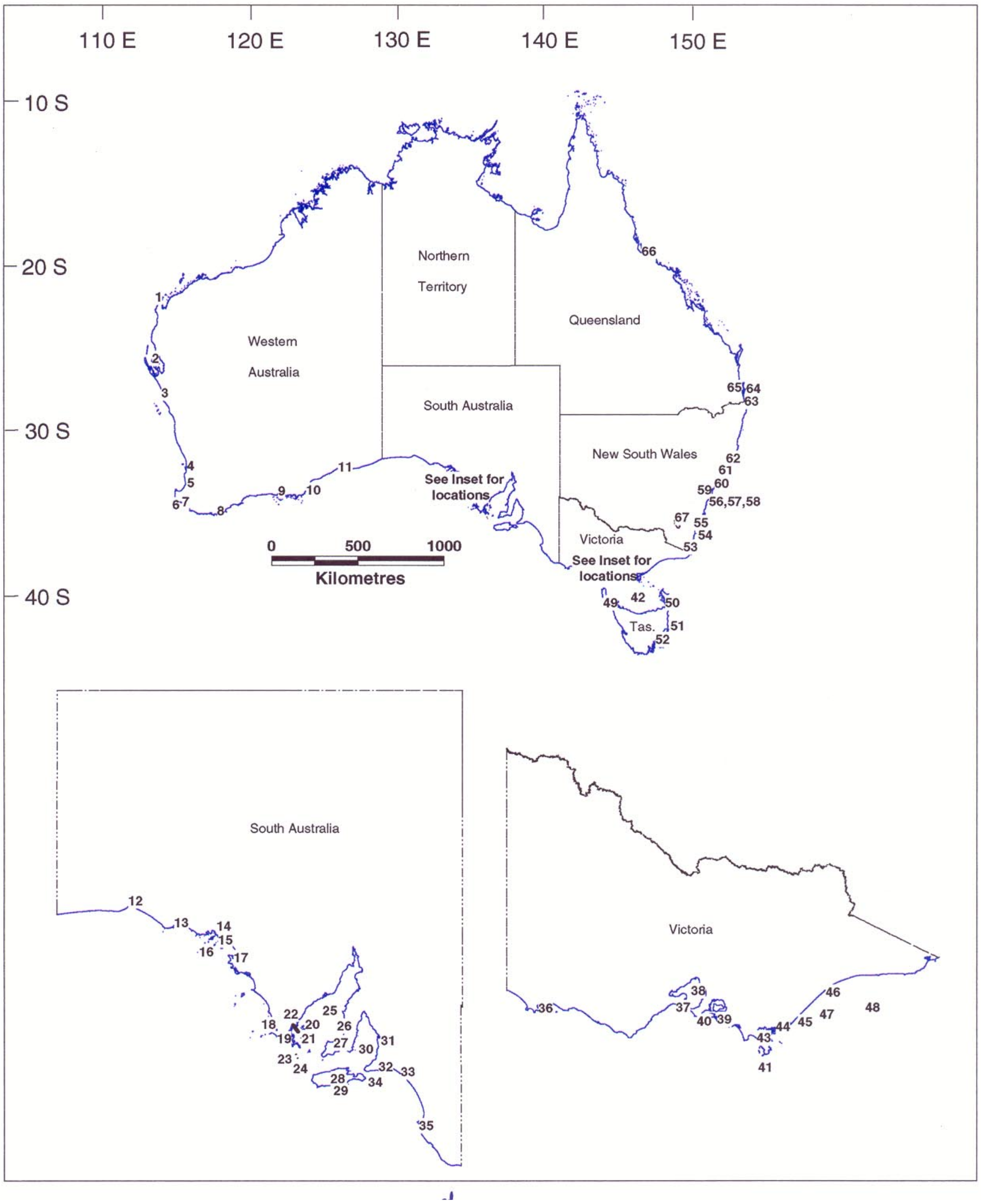

Figure 1: Locations of Places mentioned in the text.

Reporting requirements under endangered species and fisheries legislation

If white sharks are injured, taken, traded, kept or moved, in Commonwealth waters, the incident must be reported to the Secretary of EA within seven days with particulars of time, place and the circumstances under which the animal was caught. A person who reports the incident will be assisting the Commonwealth with information about the species, and will not be punished as a consequence. However, failure to report the incident within the 7 day period is a punishable offence. The address for reporting is: GPO Box 787, Canberra ACT 2601.

There are no requirements to report sightings or captures of white sharks under State legislation although a protected species sighting sheet is available from NSW Fisheries for voluntary reporting. A voluntary white shark sightings/capture sheet was developed as part of this project and distributed to members of the regional network, various fishers and contractors in the Qld shark control program.

Shark Control Programs (NSW and Qld)
Shark Control Programs in NSW and Qld are managed by NSW Fisheries and the Queensland Department of Primary Industries (QDPI) respectively. The programs are carried out by contractors, who report capture details to the relevant fisheries agency as a requirement of their contract. White sharks caught in the NSW Program have been recorded since 1951, and in Qld since 1962.

2.1.2 Fisher information surveys

Data on captures were also sought directly from various individual fishers and those involved with the fishing industry.

Individual conversations/interviews
Individual discussions were held with approximately 100 fishers across southern Australia during the course of this project. Interviews were conducted primarily by telephone due to the large area covered. Information was requested on: capture details and catch estimates, feeding observations and stomach contents, size and sex ratios, distribution and seasonal movement patterns, habitat and behaviour including links with other species, and any other general observations.

Most of the information was anecdotal, although some specific catch records were provided. Although not quantitative, anecdotal information can be a valuable source of descriptive data, especially where the provider has long-term experience and has built up a wealth of knowledge. One of the features of the shark fisheries in Australia is the long-term involvement of many of the fishers. Many of those contacted had greater than 10 years experience in the fishery and some had more than 20 years.

Many fishers recorded details in their personal or vessel logs, although that data are not easily accessed. Without being entered on a computer and able to be searched electronically, a fisher has to examine every page of each yearly logbook to obtain specific catch details. This is a huge undertaking for long-term fishers. Therefore the information provided was usually anecdotal, except where specific captures were remembered or separate records had been kept for white sharks.

Twenty fisheries compliance officers from around southern Australia were also contacted by telephone as part of this process.

Request for information through articles
Information was requested through articles in the various State fisheries magazines and through AFMA News.

Survey form (MSF)
A request for information was sent out in the South Australian Marine Scalefish Fishery (MSF) newsletter which is regularly sent to all licence holders in the fishery. A survey form was enclosed in the newsletter that could be filled out and returned.

Contact information was also requested enabling respondents to be interviewed directly if required.

2.1.3 Research fishing
Data on white shark captures were extracted from research surveys conducted by MAFRI (or precursor) over the last three decades (see Walker *et al*. 1999, Walker *et al*. 1997b, Walker *et al*. 1989, for details of cruises and methods).

2.1.4 Voluntary logbooks
A voluntary logbook (managed by MAFRI) for snapper (*Pagrus auratus*) fishing charters in Victoria included a white shark sighting sheet for the 1999/2000 snapper season (October to April). Interactions with this fishery appear to be reasonably common due to an apparent association of small white sharks with snapper.

2.1.5 Other sources of information
There are a number of non-formalised data sources where white shark captures have been documented, including reports in newspapers and other media.

In Tasmania, white shark captures, encounters and sightings are being collected through newspaper searches and detailed interviews by a private individual who is interested in white sharks. Information to date was compiled into an informative report produced for the benefit of this project (Black 1999).

2.2 Indicators of abundance

2.2.1 Capture/encounter rates - commercial fishing
The formal capture reporting mechanisms for white sharks introduced in the SSF (via the GNO1 logbook) should provide a means for assessing capture trends in the future. However, non-reporting is still a problem.

2.2.2 Historical gamefishing records
Limited data regarding game fishing captures were collated from published reports (Bruce 1992, Pepperell 1992).

2.2.3 Shark control programs.
Data from NSW were provided by the NSW Fisheries Research Institute and from Queensland, by the Department of Primary Industries. Details of the area of operations, time periods and gear used are described in Reid and Krogh (1992). Information recorded includes capture date and location, as well as size.

2.2.4 Cage dive operators and tagging program
Specific charter trips to view white sharks have been running in South Australia since 1976, although trips to specifically film white sharks have been occurring since the 1960s (A. Fox, Glenelg, SA, personal communication). These activities became regulated under National Parks and Wildlife, SA (now DEH) and the Department of Fisheries (now Primary Industries and Resources SA - PIRSA) in 1998. Five permits were issued, however, the majority of trips are undertaken by two operators. The five operators subsequently formed the White Shark Cage Dive Operators Association (WSCDOA) and developed a Code of Practice relating to viewing activities.

Operators are currently restricted to working at five sites in South Australia - Little English Is., Sibsey Is., North Neptune Is., South Neptune Is. and Dangerous Reef.

Each site has a pinniped colony. North and South Neptune Islands have both New Zealand fur seal (*Arctocephalus forsteri*) and Australian fur seal colonies (*Arctocephalus pusillus doriferus*) whereas Dangerous Reef has an Australian sea lion colony (*Neophoca cinerea*). Access to Dangerous Reef is restricted for seven months spanning the pupping period to minimise disturbance to the sea lions. Operators anchor on site and attract sharks to their vessel using fish based berley (chum) and baits. The use of mammal products for berley is prohibited. Most effort is concentrated at North Neptune Island.

Ad-hoc tagging and reporting of shark sightings has been carried out by operators over the past decade. This followed specific tagging programs initiated by South Australian Fisheries researchers in conjunction with the Cousteau Society in the early 1990s. However, prior to the start of this project, operators were not required to record sightings or their activities in any standard way. In 1999, after discussions with operators and DEH, a compulsory daily logbook was introduced to standardise a reporting system and formalise the tagging of white sharks at each site (see Appendix 1 – WSCDOA daily log book). Operators are now required to record the site they work, the time they start and finish berleying, the number of sharks sighted each day, whether the sharks are tagged or not, the tag identification number (if possible) and both the size and sex of sharks (if possible). Prior to 2001, tags were obtained from NSW FRI under their cooperative game-fish tagging program. Several modifications were made to the basic tag to allow sharks to be identified if resighted, including colour-code tubing, beads and teflon plates. Tags have now been standardised and are currently supplied by CSIRO. They are modified Hallprint game-fish tags to which is attached a teflon plate (Gordon tag) with a unique alpha-numeric code (e.g. A5). The Gordon tag allows individual sharks to be identified and recorded on resighting. Sharks are tagged while they swim close to the operator's vessel. Tag position and the nature and location of natural marks and scarring is recorded for each shark.

To date, all tagging data are compiled and available. However, some sighting and resighting data has been lost due to a lack of a co-ordinated recording system prior to 1999.

2.2.5 Australian Shark Attack File

Shark attacks in Australia are recorded in the Australian Shark Attack File, which was established in 1984 and is held at Taronga Zoo. Attacks include encounters where gear is damaged or diversionary action was required (West 1996).

2.2.6 Incidence of shark bites on sea-lions - monitoring at Seal Bay, Kangaroo Island

Sightings of Australian sea-lions with recent shark-bites have been recorded for the past 13 years by National Park rangers at Seal Bay, Kangaroo Island (P. Shaughnessy, CSIRO Sustainable Ecosystems, Canberra, personal communication). This includes date of sighting, sex of the seal and whether it was a pup, juvenile or adult, comments, and information on when the breeding season starts and ends.

2.2.7 General sightings and encounters
General sightings were collated from a number of sources. Although caution is necessary when attempting to interpret anecdotal data on sightings, some may suggest local changes in white shark activity or habitat use.

A request for information was made in the Tasmanian abalone divers newsletter. A sighting sheet was provided (via MAFRI researchers) to abalone divers in Victoria and a similar sheet was distributed to South Australian western zone abalone divers via SARDI.

Sighting forms were also provided to the Game Fishing Club of South Australia.

2.3 Biology

Existing data and samples were reviewed and collated. A national white shark reporting network was established to obtain white shark information and gain access to incidentally killed specimens. This network comprises some 40 fisheries biologists, fisheries compliance officers and National Parks and Wildlife personnel in the various State organisations. All were issued with reporting manuals, dissection and sampling guides, and reporting sheets.

2.3.1 Population structure
Distribution
The distribution of white sharks in Australian waters was determined from available historical records, capture records from fishers and sharks sampled during the course of this project.

Size structure
Data from capture records has been used to assess the distribution of different size classes in Australian waters. In many cases, size data are based on estimates rather than measured specimens and some caution is required in the interpretation of the data. Specimens available for examination were measured to the nearest cm as total length (TL), with the caudal fin in a natural swimming position. Both fork length (FL) and pre-caudal length (PCL) were also usually measured. Where possible sharks were weighed; smaller specimens on calibrated spring balances and large specimens on commercial weighbridges.

Sex ratio
Data on sex ratio of both captures and verified sightings were tested for significant differences using Chi-Square analysis.

2.3.2. Stock structure
Where possible, tissue samples were collected from sampled sharks and frozen or preserved in ethanol. Samples were analysed at the University of Colorado, USA, where a project to examine the global population structure using mitochondrial DNA is under way. Analysis involved sequencing the D Loop mitochondrial gene to determine if similar haplotypes are clustered geographically (see Pardini *et al*. 2001 for details). The project is concentrating on characterising two different genetic markers: maternally-inherited mitochondrial DNA and bi-parentally-inherited microsatellite loci. The project (at this stage) is concentrating on broad-scale analyses

(e.g. between ocean basins). However, as further samples are collected, regional differences within Australia may also be assessed.

2.3.3 Reproduction
Sampled sharks were assessed for reproductive maturity and condition. Male maturity was based on clasper length and calcification. Female maturity was based on the development of the ovary and genital tracts, and the presence of eggs or embryos in the uterus (Bass *et al.* 1973). Gonads were excised from the surrounding epigonal organ and weighed. Maximum ova diameter (MOD) was measured.

2.3.4 Diet
Prey items from sampled sharks were identified to the lowest possible taxon. Information was also obtained from some fishers that examined stomach contents. Results were expressed in terms of frequency of occurrence.

2.3.5 Age and growth
Where possible, vertebrae were collected from white sharks sampled during this study. White shark vertebrae collected prior to this study (most held frozen) were also secured from various researchers and agencies. Vertebrae used for ageing were taken from below the first dorsal fin (Stevens 1975). It was not possible to ascertain where, in the body, some archived vertebral samples were taken. In at least six cases, vertebrae were known to have come from either the caudal area or from behind the head. Vertebral sets that either did not, or could not be confirmed as coming from below the first dorsal fin, were excluded from age-analysis. The largest vertebrae from each of the remaining vertebral sets were chosen for analysis.

Frozen vertebral sets were allowed to defrost slightly to allow separation of the vertebral column into individual centra while leaving their surfaces and connective tissue frozen. Haemal and neural arches and extraneous connective tissue were removed with a knife or scalpel. Following the removal of frozen inter-vertebral fluid, the inter-vertebral disks were peeled off with forceps, taking care not to damage the centrum surface. Vertebrae used for reading were labelled, placed in perforated re-sealable bags and stored in 70% ethanol.

Measurements
Centrum diameter was measured in a transverse plane (Wintner and Cliff 1999), beginning at the midpoint of the dorsally-occurring neural arch and continuing in a straight line through the focus to the midpoint of the ventrally-occurring haemal arch.

Band counts
Age estimates were taken by counting band pairs, defined as one opaque and one translucent band (Cailliet *et al*. 1985). Additional structures, in the form of rings, were present in all centra and the distinction between rings and bands was not always obvious. In these cases, a high band pair count (including those rings that were similar to bands) as well as a low band pair count (excluding ambiguous rings) was made. All centra had a readily defined cental core with a defined birthmark boundary similar to that described by Wintner and Cliff (1999).

Five techniques were examined to determine which was best for band enhancement: staining with silver nitrate (Stevens 1975); staining with ninhydrin (Davenport and

Stevens 1988); x-radiography of whole centra; thin sections (viewed with transmitted light); and direct reading of whole centra immersed in water under a magnifier with light sources angled to best resolve band pairs (similar to that described by Francis and Ó Maolagáin 2000). Five centra from each of ten different sharks (ranging from 1.47 to 5.2 m TL) were selected for analysis.

Band pairs were visible with each technique. However, direct reading of whole centa immersed in water gave the most consistent results. This technique was used for all subsequent band counts.

2.3.6 Movements

Movement patterns of white sharks in Australian waters were examined using data collected from tagging studies, observations from commercial and recreational fishers and the seasonal timing of catches in coastal waters.

Several different types of tags have been attached to white sharks in Australian waters.

Conventional tags

Several conventional tag-types have been used on white sharks in Australian waters including standard *Hallprint* stainless-steel headed dart tags, Jumbo Rototags (cattle ear tags) and modified dart tags. Modified dart tags include those with colour-coded tubing, coloured beads and, most recently, teflon strips with readable cut-out letter/number combinations ("Gordon tags") that enable tagged sharks to be individually identified if resighted (Figure 2). Most sharks have been tagged while free-swimming after being attracted to vessels by berley either on dedicated research trips, documentary filming trips or cage-dive tourist trips. Tags have been implanted from either the surface or underwater using poles or hand-spears. Tagging from the surface has been far more successful and is the recommended method.

Some white sharks have been tagged following capture in commercial fishing operations and some were tagged following capture on game fishing gear (prior to protection). The majority of tagging has occurred in South Australia.

Acoustic tags

Several white sharks in South Australia have been tagged with acoustic transmitters by researchers. Acoustic tagging is an effective method of obtaining detailed short-term movement data by following transmitter-equipped sharks from a vessel using a hydrophone. Detailed methodology is reported in Strong *et al*. (1992, 1996). Various transmitter types have been used including Vemco, Sonotronics and purpose built transmitters (e.g. hybrid circuit/Ultrasonic Telemetry Systems – see Nelson and McKibben 1981). Some transmitters were fitted with depth and/or temperature sensors and were either attached externally or fed to free-swimming white sharks. The tags had a range of up to 1.0 km and a battery life lasting from a few days to over a week. Shark location was assumed to be the same as that of the tracking vessel and swimming speed was calculated based on the distance and time between recorded positions.

Figure 2: A three metre white shark with two colour-coded dart tags.

Archival tags

Three white sharks were tagged with Wildlife Computer Mark 7 archival tags during this project. These tags record information on the date, time, swimming depth, light level, and temperature of the surrounding water (West and Stevens 2001). Tags were programmed to record data from each of the sensors every four minutes. These archival tags must be retrieved to down-load their data. Data from the tag can be used to reconstruct the approximate track taken by the shark. The methods used to calculate position are described in detail by West and Stevens (2001). Briefly, longitude is estimated by determining the time of local solar noon (the mid-point between the times of sunrise and sunset taken from the tag's light sensor). The difference between this and the time of solar noon at Greenwich provides an estimate of longitude with each hour of difference being equivalent to 15 degrees. Latitude is estimated on the basis of day length taken from the times of dawn and dusk. Tags were attached using a stainless steel tag-head and were applied to free-swimming sharks attracted by berley to the boat at North Neptune Island in South Australia. The archival tags were fitted with a hydrodynamic nose cone to prevent uneven towing of the tag. Tagging was restricted to individual sharks that had been regularly seen by the cage-dive operators. The rationale behind tagging a regularly sighted shark was that it would provide two opportunities to retrieve the tag for data down-load:

1. if the shark was resighted again, the tag might be removed as the shark swam past an operator's vessel, or,
2. if the shark was accidentally captured in fishing operations.

A combination of the latitude-longitude estimates as well as comparison of the swimming depth and sea-surface temperature recorded by the tag was used to estimate average weekly positions and thus recreate an approximate path.

Satellite tags

Two satellite tags were deployed on juvenile white sharks during this study. The first satellite tag was attached to a 1.8 m female in March 2000 as a pilot study to assess if this method could be utilised to examine long-term movement patterns. The tag was a sealed polyurethane unit consisting of two lithium batteries, the satellite transmitter (Telonics ST-18 PTT) with a unique ARGOS identification signal, a saltwater activating switch and a mast with a mono-strand stainless steel wire aerial. The satellite tag sends a signal remotely back through the ARGOS satellite system, which calculates a position. The signal will only transmit through air, requiring the aerial to be out of the water. The saltwater switch turned the unit off when it was underwater in order to preserve power. The tag was positioned on the first dorsal fin so that the aerial extended out of the water when the fin was breaking the surface. The number of signals received by the satellite depends on how long the aerial is out of the water. The longer the aerial is out of the water, the more accurate the position that can be calculated. A signal repetition period of 45 seconds was used. The initial tagging was successful and transmissions were received for a period of 49 days after tagging. We believe that the mono-strand aerial was damaged after this time (perhaps due to the shark rubbing the unit on the bottom) and no further transmissions were recorded.

In March 2001, a second satellite tag was deployed on a 2.4 m male white shark. The aerial of the second tag was made of flexible multi-strand stainless steel wire shielded with PVC heat-shrink tubing to minimise the chance of bending and damage. This tag transmitted the position of the shark for a period of 129 days.

Tagging of white sharks in Australian waters by any method requires a permit from the relevant State or Commonwealth agency.

3. RESULTS AND DISCUSSION

3.1 Caveats on by-catch and mortality estimates

Catch information is subject to a number of biases (including deliberate misinformation). Reports of recent catch rates and captures are likely to be more reliable given that most fishers do not keep accurate records of white sharks caught. Recall of detail is also likely to decrease with an increase in the number of sharks captured.

The different frequency of captures reported between fishers may be due to a number of factors. There appears to be a loose correlation between increased catch of target species in gill-nets and a higher number of white shark interactions. A more successful fisher may therefore have more white shark interactions than a less successful fisher in the same area. At any one location, there can be large variations in the number of white sharks caught from year to year by the same fisher. For example, one fisher reported catching about 1 white shark per year in the Great Australian Bight (GAB), but in one year (1995) he reported catching 6-8 individuals. In 1990, several fishers reported the capture of large numbers of small white sharks in the GAB. There are also likely to be seasonal and inter-annual effects on catch rates resulting from the distribution and abundance of prey such as snapper and marine mammals that are independent of the population size of white sharks.

Standardising capture rates to some form of effort and then scaling up levels of capture to estimate by-catch by fishery has been a significant problem. Some fishers move between fisheries on a seasonal or annual basis and their individual effort will vary with time. Effort data in the southern and western shark fisheries are recorded by vessel. However, the capture data for white sharks has been compiled by individual fisher and not by vessel. Many of the fishers that were contacted have been in the fishery for a long time and have worked on a variety of different vessels. Determining an individual fisher's effort (as a percentage of overall effort) requires knowing what vessels each fisher operated from by year. This information has been difficult to reconstruct. In addition, effort data are usually compiled by financial year whereas white shark captures are usually provided by calendar year. Effort information is not readily available and cannot be presented by individual vessel due to confidentiality. Changes in fishing practice and the experience of the fisher can also change the rate of white shark encounters.

Estimates of average yearly catch rate can be influenced by the number of years over which the rate is determined. For example, one fisher of 20 years experience, did not catch any white sharks in his first 10 years of fishing. He then caught three in the next 10 years, with two being in one year. If he had only fished the first ten years his catch rate would have been 0; it would have been 0.3 if he had only fished the next 10 years, and 2 if he only fished the last year.

There may be considerable error associated with an estimate of annual white shark catch for fisheries based on the available data, given the temporal and spatial variability of white shark captures as well as changes in fishing effort and fisher behaviour (both individually and generally within a fishery).

3.2 Catch estimates and threat assessment

Most of the information collected on commercial by-catch of white sharks was obtained during telephone conversations with fishers, and was in the form of the number of sharks caught over a period of years fished. Articles in various fishery publications were useful for informing fishers about the project, but were an unsuccessful approach to obtaining information. Only a couple of responses were received from each article. Fifty-nine responses were received following a direct mail-out of a questionnaire in the South Australian Marine Scalefish Fishery newsletter.

White sharks are mainly caught around the southern half of Australia, with more captures in South Australia than other States (Figure 3). These data relate to captures for which there are detailed records.

Commercial captures in NSW are poorly documented to date, but occur in several regions including the vicinity of Port Stephens and Port Macquarie.

Fifty-six percent of the white sharks caught by commercial fishers (for white sharks recorded on the database), were from the Southern Shark Fishery and Western Shark Fishery.

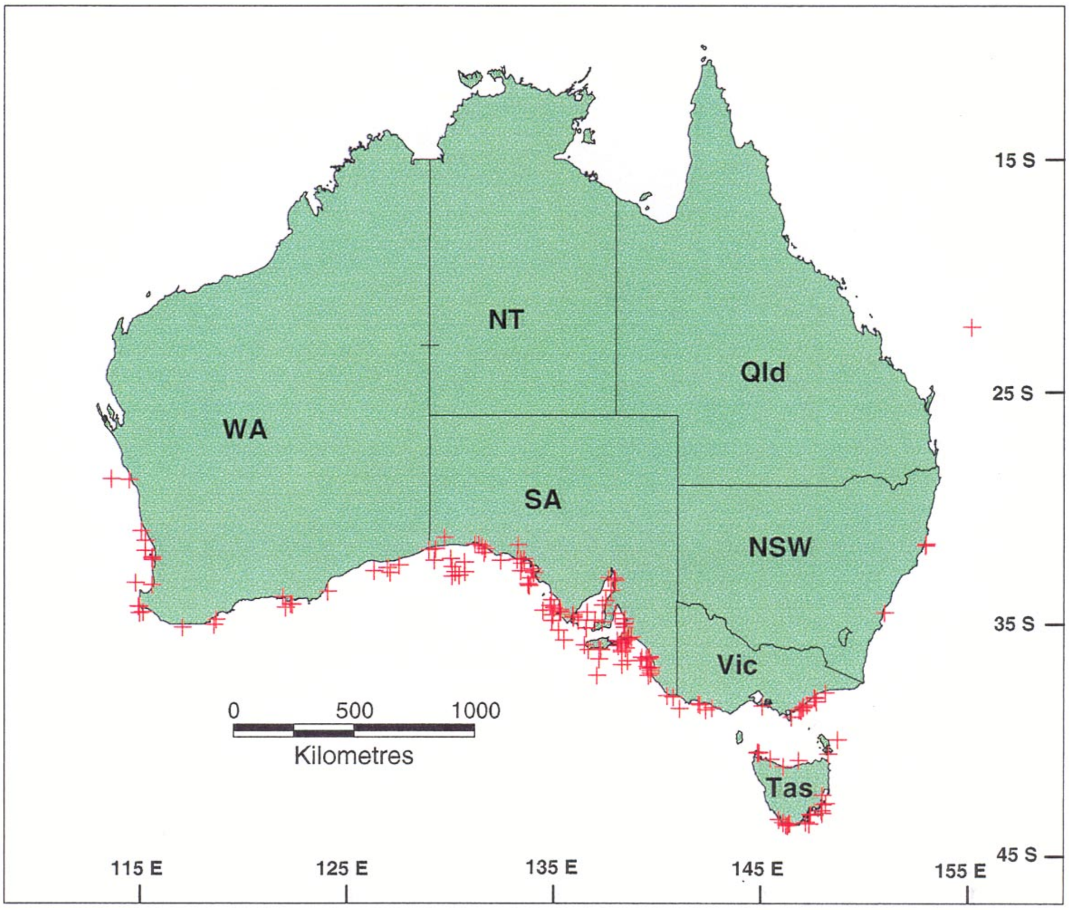

Figure 3: Locations of white sharks caught by commercial fishers (Shark Control Programs in NSW and Qld excluded)

3.2.1 Southern and Western Shark Fisheries

These are the main temperate shark fisheries in Australia, and are managed through joint State and Commonwealth jurisdiction. The SSF includes fishers from South Australia, Tasmania and Victoria whereas the WSF is restricted to Western Australian waters. There are various management units within each of these fisheries.

Southern Shark Fishery

The SSF is limited entry with permits issued to endorsement holders. Endorsements were initially allocated on the basis of catch history. Gill-net effort in the SSF is based on a net unit, with each net unit currently 420 m. Licence holders are constrained to the number of net units they can have under their endorsement (Walker *et al*. 1997a), with the maximum being 10 (Table 2) and then 6 under A-Class endorsement. B-Class endorsements are generally owned by fishers that concentrate on other fisheries such as crayfish, but who take shark in the "off-season". Some of these endorsements are not active.

Table 2. Number of vessels with Commonwealth shark permits as at 1 September 1997 (from Walker 1999)

State	Net permit						Hook permit		
	A10	A6	B5	B4	B3	B2	H2000	H1000	Total
Vic	25	14	17	0	0	2	2	12	71
Tas	2	4	10	1	1	2	3	14	37
SA	13	10	20	1	1	1	0	4	51
Total	40	28	47	2	2	5	5	30	159

During 1998, 124 entitlement holders were issued Commonwealth permits to catch shark with gill-net. Sixty-eight of these were A class permits (40 A10, 28 A6). Hook permits were issued to 37 long-liners. Four vessels hold both hook and gill-net permits. Ninety vessels were responsible for 80% of the catch (Walker 1999). Fishing effort by State of landing from 1973-97 is shown in Figure 4.

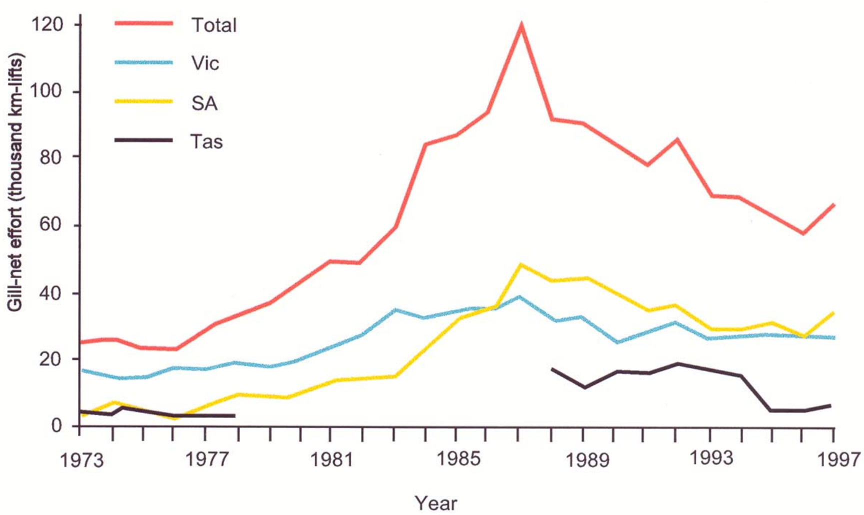

Figure 4: Fishing effort by State in the SSF (1973 – 1997).

Current input controls include the maximum length of net (4200 m) that can be set during a single fishing operation, and constraints on mesh size and net height. The length of time a net is set (soak time) is to some extent restricted by natural processes. The longer a net is set, the more spoilage and wastage due to sea-lice and other fish (including sharks and leatherjackets) damaging catch. In January 2001, output controls in the form of Individual Transferable Quotas (ITQs) were introduced for the fishery. However, the current input controls are also still in place.

There are 11 ports that vessels primarily operate out of, but are not restricted to. The four main ports are San Remo, Port Lincoln, Lakes Entrance, and Robe, closely followed by Thevenard, Streaky Bay, Victor Harbour and Port Albert.

Western Australian shark fishery
The Western Australian (temperate) shark fishery is divided into the Southern and the West Coast Demersal Gill-net and Demersal Long-line Joint Authority Fishery (SDGDLJAF & WCDGDLJAF) management units. The Southern management unit is split into two geographic zones (Zone 1 and Zone 2). The west coast consists of a single management unit termed 'West Coast' in this report. The fishery is currently managed through effort controls. Access to this fishery is regulated through time-gear units. These control the amount of net or hooks able to be used within a management area (Simpfendorfer and Donohue 1998). One net unit allows a fisher to use one net or 'hook equivalent' for a month.

One net unit was originally 600 m in 1992 but was gradually reduced to 430 m in Southern Zone 1 and 380 m in Southern Zone 2 by 1998/99. The intent is a 50% reduction in fishing effort on 1993/94 levels in the SDGDLJAF by 2000/01 due to over-exploitation of some shark stocks (Fisheries WA 1998). An interim management plan was introduced for the WCDGDLJAF in 1997/98 at which time 38 fishers had powered net drum endorsements. The intent is to reduce effort in the WCDGDLJAF to less than 70% of the 1993/94 level. Once the appeals process is finalised, substantially fewer vessels are expected to have access to the fishery (Fisheries WA 1999). Shark fishing between Shark Bay and North West Cape has been prohibited to protect breeding stocks of large whaler sharks (carcharhinids).

Effort is recorded within 1^{o} latitude/longitude blocks, and can provide total gill-net effort by year for the two management units and their respective zones (Figure 5). For the purpose of this study, Southern Zone 2 has been further divided into Albany – Esperance, and GAB (to SA Border) due to differences in white shark interactions/catches between these two areas.

A high proportion of the overall effort comes from a small number of fishers that have endorsements (i.e. a proportion of the 38 fishers with power drum endorsements on the west coast may only fish for shark over a small percentage of the year). The WA fishers who provided information about white sharks for this project currently account for more than 40% of total effort in the Western Australian (temperate) shark fishery, although this has not been consistent over the past decade.

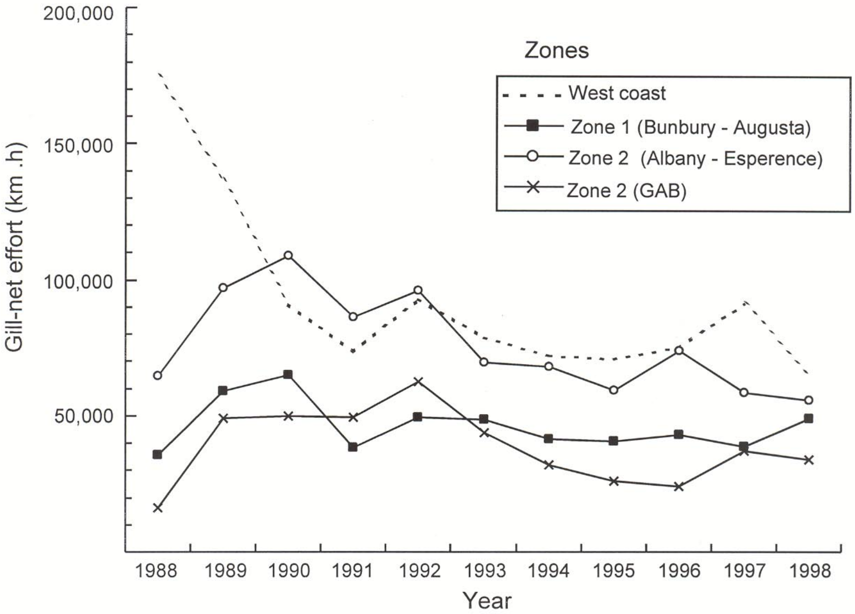

Figure 5: Gill-net effort by zone in the WSF.

Equipment and target species
The primary gears used by shark fishers are gill-nets or long-lines. Net configuration is targeted towards catching smaller sharks. The main target species are gummy shark (*Mustelus antarcticus*) and school shark (*Galeorhinus galeus*) in SA, Vic. and Tas., and gummy shark, whiskery shark (*Furgaleus macki*) and dusky whaler (*Carcharhinus obscurus*) in WA.

Nets are made from light mono-filament polyamide webbing. Where gummy sharks are targeted, 30 ply mesh is generally used. Where school sharks are targeted, slightly heavier, 36 ply mesh is often used. Mesh size (distance across each mesh when stretched tight) varies by location in the two main fisheries. A maximum mesh size of 165 mm stretched mesh was introduced to the SSF in 1997 to reduce the catch of large sharks (Walker *et al.* 1997a). The minimum gill-net mesh size is 165 mm in Zone 1, and 178 mm in Zone 2 in the WA fishery (Simpfendorfer and Donohue 1998).

Net height in the Southern Shark Fishery is 20 mesh drops, with maximum net length as previously described. Maximum net height in the WA shark fishery is 15 or 20 mesh drops depending on zone.

Soak times vary from 4-20 h depending on the fisher and location.

Interactions
White sharks interact with fishing gear by more than just passive or chance encounter as they are moving through an area. White sharks will swim along (or go through) a net or long-line, biting off sharks and other fish that are enmeshed. Scavenging behaviour was mentioned by most of the shark fishers contacted and was verified from the stomach contents of some of the white sharks caught.

The signals given by netted or hooked sharks and fish (vibrations, smell) may attract white sharks in the vicinity, and bring them into contact with nets One shark long-liner believed that sharks could be attracted to baits from up to 3-4 km either side of a set, including up-current. This was based on fishing results from adjacent set-lines. He believed that upstream attraction was a result of white sharks keying into vibrations from fish that have been caught.

Some fishers were certain they could distinguish between white shark bites and those from other large sharks by the way the catch was bitten off, or the type of bite. Fishers often reported holes being bitten through nets by white sharks and other large sharks. A few fishers reported having their net snapped in half by a white shark. In one case, the shark was still loosely tangled but dropped out just before being pulled in. Long-line gear was also sometimes bitten in half.

Fishers consistently reported that white sharks were more likely to be entangled than enmeshed, and that the head-line or foot-rope was often involved in entanglement. However, entanglement was not specific to nets. White sharks also entangled themselves in long-lines and ropes attached to rock lobster pots. The chance of entangling on long-lines may increase if hooks are set too close together. In some cases, white sharks initially hooked on a single snood became foul-hooked in the body by adjacent snoods, thereby increasing the chance of entanglement. Fishers reported advantages and disadvantages of using lighter or heavier gear. Although a lighter line may be more easily bitten through by a white shark, heavier gear could be set more rigidly which decreased the chance of entanglement.

An entangling technique has been used by at least one long-liner to ensure large sharks did not break off the hook (when the line was pulled). He would gather up some loose line, and then throw it out at once so the shark would become tail-wrapped. This method was developed for large carcharinids as well as white sharks (prior to protection) during 40 years of long-lining experience.

White sharks have been observed to roll out of a net while the net is being hauled. Fishers vary in their opinion as to whether sharks that fall out of the net have actually been caught. Observations of white sharks rolling out of the net were interpreted in at least three different ways by various fishers. These included:

1. White sharks swimming into a net may continue to keep pushing into the net, becoming lightly enmeshed around the head. What happens then will depend on the substrate. If the bottom is sandy and the net can be moved, a white shark may slowly push the net and will not break through, eventually becoming exhausted and starved of oxygen through moving too slowly. It will then fall out when the net is hauled. If the bottom is reef, the net is more likely to snag, and the shark will break through.
2. White sharks can become lightly enmeshed, in some cases, but eventually break free either prior to, or when the net is being hauled and tension is applied. However, in most cases white sharks will bite or break through the mesh.
3. White sharks occasionally follow the net and attack the catch as it is being hauled. They can become momentarily trapped in the body of the net near the roller as the foot-rope and head-rope come together. They then fall out as it is raised.

If the first two cases occur and the shark falls out in poor or dead condition, any catch estimates may underestimate the number of sharks affected by nets. One fisher estimated he would catch about three white sharks per year by entanglement but would also see another one or two sliding down the belly of the net. If only a portion of sharks sliding out of the net were observed, then catches in that area would be underestimated, providing that this was a representative case. The third case is unlikely to have an affect.

Some white sharks have been enmeshed (rather than entangled) and have not escaped. This has been documented a number of times with smaller white sharks.

Catch records and reporting
White sharks are not targeted by shark fisheries in Australia, but are unintentionally caught as by-catch. The number caught is highly variable between year, season, location and fisher. Data are based on available catch records and on anecdotal information from 72 shark fishers in the SSF and the WSF.

Very few catches of white sharks are officially reported. In some cases this is due to non-existent, ineffective or unrealistic reporting mechanisms. In some cases it is due to poor reporting. Twenty-five white shark captures have been recorded in the AFMA GNO1 Logbook since May 1997 of which 21 were released alive. Thirteen of these were in the first six months of 1999. In comparison, only three white shark captures were recorded in the GNO1a logbook in the 10 months after July 1999. Only three captures have been reported to EA since white sharks were protected under the Endangered Species Protection Act. Two sharks were incidentally captured and killed in Commonwealth waters and were sampled through this project. They were reported by CSIRO both as a permit requirement for obtaining samples and on behalf of each fisher. The capture of a white shark in a tuna tow cage was also reported to EA by PIRSA.

Generally most of the fishers contacted were co-operative and willing to share their knowledge. This information was reasonably consistent between fishers and was informative about distribution and by-catch. In some cases, limited cross-referencing was possible and generally matched, although in a few cases misinformation appears to have been provided. Only one fisher, of those contacted, refused to discuss interactions with white sharks.

A number of the fishers contacted were supportive of conserving white sharks (some strongly so), although generally they did not believe white shark numbers threatened.

Catch estimates
The SSF and WSF were arbitrarily divided into a number of areas for the purposes of this report, based on differing catch rates and interactions from anecdotal information, and utilising existing management units where possible (Figure 6).

White shark capture rates differ markedly between these areas (Figure 7).

The highest capture rates in both the SSF and WSF occurred in the GAB, where captures of 2-5 white sharks per year were reported by most fishers. Some fishers reported even higher catch rates of up to 12 per year when working between Streaky

Bay and the Head of the Bight. Reported catch rates were highly variable between years. In 1990, numerous white sharks were reportedly caught in the GAB. In 1995, one WSF fisher reported catching at least 8 (but possibly up to 20) white sharks in the GAB.

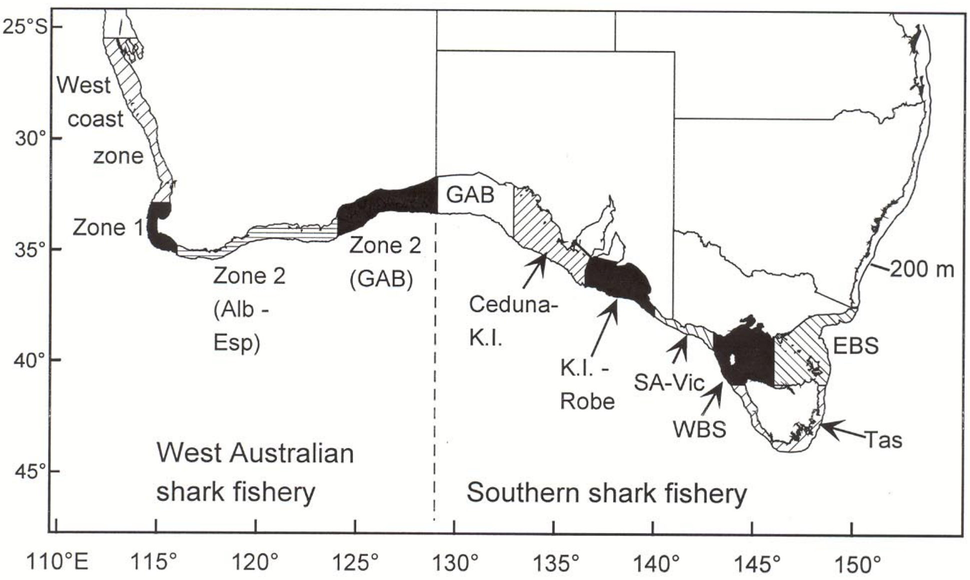

Figure 6: Arbitary areas chosen for analysis of catch data in the WSF and SSF (WBS = western Bass Strait; EBS = eastern Bass Strait).

In some cases fishers catch information could only be assigned to broad regions as opposed to the areas listed above (e.g. Kangaroo Island to the GAB). These data are shown in Figure 8.

The majority of white sharks caught in the GAB were small juveniles (mean length 2.6 m). A number of fishers reported catching most of their white sharks in the area between longitude 126° and 132° (Eyre, WA to Fowlers Bay, SA – including the Head of the Bight) and in water generally less than 60 m depth.

Reported catch rates between Ceduna and Coffin Bay were slightly lower than near the Head of the Bight, but still around 1 to 2 sharks per year. Several fishers reported catching large sharks (particularly females) in this area.

Catch rates from KI to Robe are lower than to the west and highly variable with an average of around 1 shark every couple of years over the past decade. Juvenile white sharks (1.5-2.5 m) were caught between Victor Harbour and the Coorong. Catches of large white sharks were also reported between KI and Robe, particularly in the vicinity of KI and The Pages.

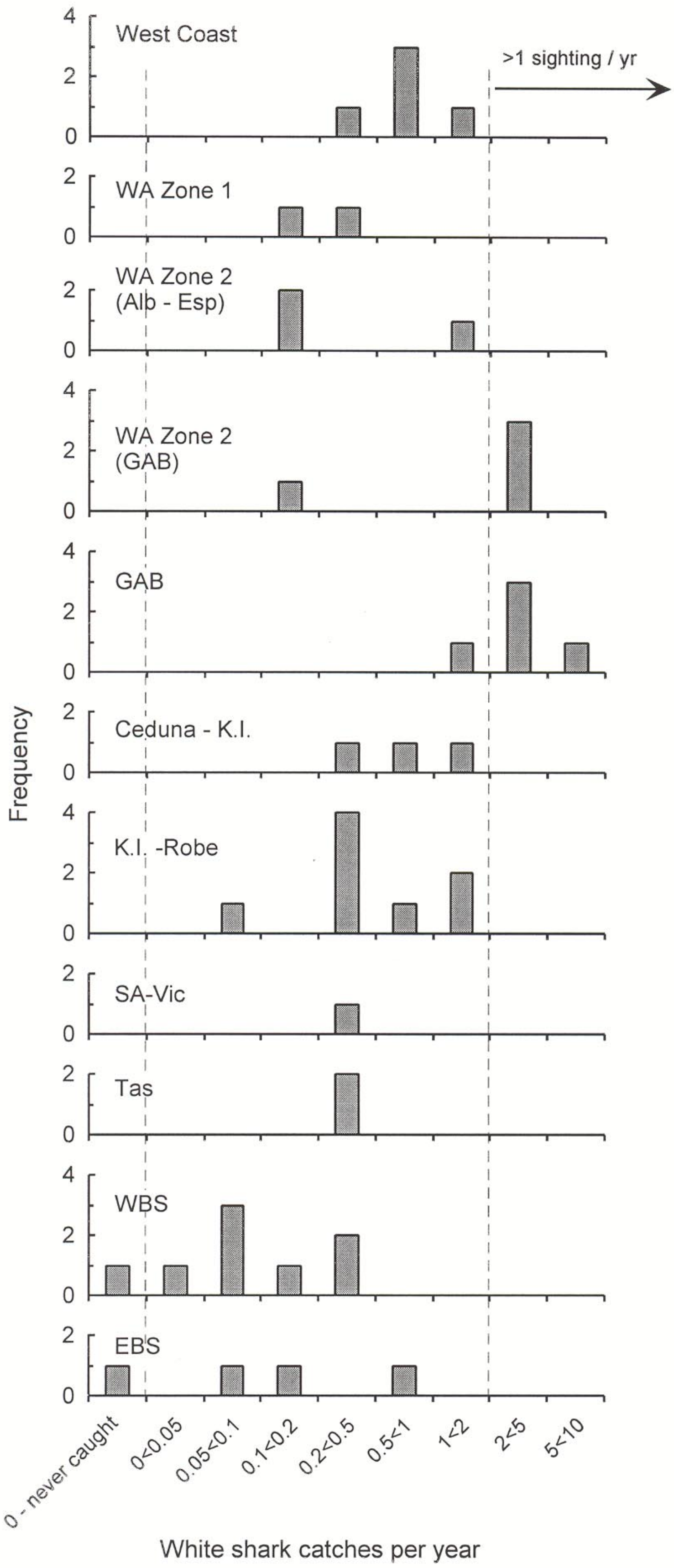

Figure 7: Reported capture rates of white sharks by WSDF and SSF fishers by area.

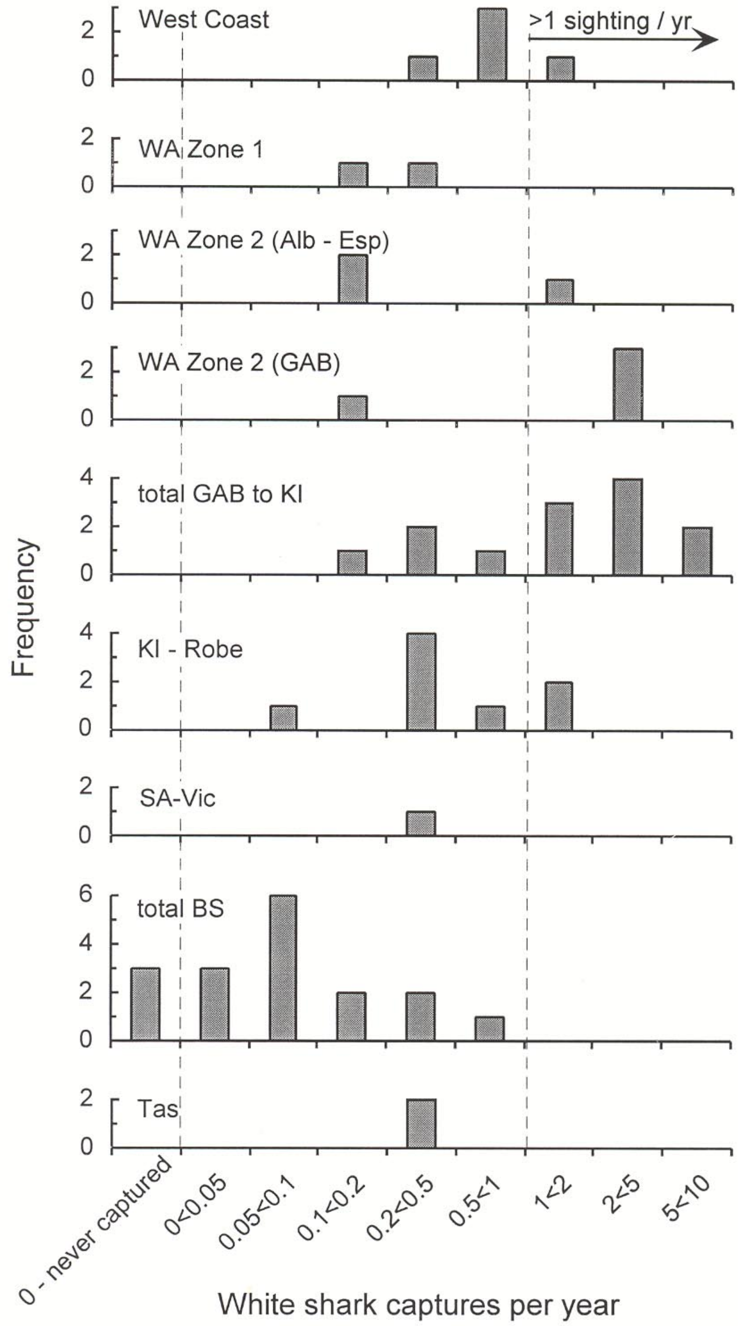

Figure 8: Additional capture records by WSF and SSF fishers by area.

There were generally lower catches in Victoria and Bass Strait than further west, with most fishers catching fewer than one white shark in ten years. However, at least two fishers in Bass Strait reported higher capture rates. One fisher reported catching about one per year prior to 1980 with a capture rate of about one every two years since. Another fisher reported just under one per year, but this included some caught close to shore, prior to the three nautical mile closure to shark netting. Juvenile white sharks were occasionally caught by shark fishers along Ninety-Mile Beach, and along Gunnamatta Beach near Port Phillip Bay, prior to this inshore closure.

Areas where white sharks have been caught in Bass Strait include near the oil rigs, and around Australian fur seal colonies such as Moriarty Rocks, and Reid Rocks. A number of white sharks have also been caught in the Everard Horseshoe off eastern Bass Strait. A recent CSIRO survey in this area recorded extensive fish and seal activity in this canyon (Bax and Williams 2000).

Capture as a function of effort

Total effort within the two shark fisheries was collated by one-degree blocks by decadal period and is shown in Figures 9 and 10.

Individual effort data has not been used to calculate white shark captures for most of the information obtained. Estimates of annual captures of white sharks were made by multiplying the average catch rate for fishers in each area by the number of vessels operating in that area (Table 3). There are several constraints to this approach. Anecdotal catch rates are related to individual fisher and not vessel. It assumes equal effort and catchability between fishers/vessels, which are unlikely to be valid assumptions. Finally, it is difficult to assess how many vessels fish in each area as vessels can target a variety of areas. This has been approximated by using the number of vessels registered at home-ports within each area. In general, however, it can be assumed that a vessel based in Lakes Entrance does not fish in the GAB (or rarely). The number of vessels refers to those that comprise most of the effort (and thus those most likely to capture white sharks). Due to difficulties in standardising and comparing effort, no attempt has been made to account for vessels where shark fishing is a minor component of their fishing activities. Despite these constraints, estimates are expected to be in the right order of magnitude.

Table 3: Catch estimates by area. Based on average catch rate by number of vessels contributing the significant proportion of effort

Area	No. of fishers from which catch rate was determined	Mean catch rate per year	Standard deviation	Estimated No. of vessels comprising most effort	Estimated catch (± SD)
1. SSF					
Total Bass Strait	17	0.15	0.19	30	4.5 (± 5.7)
Southern Tas	2	0.34	0.15	3	1.0 (± 0.45)
SA – Vic	1	0.40		3	1.0
Robe – KI	8	0.66	0.68	20	13.0 (± 13.5)
Total KI to GAB	13	2.70	2.07	20	54.0 (± 41.5)
Total SSF					**73.5 (± 61.5)**
2. WSF					
West coast	5	0.80	0.30	5	4.0 (± 1.5)
Southern Zone 1	2	0.20	0.07	7	1.5 (± 0.5)
Southern Zone 2 (Alb – Esp)	3	0.77	1.10	7	5.5 (± 8)
Southern Zone 2 (GAB)	4	2.70	1.80	5	13.5 (± 9)
Total WSF					**24.5 (± 19)**

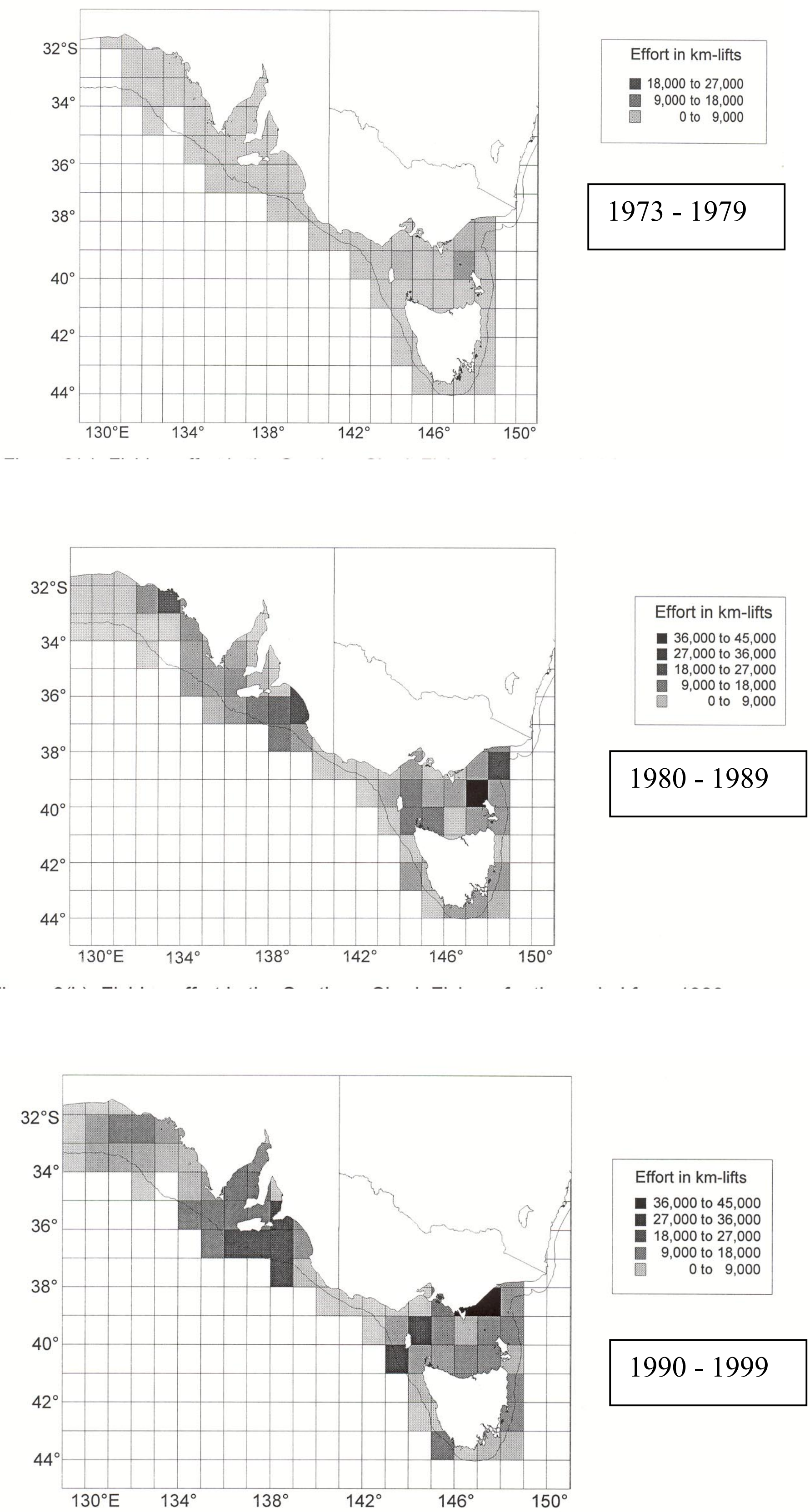

Figure 9: Fishing effort in the SSF by decade.

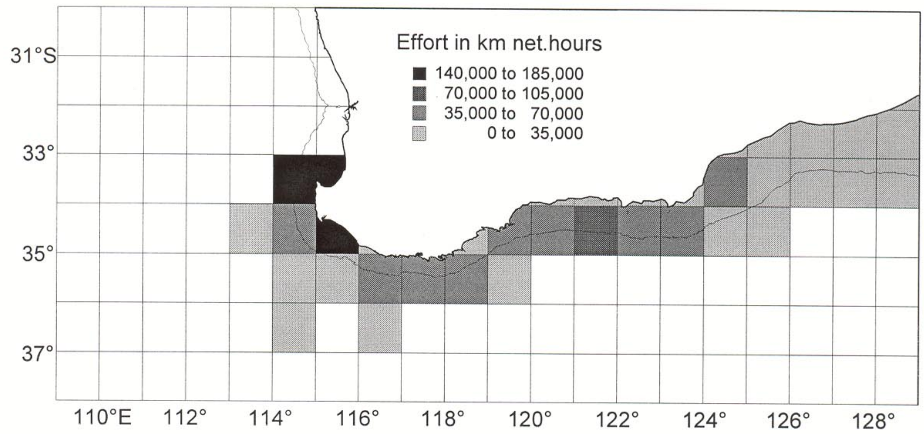

Figure 10 (a): Fishing effort in the WSF for the period 1980 – 1989.

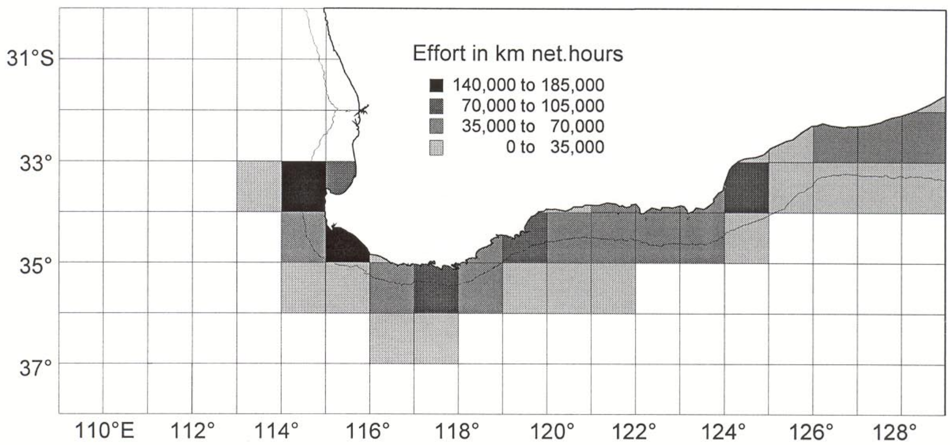

Figure 10 (b) Fishing effort in the WSF for the period 1990 – 1999.

On this basis, within the SSF, there are about 30 boats operating in Bass Strait from Victoria and Tasmania, about 20 in the Robe to KI area, and 20 from KI to the GAB. Very few shark boats operate in southern Tasmania. Similarly, for the WSF, five vessels primarily operate in the GAB, seven in the Albany-Esperence area, seven in Zone 1 and five on the west coast.

Estimated catch rates in the WSF by the above area method were compared with a second method using effort and catch rate estimates from individual fishers. Estimates were based on summed individual white shark catch rates and effort from fishers interviewed within each area (Figure 11). Estimates were calculated following the hypothetical example below. Actual calculations cannot be provided due to confidentiality. This method similarly does not take into account situations where fishers work in more than one area. In addition, effort is averaged over the number of years for which data and catch rates are available and thus does not allow for changes over the past decade.

Example of how estimates were calculated: *Fisher A catches 8 white sharks in 10 years (rate = 0.8 per year), and his average effort for those years was 12% of the total effort in the area he fished. If total catch per year for the area was based on just this estimate, it would be 0.8*100/12 = 6.7 sharks per year. However Fisher B catches 3 white sharks in 6 years (rate = 0.5 per year) and his average effort over those six years was 15% of the total effort. This would equate to 3.3 white sharks per year if total catch was based on just this estimate. Using summed estimates, an average 1.3 white sharks per year were caught from 27% of the effort. The 'average total annual catch' estimate for that area is therefore determined as follows: 1.3*100/27 = 4.8.* *The more estimates and the higher the proportion of effort able to be used in the calculation, the better the total estimate will be.*

Estimates of the 'average total number of white sharks caught per year' were calculated for each of the four areas in WA (see Figure 6). Overall, it is estimated that an average of about 22-35 white sharks are caught by the WSF per year by this method, although this may vary from 0-70 depending on the year. This compares with 24.5 estimated by the first method.

Catch estimates are mainly for gill-netting. Long-line effort is small compared to gill-net, and catches of white sharks by long-line in the WSF are expected to be correspondingly low. One retired shark fisher who long-lined extensively out of Albany during the whaling years did not catch any white sharks, but subsequently caught about six during five to six years of meshing.

As noted in the SSF, there is considerable variation in captures of white sharks between years in the WSF. This inter-annual variability seems to be greatest in the GAB. The reason for this variability is not readily apparent, but may be related to either environmental conditions (e.g. changes in the Leeuwin Current) or the distribution and abundance of prey (e.g. salmon *Arripis trutta*, snapper and commercial shark species). Inter-annual variability in recruitment may also be a factor in the GAB as many of the white sharks caught in that area are small juveniles.

Estimated white shark catch rates do not correlate well with the distribution of effort in either the SSF or the WSF. Highest effort in the WSF is from Bunbury around Cape Leeuwin to Albany, and around Israelite Bay. Effort in the SSF is concentrated between longitudes 135˚-139˚E off South Australia, particularly south and east of Kangaroo Island, off Ceduna and in areas of eastern and western Bass Strait. The higher catch rates of white sharks in the GAB and in the west coast zone of WA appear to be due to greater white shark abundance in those areas. Catch rates of white sharks are generally low in Bass Strait where effort is relatively high. There is some agreement between high effort and white shark catches off Ceduna and in the Albany to Esperence region.

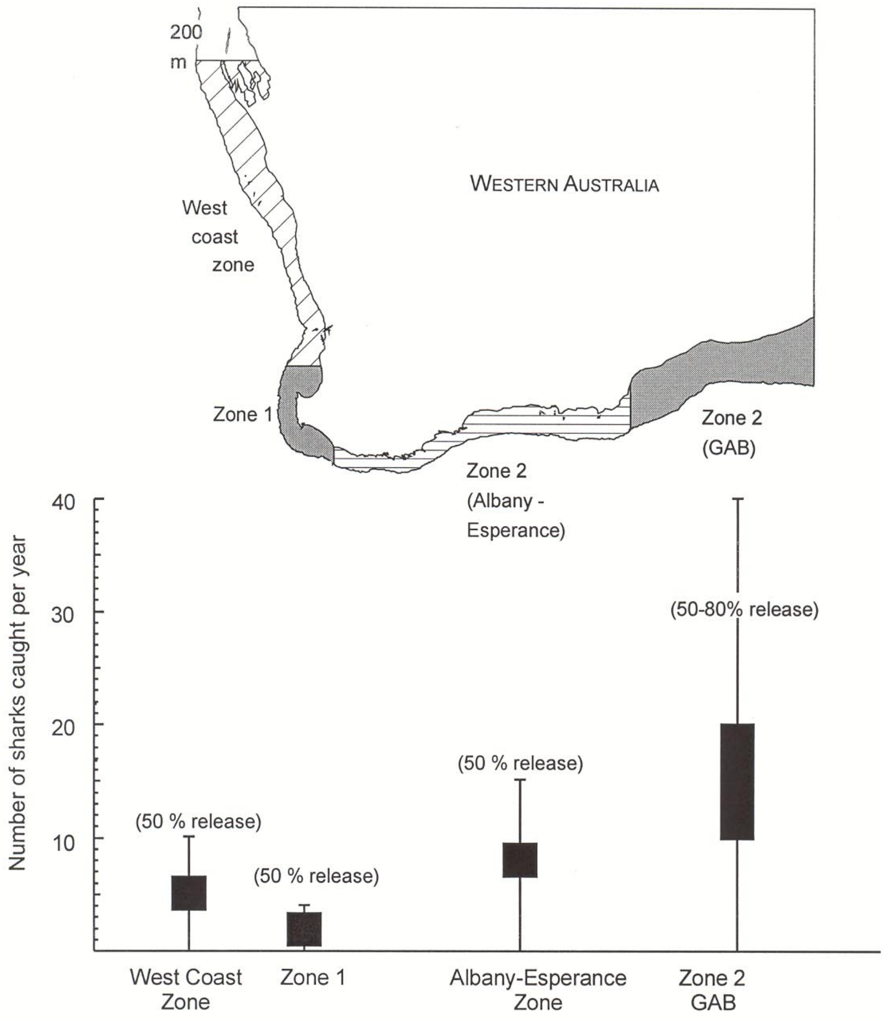

Figure 11: Estimates of the average annual capture of white sharks by area in the WSF.

Catch rates from research fishing.
The Marine and Freshwater Resources Institute (MAFRI) completed a number of research surveys in the Southern Shark Fishery using commercial vessels.

From 1973-1976, MAFRI carried out seven cruises, comprising 162 fishing stations. Overall effort was 243 km gill-net lifts over the three years (T. Walker MAFRI, Queenscliff, personal communication). This was equivalent to 0.34% of overall gill-net effort (71,000 km gill-net lifts) in the Southern Shark Fishery during those three years (Walker *et. al*. 1999). Two white sharks were captured during this survey. Assuming equal catch rates for all areas (which may not be realistic) this equates to approximately 200 white sharks caught per year (1/0.0034 * 2 sharks/3 years). This suggests that even with low catch rates per fisher, the number of captured white sharks can be substantial.

In 1987, 144 stations were sampled in Bass Strait and South Australia to examine net selectivity. Two kilometres of net were set at each station using four different mesh sizes within each net. Overall effort was 288 km gill-net lifts (Walker *et. al*. 1989). This survey was equivalent to 0.24% of overall gill-net effort in the Southern Shark Fishery during that year. One, or possibly two, small white sharks were captured during this survey (P. Moulton, I. Knuckey, MAFRI, Queenscliff, Vic., personal communication).

From 1994-1996, MAFRI carried out 32 research cruises as part of the Southern Shark Tagging Program (Walker *et. al*. 1997b). Overall, 460 gill-net shots were completed, with 261 of these shots in the GAB. Overall gill-net effort was 1,932 km lifts, with 1,096 km lifts in the GAB. This was equivalent to 1.4% of overall SSF gill-net effort during the two years, and 1.8% of the effort in South Australia. One white shark was captured by gill-net during these surveys in the GAB. Multiplying this catch rate by total effort for South Australia would equate to 27 white sharks caught per year. However the calculated catch rates for the other States would be 0, which is not the case. Fifty-eight long-line shots were made during these research surveys but no white sharks were captured.

A pilot, fishery-independent, fixed station survey for southern shark stocks was undertaken in 1998–1999, in anticipation of a move to ITQs. No white sharks were caught, but the effort was very low (T. Walker, MAFRI, Queenscliff, Vic., personal communication).

The percentage of overall effort and the numbers of white sharks caught in these research surveys were very low. This makes conclusions from these data difficult. However, catches of white sharks per unit effort in research cruises was lower in the mid-1990s compared to the earlier survey periods.

Shark fishery catch estimates from other sources of information
The information regarding the number of white shark jaws entering the market was provided to researchers from Fisheries Western Australia (FWA) by a dealer in jaws, in 1996 (Simpfendorfer 1996).

> "The jaws from the majority of white sharks captured in WA are sold through a single buyer… Since entering the market about three years ago (1993) he has purchased approximately 100 sets of jaws from around the State. Many were old sets…. During the past three years the number of fresh specimens obtained by the buyer has been around 25. The buyer estimates that during this time he did not get access to another 10 (fresh) sets. His estimate for the past three years was that 35 specimens had been caught. This averages out to about a dozen individuals per year."

This would be an underestimate of actual catch, as it refers to white sharks that were dead or killed at the boat, and does not include white sharks that were released or dumped without further processing, or whose jaws were retained by the fisher. The buyer's estimate of about 12 white sharks killed per year in WA in the mid-1990s is similar to our estimates based on catch rates and percentage effort (10-20 killed per year over the last decade).

When contacted in 1999, this buyer estimated he had bought another 50 jaws since 1996, although this also included jaws from South Australia.

A long-term, and now retired, commercial fisher (fishing shark and other species) estimated he had caught nearly 100 white sharks over a 25 year period fishing in the Esperance area and the western GAB, with most caught in the earlier years. A decrease in captures is not obvious over the last ten years based on comments from other WA fishers and it is possible that the biggest decrease in white shark numbers occurred in early years. However, changes in gear and effort over time have also influenced catch, and may affect this trend. Other anecdotal information from long-term, or retired, fishers in SA also suggest that there were initially high catches of white sharks in SA and WA (south coast from Albany, east to SA Border) and that capture rates have decreased over time.

One retired fisher reported catching white sharks relatively frequently in the "early days" (years not specified) in Bass Strait, but none in later years, again suggesting a possible rapid initial decline during earlier years of the shark fishery. Some fishers reported 1-2 white sharks being landed per week at Ceduna- Streaky Bay prior to protection, equating to about 50 white sharks a year. A retired fisher reported catching about 12 per year in this area. If these catch rates still occur, a total catch of 54 (± 41) per year for the KI to GAB area, may be an underestimate.

In 1998, 480 additional boats (to those issued with Commonwealth permits in the SSF) landed shark from State proclaimed waters of South Australia, Tasmania and Victoria under various State licences. In South Australia, these vessels are managed as part of the MSF (see Section 3.1.2).

Release rates and survivorship

Some white sharks that are either entangled or enmeshed are still alive when nets are retrieved. These sharks may:

- be killed (although this is now illegal),
- die before they can be released,
- be released alive but do not survive,
- be released alive and survive.

The percentage of white sharks that are successfully released alive compared to those that die before release, or are killed subsequent to capture, is unknown. According to fishers, about 50% of white sharks caught in the WSF are released, although this varies between years and areas.

Comparing the 115 captures (where details are available) in the WSF and SSF over the past decade suggest that a reasonable proportion either are or could have been released. Release rates appear to have increased since the mid-1990s (Table 4).

Table 4: Number of sharks released, dead or killed by year since 1990, from records on the database.

Year	Released	Dead	Killed	Dead or killed?	Escaped	Total
Not specified	2	1		1		4
1990		4	1	1		6
1991	1					1
1992	2	8		3		13
1993	1	4		2		7
1994	1	2		3		6
1995	4	1	1	1		7
1996	4	4	1	2		11
1997	7	4		1		12
1998	9	6				16
1999	20	8			1	29
2000 (to May)	1	1			2	4
Total	52	43	3	14	3	115

From records and anecdotal information, some fishers were releasing white sharks well before the mid-1990s, although the percentage of fishers doing so was probably low. Only one white shark was reported as released out of the 15 catch records on the database prior to 1990 (from commercial shark fishing).

Since 1990, 52 captured white sharks are known to have been released alive, three escaped and at least three were killed. Forty-three sharks were already dead and another fourteen were either dead or killed upon retrieving the gear. If these 14 were already dead, the proportion able to be released is about 50:50 overall. If some or all of these 14 were killed, the proportion able to be released should be higher.

This comparison is unlikely to provide an accurate estimate of the percentage able to be released, as most captures are not reported and the survival rate of white sharks after release is not known. From anecdotal information, release rates appear to be highly variable between fishers (from 0-80%) and may depend on a variety of factors including the:

- degree of entanglement, and method used to untangle and release the shark
- location and length of set
- size of shark, and
- fisher's attitude and experience.

The size range and mean estimated lengths of sharks successfully released were not significantly different to sharks that were already dead (t-test, $p = 0.2$) (Figure 12). This suggests that size may not have a major influence on release, although handling time would be expected to increase with size of shark, and this could increase post-release mortality.

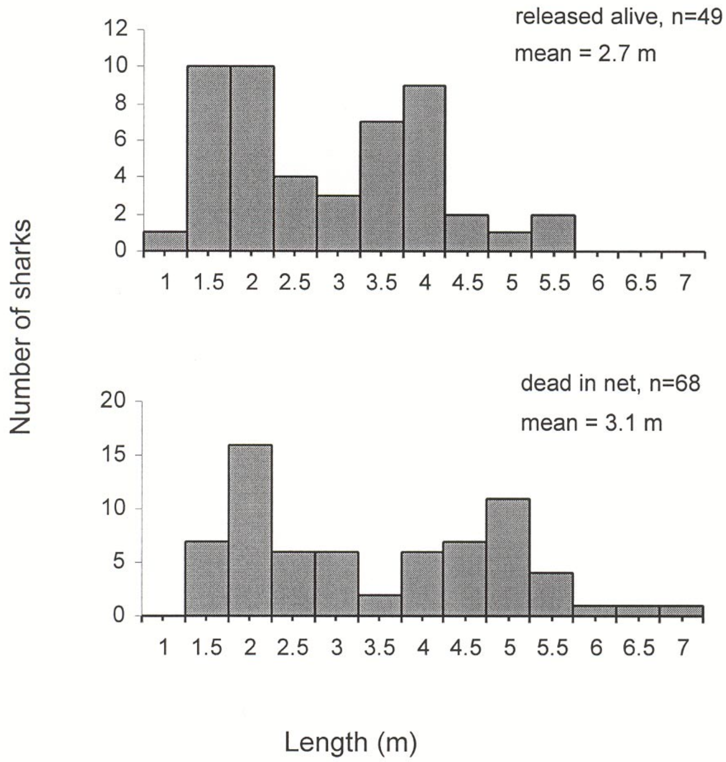

Figure 12: Size range and mean lengths of sharks released alive and found dead in gill-nets (SSF and WSF combined).

The percentage that could have been released since protection, but which were (illegally) killed is unknown.

Some white sharks are also killed because it is too dangerous for fishers to attempt to release them, although this depends to some extent on the personal attitude of the fisher. Some shark fishers will shoot larger sharks that they capture prior to bringing them into the boat to reduce the chance of the shark causing damage. Some shark fishers have stated they will do everything they can to release a white shark if it is alive.

It may be impossible to release a live shark if it is too badly entangled. One fisher reported spending up to two hours cutting a badly entangled white shark out of his net ropes.

Some net fishers report having considerable success at releasing white sharks alive. This may be in part due to the technique used. Some successful techniques have included:

- ‘jerking’ the drum or shaking the net where the shark is lightly meshed

- cutting a few meshes where a shark is lightly meshed
- taking the weight off the net to enable any wrapped rope and net to be cut free from the shark
- turning sharks around if they come to the boat head-first (to reduce weight, reduce the danger to the person, and to get access to any rope caught around the tail). This technique requires getting a tail-rope onto the shark.

The post-release survival rate of white sharks is unknown. White sharks need to swim to pass water over their gills and oxygenate their blood. They will become hypoxic if prevented from swimming (such as through entanglement) and eventually die. Some of those released alive may be in a critical condition and not recover. However, white sharks can survive some degree of hypoxia and an attempt at release is worthwhile. A study of post-release mortality of gill-netted sharks found an overall rate of about 35% that were released alive subsequently died (Heuter 1994). This was based on a number of species (not including the white shark), and cannot be directly applied in this case. However, it does suggest that a proportion of white sharks released from gill-nets, may not survive.

There are two cases in Australia where white sharks have been tagged and released after being entangled, and then later recaptured. A 1.7 m shark caught in a commercial shark gill-net was captured 4.5 months later by another commercial fisher. A 4 m shark entangled in tethering cable was captured nearby six months later by a commercial fisher.

Two small white sharks (1.8 m and 2.4 m) that were satellite tagged (as part of this project) were on a set-lines for up to two hours (if captured at the start of the set), and were out of the water for 4.5 –6 minutes. However, these sharks were handled more gently than could be expected on a fishing boat and were also towed prior to release to help re-oxygenate the blood. These sharks were tracked for seven and 18 weeks respectively before contact was lost. Although constrained by the set-line, both sharks were swimming on the surface and into a current when first observed. White sharks caught on long-lines may continue to get some water movement across the gills through constrained swimming, provided they are not entangled.

Recovery of an archival tag from a white shark that was captured in a net also provides some data on the time taken to succumb following entanglement. From the depth profile, the shark was in the net for 4.75 hours (Figure 13). Based on the report by the fisher, the shark was "almost dead" when the net was first pulled and had died by the time it was untangled. The shark had tangled up 50 m of net and both the head-line and foot-line were wrapped around the body.

The effect of capture on the survivorship of sharks that slide or roll out of the net as it is being pulled is not known.

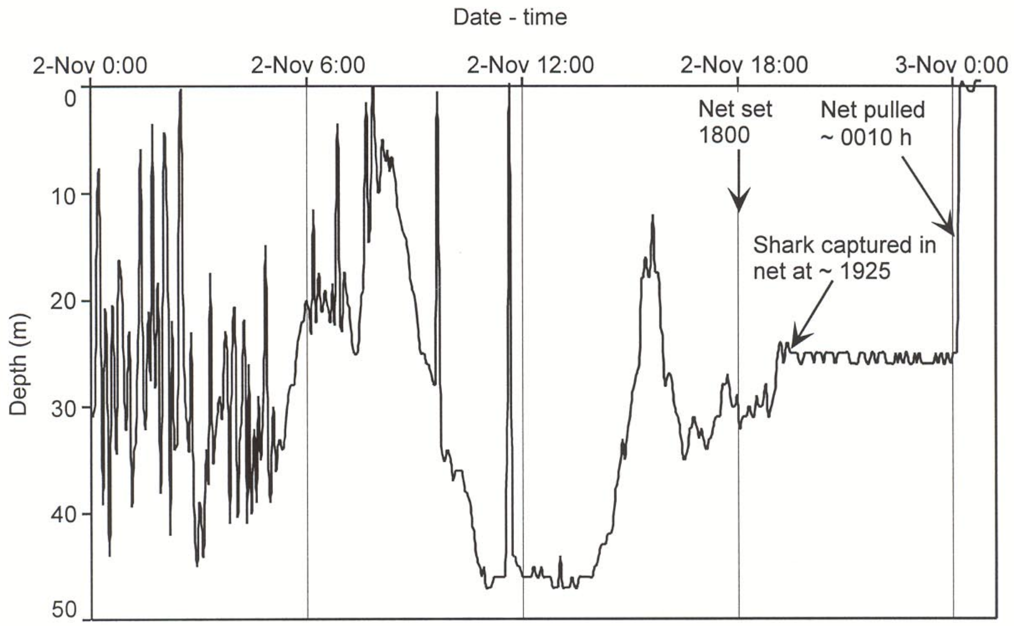

Figure 13: Time of capture and duration of entanglement of the archival tagged white shark in a commercial shark net.

3.2.2 South Australian Marine Scale-fish Fishery (MSF)

This is a multi-species fishery in South Australian State waters targeting mainly snapper, shark, whiting (*Sillaginodes punctata*), squid (calamari, *Sepioteuthis australis* and arrow squid *Nototodarus gouldi*) and crab (primarily blue crab *Portunus pelagicus*). Fishers use a range of gear including large mesh nets, long-lines, handlines, jigs and crab nets. There are a large number of existing licences (477 in 1996-PIRSA 1996) that have different gear endorsements.

Gill-netting for shark and scale-fish

Gill-nets are used for sharks and some scale-fish. Fifty-five licences have large mesh net endorsements, some of which belong to fishers in the SSF. A number of endorsements are probably not used on a regular basis (all MSF licence holders have a handline endorsement for hooking).

Replies to the MSF questionnaire were received from six gill-net licence holders, of which three also had Commonwealth SSF licences. Two of the 'State-only' fishers operate within the Gulfs. One fisher targets shark and reported catching two white sharks in 32 years (1994 and 1995). The other fisher targets scalefish in Gulf St. Vincent and had not caught any white sharks. Other State gill-net fishers are also known to catch white sharks; this includes two incidentally caught near Victor Harbour in 1999. This fisher used short nets with large mesh (7-14 inch = 178-356 mm stretched mesh) set overnight adjacent to reef. Information from various sources indicate that another State fisher operating in the eastern GAB caught between 12 and 14 white sharks in 1999, although in this case there may have been some intentional targeting.

Catch by MSF gill-net fishers seems to be highly variable from negligible to high depending on the fisher and the location fished.

Long-lining for snapper and shark
Long-lines are used for snapper and shark and are restricted to 400 hooks (SARDI 2000). A total of 350 MSF licences have long-line endorsements. There is considerable latent effort with many endorsements either not used or used infrequently. There are currently about 10 main long-liners in northern Spencer Gulf, and three in northern Gulf St. Vincent. The number of long-liners has decreased due to part-time licences gradually being removed. There are probably similar numbers of long-liners in the southern gulfs (K. Jones, SARDI, West Beach, Adelaide, personal communication). There is also a small long-line fishery on the west coast (Streaky Bay and Ceduna) with between six and twelve vessels fishing the area. There are a few long-liners along the southeast coast, including Kangaroo Island and the Pages. Long-liners in these above areas account for 10% of total endorsements.

There are specific differences in the way that fishers long-line in different areas. In the northern gulfs, the peak long lining period is from autumn to early spring when fishers target large adult snapper. Long-lines are often set overnight due to regular strong winds and rough seas in the upper gulfs during the day.

In the southern gulfs, fishers only use handlines during the peak summer months when snapper aggregate to spawn. This is not controlled through regulation but by a general agreement between the fishers. Long-line fishers, who target gummy shark, whaler sharks and snapper until May/June, will also handline until late February.

On the west coast of SA, long-line fishers generally restrict soak time to a maximum of four hours, with sets usually lasting three hours or less.

White sharks have been caught by long-liners targeting shark and snapper on the west and southeast coasts of SA, as well as in Gulf St Vincent and Spencer Gulf where they are associated with the snapper grounds. This includes large white sharks (> 4.5 m) that are occasionally captured in the upper gulfs.

Sharks scavenge catch from long-lines and can be caught either by being hooked or by entanglement. They are most likely to be retained by the gear when they entangle in the mainline, either by spinning and getting a tail-hitch or by foul-hooking on adjacent snoods. This is most likely to occur when there is ‘slack’ in the gear and when snoods are close together. One snapper and shark long-liner in Spencer Gulf has changed from light gear (4 mm main-line) and light anchors to heavy main-line (10 mm rope) anchors and chain, high breaking strain stainless steel trace, and about eight m between each trace. Since changing gear, he has not caught a white shark and he also catches fewer large female whaler sharks.

Fishers that make short sets also catch fewer white sharks (this presumably leads to a decrease in attraction time) and are more likely to be able to release them alive. One fisher in upper Spencer Gulf, who only fishes during the day with a three hour maximum set, reported never catching a white shark in 40 years of long-lining. Long-liners on the west coast also rarely capture white sharks, except in the case of a fisher who developed a method to entangle them once they were hooked. Three white sharks were caught in 1999 by a single long-liner on the west coast, and he was able to release all three. These were the first he had caught on long-line in 20 years of fishing.

Overall, it is difficult to estimate the total number of white sharks caught per year on long-lines in the MSF. Captures are highly variable even within one area, and are strongly influenced by location and fishing method. From survey returns and telephone conversations, catch rate estimates from 14 fishers were used to estimate an average catch rate of 0.56 white sharks per year (sd = 0.87). When separated by location, catch rates were highest in upper Spencer Gulf, although this is only based on 6 estimates (Table 5) and these rates were highly variable between fishers (Figure 14).

Table 5: Average long-line catch rate estimates for white sharks in the MSF.

Area fished	N	Average rate per year	Standard Deviation (sd)	Expected range (average +/- sd)
Upper (northern) Spencer Gulf	6	1.00	1.20	0 to 2.2 per year
Lower (southern) Spencer Gulf	3	0.26	0.26	0 to 0.5 per year
Gulf St. Vincent	1	0.16*		*
West coast (Streaky - Ceduna)	3	0.16	0.16	0 to 0.3 per year
KI -Pages	1	0.30*		*

* average/range not calculated – only 1 record available

Based on estimated catch rates and numbers of long-liners in each area, approximately 16 white sharks per year are caught on average. Researchers working on snapper reported hearing of "about two" white shark captures per year. If the higher catch rates experienced by some fishers are more prevalent than indicated by the survey, the overall catch rate could be considerably higher than estimated. A proportion of these sharks either are or could be released, depending on location and method.

Survey returns were received from 18 fishers who had never caught a white shark. However, these returns did not indicate fishing method. If some of these were long-liners, this would decrease the average estimates.

Hand-lining for snapper and whiting

Hand-lining is mainly used for snapper and whiting. White sharks interact with snapper hand-liners by swimming around their boats and occasionally biting off the catch. Interactions with white sharks were reported by fishers to occur on an average of 4.5 trips per year (range 0-10; data from ten fishers).

Overall effort targeted at snapper (all fishing methods) declined significantly in the 1980s and early 1990s but has since stabilised at about 4000 boat days. However, the distribution of effort between the long-line and hand-line sectors changed in 1989/99 with long-line effort decreasing (30%) and hand-line effort increasing (McGlennon and Jones 1999). The probability of catching a white shark decreases significantly when hand-lines are used instead of long-lines. For example, one snapper fisher in upper Spencer Gulf reported catching 13 white sharks during six years of long-lining, but had not caught any in the seven years of hand-lining. A shift towards hand-lining may thus result in a decrease in catch of white sharks, unless interactions with white sharks are also increasing by a similar amount.

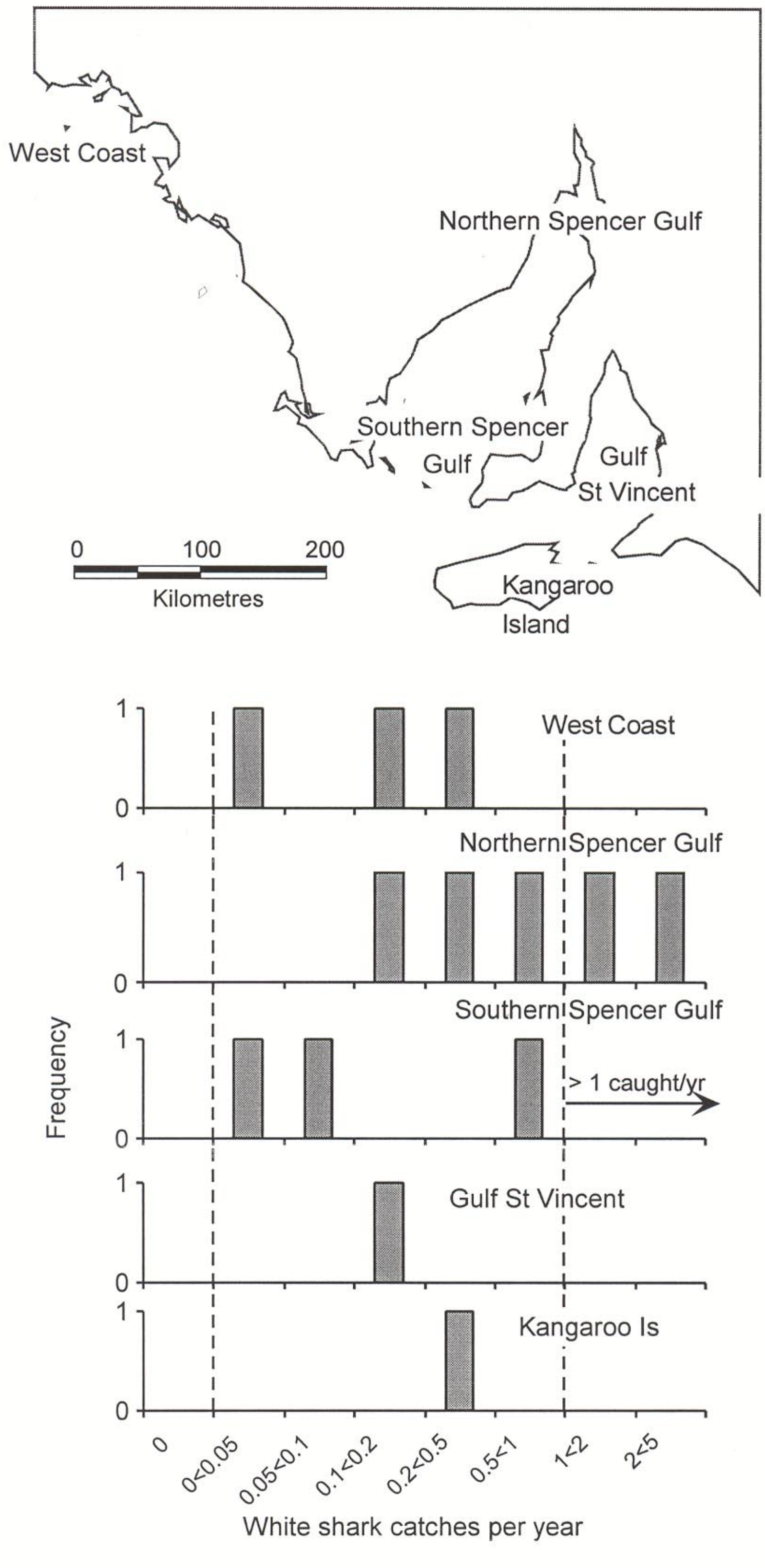

Figure 14: Estimated catch rates of white sharks by fishers in the MSF.

White sharks were occasionally hooked on hand-lines but generally escaped by bending the hook or breaking off. Data available from the ten snapper hand-liners suggested that catch rates were negligible. Seven fishers, who had been hand-lining over periods of 9-51 years, reported never catching a white shark. One fisher had caught three in 40 years (all released); another had caught two in 16 years (using rod and reel) and a third fisher had hooked two white sharks over 12 years but both had broken off.

White sharks swimming around snapper boats are unlikely to be caught using hand-line, and the threat from this method is expected to be negligible. However, sharks swimming around a vessel may be intentionally hooked with heavy gear or shot by fishers. It is unknown to what extent this occurred prior to protection, or if it still occurs in the fishery.

From the available reports, whiting fishers generally do not catch white sharks although some reported seeing them in the Ceduna, Streaky Bay and Wardang Island areas.

3.2.3 Other commercial fisheries

Victorian charter, hook and long-line snapper fishery

Juvenile white sharks are associated with snapper grounds from Corner Inlet to Lakes Entrance during the snapper season (October to April). Small white sharks were caught on game-fishing gear, snapper long-lines and occasionally on rods rigged for snapper prior to protection. One fisher reported catching 39 white sharks in 11 years in this area.

White sharks are still caught incidentally in this region using various methods, although it is generally possible to release them. A small white shark was caught, and died, in April 2000 after becoming tangled in a snapper long-line. A different long-line hook was found in its mouth, indicating that it had previously interacted with long-line gear.

To May 2001, only one of the voluntary logbooks has been returned from this fishery; no white shark interactions were recorded. This operator made considerably fewer trips than normal in the 1999/2000 snapper season due to poor fishing.

Inshore scale-fish fishery, Tasmania

This is a multi-species and multi-gear fishery that includes gill-netting, line fishing and seine-netting. White sharks have been caught in gill-nets targeting scale-fish and shark. However, only a few catch rates are available. These range from zero in seven years, up to 10 in about 30 years. Detailed capture records are available for 13 white sharks caught in this fishery by gill-netting. Six sharks were dead on capture, five were killed and two were released. Estimated lengths ranged from 1.5 m - 5.5 m (average 4 m). These figures are probably not an accurate reflection of the number of white sharks caught in this fishery and further work is required to assess the level of catch. Inshore commercial gill-net effort in Tasmania is exceeded by the recreational sector (Lyle 2000).

NSW ocean haul-net fishery
Small (generally 1.8 to 2.2 m) white sharks are occasionally captured in the ocean haul net fishery in NSW (and possibly in similar haul or seine fisheries in other States), although not in all locations or by all fishers. This fishery mainly targets sea mullet (*Mugil cephalus*) and Australian salmon. White sharks have been reported with Australian salmon schools, particularly in the Newcastle – Port Stephens region. In one case, three small white sharks were caught in a single haul. At least two were captured in 1999 near Port Stephens. As nets are hauled rather than set, it should be possible to release captured white sharks alive and in good condition, as is required under protective legislation.

Demersal long-line and other inshore scalefish fisheries in NSW
Demersal long-lines (each with several hundred hooks) are set overnight on reefs and target mainly wobbegong sharks (*Orectolobus* spp.) and various scalefish species. Fishers reported catching white sharks (e.g. two captures were reported by a demersal long-liner in 1999). However, captures are irregular and fishers report they can go for "years" without seeing a white shark. The total number caught in this fishery is unknown.

Some other fishers reported occasionally catching white sharks in areas such as Forster in association with trevally (*Pseudocaranx* spp.) or mulloway (*Argyrosomus hololepidotus*).

Crustacean trap fisheries (all States)
There are five records on the database of white sharks having being entangled in the float ropes of crab nets and rock lobster pots. However, white shark captures by these fisheries are expected to be rare.

Demersal trawling
A small number of white sharks may be caught by this method based on a specimen seen on a trawler in Portland (Victoria) by a fisheries compliance officer. A single (unverified) capture of a white shark by a South Australian prawn trawler prior to 1986 was also reported (year not specified). Overall capture rates by demersal trawling are unknown, although expected to be very low.

Tuna long-lining
No white sharks have been recorded by observers on Japanese tuna long-line vessels fishing in the Australian EEZ (Stevens and Wayte 1999). There is currently no observer program on domestic tuna long-liners. Neither of the two domestic operators that were contacted, reported captures or interactions with white sharks.

Tuna long-liners operate mainly beyond the continental shelf. Although white sharks are known to associate with tuna schools, the number of captures by this fishing method is likely to be low.

Set or drum-lining (all States)
Set-lines or drum-lines have been used to target larger sharks for fins, meat, bait, or teeth by both commercial and recreational fishers. It is usually an incidental and minor part of a fishing operation. However, in some cases this method has been used to target a specific (nuisance) shark (see Section 3.1.6).

Historically, drum-lines were set off a number of areas in the SA Gulfs by fishers specifically targeting white sharks for their jaws and meat, and as a way of relieving shark predation on long-line catch. Other commercial shark fishers have used this method in different locations but not specifically for white sharks.

Some rock lobster fishers have reportedly set a shark line overnight to capture sharks for bait. The line is either attached to their pot floats or to the vessel. The percentage of rock lobster fishers that carry out this practice is unknown. The number of white sharks that are caught is also unknown but will be highly variable depending on location. Samples were obtained from two white sharks caught by rock lobster fishers in this way (prior to protection).

Some shark vessels also run a set-line from the vessel while it is at anchor. A 3.3 m female white shark was caught on a chain and hook set from a shark vessel in April 2000, but was lost when the line was retrieved.

3.2.4 Tuna farming and other fin-fish cage mariculture

There are several reports of white sharks being captured in tuna tow cages and in inshore tuna farm cages. There were three confirmed captures and one unconfirmed in 1999. In total, there are nine confirmed captures by the tuna farming industry over a period of about five years. In six of these cases the shark was killed, usually by power-head. In three cases the shark was already dead. White sharks captured in the tuna cages have ranged in length from 3.0 - 5.0 m and include both sexes.

There are unsubstantiated reports of up to10-20 captures of white sharks by the tuna farm industry and multiple interactions each year. Further work is required to accurately estimate the number of sharks that they catch.

Cage based mariculture of finfish species such as snapper and kingfish (*Seriola lalandii*) are also likely to incur interactions with white sharks and should be monitored.

Releasing white sharks from cages

There are two reports of attempts to release white sharks from tuna cages. Tow cages are usually 50 to 80 m in diameter and about 16 m to 18 m deep. Removing an active white shark from a tuna tow cage is difficult and presents a risk to those involved. At least one attempt (based on an anonymous report) to release a white shark was made in 1999. In this case the shark was found lying on the bottom of the net, in poor condition but still alive. A diver tied a rope to its tail and it was hoisted out of the cage then released over the side where it subsequently sank. A second report of an attempted release was received in 2000, however details were not available.

3.2.5 Shark control programs

Shark control using heavy-duty nets with large meshes, or drum-lines, is carried out in New South Wales and Queensland. The intent is to provide swimmers with protection from sharks at certain beaches by reducing the density of sharks within a particular area.

New South Wales
The netting of beaches in the more populous sections of NSW started in 1937 in Sydney. Beach meshing is presently carried out from September to April. Records have been kept since 1950-51. The total number of white sharks caught from 1950 to the end of the 1999/2000 season was 517 (Figure 15). The increase in catch during the 1970s can be partially attributed to a substantial increase in effort during this period (Reid and Krogh 1992).

Between 1972 and 1990, 54% of white sharks were caught in the Newcastle region (D. Reid, NSW Fisheries, personal communication), an area which accounts for about 25% of the effort. Watamolie and Garie beaches off the Royal National Park also had high catches during this period. Eight white sharks were caught during the 1999/2000 season, all within the Newcastle region. Five of these were caught during a single weekend at adjacent beaches and ranged in length from 1.75-2.16 m. Two of the eight were still alive when found, and were released. For white sharks where life status was recorded, 105 of 227 (46%) were alive when found.

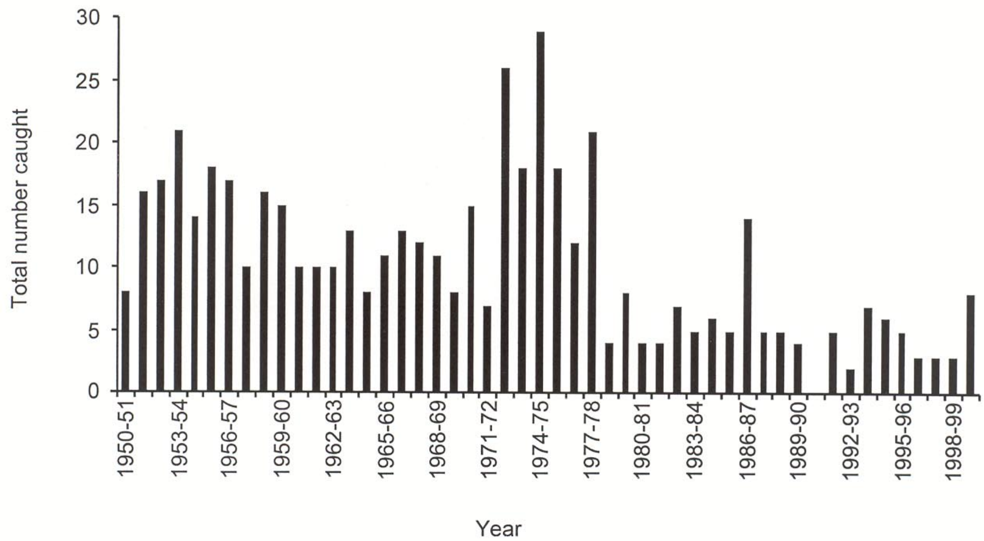

Figure 15: Total numbers of white sharks caught in the NSW shark control program 1950 – 2000 (data supplied by NSW Fisheries).

Queensland
The Queensland Shark Control Program (QSCP) started in 1962. From 1962-1998 there were 631 white sharks caught in this program (G. McPherson QDPI, personal communication). Both drum-lines and shark nets are used in Queensland, and white sharks are caught by both methods. Most of the white sharks were caught in southern Queensland. The number caught per year is highly variable (Figure 16), but has generally decreased through time. White sharks are not released from the QSCP.

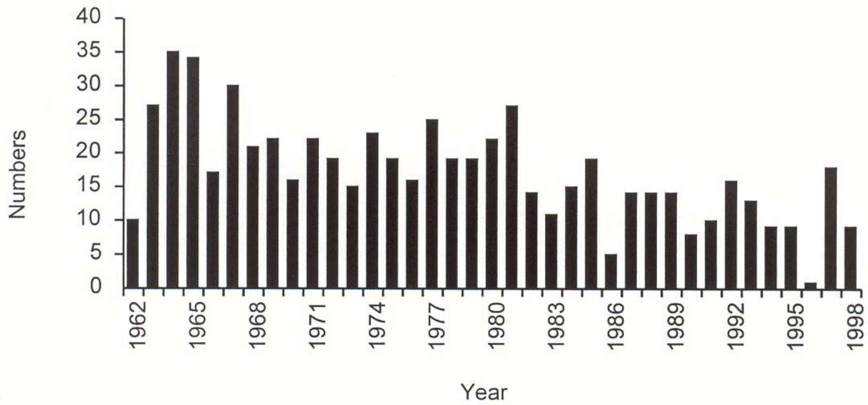

Figure 16: Total numbers of white sharks caught in the Qld shark control program 1962 – 1998 (data supplied by QDPI).

3.2.6 Targeting

Intentional targeting

Pressure to kill white sharks can arise after an attack, especially when one or more large specimens are observed close to a popular beach area.

A number of white sharks interacted with small fishing vessels around Ceduna in 1999. Local concerns resulted in a request to PIRSA asking that some white shark control be considered in this area. At Point Turtin, where a windsurfer disappeared earlier in 1999, there were anecdotal reports about targeting a white shark regularly observed in the area. There were also anecdotal reports about a reward on a white shark that was observed around Phillip Island in 1999, although the veracity of this is unknown. More recently, there have been calls for the removal of white sharks sighted in the Port Lincoln area.

Prior to protection, there were a number of examples of targeting of white sharks following an attack. This often included the involvement of professional shark hunters. It is still possible that local residents will continue to remove white sharks that are perceived to be a threat.

Defacto targeting and indiscriminate killing

There are many anecdotal reports of both recreational and commercial fishers catching or shooting white sharks observed swimming near vessels because the shark has disrupted fishing either by stealing the catch or dispersing the target species (e.g. snapper).

Some people may kill, or attempt to kill, white sharks because of a genuine concern for safety, irrational hate or fear, a false sense of bravado, or simply through a total disregard for other life-forms. The number of sharks killed for these reasons is unknown. The incidence of these targeted killings will presumably decrease with changing attitudes and an increase in more accurate information on the species. However, there will probably always be a small proportion of people who will continue to target white sharks.

Illegal fishing
There are a number of unlicensed fishers that illegally capture and sell fish in Australia. Some of these fishers set drum-lines as part of their illegal activity. An anonymous report was received in December 1999 of two white sharks that had recently been caught off Ninety-Mile Beach in Victoria. These fishers were reportedly targeting snapper, but also set drum-lines for shark. There are unconfirmed reports of fishers setting drum-lines targeting white sharks in other areas of southern Australia for their jaws and teeth.

Historical targeting at whaling stations
White sharks were attracted to whale carcasses that were brought into the Albany whaling station for processing up until the 1970s. The dead whales would create a large oil slick that attracted white sharks to the area. During these years, a large number of specimens (estimated in the hundreds) were killed at the whaling station and around Albany using a variety of methods. These included large shark hooks on heavy cable, lassoing with a steel cable, shooting, and game-fishing using rod and reel. One ex whale-towboat operator reported seeing about 20 white sharks killed during the two years he worked at the whaling station. A former fisheries inspector caught 12 white sharks on rod and reel and a number with lasso (Western Fisheries Spring 1999). White sharks were no doubt targeted at other whaling stations on occasions (e.g. Eden, NSW and Moreton Bay, Qld).

3.2.7 Game-fishing
Game-fishing for white sharks in Australia is currently prohibited under protective legislation. However, game fishing for white sharks was actively pursued in South Australia, New South Wales and to a lesser extent in Victoria and Western Australia prior to protection.

The capture-kill of white sharks was at its height in South Australia during the 1950s, based on numbers caught (Bruce 1992). Large white sharks were captured around sea-lion and fur seal colonies in locations such as the Pages, Dangerous Reef, Sir Joseph Banks Group, Streaky Bay and Ceduna. A few individuals accounted for a high number of capture-kills including identities such as Alf Dean, Ern Palmer and Bob Dyer. The emphasis changed to tag-release in the early 1990s, although some sharks were tagged and released as early as 1975 (NSW FRI game-fish tag database) and capture-kill was still carried out for trophies such as the well-publicised shark taken by golfer Greg Norman in 1990 (Starling 1990).

The overall number of white sharks that were killed throughout Australia by game-fishing has not been determined. Compiling and analysing historical capture information from game fishing clubs would be a worthwhile future project as part of the ongoing assessment of white sharks in Australia. Game fishers are also a valuable source of current and future encounter rates (e.g. the number of white sharks sighted during fishing tournaments) and liaising with clubs to report sightings is recommended. Several game fishers have expressed interest in assisting with such work.

Some limited information has already been compiled. In total, 162 white sharks were landed by the 10 main NSW game-fishing clubs from 1961-1990 (Pepperell 1992). Most sharks were between 50 and 200 kg. This compares with 45 white sharks landed by members of the Game-Fishing Club of South Australia (GFCSA) in the same period. A total of 171 white sharks (Figure 17) were landed by the GFCSA from 1938-1990 (Bruce 1992). South Australian game-fishing identity, Alf Dean, caught a large number of white sharks in South Australia. He estimated the biomass at more than 50 tons (Ellis and McCosker 1991), with seven of the sharks weighing more than 780 kg (Palmer 1981). Ern Palmer reported more than 200 interactions with white sharks over a 40 year period.

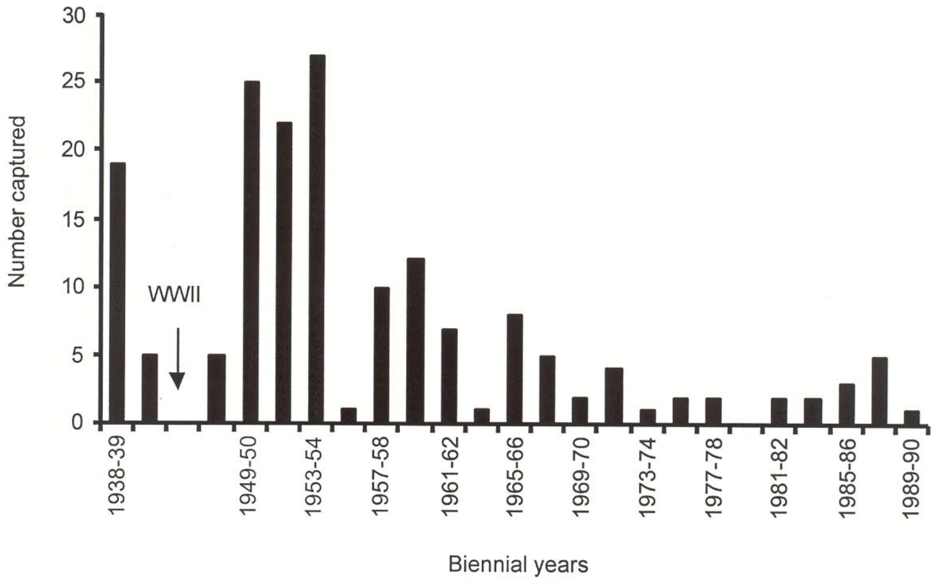

Figure 17: White sharks caught by the GFCSA (1938 – 1990).

Some game-fishers have concentrated on landing large white sharks on light gear in the pursuit of records. This resulted in a large number of sharks breaking off prior to capture. One game-fisher, using 14-23 kg line with a 9 m steel trace, reported landing two large sharks but broke off about 30 to 40 sharks in the late 1980s. Another fisher in the same area reported hooking about 20 to 30 in total, and would 'play' them to the boat but then release them due to the small size of the boat.

The effect of capture stress on white sharks is not known. Effects will vary depending on a range of factors such as shark size, the time taken to bring the shark alongside the boat, the location (jaw, throat or stomach) and type of the hook and trace (stainless steel or galvanised) and the way it was 'played'. Capture may result in subsequent mortality or a range of sub-lethal effects. These may include reduced growth, a temporarily reduced capacity to feed, interrupted reproductive activity, or greater chance of attack from other white sharks. Effects may be acute, chronic, or negligible depending on the particular shark and nature of capture. At least one shark has been observed to sink after being hooked "deep in the gills". There are also confirmed records of white sharks surviving capture. This includes a 3.5 m shark that was sighted at the Neptune Islands in May 1999 with marks around the body and hook damage on the head and mouth. This shark was probably caught using galvanised trace that was intended to rust away (R. Czabayski, Calypso Star Charters Adelaide**,** personal communication). There are two recaptures on the NSW tagging database of white sharks tagged by game fishers; one of these was re-caught a few hours later by the same fisher, suggesting little trauma following the original capture.

The time taken to bring a white shark alongside a boat is highly variable and depends on a number of factors including the size of shark, strength of line, depth of water, skill of both the angler and skipper, as well as the individual shark. Some sharks have taken a number of hours to land. Details available include the hook and trace being cut off a 4.2 m, 680 kg shark after 55 minutes and a 4 m, 520 kg shark fought for 55 minutes before coming in "belly-up". The trace was cut close to the mouth in the latter case whereupon the fish sank, and then slowly righted itself and swam away. Alf Dean was reported to have taken five hours to bring a 5.5 m, > 1800 kg shark to the trace (Palmer 1981).

Other anecdotal examples of the duration and effects of capture (validity unknown) on white sharks are as follows:

- A 5.3 m shark caught in 1985 near Ceduna was reported to take 4 hours to land.
- A 5 m, 1520 kg shark caught in April 1990, reportedly took more than 5 hours to get alongside the boat.
- A 4.5 m, 750 kg white shark broke off after 4.5 hours in December 1990.
- A 3.5 m, 480 kg shark was reportedly landed in only 30 minutes after it became 'tail-wrapped' in the trace and 'drowned'.
- A 4 m shark took one hour to bring alongside the boat but was too lively to tag effectively. It was then physically exhausted after a further 25 minutes on the line.

Tagging of white sharks by game-fishers occurred, prior to protection, under the NSW Fisheries Research Institute co-operative game-fish tagging program. Current protective legislation in Australia prohibits the intentional capture-tag-release of white sharks by game-fishers in all State and Commonwealth waters. However, there is considerable interest among game-fishers to reinstate tag-release.

Game-fishers in South Australia can successfully target white sharks. The shark is often sighted prior to capture and there is little doubt that reinstating tag-release would result in increased targeting. The size of these sharks is usually > 3 m. Most tagging in NSW appears to be of incidentally captured individuals, although there are some areas (e.g. Newcastle-Port Stephens) where small specimens might be targeted. Victorian tag-releases include both targeted and non-targeted captures. Tagging in Victoria has been far less active than in either NSW or SA. There are areas where small (e.g. eastern side of Wilson's Promontory) and large (e.g. Warnambool region, Phillip Is.) individuals could be targeted.

3.2.8 Recreational netting

Recreational gill-netting is only permitted in Tasmania and Western Australia. Nets in Tasmania are known as 'grab-alls' and can be up to 50 m long and 33 meshes deep with a stretched mesh size of 10-14 cm. A licence allows the use of two grab-alls by a fisher.

Recreational gill-netting is a significant activity in Tasmania with effort exceeding that of the commercial sector. In 1999, approximately 10,000 recreational fishing licences in Tasmania included an endorsement for at least one grab-all net. Over 75% of all sets are fished overnight, and at least one quarter of all sets have soakage times in excess of 24 hours (Lyle 2000). Restrictions on setting overnight were introduced but were overturned due to safety considerations. New management proposals include restrictions on soakage time to a maximum of 14 hours (DPIWE 2000). This is still considerably longer than a white shark will survive entanglement.

At least 24 white sharks have been caught in recreational grab-all nets in Tasmania since the 1950s (Black 1999), although the actual number is expected to be considerably higher. Twelve of these occurred in the past 20 years. Only one shark was reported to have escaped, and none were released. In at least five cases the shark was killed, usually by shooting. Many of the sharks were caught around the Tasman Peninsula and in Storm Bay.

Sharks ranged in length from 2.4 m to 5.5 m with an average length of 3.3 m (sd = 0.65). There was no obvious bias in the sex ratio from those records where sex was identified and recorded. It is possible that some small white sharks are caught but incorrectly identified. There are no formal requirement to report recreational capture of white sharks other than the fisher surrendering the shark (if it is dead) to police and it then being transferred under permit to CSIRO for examination.

Recreational netting is permitted in most marine waters in WA but no more than 800 m from the low water mark. Nets can be a maximum of 60 m in length and 25 mesh drop with a mesh size of 75-114 mm. Effort is considerably less in WA compared to Tasmania. Only one recreational vessel (out of 7,844 surveyed) from September 1996 to August 1997, in the area between Augusta and Kalbarri, reported using a net (R. McAuley, Fisheries Western Australia, personal communication). Only one white shark was reported captured in the same survey (gear not specified).

3.3 Abundance indicators

3.3.1 Capture and encounter rates from commercial fishing

A number of long-term shark fishers have described an overall decline in sightings and catches over the past three to four decades. One long-term shark fisher described a period during the 1980s when very few sharks were seen or caught. During the past decade, catch rates appear to have been relatively stable overall, although they are highly variable from year to year. Some fishers believe white shark numbers are currently increasing in South Australia.

A questionnaire sent to Marine Scale Fishery fishers in South Australia, included an assessment of whether interactions with white sharks were changing (Table 6). Fifty-nine responses to the questionnaire were received. Views were dependant on the number of years fished, likelihood of encounter (areas fished and gear used) and the length of time over which interactions were recalled. In most cases, responses probably refer to perceived trends over the last decade. Half of the respondents believed that interactions with white sharks have remained the same. Of the remainder, slightly more believed that they had decreased rather than increased. It is difficult to interpret these results, other than attribute it to variation between fishers. Roughly the same trend was apparent when fishers were asked to compare 1999 encounters with previous years.

Table 6: MSF questionnaire: proportion of responses within different categories

Question	Category	Proportion of responses (%)
Have number of interactions?	Decreased	16
	Stayed the same	50
	Increased	13
	Unknown or n/a	21
How does last year compare to previous years?	Less	21
	Average	40
	More	16
	Unknown or n/a	23

3.3.2 Historical game-fishing records.

Game-fishing for white sharks in South Australia was at its height in the 1950s with greater than 10 individuals per year captured by members of the Game-Fishing Club of South Australia (GFCSA). By the 1980s, fishing effort and captures were much lower with an average of 1.4 white sharks killed per year from 1980-1990 (Bruce 1992).

This may be explained partly by a decrease in effort, but may also have been due, to some extent, to a decrease in sharks. An excerpt from an experienced white shark game fisher in 1980 stated: "..these magnificent sharks are declining rapidly so that many sports fishermen are now diffident about fishing for them" (Palmer 1981).

Pepperell (1992) using game fishing data for NSW, calculated that the ratio of white sharks to all other species of sharks caught changed from 1:22 in the 1960s to 1:38 in the 1970s and 1:651 in the 1980s. However, he notes that this may be explained by a tendency for anglers to fish further offshore in recent years, thus concentrating effort away from areas where they were more likely to encounter white sharks.

3.3.3 Shark control programs.

Assuming that catch per unit effort, or numbers, equate to abundance then there has been a significant decline in white shark abundance in both the NSW and Queensland programs (Figures 18, 19, and 20). The trend would be more pronounced for NSW if the whole time series were available, as greater numbers of white sharks were almost certainly caught in the first few years of the program (species-specific data on catch are only available since 1950).

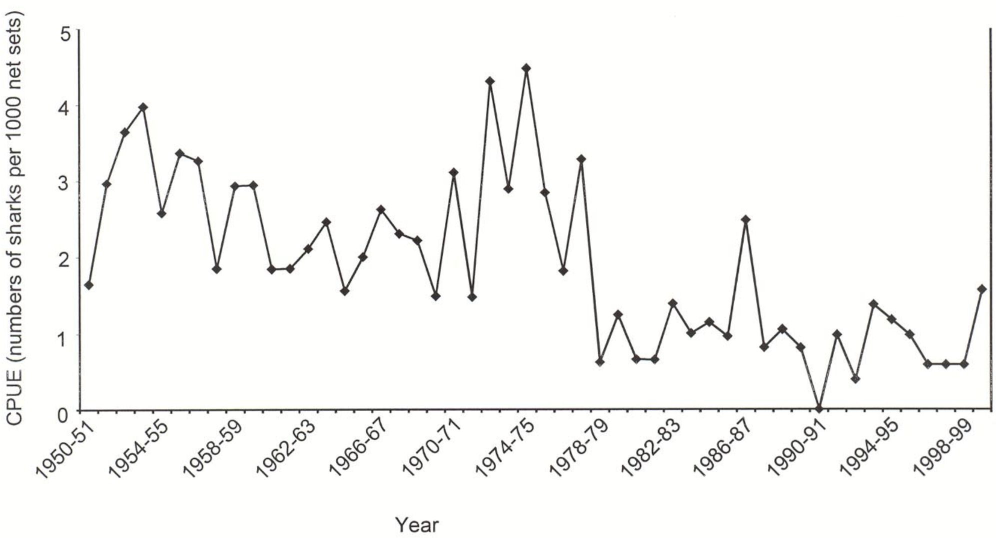

Figure 18: Catch per unit effort of white sharks in the NSW shark control program (information supplied by NSW Fisheries)

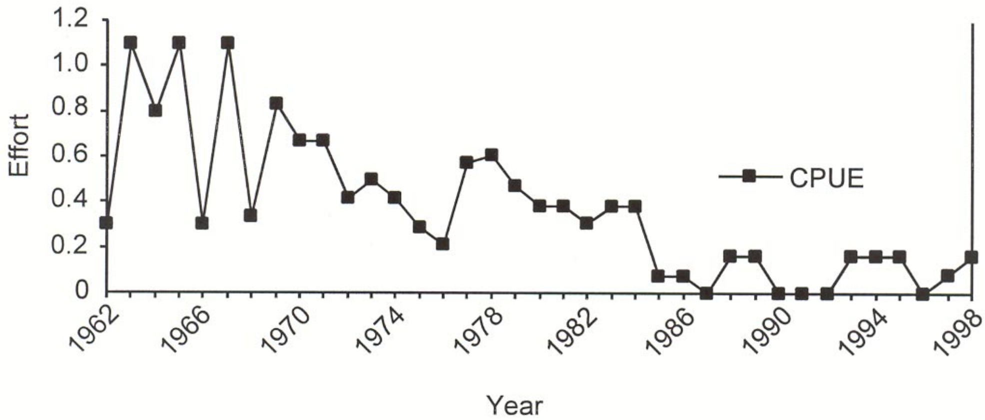

Figure 19: Catch per unit effort of white sharks in the Qld shark control program (Gold Coast – nets)

With the exception of the early 1970s, when there was a significant increase in netting effort, there has been a distinct decrease in white shark catch from the 1950s through to the 1980s. This could be due to localised depletion of more resident fish; or a more widespread effect on the population in the NSW-Qld region. The declining trend appears to have flattened out over the past decade, although annual variability makes this hard to interpret. If this is the case, then either the white shark population in NSW and Qld has stabilised under the current level of fishing mortality, or the inherent variability in the data is masking a continued downward trend. At this stage it is unknown if white sharks in NSW are the same population that occur in Qld, although the seasonality of captures and recent movements of a satellite tracked shark suggest that this may be the case (see Section 3.3.5, movement patterns).

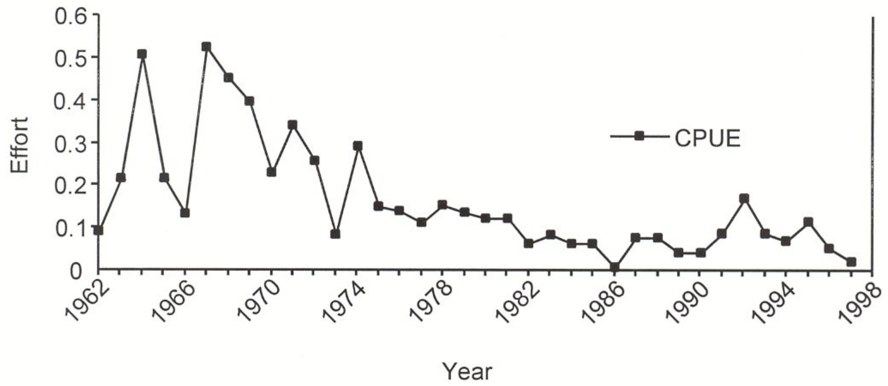

Figure 20: Catch per unit effort of white sharks in the Qld shark control program (Gold Coast and Pt Lookout – drum-lines)

The average length of white sharks caught in NSW meshing operations has also declined over the period, though this is not evident in the Qld data. Only one shark over 2.5 m FL was caught in NSW during the 1990s (Figure 21).

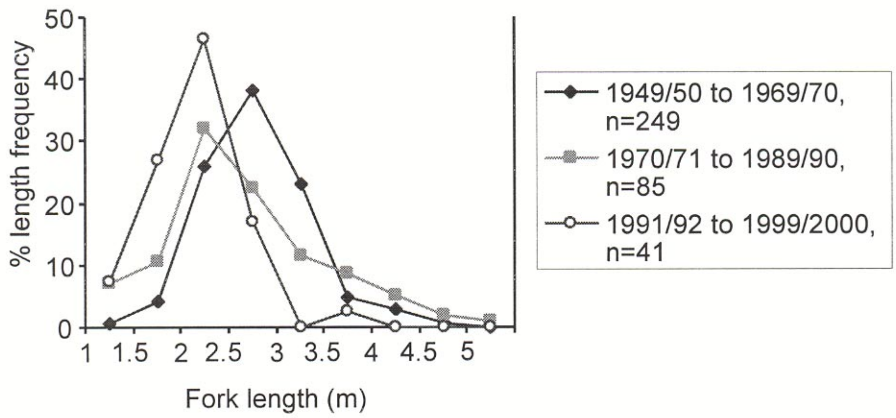

Figure 21: Length frequencies of white sharks caught in the NSW shark control program (data supplied by NSW Fisheries).

The overall mean length of white sharks caught in Qld is about 2.75 m (raw data not available from QDPI). Although there is some variation from year to year, the mean length appears to have remained reasonably constant (Figure 22).

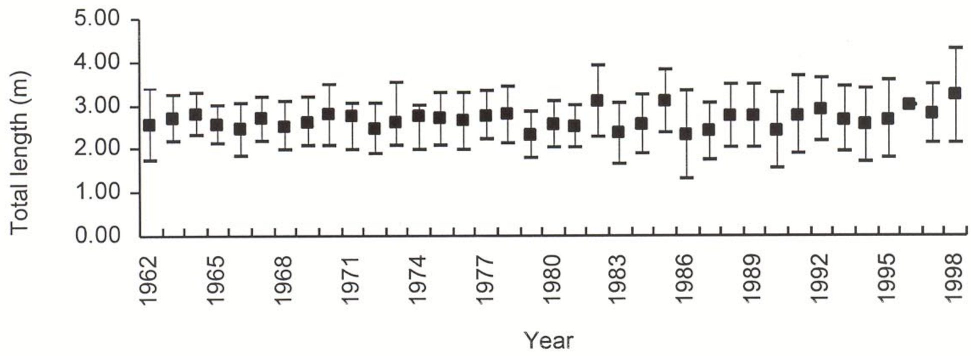

Figure 22: Mean lengths of white sharks caught by year (+/- 1 sd) in the Qld shark control program (data supplied by QDPI).

3.3.4 Cage-dive operations and tagging program (South Australia)

Tagging

A total of 143 white sharks were tagged by cage dive operators or researchers at four sites in the lower Spencer Gulf region of South Australia between January 1990 and January 2001 (Table 7). Most of the tagging effort (particularly over the last 5 years) has been concentrated at North Neptune Island.

Table 7: Numbers of white sharks tagged (free-swimming) in lower Spencer Gulf (Jan 1990-Jan 2001)

Site	Number of sharks tagged
North Neptune Is.	96
South Neptune Is.	16
Dangerous Reef	30
Little English Is.	1
Total	143

Tagging effort has been uneven between years, with 37% (53) of sharks tagged since the tagging program was formalised in 1999 (Figure 23).

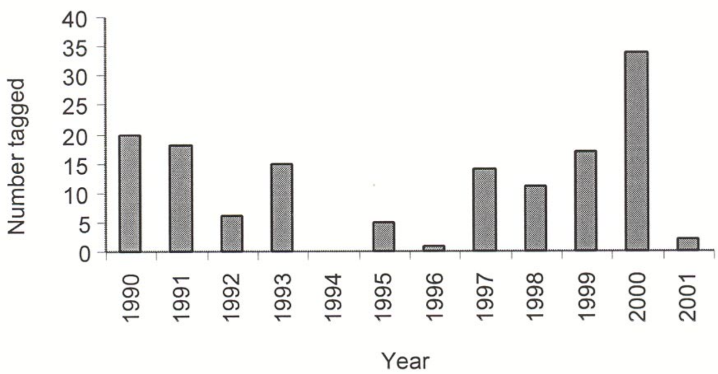

Figure 23: Tagging effort by year in southern Spencer Gulf, SA.

Resightings
Of the 143 sharks tagged, 71 individuals (49.6%) have had confirmed resightings. The number of individual sharks resighted undoubtedly exceeds this figure as not all those tagged can be identified. This is because some were tagged with plain game-fish tags (i.e. no visual ID code) or because the visual ID code (coloured tubing, beads or Gordon tag) may have fallen off the base tag. In some cases ID tags are sighted but the code cannot be determined.

The most frequently resighted shark was seen on 31 separate days from 18 April 2000 to 27 August 2000. The longest period between tagging and resighting was 580 days.

Most sharks were resighted at the site where they were tagged. Only two sharks were observed at another site. One tagged at South Neptune Is. on 24 March 1998 was subsequently resighted at North Neptune Is. on 20 April 1998. The second shark tagged at North Neptune Is. on 2 April 2000, was resighted at South Neptune Is. on 11 and 12 April 2000.

Most resightings occurred over a relatively short period after tagging. Of those sharks whose identification could be confirmed, 50% were only resighted within 21 days of tagging, 25% were resighted over periods greater than 84 days and 10% were resighted over periods greater than 311 days. Only 7% of sharks were confirmed as being resighted after periods in excess of one year. Interpreting these data is difficult due to the variety of different tag identification (ID) codes used to date. The confounding factor is how long ID codes (colour coding or Gordon tags) remain attached to the base tag. None of the earlier (colour coding pre 1996) ID codes are likely to remain intact and it is possible that some of the Gordon tags have also detached. Operators occasionally report the sighting of sharks with unidentified base-tags that are covered in algae. This suggests that a larger number of sharks are resighted after tagging. Gordon tags are now attached directly to a stainless steel wire running through the length of the *Hallprint* base tag. This configuration may reduce tag loss and provide more reliable resighting estimates in future. However, Gordon tags are still difficult to read in some circumstances and some further modifications to the tag may be required.

The percentage of white sharks observed at North Neptune Is. that were already tagged averaged 59% for the period August 1999-April 2001. With 96 sharks tagged at the site, assuming that no base-tags have been shed, the likelihood of seeing a tagged shark is the same as that for an untagged shark and no immigration or emigration of sharks occurs, then this equates to a rough estimate of 163 sharks utilising this site. If the 16 sharks tagged at South Neptune Is. are included in this analysis (on the basis of observed movement between the two islands), an estimated 190 sharks utilised these sites during the period.

In reality, movement into and out of the Neptune Islands area undoubtedly occurs (see Section 3.3.5, movement patterns). Further tagging and observations will be required before the number of sharks using the region can be adequately estimated.

Shark sighting index (North Neptune Is.)
The number of individual sharks sighted each day by cage-dive operators was used to provide an index of sightings at North Neptune Is. for the period August 1999 to April 2001. Too few trips were made to other sites to give a useful index. Shark sightings for each day were summed to get a total for the trip and then a trip index (mean number of sharks sighted per day) was calculated. Trip indices for both active operators were pooled by month and a monthly mean was calculated (Figure 24).

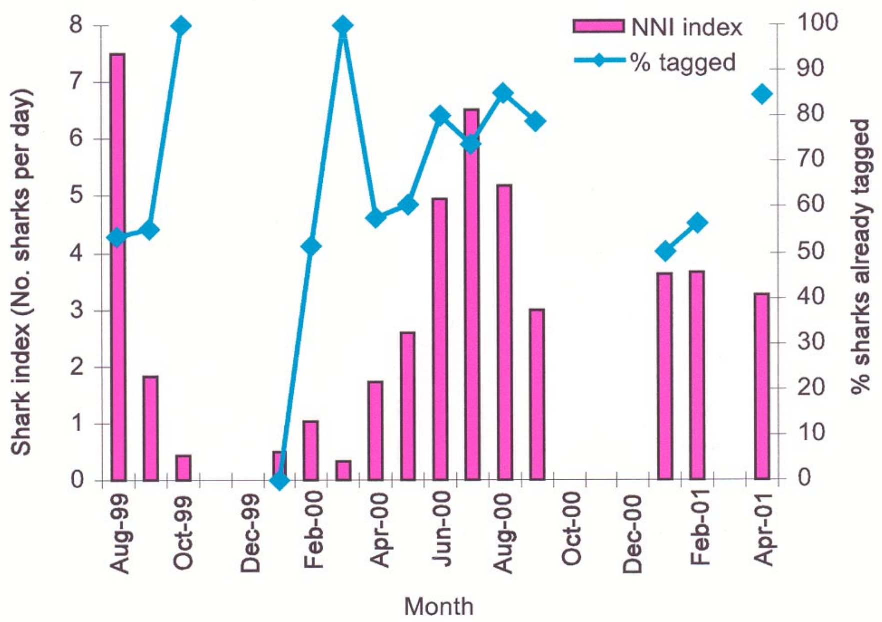

Figure 24: White shark sightings at North Neptune Is. (NNI) August 1999 – April 2001.

Operators made 40 trips during the 21 month period and berleyed on 163 days. No trips were undertaken in December 1999 or from October to December 2000. Data for each operator was remarkably consistent (individual operator's data are not presented here). Shark activity varied seasonally with peaks in winter/spring. Very few sharks were observed in late summer-early autumn 2000 (despite a relatively high trip effort). Shark sightings were considerably higher, however, for the corresponding period in 2001. Operators have reported a degree of seasonality to white shark sightings in previous years with a recent tendency towards more sightings in winter. However, it is too early to confirm, from our data, if this is consistent between years.

Sex composition (North Neptune Is.)
The percentage of male (M) and female (F) sharks as well as those where sex was not recorded or was unknown (U) that were sighted at North Neptune Is. was analysed for the period August 1999 to August 2000. Analyses assume that sex was correctly recorded. It is noted, however, that sex is sometimes difficult to establish from surface based observations. North Neptune Island had a higher percentage of females than males for the period - all months combined (% M:F:U = 20:58:22). When grouped by

season, a higher percentage of males than females were sighted in summer whereas a higher percentage of females were sighted in all other seasons (Table 8).

Table 8: Seasonal sex composition at North Neptune Is.

Season	% Males	% Females	% Unknown
Summer	55	9	36
Autumn	19	52	29
Winter	20	67	13
Spring	18	55	27

The dominance of males in summer was less obvious when viewed as a monthly index (Figure 25). Males only exceeded females in sighting frequency during February 2000. A higher number of males were sighted in winter than in summer, however, the large increase in female sightings skews the data. Cage dive operators have reported that small males tend to be more commonly sighted during the summer months. Further data are required to assess this.

The sex of 13–36% of sharks sighted (Table 8) was not determined, and this may also influence the results.

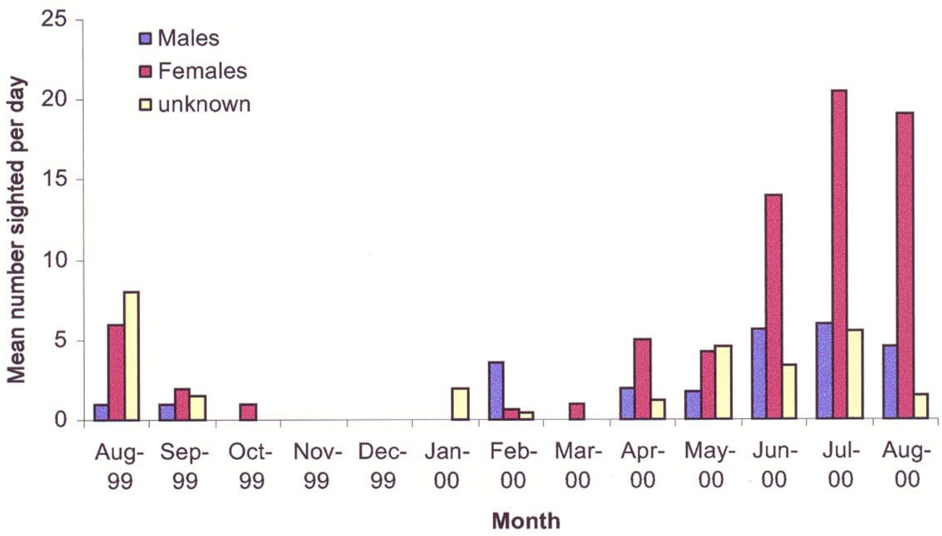

Figure 25: Monthly white shark sightings at North Neptune Is. indexed by sex.

Historical trends in sighting frequency

It is difficult to assess what changes in sighting frequency have occurred at the sites where cage-dive operations have been carried out (since tours began) because of a lack of standardised reporting prior to 1999. Anecdotal reports suggest a decrease in white shark activity (R. Fox, Glenelg, SA; V. Taylor, Roseville, NSW, personal communication) however, there appears to be considerable seasonal and interannual variability. For example, the frequency of sightings at Dangerous Reef was low during the late 1980s but recovered during the early 1990s. Similar good and bad years for white shark sightings/captures have been reported both in other areas of

Australia (fisher's responses, beach protection programs – Reid and Krogh 1992, this study) and in South Africa (Cliff *et al*. 1996b).

The current standardised reporting method will allow the activity of white sharks to be monitored within the lower Spencer Gulf region and specifically at North Neptune Is. (provided effort continues to be focussed there). Changes in the activity index over time may indicate trends in population size and/or give some insight into factors affecting shark activity.

Expressions of interest to establish white shark cage diving operations have been submitted to agencies in States other than South Australia. Should these ventures be approved it would be extremely valuable to impose a similar reporting system to that established through DEH in South Australia.

3.3.5 Australian Shark Attack File

The Australian Shark Attack File (ASAF) was established in 1984 and is archived at Taronga Zoo in Sydney. It is affiliated with the International Shark Attack File, which is coordinated by the American Elasmobranch Society (West 1996).

Both white shark encounters and attacks (where injury to a person occurs) are recorded. West (1996) reviewed documented white shark attacks in Australian waters up to 1992. The following section briefly updates these statistics based on data in the ASAF.

A caveat regarding shark attack information is that the identity of the species involved is not always conclusive. In some cases the identity of the shark is assumed and in other cases, it is mistaken. Direct evidence is rare (e.g. tooth fragments), however in some cases, wound patterns or bite marks in objects either worn by, or accompanying the victim, can be used to determine the identity of the shark involved.

There are currently 58 white shark attacks recorded on the ASAF for the period 1876-2000, of which 31 were fatal. The highest number of attacks occurred in South Australia (19) which is consistent with white shark numbers being relatively higher there than in other States. By decade, the highest incidence of attacks overall was during the 1980s (8), 1930s (10) and the 1990s (16) – (Figure 26). The 1930s data can only be regarded as tentative due to problems with confirming the identity of the attacking shark. All of the 1930s attacks occurred in NSW and it is likely that the decrease in the decades immediately following was a result of implementing the shark control program. There has been a steady increase in the number of attacks attributed to white sharks from the 1940s to the present. However, there are several factors that make these data difficult to interpret including:

- A higher number of people using the water (associated with increases in population size and lifestyle changes)
- Better reporting and recording of shark attack data for the last two decades since the ASAF was established in 1984
- A tendency for increased use of remote water-ways where sharks may be more likely to be encountered

During the last two decades, there has been an average of 1.3 white shark attacks per year in Australia. More than one white shark attack occurred in six of the last 20 years with the highest numbers in 1989 and 2000 (four attacks each).

The ASAF may be of greater value as an abundance indicator in the future, given the now established reporting mechanisms. However, the low number of encounters, temporal changes in monitoring and reporting attacks, and changing human demographics may limit its use.

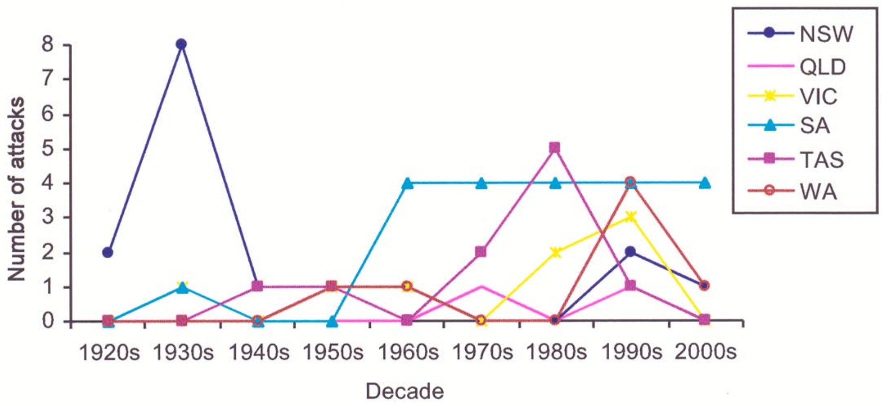

Figure 26 (a): White shark attacks on humans in each state by decade.

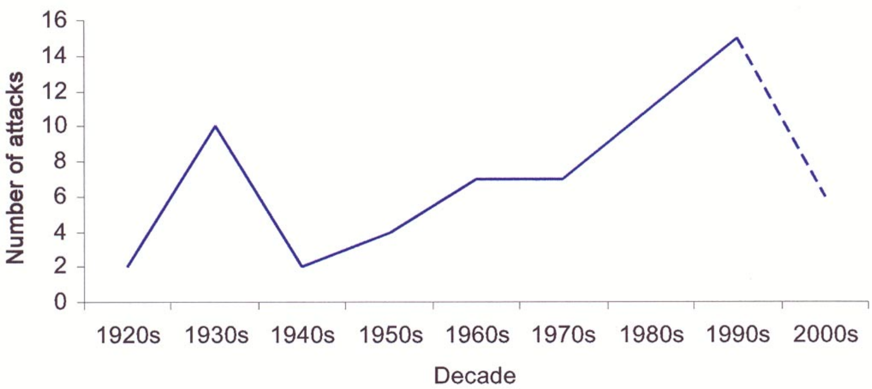

Figure 26 (b): White shark attacks on humans in Australia by decade.

3.3.6 Incidence of white shark bites on pinnipeds (seals and sea lions)

The relative frequency of shark bites on pinnipeds that haul out at colonies may provide a crude measure of white shark activity (and hence abundance) at particular sites around southern Australia. Similar data has been used to infer changes in the abundance of white sharks at the Farallon Islands off the Californian coast (Long *et al.* 1996).

The presence of shark bites on Australian sea lions has been monitored at Seal Bay, Kangaroo Island (SA) since 1988 (P. Shaughnessy, CSIRO Sustainable Ecosystems, Canberra, personal communication). These data are briefly presented here but are currently being analysed in greater detail by P. Shaughnessy.

A total of 154 wounded sea lions have been recorded over the thirteen years (to August 2000). The number of wounded sea lions observed has varied between years (Figure 27) with peaks in 1990 and 2000. Several factors may influence the activity levels of white sharks around Seal Bay on both a seasonal and interannual basis that make interpreting the current data set difficult. Apart from the interannual variability in white shark activity, the behaviour and biology of sea lions may influence the temporal presence of white sharks. Australian sea lions have a non-seasonal breeding cycle and its timing is not synchronous between colonies (Gales *et al.* 1994). The pupping interval is 17.6 months (Higgins 1993) and so pupping occurs in summer one year and then in winter the next. The behaviour of sea lions during pupping and the timing of pups entering the water may influence the presence and behaviour of sharks in the area.

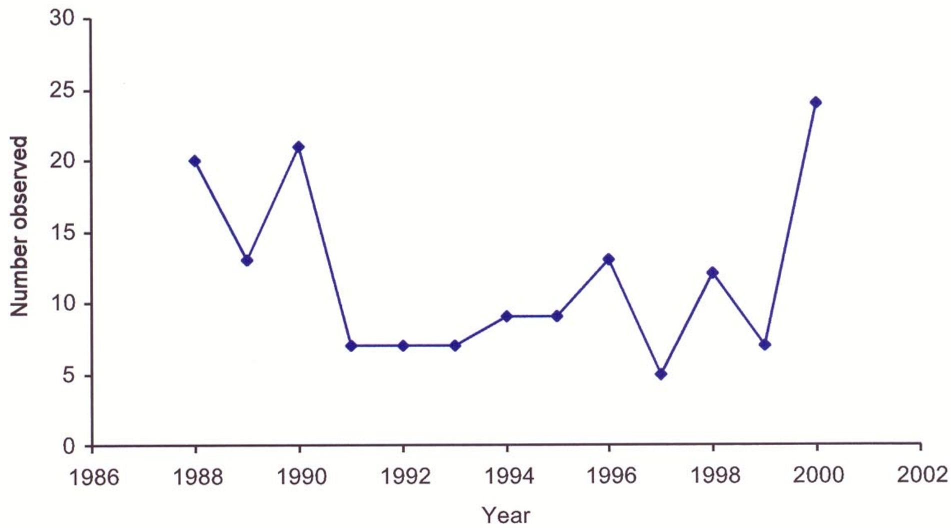

Figure 27: Number of wounded sea lions recorded per year at Seal Bay, Kangaroo Is.

The number of wounded sea lions observed by month at Seal Bay was compared to the monthly Neptune Is. shark activity index for the period August 1999 to September 2000 (Figure 28). The number of wounded sea lions peaked at Seal Bay from January-March 2000 and then gradually declined to a low in July-August. Conversely, the shark index at North Neptune was lowest during the November-March and slowly increased to a peak in July-August 2000. It is unclear if this inverse relationship will hold in coming seasons but it may suggest a movement of white sharks between the two sites. Seal Bay and North Neptune Is. are separated by a distance of approximately 160 km.

Pinniped wounds may provide useful data on white shark activity in various areas across southern Australia and such data would be worth recording for a variety of colonies on a regular basis.

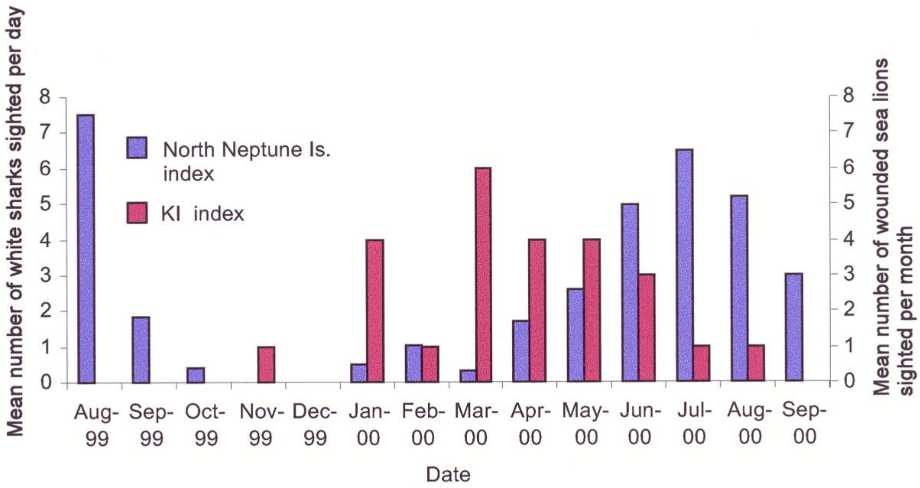

Figure 28: North Neptune Is. shark index vs shark attacks on sea lions at Seal Bay, Kangaroo Is.

3.3.7 General sightings and encounters

Abalone divers

Abalone divers occasionally encounter white sharks as part of their diving operations. Reported encounter rates from WA divers varied from one sighted in eight years to seven sighted in 21 years diving. The largest reported shark was estimated at 6 m. A long-term, now retired, diver in Esperance reported seeing a single white shark in 1994, the first he had seen in about ten years. In 1995, five white shark sightings were reported by various divers in the Esperance region. Since then about one shark has been reported each year in that area. Another long-term diver in the Esperance region had not seen a white shark in thirty years diving, until 1998 when he saw two (one while he was in the water, and one observed from his vessel).

Without taking into account individual diving effort, and diving conditions, it is difficult to interpret abundance indices from such sightings (even if they were all reported). However, if reporting sightings is further encouraged, they may be useful in detecting major changes in abundance or regional levels of activity. South Australian abalone divers started recording white shark interactions after two fatal attacks (on surfers) and several sightings by divers in west coast waters during the latter part of 2000.

Game-fishers

Sightings by game and recreational fishers remain an untapped resource for monitoring white sharks and a coordinated effort to record such data is recommended. However, in order to interpret sightings (as an indicator of abundance) it would be necessary to standardise sightings by some form of effort (e.g. number of trips, number of fisher/boat hours). Concentrating recording effort during annual fishing tournaments, where the number of vessels, number of anglers, area fished and time spent on the water are more easily quantified may offer a useful index in some regions (e.g. NSW).

Sightings by the general public
Sightings of white sharks by the general public are reported in a variety of ways including to the media, National Parks and Wildlife officers, Fisheries Compliance officers, police and to researchers at various institutions. There has been little coordinated effort placed in recording such sightings except in NSW where NSW Fisheries has a reporting proforma to record sightings of threatened species. White shark sighting forms were issued to people and agencies cooperating in the regional network established as part of this project. However, only a relatively small number have registered sightings and returned forms.

Although the recording of sightings made by the general public may give some information on overall distribution patterns, several problems exist with using such data as an indicator of abundance:

1. Species identification is difficult to verify
Despite their distinctive physical characters, white sharks are not always easy for members of the general public to identify, particularly if the observation is brief or from a distance. White sharks (particularly small ones) can sometimes be mistaken for other species. There are a number of incidents (including one tag release by a game fisher) where small white sharks have been mistaken for the related mako shark (*Isurus oxyrinchus*). Larger sharks (e.g. > 2 m) are often assumed to be white sharks in southern Australia, despite several other large species occurring in the region. The dorsal fin of sunfish (Molidae) is also sometimes mistaken for that of a white shark and has been the source of several erroneous reports.

2. Size data are generally inaccurate
Estimating the size of sharks is very difficult, particularly if the encounter is brief or unexpected. Interestingly, the size of small white sharks (< 2.5 m) is usually under-estimated, while that of larger whites (> 3.5 m) is usually over-estimated. Large white sharks observed by fishers are commonly estimated to be as long as, or just longer than their vessel. For some reason sharks of approximately 3 m in length are generally correctly estimated by both recreational and commercial fishers.

3. The source and veracity of information is sometimes difficult to establish
Many sightings are not reported first hand and the details of the same report can vary. In some cases, the source of the initial observation is either impossible to verify or incorrectly reported. For example, recent sightings of large numbers of white sharks in South Australia were attributed to observations from spotter plane flights during periods when the planes were not operating.

4. The enthusiasm to report sightings varies over time
The reporting of white shark sightings and encounters can vary according to the effort expended in seeking reports and in response to events such as shark attack. Shark attack, and the ensuing media coverage, can result in a dramatic increase in reported sightings, some of which are no-doubt legitimate, while others may be floating objects or other species.

5. Success is dependent on regular advertising and timely feed-back
Encouraging the general public to report sightings on a regular basis requires on-going commitment and advertising, as well as a standardised reporting procedure. Feedback to those making the report is an essential part of this process to ensure the continued success of any such system. However, this is both time consuming and difficult to achieve in a timely manner unless staff-time is specifically dedicated to it.

There is no doubt that reported sightings from the general public can provide some useful information. However, the benefit of advertising and establishing an Australia-wide reporting system specific to white sharks for the purpose of estimating population trends, is unlikely to warrant the effort for the above reasons. There may be some benefit in targeting a reporting system in areas where white sharks are more commonly encountered (e.g. west coast waters of South Australia). Reporting effort is likely to be more stable and feed-back more easily managed in these areas. Regional reporting systems might make use of existing networks (e.g. FISHWATCH).

The reporting of notable sightings that are more easily verified will undoubtedly continue and there will be some benefit in registering these, particularly if feed-back can be provided to those making reports in the form of information packages on white sharks (e.g. NSW threatened species information sheets, CSIRO facts sheets – see Appendix 2).

3.4 Biology

At least 75 white sharks have been sampled in Australia over the past 15 years. This includes at least 34 caught by commercial shark fishers, seven caught by snapper fishers, three caught by recreational net fishers, four caught in tuna cages, six caught in the Qld shark control program and five caught in the NSW shark control program. Nineteen sharks were sampled during this project (April 1999 to January 2001). Samples have usually been collected by the fisher or by fisheries scientists. Necropsies have involved a range of measurements including the collection of vertebrae for ageing, DNA samples and the examination of reproductive status and stomach contents.

Information from sampling, in conjunction with other capture data and references from other studies, have been used to assess various aspects of the biology of white sharks in Australia.

3.4.1 Population structure

Distribution
White sharks have been recorded from central Qld, around the south coast to North West Cape in WA (Last and Stevens 1994). Unconfirmed records suggest that the species may occasionally reach as far north as Townsville, on the eastern seaboard and the North West Shelf in WA. (Figure 29). They are most abundant in South Australia. White sharks usually occur on the continental shelf (often close inshore) but have been recorded down to 1280 m and at oceanic islands such as Seychelles and Hawaii (Last and Stevens 1994).

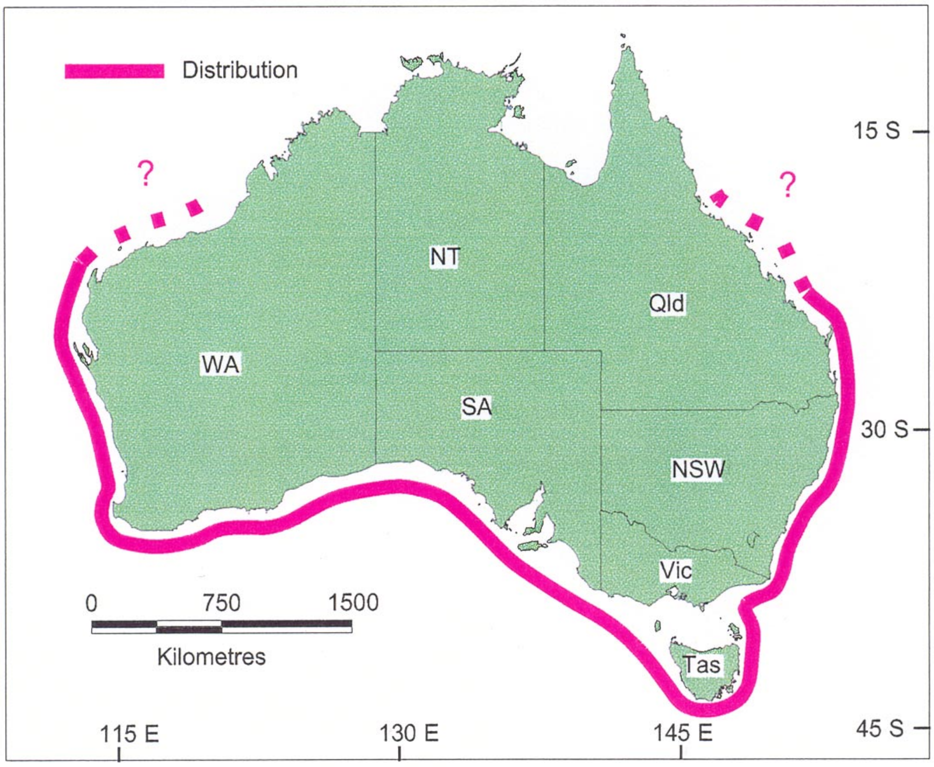

Figure 29: Distribution of white sharks in Australian waters

Size structure

Although there is overlap in the size range of white sharks caught by region in southern Australia (Figure 30), there is a tendency for juveniles to occur in different areas to sub-adults and adults.

There are a number of locations that appear to be seasonally important for juveniles. These tend to be close to shore in the GAB, adjacent to Victor Harbour and the Coorong in SA, along Ninety Mile Beach and off Portland in Vic., and between Newcastle and Port Stephens in NSW. Juvenile white sharks are associated with snapper aggregations off Ninety Mile Beach in Victoria. Snapper move into this area between October and April and juvenile white sharks (predominantly 1.9 m to 2.7 m) are found there at that time (Figures 31 and 32). Reports from recreational fishers at Portland also suggest that juvenile white sharks are present in that area from October to March, at which time snapper (and a variety of other fish and squid) are also present. Other juvenile habitat areas may also have a strong association with high scalefish abundance. Juvenile white sharks have been caught in ocean-haul nets targeting Australian salmon around the Newcastle-Port Stephens region.

Spencer Gulf and Gulf St. Vincent are important feeding grounds for sub-adult white sharks, although large adults and small juveniles also utilise this area. The gulfs have abundant dolphin and finfish populations. White sharks of all sizes, from less than 2 m to over 5 m, occur in areas where snapper are abundant. Anecdotal information suggests that large female white sharks are found around Streaky Bay and Ceduna. One fisher suggested that the Nuyts Archipelago is a pupping ground for white sharks. Small specimens (< 2.0 m) are commonly encountered between Streaky Bay and the Head of the Bight. Fur seal and sea lion colonies are important locations for sub-adult and adult sharks, in South Australia, Victoria and Tasmania.

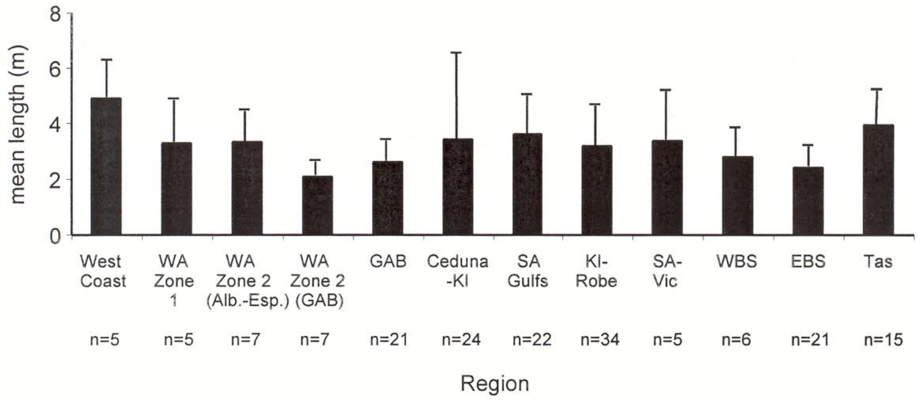

Figure 30: Mean lengths of white sharks captured by region in southern Australia (bars = 1 sd).

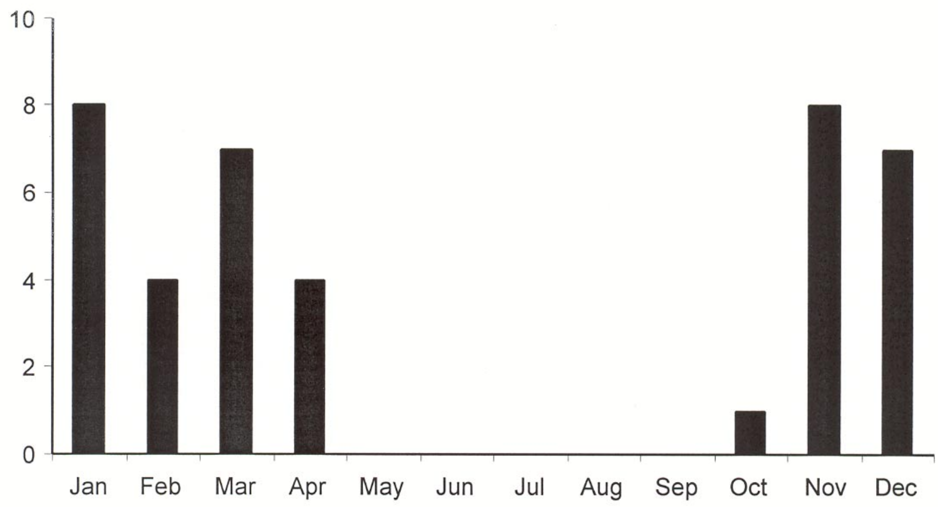

Figure 31: Total number of white sharks caught by month off Ninety Mile Beach, Vic. (1990 – 2000).

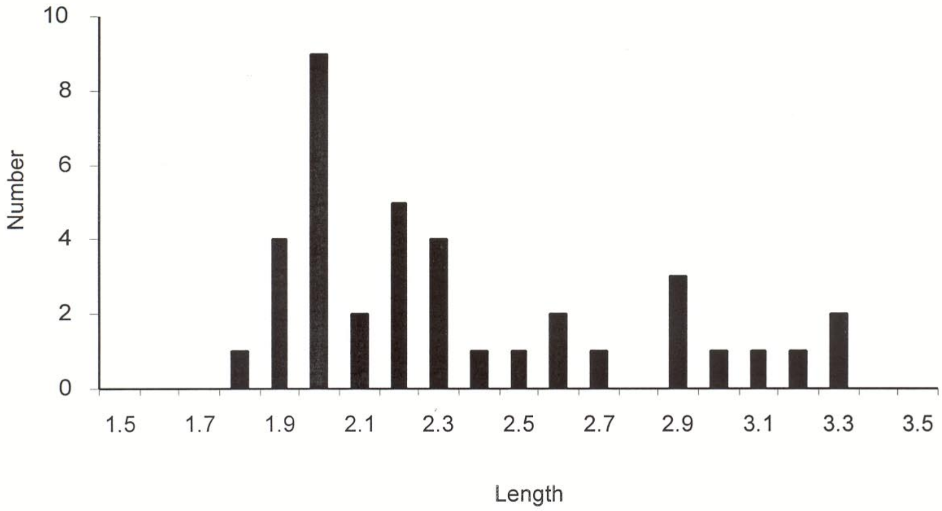

Figure 32: Length frequency of white sharks caught off Ninety mile Beach, Vic. (1990 – 2000).

Sex ratio

The overall sex ratio of white sharks captured in Australian waters by commercial fishing is not significantly different from 1:1. However, some segregation by sex is suggested by regional and site specific data (Table 9).

Table 9: Sex ratio of white sharks in Australia

Region/method	n	% female	Variation from 1:1 (Chi squared test)
NSW shark control program (1971-2000)	226	57	*
NSW shark control program (1971-2000, Newcastle region only),	123	63	**
All commercial captures	165	55	NS
Dangerous Reef (sightings, 1989-1991)	25	84	**
North Neptune Is. (sightings, 1999-2001)	314	70	**

* Significant at 5% level
** Significant at 1% level
NS - not significant ($p > 0.05$)

Segregation by sex has been reported for adults of several species of shark (Springer 1967). The reasons are not clear but this behaviour may reduce the risk of predation of new-born sharks by con-specifics (Moss 1984). White sharks caught in the NSW and Qld shark control program are almost entirely juveniles. Most females sighted at Dangerous Reef and North Neptune Is are sub-adults. It is unclear what advantage sexual segregation may confer on juvenile white sharks, nor why the ratio in each case favoured females.

Sex ratios varied between seasons at North Neptune Is.

3.4.2 Reproduction

As noted by Pratt (1996), our knowledge of the reproductive cycle of white sharks is limited because examination of mature adult specimens (particularly females) is rare. Adults are large, relatively uncommon and when they are captured their size makes retention and examination of specimens difficult. White sharks are oophagus, the young being nourished by a supply of unfertilised eggs, which the female continues to ovulate during pregnancy. Males have been reported to mature at about 3.8 m and females at 4.5-5.0 m TL (Francis 1996; Pratt 1996). Relatively few pregnant white sharks have been examined; litter sizes have varied from 2-10 with the length and weight at birth being 120-150 cm TL and up to 32 kg respectively (Francis 1996; Uchida *et al*. 1996). The gestation period is unknown, but may be approximately 18 months with females breeding only every 2-3 years (Mollet *et al*. 2000). The reproductive biology of the white shark was recently reviewed by Francis (1996).

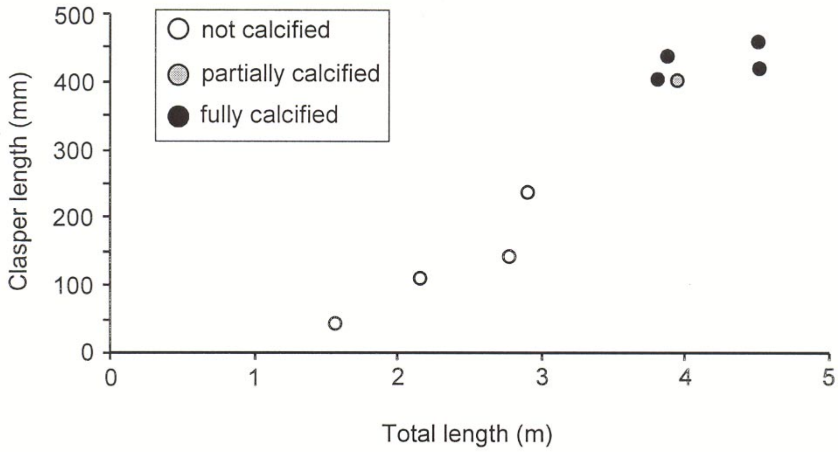

Figure 33 (a): Clasper development vs total length.

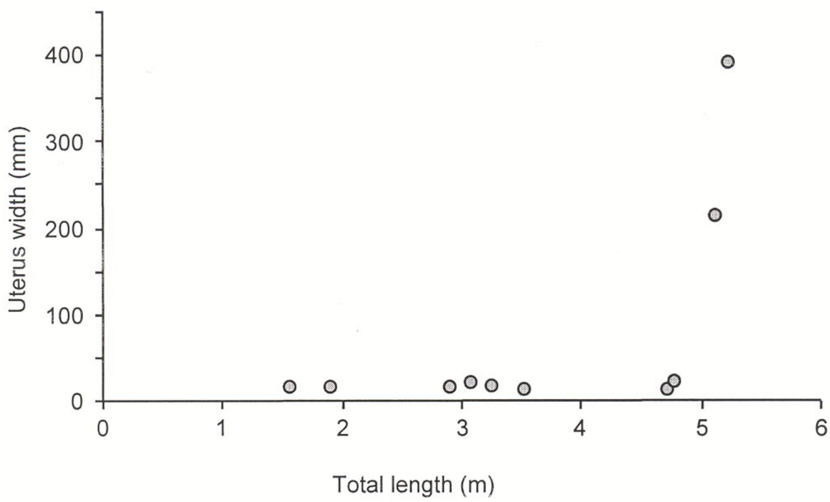

Figure 33 (b): Uterus width vs total length.

Limited reproductive data were available from about 20 individuals in this study. Most of the information was for clasper length in males, and uterus width in females and these data are shown in Figure 33. Based on clasper length and calcification, male white sharks in Australia mature at about 3.6-3.8 m TL. Increasing uterine width in females suggest maturity by 5 m TL. These observations are similar to size at maturity reported from other areas.

To date, there have been no confirmed records of pregnant females examined in Australia. In March-April 1994, two very small white sharks were captured in a net off South Australia. The net also had a large hole in it. One of the small sharks was examined and it measured 1.27 m TL (1.17 m FL) with a weight of 14 .5 kg. Although within the length range reported for full-term pups, this is well below reported full-term pup weights (26-32 kg, Francis 1996). It is possible that the South Australian pups were aborted when a pregnant female was entangled in the net, but subsequently escaped. The smallest (confirmed) free-swimming white sharks (122 cm), however, weighed only 12-16 kg (Casey and Pratt 1985). Francis (1996) noted that new-born white sharks may lose weight initially while they are learning to feed.

There are three records of pregnant white sharks in the Queensland Shark Control Program. Two were recorded from one net on 26 November 1982; a 4.2 m female with 14 pups and a 4 m female with 11 pups. The third shark, a 3.2 m female with 4 pups was captured on 17 November 1981. These records were not verified and must be considered questionable, especially considering the small size of the sharks.

A 5.2 m TL female white shark caught at the end of January 1993 and examined by two of the authors (JS and BB) had enlarged, flaccid uteri and appeared to be spent. Two other large females of 5.1 m and 5.18 m TL had ovaries weighing 3700 and 2002 g respectively and GSIs of 0.28% and 0.13%. These GSIs fall within the range for mature, non-pregnant females with inactive ovaries in the related shortfin mako shark, *Isurus oxyrinchus*, (Mollet *et al*. 2000).

Francis (1997) reviewed existing data on the size of embryos and the size and occurrence of neonates. He concluded that birth probably occurred from spring to summer. While the spent female examined in 1993 was captured in summer, evidence from the capture of neonates in Australia is not conclusive. There are 21 commercial capture records in Australia for white sharks with length estimates ranging from 1.0-1.5 m. Captures were reported in all months except July, August and November. Captures were most frequently reported between December and May (Figure 34). The length of small white sharks tends to be underestimated by fishers and this may partially explain the spread of captures throughout the year. Only five of those captured were measured (including the presumed aborted pup referred to above) and these were caught between December and June (1.27 m specimen caught in March-April, 1.47 m caught in May, 1.38 m caught in June, 1.40 m and 1.44 m caught in December).

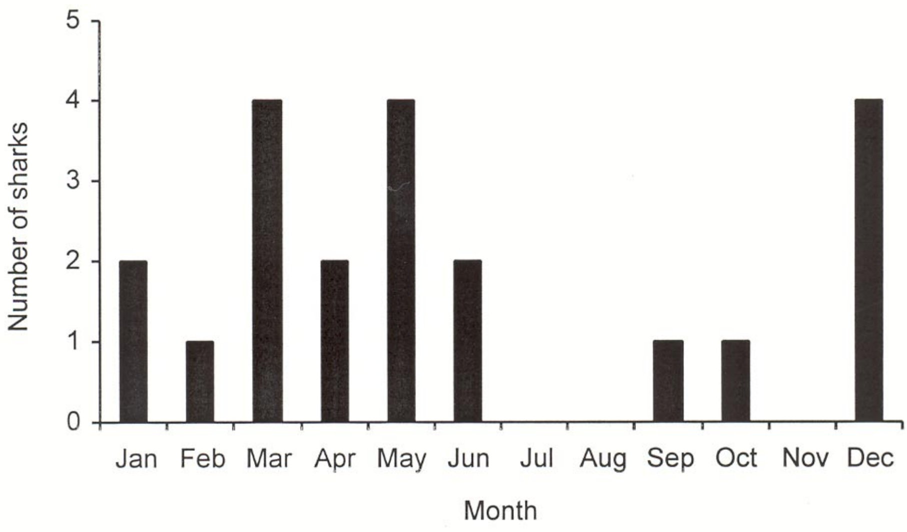

Figure 34: Captures, by month, of white sharks estimated to be less than 1.5 m.

3.4.3 Diet

Information on the diet of white sharks has been summarised in Compagno (1984), Last and Stevens (1994) and, for South Australian white sharks, by Bruce (1992). In general, smaller individuals feed on a variety of teleosts (finfish) and chondrichthyans (sharks, rays and chimeras) as well as cephalopods (squid, octopus, etc.) and some crustaceans (e.g. crabs). Marine mammals are an important part of the diet of white sharks larger than about 3 m.

In this study, data on stomach contents were available for 66 white sharks ranging in TL from 1.4-5.5 m. Data came from both scientific examination of specimens, as well as from fishers. Only a broad assessment of diet (% frequency of occurrence) by major class of prey item has been attempted here. Seventeen of the sharks (25.8%) had empty stomachs. However, some stomachs were probably everted during capture, and two stomachs recorded as 'almost empty' may have contained some food items. Some white sharks had been caught while feeding on prey captured by the fishing gear. These individuals have been included in the analysis.

Of the 49 white sharks containing food in their stomachs, 46.9% contained marine mammals, 40.8% chondrichthyans, 28.6% teleosts, 14.3% cephalopods, 4.1% crustaceans and 2.0% birds. Of the sharks containing chondrichthyan remains, 24.5% of stomachs contained other shark species, 16.3% contained rays and 2.0% chimaerids. Of the sharks containing marine mammals, dolphins occurred in 18.4% of stomachs and pinnipeds (seals/sea lions) in 28.6% of stomachs.

Marine mammals were only recorded in sharks greater than 2.7 m in length, although most of the marine mammals were in sharks longer than 3.5 m (67.9% of stomachs). This includes four small pinnipeds in a 3.6 m shark, two pinnipeds of about 36 kg each in a 5.4 m shark, and an adult male Australian fur seal of about 280 kg in a 5.2 m shark. Adult pinnipeds were only recorded in sharks greater than 3.6 m.

Larger white sharks (> 3.0 m) are frequently (but not exclusively) found near pinniped colonies in Australia. Of ten white sharks examined at Seal Rocks (Vic) in the late 1960s, five contained fur seal remains, with one containing three seals (Warneke 1975). White shark-pinniped interactions have been well documented elsewhere (Ainley *et al*. 1985; Klimley *et al.* 1996; Pyle *et al.* 1996).

Teleost and chondrichthyan prey were found in all sizes of white sharks from 1.4–5.2 m.

3.4.4 Age and growth

Vertebrae from 51 white sharks (1.4–5.2 m TL) sampled across southern Australia have been analysed to date.

Centrum diameter

Centrum diameter (CD) was linearly related to shark TL (Figure 35) by the equation:

$$CD = 15.933TL - 3.024 \quad (R^2 = 0.9771)$$

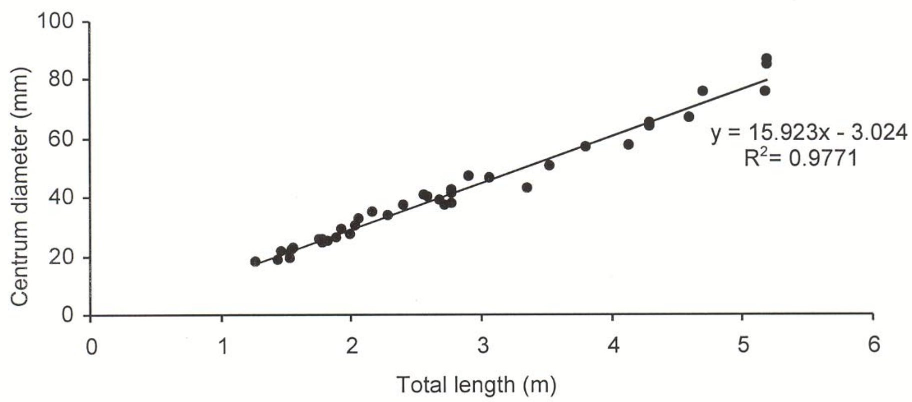

Figure 35: Centrum diameter vs total length (sexes combined).

Age estimates

Von Bertalanffy growth parameters were calculated for both high and low band counts (Figures 36 and 37).

Using the "high" band counts, white sharks were estimated to reach lengths of 2 m in 3 years, 3 m in 8 years, 4 m in 15 years and 5 m in 23 years. Age at maturity is reached in 13 years for males and 23 years for females.

Using the "low" band counts, white sharks were estimated to reach lengths of 2 m in 3 years, 3 m in 6 years, 4 m in 11 years and 5 m in 18 years. Age at maturity is reached in 10 years for males and 18 years for females.

Age estimates have not yet been adequately validated for white sharks, however our results (and, in particular, the low band counts) are consistent with other preliminary age and growth studies from California (Cailliet *et al*. 1985) and South Africa (Wintner and Cliff 1999). In the Californian study, sharks were estimated to reach 3 m, 4 m and 5 m in about 5, 10 and 16 years respectively, while in South Africa these sizes were reached about 6 months earlier in each case. Age at maturity from both studies was estimated to be 8-10 years for males and 12-13 for females. The higher estimate of age at maturity for female white sharks from our data reflects the larger estimate of size at maturity (5 m).

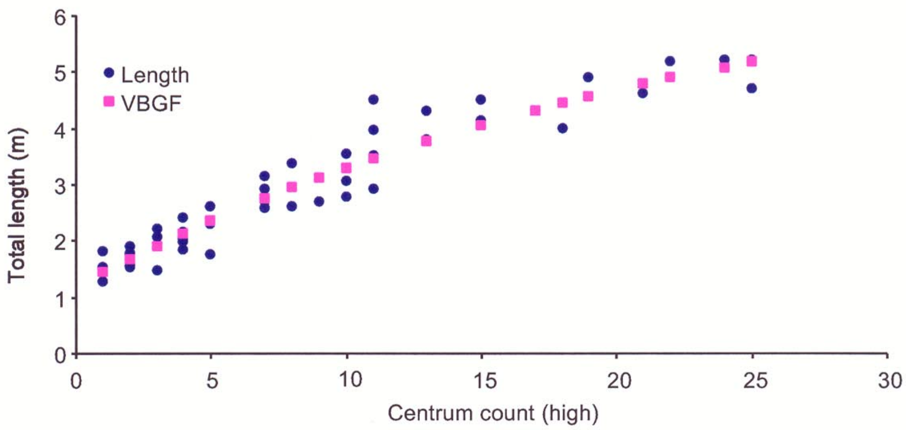

Figure 36: Von Bertalanffy growth parameters (high).
$L_\infty = 7.323$, $k = 0.042$, $t_o = -4.173$, $R^2 = 0.918$

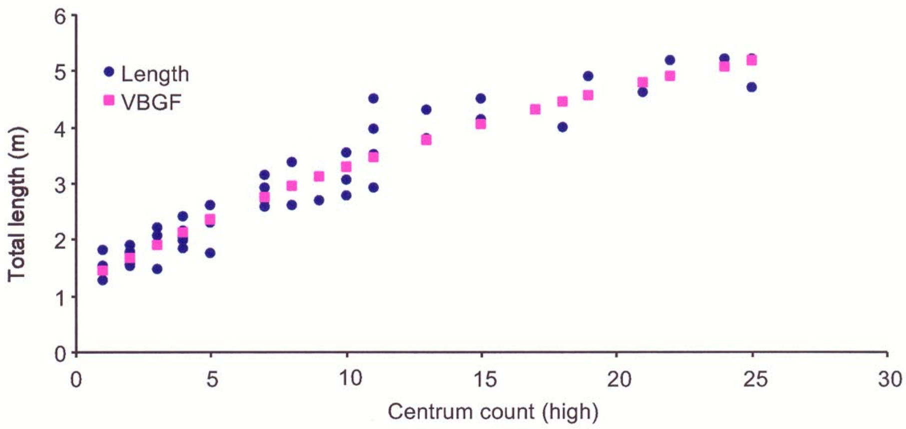

Figure 37: Von Bertalanffy growth parameters (low).
$L_\infty = 6.598$, $k = 0.071$, $t_o = -2.330$, $R^2 = 0.909$

Length-weight relationship
Validated lengths and weights for 23 white sharks (sexes combined) were available from this study (Figure 38) and these data were used to produce a preliminary total length-weight relationship:

Weight = $9.3802\text{TL}^{2.9942}$ $R^2 = 0.9818$

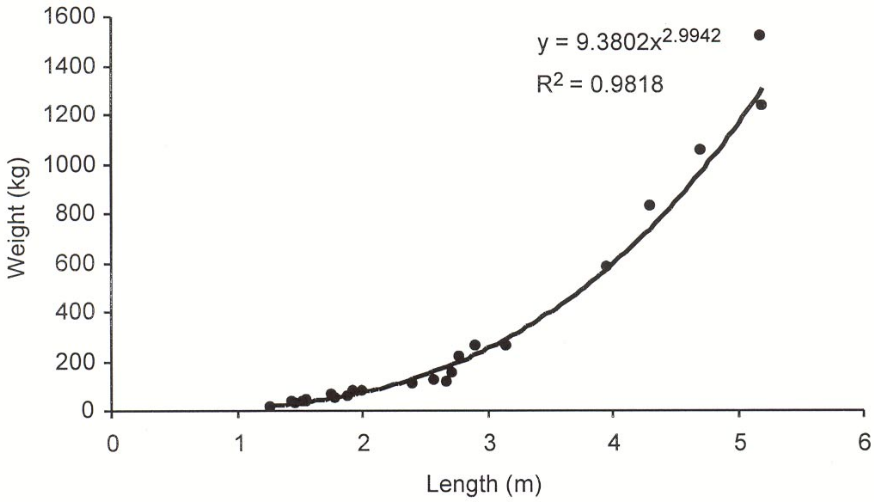

Figure 38: Length-weight relationship for Australian white sharks.

3.4.5 Movements
A total of 219 (up to March 2001) white sharks have been tagged using a variety of tags in Australia. Tagging has occurred using five methods;

- Game-fish tag-release (58 sharks),
- Tagged free-swimming by researchers and cage-dive operators (143 sharks)
- Tag-release of by-catch from commercial fishing operations (15 sharks)
- Intentional capture for satellite tagging (2 sharks)
- Tag-release of a white shark held (temporarily) in an oceanarium (1 shark)

The tag-release of white sharks from game fishing is no longer permitted and other tagging requires either State or Commonwealth permits.

Up until January 2001, all white sharks tagged with stainless steel headed dart tags were logged on the NSW FRI Cooperative Game-Fish Tagging Program database. However, it must be noted that the records on this database do not distinguish between tagging methods and include nearly all those tagged that were free-swimming. All are registered as game-fish tag releases. In January 2001, stainless steel headed dart tags specific to the white shark program were made and issued, under permit, to cage-dive operators and select commercial fishers. All tagged white sharks are registered on the database held at CSIRO Marine Research (CMR), Hobart.

Nine of the 219 tagged white sharks have been captured (Table 10, Figure 39). Distances (point to point) and periods between tagging and capture ranged from 2-600 km and 0-2200 days.

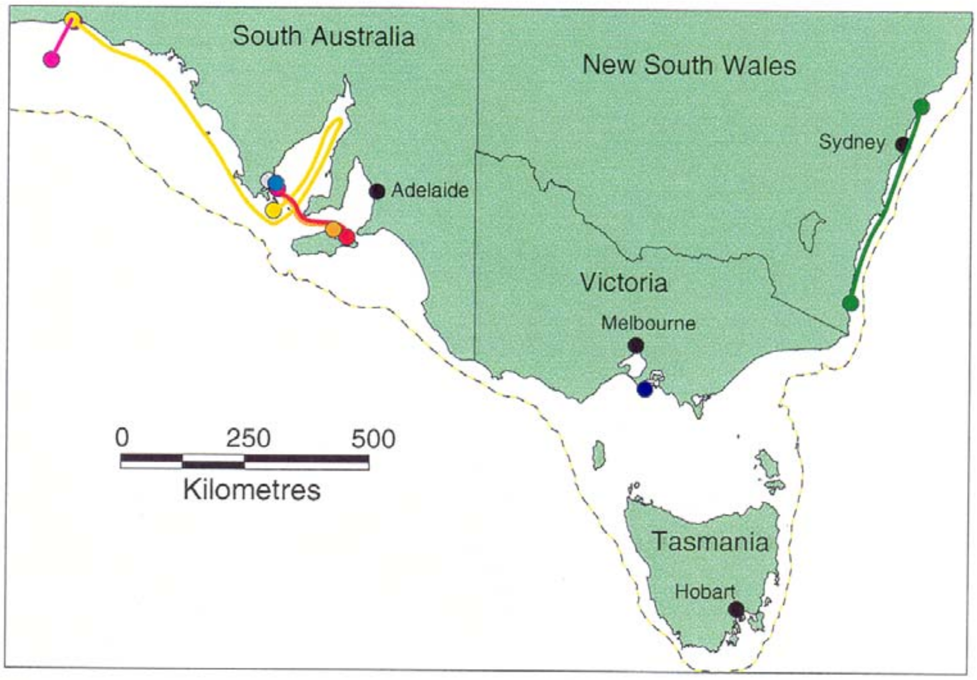

Figure 39: Recaptures of tagged white sharks in southern Australia (colours signify individual tag recaptures).

Overall, this equates to a 4.1% recapture rate. There was a 33% recapture rate of sharks tagged with archival tags by May 2001, however this was from just one capture.

Two recaptures (3.4% recapture rate) have been recorded from the 58 sharks tagged by game-fishers through catch and release over the past three decades. One of these was a small, juvenile shark recaptured by the same fisher on the same day. Despite being the most active State for game-fish tag-release of white sharks, there have been no reported recaptures of South Australian specimens tagged by this method.

Six (4.2%) white sharks that were tagged free-swimming have been subsequently captured. These were either dead upon retrieving the fishing gear or subsequently killed. Three of these sharks were caught in commercial shark fishing nets, two were captured by game-fishers (prior to protection), and one was caught in a tuna cage. There has been a single recapture of a white shark tagged by a commercial fisher (6.7% recapture rate).

Table 10: Number of white sharks that have been tagged by various methods, and captures of tagged sharks by those methods

Method of tagging	Number tagged	Tagged sharks later caught by game-fishing	Tagged sharks reported caught by commercial fishing operations	Total % caught
Tagged free-swimming	143	2	4	4.2
Game-fishing tag release	58	2*	0	3.4
Commercial shark fishing	15	0	1	6.7
Satellite tagging	2	0	0	0
Oceanarium tagging	1	0	0	0
Total	219	4	5	4.1

* one recaptured on same day

In a cooperative tagging program coordinated by the National Marine Fisheries Service, 36 white sharks were tagged, of which two (5.6%) were subsequently recaptured (Kohler *et al.* 1998). Maximum distance travelled was 1010 km, maximum speed was 1.67 km/day and maximum time at liberty was 2.5 years. In South Africa, 73 white sharks were tagged of which six (8.2%) were recaptured (Cliff et al 1996). The greatest distance travelled was 1409 km and the maximum time at liberty was 527 days. Although the overall capture rate of tagged white sharks is comparable to the capture rate of some other tagged sharks, the low numbers tagged (and thus low numbers recaptured) limits the benefit of using conventional tagging to examine broad-scale movement patterns. More sophisticated tracking methods using satellite, archival and acoustic tags have been utilised to examine movement patterns and swimming depth behaviour.

Detailed short-term movements from acoustic tagging

At least 10 white sharks in southern Australia have been fitted with short-term acoustic pingers. This includes one shark (Heather) that was also fitted with a satellite transmitter. Heather was tracked acoustically for 3 hours to follow her initial behaviour after capture. Continuous track records range from 2-26.5 hours. At least one of the tagged sharks was not followed after leaving the vicinity of the tagging vessel and some were not followed continuously (i.e. they were followed for short periods, tracking was suspended and then they were tracked again if they returned to the tagging site).

Tracks have revealed three consistent movement patterns. These have been discussed by Strong *et al*. (1992, 1996) and are briefly described below. In all cases (with the exception of Heather), tracked sharks were attracted by berley to the tracking vessel, tagged while free-swimming and then tracked after berleying was terminated.

Downstream circling

Downstream circling was observed in nearly all sharks tracked. During this behaviour, sharks swam back and forth over a relatively restricted area for a period of up to six hours after berleying was terminated (see Figure 40). Sharks abruptly changed swimming patterns after the period of downstream circling and adopted either “island patrolling” or “inter-island cruising” behaviour.

Downstream circling was almost certainly a searching pattern in response to the remnant odour of the berley trail.

Island patrolling
Island patrolling consisted of the shark swimming around and away from the tagging site and subsequently returning to the site (Figure 40).

Island patrolling may represent movements of a shark that has taken up temporary residence at a site. Island patrolling type behaviour has also been reported for white sharks at the Farallon Islands off California (Goldman *et al*. 1996).

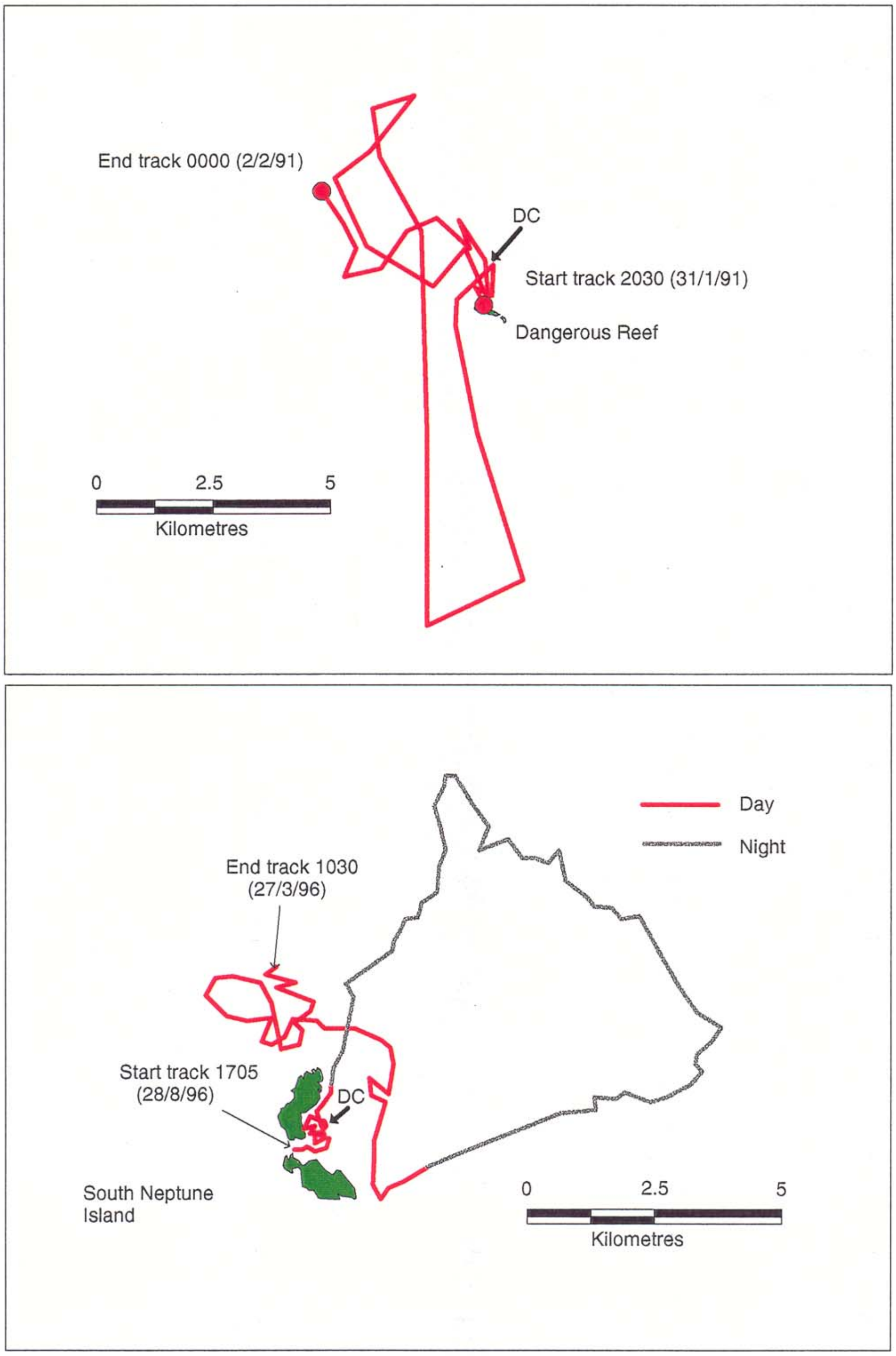

Figure 40: Tracks of acoustic tagged white sharks at Dangerous Reef and South Neptune Island showing ‘downstream circling (DC)’ and ‘island patrolling’.

Inter-island cruising
Inter-island cruising was a linear swimming behaviour at a consistent speed of 2-3 km per hour. It consisted of directed movement between sites (Figure 41).

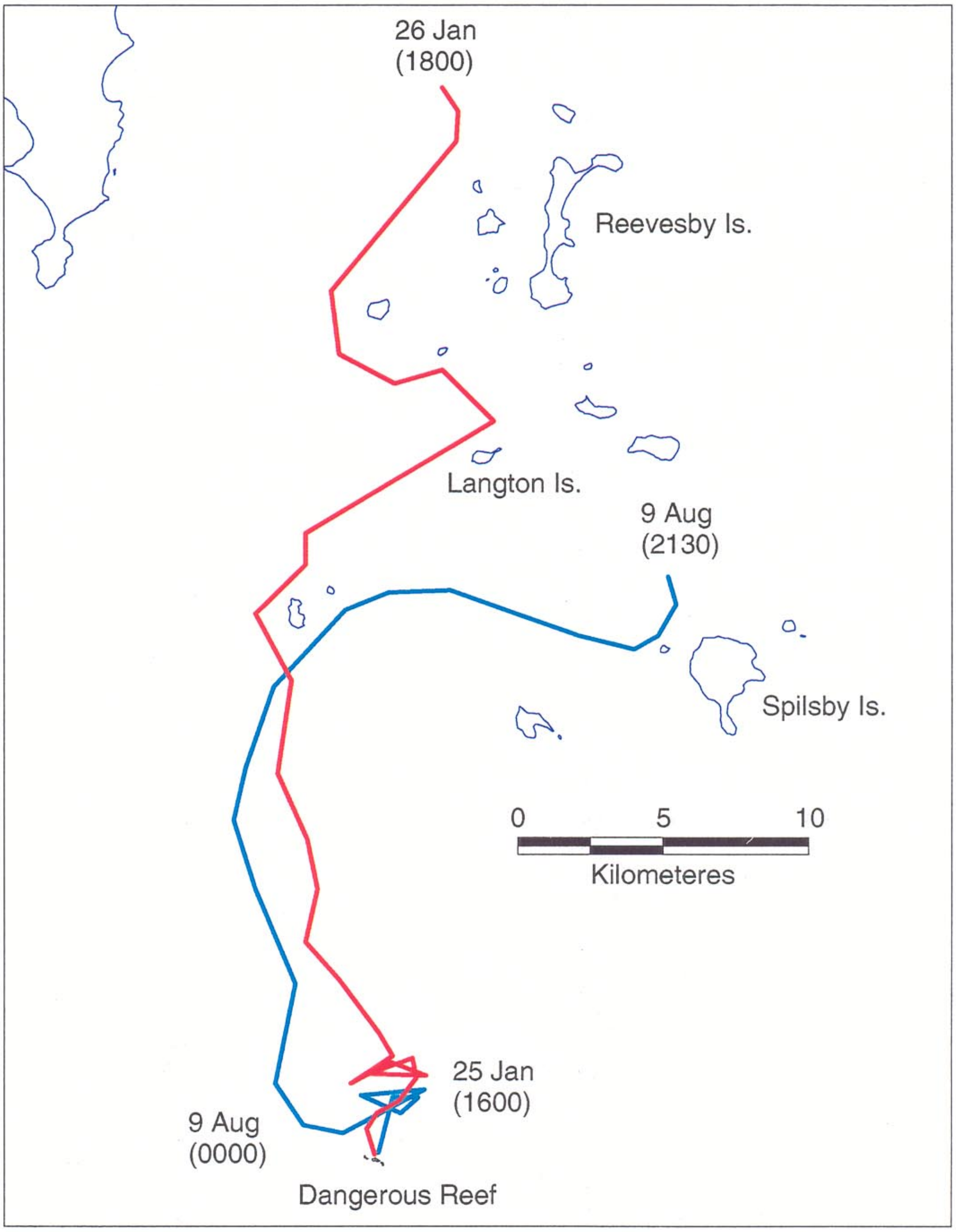

Figure 41: Examples of 'inter-island cruising (IC)' in two acoustic tracked white sharks in SA.

Long-term movements – archival and satellite tagging
Long-term tracks (exceeding 40 days) are available for three white sharks tagged in southern Australia. Two were tagged with satellite tags and one with an archival tag.

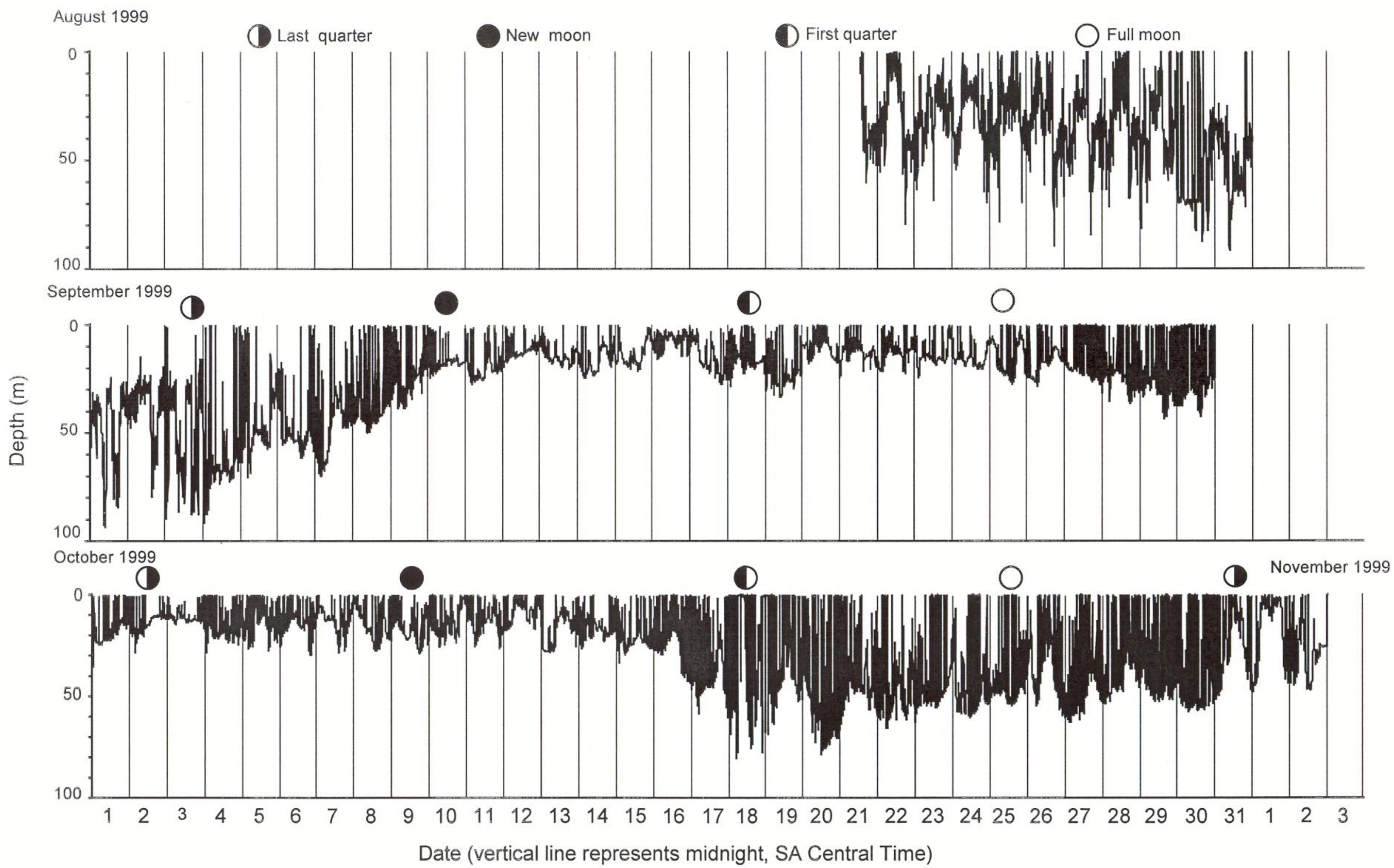

Figure 42: Total depth trace from Grace's archival tag.

Archival tagged shark

The archival tag from a 3 m female white shark (named Grace) was returned after 74 days at liberty. Grace was tagged at North Neptune Island in August 1999 and captured by a commercial fisher near the Head of the Bight in November 1999. The point-to-point distance between tagging and capture was approximately 600 km. The detailed depth track is shown in Figure 42.

Acoustically tagged white sharks regularly moved between the surface and the bottom during all daily tracks. Based on these observations, bottom depth during Grace's track was estimated from averaging the 10 greatest depths recorded on each day (Figure 43).

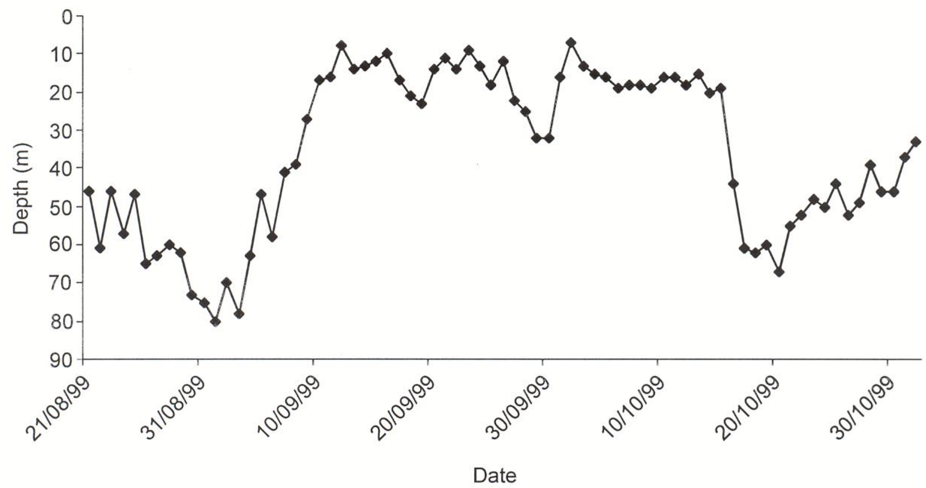

Figure 43: Estimated bottom depth during Grace's track.

Daily longitude estimates, depth and temperature records when the shark was at the surface suggest that Grace remained within the vicinity of North Neptune Is. for the period 21 August – 2 September. Between 3-10 September, she moved east, into shallower water within a restricted longitudinal band until 14 October when she headed rapidly west and moved into deeper water. Between 10 September and 12 October, Grace moved into water of increasing surface temperature (from 15 to 19^{o} C), then into cooler water until 17 October (16.6^{o} C) before again moving into increasingly warmer water of 18.5^{o} C (Figure 44).

Daily latitude estimates are highly sensitive to weather (e.g. cloud cover) and are more variable when close to the spring equinox, which occurred during Grace's track. For these reasons, an average weekly latitude estimate was calculated and combined with an average weekly longitude estimate to approximate the track taken by Grace during the 74 days at liberty. Daily latitude estimates less than 30^{o} S (300 km north of upper Spencer Gulf) and greater than 38^{o} S (300 km south of North Neptune Is.) were assumed to be spurious and were excluded from the weekly averaged estimates.

The average weekly position, depth estimates and sea-surface temperature record are consistent with Grace leaving North Neptune Is. in early September, before tracking north-east into mid-upper Spencer Gulf by mid October, then rapidly moving out of the gulf and heading west reaching the Head of the Bight in late October (Figure 45).

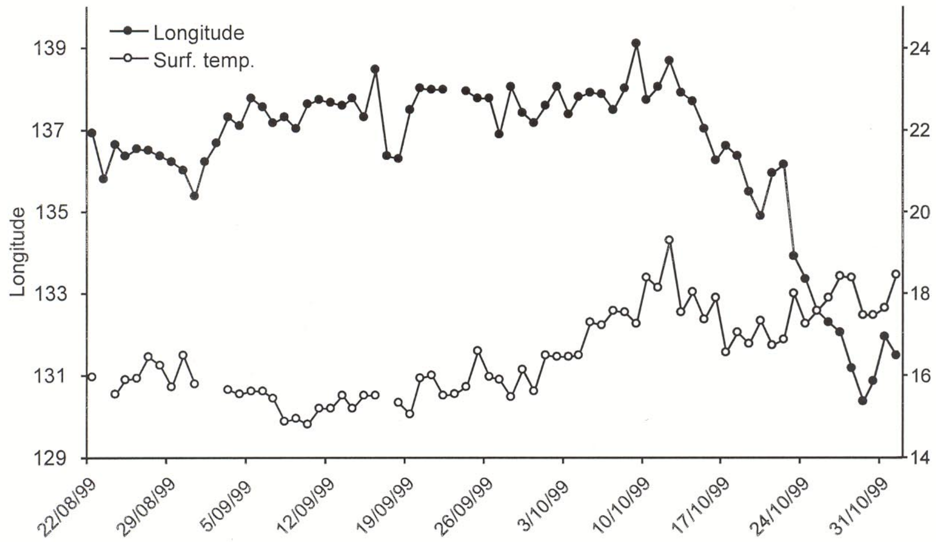

Figure 44: Estimated surface temperature and longitude during Grace's track.

Estimated swimming speed for the two weeks of the track in late October, when Grace was travelling west, was approximately 3 km per hour. This is consistent with swim speeds recorded during acoustic and satellite tracking.

Satellite tracked sharks

Movements of the two satellite tracked sharks are shown in Figures 46 and 47.

Both sharks (Heather and Neale) spent the first few weeks of their tracks swimming back and forth along a 75-100 km stretch of the Victorian coast centred around the area where they were tagged (Port Albert). This encompassed the reef areas where snapper aggregate during summer and autumn. Local fishers have reported that when the snapper disperse at the end of March, the white sharks move out of the area as well. This was reflected in both tracks. Heather changed behaviour on 25 March 2000 and swam northeast along the coast until reaching an area north of Montague Island (NSW) after which her signal was lost. Neale left the Port Albert area on 19 April 2001, initially heading northeast on a similar track to Heather, before turning offshore then heading south across Bass Strait. He then headed down the east coast of Tasmania, as far as Bicheno, before turning back and returning to Bass Strait. Neale then continued steadily northeast along the Victorian coast before heading north along the NSW coast and finally loosing contact on 23 June 2001, just north of Coffs Harbour

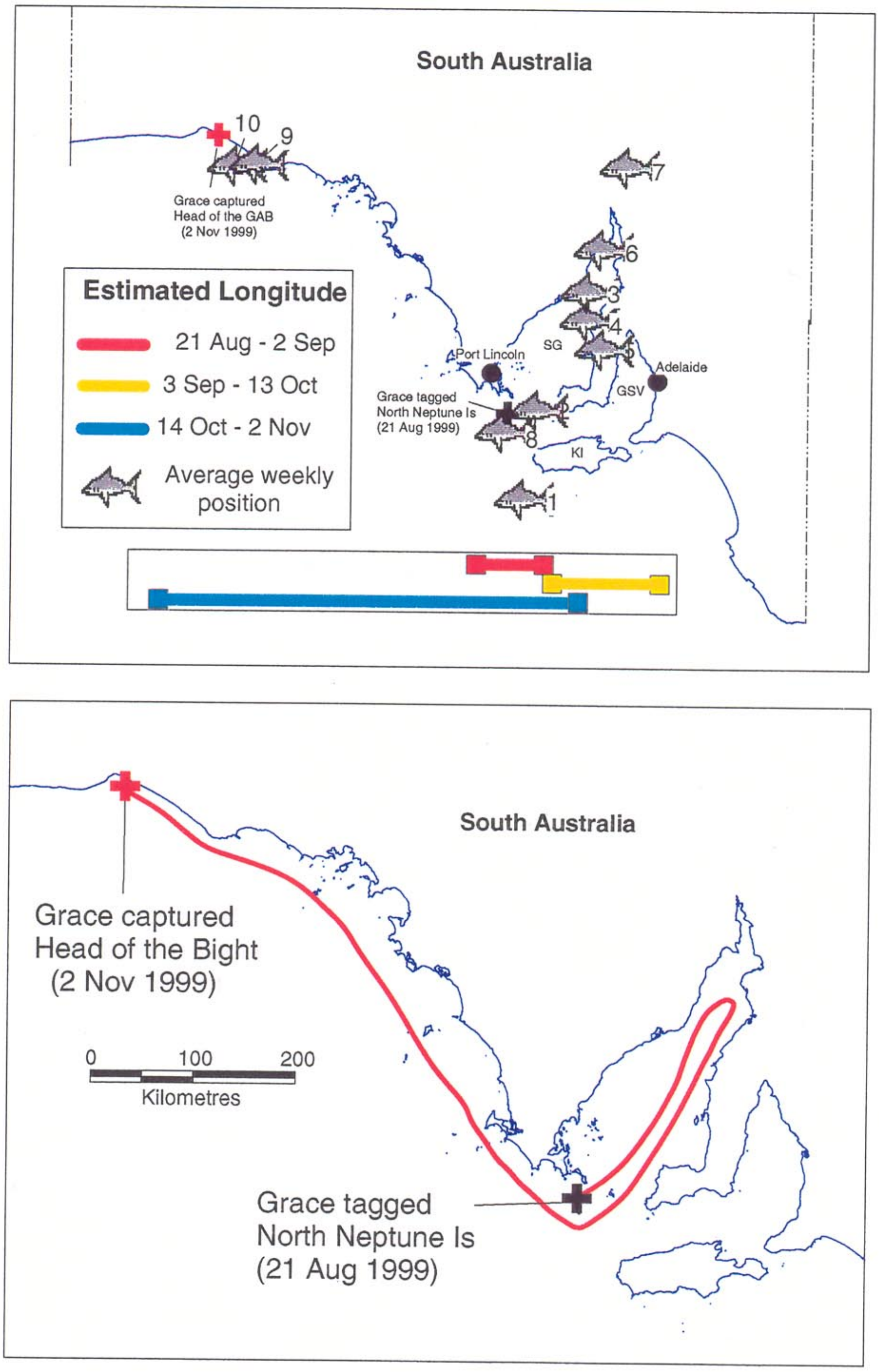

Figure 45: Reconstructed track for Grace.

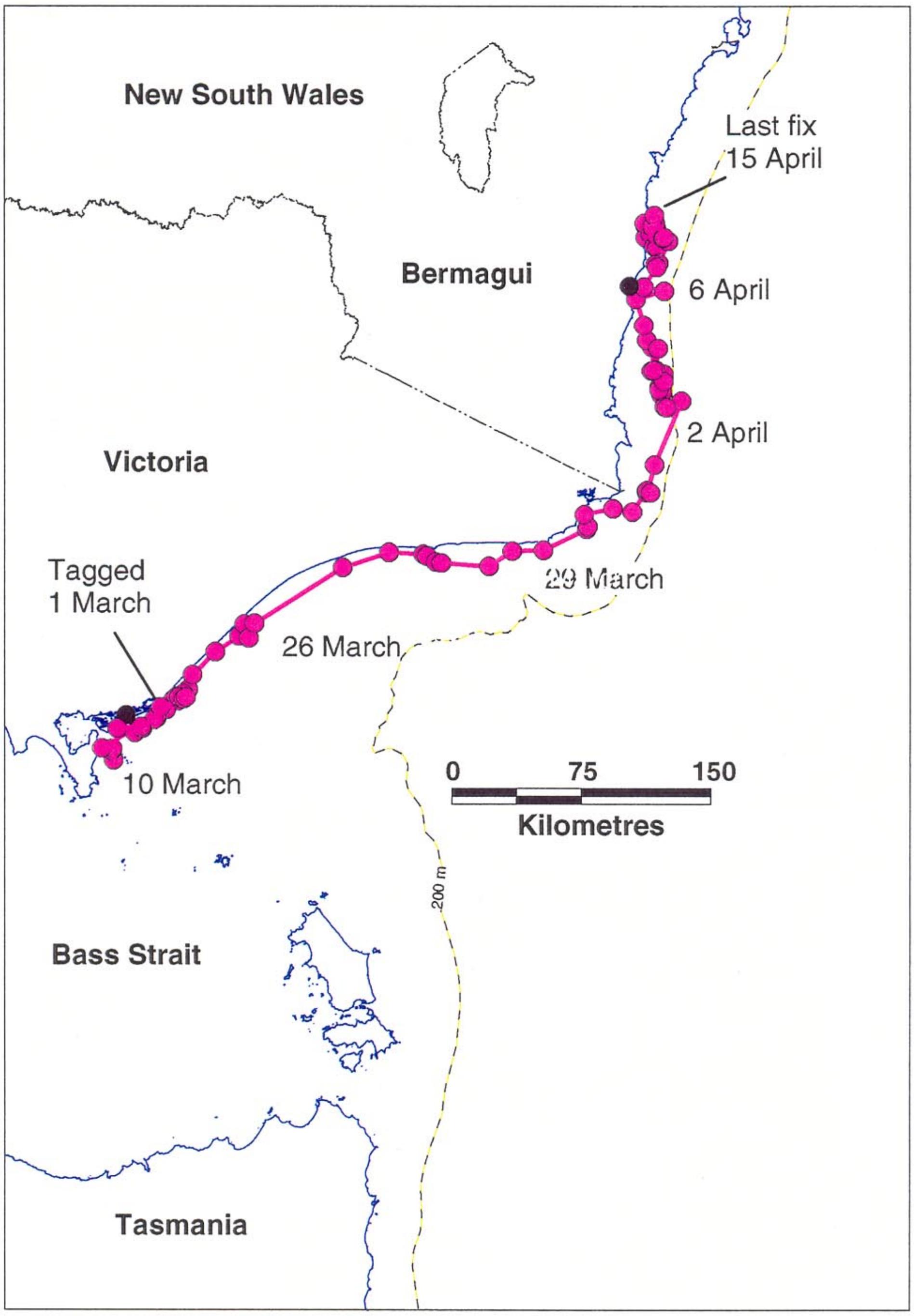

Figure 46: Heather's track.

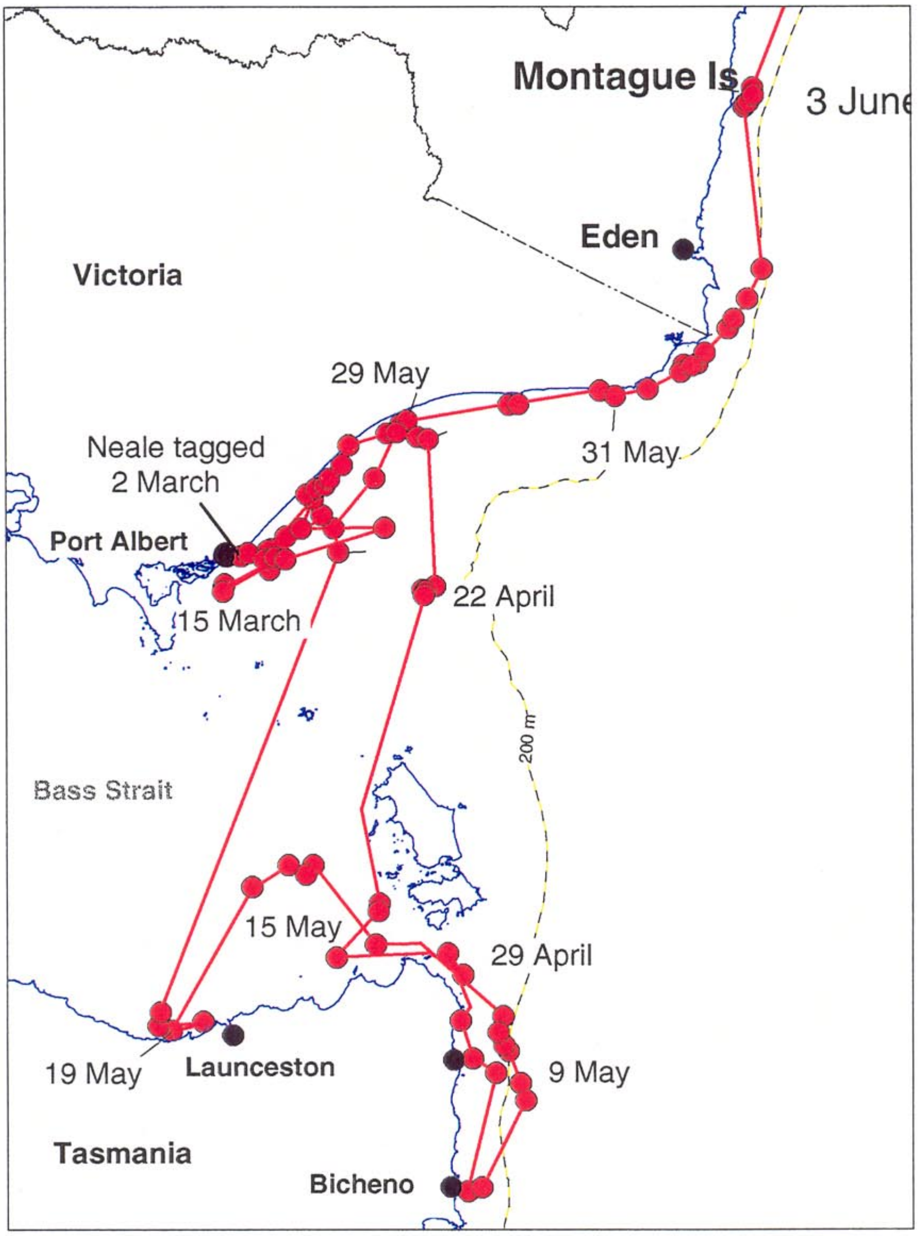

Figure 47 (a): Neale’s track (2 March – 3 June, 2001).

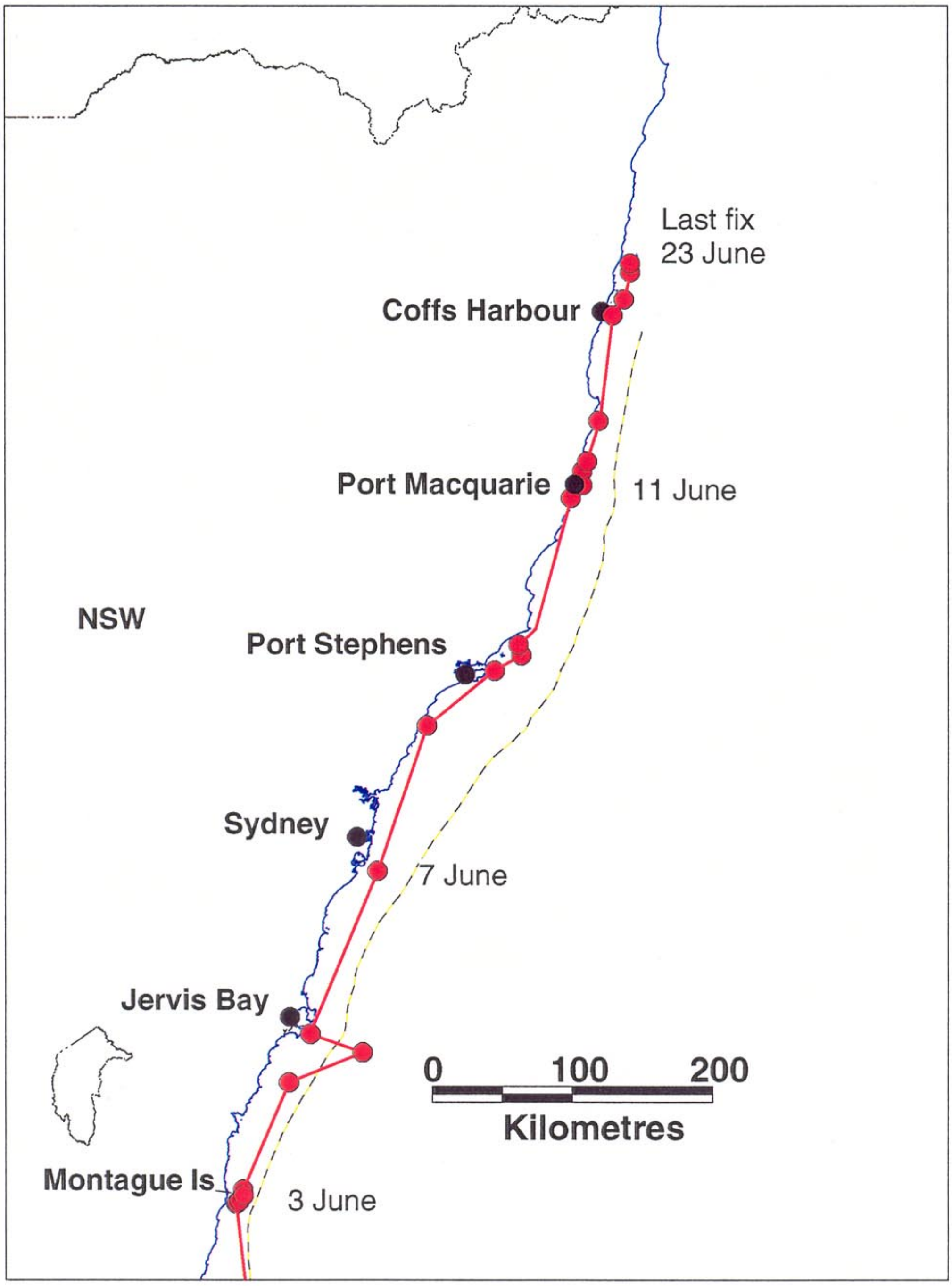

Figure 47 (b): Neale's track (3 June – 23 June, 2001).

There were elements of both "inter-island cruising" and "island patrolling" type behaviour evident in the tracks of both sharks. Their swimming patterns were linear and directed during periods of travel at a rate of 2.5-3.3 km per hour (inter-island cruising). Both sharks also re-visited some sites repeatedly during the first few weeks and Heather remained within an 18 x 10 km area for the last seven days of her recorded track, repeatedly visiting an area of 5 x 3 km (Figure 48). This area was just south of a major oceanographic front separating cooler shelf water from a warmer East Australian Current (EAC) eddy. Local fishers reported abundant jack mackerel

(*Trachurus declivis*), blue mackerel (*Scomber australasicus*) and striped tuna (*Katsuwonus pelamis*) in the area at the time which Heather may have targeted as a food source.

Heather and Neale covered distances of 880 km (46 days) and 2,946 km (113 days) respectively.

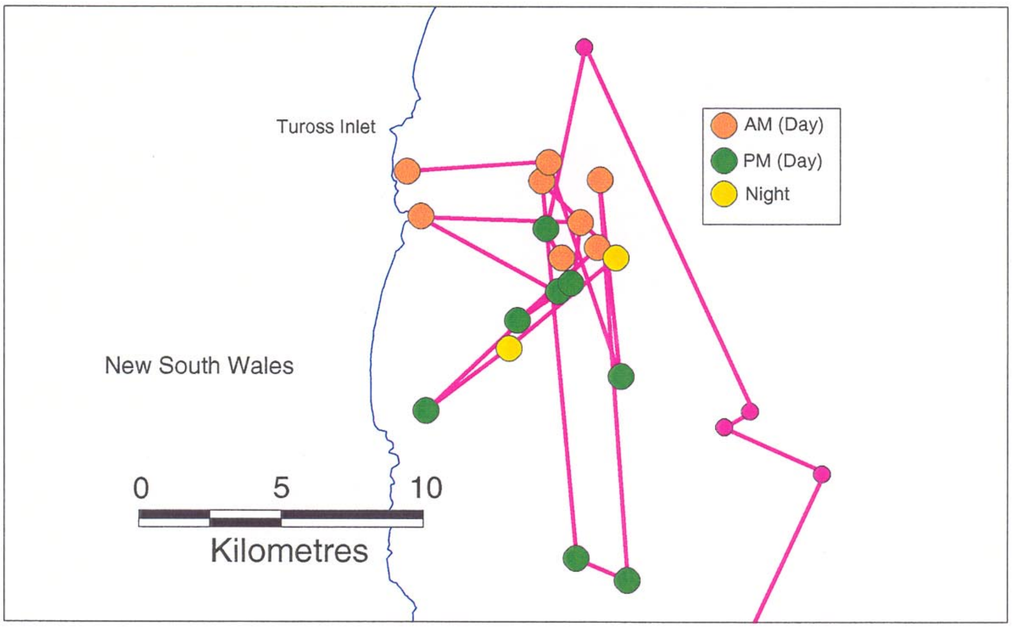

Figure 48: Island-patrolling behaviour during the last seven days of Heather's track

Swimming depth

Several acoustic transmitters, and the archival tag, were fitted with pressure sensors that enabled the swimming depth of white sharks to be recorded. The two most complete tracks are shown in Figures 42 and 49.

The tracks were typical of others obtained by the authors and other researchers in southern Australia (see also reports in Strong *et al*. 1992). The archival-tagged shark (Grace) made regular excursions from the surface to depth. In most cases we suspect that the deepest dives were to the bottom (as recorded in acoustic tracking). Grace spent approximately 8% of the time at the surface.

Grace's swimming depth behaviour can be broken into three periods, which equate to the times she spent in deeper water (50-90 m) in the vicinity of North Neptune Island, the period in shallower Spencer Gulf waters (20-40 m) and the period travelling in deeper water (40-80 m) between Spencer Gulf and the Head of the Bight. During the two deep-water periods, Grace exhibited diel swimming patterns typified by regular excursions to the surface during the day and remaining generally at depth at night. Swimming behaviour was more complex during the period in Spencer Gulf with no obvious diel pattern apparent.

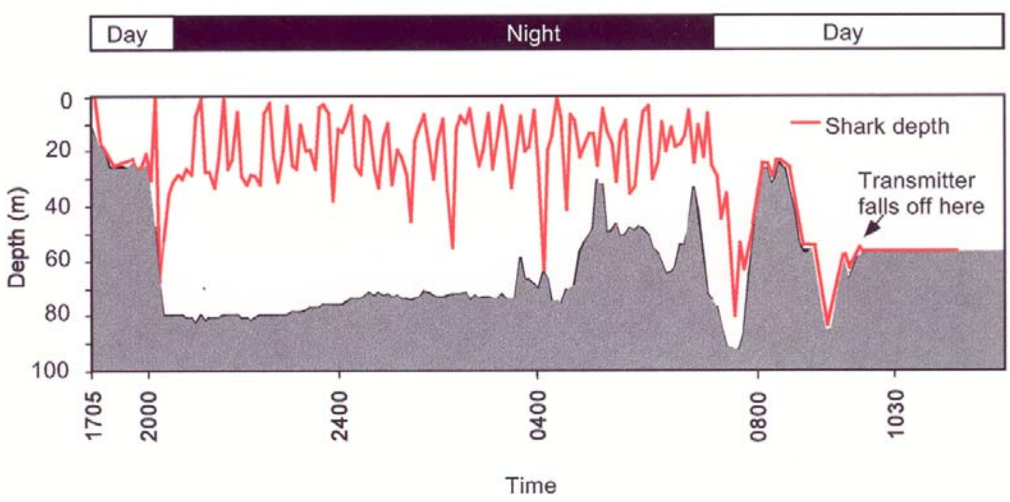

Figure 49: Depth track of a 3 m white shark tracked at South Neptune Is. (shaded area represents the bottom).

3.4.6 Genetics

A total of 54 (up to March 2001) sharks have been sampled for DNA from Australia.

Preliminary genetic results suggest that female sharks sampled from New Zealand and Australia are not significantly different, but that sharks from the SW Pacific comprise a population distinct from SW Indian Ocean sharks (F_{ST} = 0.89 and 0.81 for the pair-wise F_{ST} values between South Africa and New Zealand/Australia, respectively; $p < 0.0001$ for both comparisons). The estimated differentiation approaches the theoretical maximum of unity, suggesting long-term isolation of populations. There is some suggestion however that exchange between populations may occur via movements of males (Pardini *et al. 2001*).

3.5 White sharks in captivity
(data collated by Ian Gordon, Off the Edge, Sydney)

Due to their high public profile, white sharks have long been sought by oceanariums for display. The longest period that a white shark has been held in captivity is 16 days at Sea World, San Diego, USA. In Australia, white sharks have been held at three of the six major oceanariums for periods ranging from 1-5 days (Table). The longest period achieved was for a specimen held at Ocean World, Manly (previously called Manly Marineland), Sydney in 1994. This shark was released after showing signs of stress.

The most promising animal in captivity was destroyed by power-head after allegedly attacking fish and divers in Manly Marineland. This specimen was the only white shark that has been reported to feed in captivity.

Table 11: White sharks held in captivity in Australian oceanariums

Oceanarium	Year	Length (m)	Sex	Method of Capture	Time in Captivity	Survival
Sea World, Gold Coast	1976	3.0	Unknown	Drum Line	3 days	Died
Underwater World, Mooloolabah	1998	1.6	Female	Drum Line	2 Days	Released
Ocean World, Manly	1968	1.6	Female	Hook	4 day	Destroyed
	1974	1.3	Unknown	Net	1 day	Died
	1983	2.0	Female	Net	1 day	Died
	1984	2.0	Female	Net	1 day	Died
	1994	1.6	Male	Drop line	5 day	Released

Attempts to keep white sharks in captivity have thus far been unsuccessful. The reasons for this lack of success are undoubtedly a combination of capture stress as well as tank configuration and conditions.

White sharks have been inadvertently held after entering tuna pens in the Port Lincoln region for short periods (days). Reports indicate that some of these sharks swam seemingly unperturbed around the enclosure. This suggests that white sharks may survive short periods of captivity although the long-term effects on specimens are unknown.

4. Mortality estimates and population status

4.1 Total mortality estimates

In 1996, a very rough estimate of human induced mortality for white sharks was made at the National White Shark meeting in Sydney (Table 12). This was based on the outcome of a discussion involving a wide range of people with involvement in sharks. The upper estimate of annual mortality was 442, and the lower estimate was 102.

Table 12: 1996 mortality estimates

Source	1996 upper estimate	1996 lower estimate	Comments
Shark Control Programs	17	17	Qld and NSW only
Game-fishing	5	5	Excludes cryptic mortality from tag release
Commercial fishing:			Needs further consultation
- SSF	290	32	
- other States (shark)	20	8	WA/NSW/Qld
- Vic snapper	30	5	
- SA snapper	30	5	
- SA tuna farms	30	20	
Recreational gill-netting	10	0	Tas only, negligible in WA
Other (including permits)	10	10	Qld for display
Totals	442	102	

These estimates refer to catch rates prior to protection, and included some causes that no longer (legally) occur. Estimates have been re-assessed and updated from more detailed information obtained during this project and some additional sources of capture have been identified (Table 13). The number of captures does not equate to total mortality. Approximately 40% of captured white sharks are released. However, this is highly variable by fisher, fishing method and fishery. The percentage surviving release is unknown and may be considerably lower, especially for sharks released in poor condition.

Table 13: Capture and mortality estimates per year of white sharks in Australia for the period since protection

Source	Average estimated no. captures/year	Expected range	Average annual mortality (%)	Comments
NSW Shark Control Program	5*	0-10	4 (80%)	100% mortality prior to 1998
Qld Shark Control Program	10*	0-20	10 (100%)	
Game-fishing	2	0-5	0%	Not targeted since protection, but occasionally caught and released
Recreational fishing	10	1-20	5 (50%)	Small white sharks; mortalities result largely from mis-identification
SSF	72	12-132	37 (51%)	
WSF	28	0-70	14 (50%)	
MSF	30	15-40	15 (50%)	High number due to a few individuals
Vic snapper	5	1-10	1 (20%)	
Other fisheries	> 10	5-20	> 5 (50%)	Various fisheries in various States
Tuna farming	20	2->20	20 (100%)	Little information on upper estimate. Lower based on actual records
Recreational netting	4	0-10	4 (100%)	Tas and WA
Illegal targeting	>5	>5	>5 (100%)	Expected to be considerably higher than 5
Totals	201	46-362	120 (60%)	

* average for past decade

In total, an estimated average of 201 white sharks are captured per year in Australian waters. However, inter-annual variability is likely to be high and in some years catch rates may be either significantly lower or higher. In high interaction years, an annual catch of at least 362 may be expected. Given an average release rate of 40%, about 120 sharks are expected to die each year from fishing, although this is likely to be an under-estimate due to post-release mortality. This is comparable with the lower estimates from 1996, which assumed significantly lower levels of release.

At least 74 white sharks were reported captured in 1999, although this will be only a proportion of those actually caught.

The numbers of white sharks incidentally captured that are found alive and then intentionally killed (instead of being released) are unknown, as are the number intentionally targeted and killed.

4.2 Population status

The population status of white sharks in Australian waters is still difficult to determine. Although variable, the majority of data suggest a long-term decline in abundance. However, there are considerable inter-annual and between season variations in apparent shark abundance (as measured by catch or encounter rate) for all areas. Standardised reporting protocols established during this project will help assess status over time, but considerably more data are required. There are still areas and fisheries where white shark interactions are not well recorded and these may offer additional indices useful for monitoring population trends. Reports of interactions with white sharks in most areas have been relatively high in the last few years (1998–2001). It is very unlikely that this increase in interaction rate is due to an increase in population size as a result of reproduction since protection. It is estimated that white sharks reproduce, at best, every three years and thus insufficient time has elapsed since protection to allow for population rebuilding. In addition, interactions have been reported for all size ranges of sharks and not just small ones (which would be expected if increases were due to reproduction). The frequency of white shark sightings and interactions in Australian waters, as well as in other areas across their global range, varies from year to year. These variations are independent of population size and most likely reflect changes in distribution in response to environmental effects, the distribution and abundance of prey, or both. Understanding movement patterns on a seasonal and inter-annual basis is critical for interpreting observed variations in the frequency of interactions, and for understanding population status.

4.2.1 Estimates of minimum population size for white sharks, given current catch levels

(section by Robin Tompson, CMR)

A deterministic model combining available biological data with catch estimates obtained during this study was used to estimate the minimum population size of white sharks in Australian waters, which could support current catches (assuming that these catches are sustainable). There is no current way of determining if this assumption is valid and it must be emphasised that this is not a stock assessment and we cannot currently draw conclusions about population size.

Future stock assessment work will require a longer time series of catches together with either a trend in relative abundance, or at least one estimate of absolute abundance.

Data and parameter values

The parameter values used for the base-case model and several alternative models (sensitivity tests) are shown in Table 14. The data that were used to calculate selectivity are shown in Table 15.

Table 14. Parameter values and model dimensions used

Parameter	Symbol	Base-case value	Alternative values
Sex ratio at birth		0.5	-
Pups per female	τ	9	3-15
Pupping rate	γ	1/3 y	-
Multiplier for mortality during first year	M^0	3	1, 6
Natural mortality	M^{adult}	0.07	0.05, 0.09
L_∞	L_∞	7.323	6.598
k	k	0.042	0.071
t0	t0	-4.173	-2.330
Length-weight	$\hat{a}$	9.3802	-
Length-weight	$\hat{b}$	2.9942	-
Length-at-first-maturity	l^{m1}	4.5	-
Length-at-full-maturity	l^{m2}	5.0	-
Maximum age	x	60	40, 80

Table 15. Number of sharks caught by length class (sexes combined, data for all years summed).

Length (m)	Number captured	Proportion captured
0-2	66	0.2882
2-3	60	0.2620
3-4	49	0.2140
4-5	37	0.1616
5-6	15	0.0655
6+	2	0.0087

Methods

Length and weight

The length of a shark of age *a* is given by the von Bertalanffy growth curve:

$$l_a = L_\infty\left(1-\exp(-k(a-t_0))\right) \qquad (1)$$

and its weight by:

$$w_a = a'\,(l_a)^{b'} \qquad (2)$$

Maturity

The proportion of females in the population that are mature is assumed to be zero until length l^{m1}. Thereafter it increases linearly, reaching 1 at length l^{m2}, after which all females are mature. The proportion of mature females in the population that are of age *a* is therefore given by:

$$\rho_a = \begin{cases} 0 & for\ l_a <= l^{m1} \\ \hat{a}\ l_a + \hat{b} & l^{m1} < l_a < l^{m2} \\ 1 & for\ l_a >= l^{m2} \end{cases} \qquad (3)$$

where $\hat{a}$ and $\hat{b}$ can be calculated once the values of l^{m1} and l^{m2} are known.

Number of reproductively active females
The number of mature female sharks that will reproduce in a given year is:

$$N^m = \sum_a N_a \,\gamma\, \rho_a \qquad (4)$$

where γ is the pupping rate (i.e. the reciprocal of the birth interval).

Selectivity
The probability that a shark of age *a* will be captured was calculated using the data on the proportion captured at length (Table 15). The probability that a fish of age *a* will be captured (S_a) is given by:

$$S_a = \sum_l S_l \, P_{a/l} \qquad (5)$$

where S_l is the probability that a shark of length *l* will be captured (given by the proportion captured at length data, Table 15); and
$P_{a/l}$ is the probability that a shark will have age *a* given that it is length *l*.

$P_{a/l}$ is given by the rudimentary assumption that all sharks follow the von Bertalanffy equation exactly. $P_{a/l}$ is therefore calculated by separating the von Bertalanffy into length groups and into age groups and calculating the proportion of each age group that falls into a given length group. More sophisticated assumptions (such as that the length distribution of each age group following a log-normal distribution with mean given by the von Bertalanffy and some assumed c.v.) could have been made but this was deemed unnecessary given the uncertainty regarding the majority of the model parameters.

S_a was forced to have a maximum value of 1 by dividing all S_a by the maximum S_a value for all ages *a*.

Population numbers
The number of sharks in the population (N_a) is given by:

$$N_a = \begin{cases} N_0 & \text{for } a = 0 \\ N_{a-1}\, e^{-M_a} \left(1 - Q\, S_a\right) & \text{otherwise} \end{cases} \qquad (6)$$

where Q is the exploitation rate; and
M_a is the natural mortality rate for sharks of age *a*. It is taken to be constant for all age groups except for the first year of life when it is increased by a factor M^0 (i.e. $M_0 = M^0 * M^{adult}$).

Number of pups
The number of pups (N_0) is assumed to be a function of the number of reproductively active females in the population (N^m):

$$N_0 = 0.5\, \tau\, N^m \left(1 - \beta\, \xi\right) \qquad (7)$$

where τ is the maximum number of pups (of both sexes) produced by each female,

0.5 is the sex ratio at birth,
β is the parameter that scales density-dependence, and
ξ is the ratio that governs density-dependence:

$$\xi = \begin{cases} N_0 / N_0^0 & \textit{the ratio of the number of pups to that at pristine} \\ N_{1+} / N_{1+}^0 & \textit{the ratio of the } 1+ \textit{ biomass to that at pristine} \end{cases} \tag{8}$$

The density-dependent parameter (β) is chosen so that the population is in equilibrium in the absence of catches (i.e. when ξ = 1). Therefore:

$$\beta = \left[1 - 1/\left(0.5\,\gamma\,\tilde{N}^{m0}\right)\right] \tag{9}$$

where $\tilde{N}^{m0}$ is the number of reproductively active sharks at equilibrium in the absence of catches when the number of pups (N_0^0) is assumed to be equal to 1. Alternatively it can be regarded as the number of reproductively active sharks per female birth.

When catches are taken, the number of pups required to maintain equilibrium conditions is:

$$N_0 = \psi\left(1 - \frac{1}{\tilde{N}^m \gamma\, 0.5}\right) \Big/ \beta \tag{10}$$

where:

$$\psi = \begin{cases} N_0^0 \\ N_0^0 \dfrac{\tilde{N}_{1+}^0}{\tilde{N}_{1+}} \end{cases} \quad \text{if} \quad \xi = \begin{cases} N_0 / N_0^0 \\ N_{1+} / N_{1+}^0 \end{cases} \tag{11}$$

Catches

The number of sharks caught during a year (C^{tot}) given by:

$$C^{tot} = \sum_a N_a\, e^{-M} Q\, S_a \tag{12}$$

Estimation

The per-recruit quantities ($\tilde{N}$) can be calculated given the values in Table 14 and in the equations above. The density-dependent parameter is given by equation 9. If N_0^0 is assumed to be 1 then a range of Q values will result in a corresponding range of values for N_0 (from equation 10) and a range of C^{tot} values (Figure 50). Because the number of pups that can be born to each female has a maximum limit there is a corresponding maximum limit for Q (Figure 50).

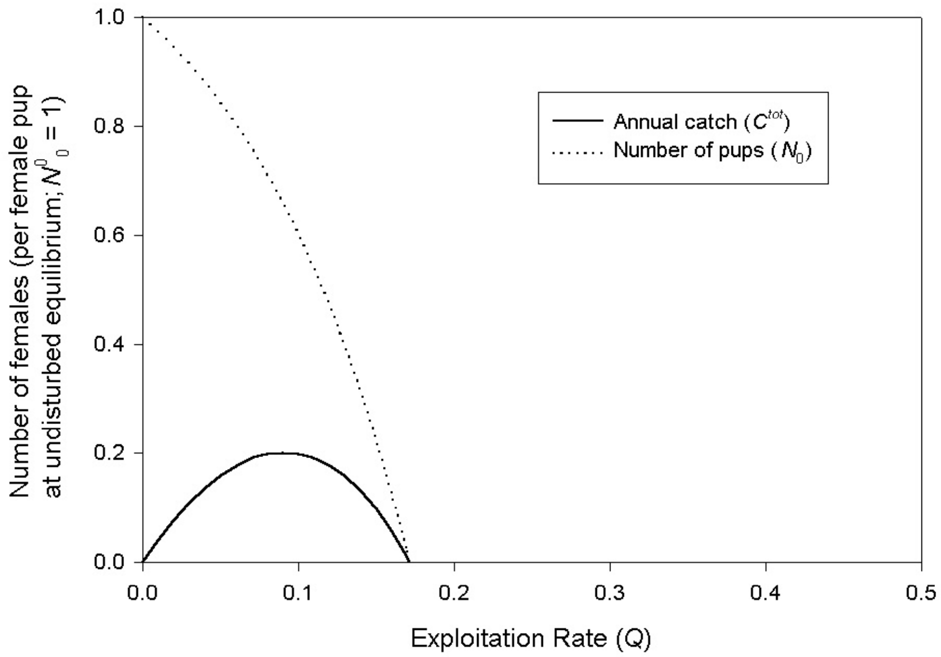

Figure 50. The total annual catch in number of sharks (C^{tot}), and the number of pups required to maintain equilibrium conditions for a range of exploitation rates (Q).

A minimisation method (the 'golden section method', Press *et al.* 1992) was used to find the maximum value of C^{tot} and the corresponding N_0. This represents the minimum population size from which a catch of C^{tot} can sustainably be taken. The number of sharks that are caught in a year is estimated to be approximately 200 (based on Table 13). If half are assumed to be females then the minimum undisturbed population size is given by multiplying the population numbers by 100 / C^{tot}. The minimum population size when these catches are taken is given by equation 6 (with N_0 equal to its value from equation 10), multiplying each N_a by 100 / C^{tot}. Various quantities of interest were calculated in this way for the base-case model and for a range of models that differed slightly from the base-case.

Results

For the base-case model, a peak in the annual sustainable catches occurs for an exploitation rate of 0.091 (Figure 50). The value of the density-dependent parameter (β) is 0.765.

Not surprisingly the sensitivity test that has the greatest influence on the results is that which varies the number of pups that each female produces (τ) (Table 16). The minimum number of pups estimated to have been present in the pristine population decreases with increasing τ (Figure 51). The value of β, correspondingly, decreases. A lower value of β means a weaker density-dependent response and therefore a population that is less resilient to fishing.

Table 16: The values of various quantities of interest for the base-case model and a range of models that differ from the base-case in only one respect. Calculations assume an annual sustainable catch of 100 female sharks. All values pertain to equilibrium conditions and describe **females only**. Numbers have been rounded to the nearest 1.

	Pristine (unfished) equilibrium							Fished equilibrium							
Model	N_0^0	N_0^{1+}	N_0^m	N_0^{av}	W_0^{1+}	W_0^m	W_0^{av}	N_0	N^{1+}	N^m	N^{av}	W^{1+}	W^m	W^{av}	W^{1+} / W_0^{1+} %
Base case	1097	12952	1036	4114	8393	1768	950	719	5295	320	2689	542	2802	386	6%
ξ (N^{1+})	919	10859	869	3449	7037	1482	797	887	5977	340	3177	576	3030	433	8%
"fast" growth	644	7600	888	1847	6285	1514	491	449	2728	240	1281	406	1815	180	6%
$M^0 = 1$	999	13572	1086	4311	8795	1853	996	669	5416	318	2714	538	2805	391	6%
$M^0 = 6$	1285	12300	984	3907	7971	1679	902	815	5207	329	2708	558	2845	385	7%
$M = 0.05$	750	12583	1425	3338	10633	2592	896	546	4309	339	2041	610	2746	305	6%
$M = 0.09$	2007	17722	980	6438	8959	1578	1295	1173	8161	382	4368	613	3689	602	7%
$x = 50$	1281	14422	975	4807	7998	1464	1114	812	6165	327	3139	489	2903	470	6%
$x = 70$	1063	12702	1052	3988	8591	1865	919	702	5138	319	2606	561	2812	370	7%
$\gamma = 4$	2513	29681	2374	9429	19234	4052	2177	1433	13746	979	6115	1666	8188	1020	9%
$\gamma = 14$	838	9897	792	3144	6414	1351	726	585	3740	205	2044	347	1847	270	5%

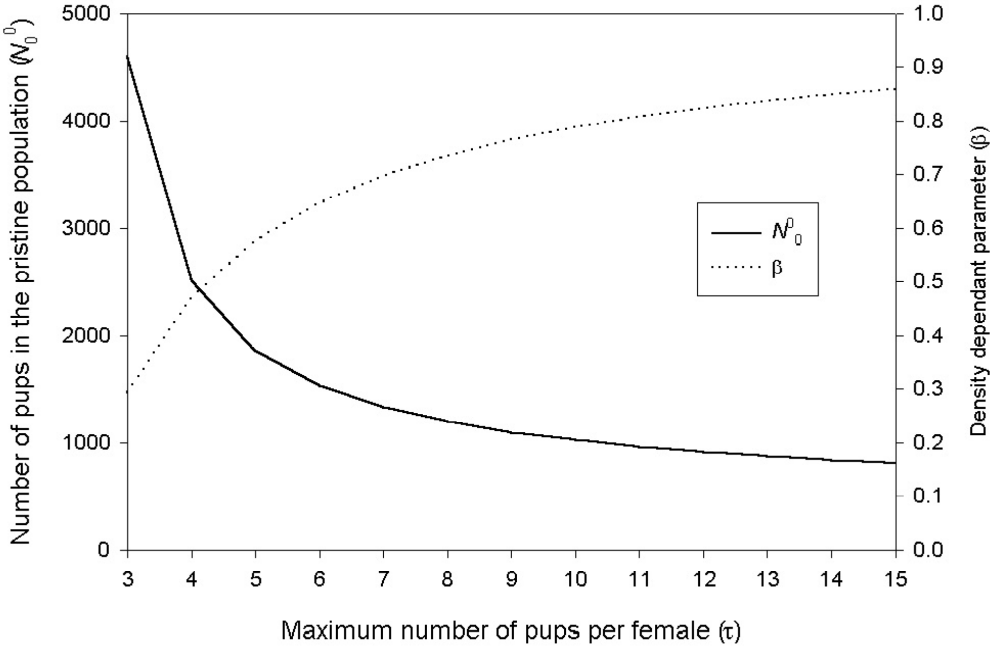

Figure 51. The minimum number of pups present in the pristine population at equilibrium, and the estimated value of the density-dependent parameter (β) as a function of the maximum number of pups produced by each female.

The results are also sensitive to the von Bertalanffy growth curve used, and the adult natural mortality rate. The estimates for the population when catches are taken are particularly sensitive to the adult mortality rate and also show more variation among tests than is the case for the pristine population.

The estimates for the minimum size of the pristine population, assuming that the current catch of 200 sharks is sustainable, range from a female 1+ biomass (age 1 and above) of 6,285-19,234 t (7,600-29,681 female sharks). The ranges for these quantities when the catch is being taken are: 347-1,666 t (2,728-13,746 females). The depletion (defined here as 1+ biomass when catches are taken divided by pristine 1+ biomass) ranges from 5-9%.

4.2.1 Global data sets

There are few data sets from which assessments of other populations of white sharks can be made.

Game fishing data from the east coast of North America indicate declines (similar to those reported off eastern Australia) in the proportion of white sharks caught relative to other shark species. Casey and Pratt (1985) reported a decrease from 1:67 in 1965 to 1:210 in 1983 for the mid-Atlantic Bight region.

Cliff *et al*. (1996a) report a significant decline in white shark captures in the South African beach-meshing program between 1973 and 1993. They also note a marked inter-annual variability in the capture rate with a cyclical period of 4-6 years.

Seasonal residency of the same individuals has been documented in South Africa (Ferreira and Ferreira 1996) and California (Klimley and Anderson 1996). The capture of four adult white sharks at the Farallon Islands in 1982 significantly reduced the frequency of white shark sightings during 1983- 1984 (Ainley *et al*. 1985). Data collected from the Farallon Islands since 1984 indicate a possible slow increase in white shark abundance (Pyle *et al*. 1996).

Incidental captures of white sharks occur in fisheries throughout the species range (Cliff *et al*. 1996b; Francis 1996; Uchida *et al*. 1996; Fergusson 1996). However, only a few of these fisheries are required to report these catches and so this source of mortality is difficult to quantify.

4.3 Other issues influencing catch

4.3.1 Trade

White shark body parts can be of considerable value, although international trade is not well documented. Compagno (1991) reports prices of up to 14,000 rand ($3,790 Aus) paid for Australian white shark jaws prior to protection in South Africa. There are recent reports of up to $5,000 paid for jaws in Australia, and about $500 for single teeth. The Internet has increased the capability for people to buy and sell white shark parts without requiring access to an intermediate dealer. There are a number of web sites in the USA advertising white shark jaws, often with auctions being used to set the price.

There is a "black market" trade in white shark parts from sharks captured since protection. A number of fishers during the course of this project have mentioned that illegal jaw selling is occurring in Australia. One fisher reportedly caught 14 to 16 white sharks in South Australia in 1999 and sold their jaws through the internet. The international organisation TRAFFIC reports white shark fins, jaws, teeth and meat are traded in Hong Kong, Taiwan, Thailand and South Korea (Chen 1996, Rose 1996). There is also a local trade because of people wanting jaws to hang on their walls, or teeth for necklaces.

The increasing world demand for shark fins is also reflected in prices paid for white shark fins, which are among the species preferred by Hong Kong traders (Lai 1983). In Taiwan, white shark fins are considered of medium grade (Chen 1996), although they are likely to have special appeal because of the species reputation.

4.3.2 Problems with identification

Large white sharks are generally easy to identify. However, miss-identification of small individuals (< 200 cm TL) appears to be a problem in areas where they are more common such as inshore Victoria. Neonate and one year old white sharks have been mistaken for whaler (*Carcharhinus* spp.) and mako sharks (*Isurus* spp.) and are taken by both commercial and recreational fishers. White sharks are sometimes, deliberately, processed through Australian markets and carcasses may be difficult for fisheries compliance officers to identify.

4.3.3 Knowledge of the regulations

There is still confusion and ignorance among some fishers and even some enforcement officers regarding protective legislation for white sharks. The problem is exacerbated because different regulations apply to Commonwealth waters and between the individual States. This needs to be addressed by ensuring information on regulations is more accessible. Reporting requirements, where they exist, are generally not well understood, or they are often ignored.

4.4 Recent reductions to threatening processes

Various actions have already led to a reduction in the level of threat to white sharks over the past decade or so. These include changes in fishing gear and reductions in fishing effort, nation-wide laws prohibiting intentional targeting and take of white sharks and changes in community attitudes towards sharks in general.

4.4.1 Changes in commercial fishing practises

There have been reductions in fishing effort in the commercial shark fisheries in southern Australia over the last 15 years, and thus presumably in the numbers of white sharks taken as by-catch. In 1996, effort in the Southern Shark Fishery was less than half the peak effort of 1987, partly due to a reduction in the amount of net permitted per fishing operation (Walker *et al*. 1998). It is not known how the recent move to quota management in this fishery will affect white shark catches. In Western Australia, there have been significant reductions in effort during the 1990s through gear reduction. The management objective is a 50% reduction of effort on 1993/94 levels by 2000/01 (WA State of Fisheries Report 1997/98).

Fishing gear used by commercial shark fishers has also changed since the 1970s. Nets are now made from lighter monofilament polyamide webbing, which can be broken by larger sharks. Mesh-size has also decreased since the early 1970s becoming more selective towards catching smaller sharks.

Net height has increased in the Southern Shark Fishery (generally from 12 mesh drops to 20 mesh drops) over the past two decades, which has had the benefit of separating the head-line and foot-line. Some fishers believe this has reduced the probability that a white shark scavenging from a shark-net will become entangled. When the head-line and foot-line are further apart, a white shark has less chance of biting through or snagging the rope when feeding on fish from the net. However, some fishers have taken an alternative view, and believe the increase in net-height has meant that nets develop a bigger ‘belly’, which increases the chance of entanglement. This will depend on how tightly the mesh is strung onto the head and foot-line, and how much flotation is provided to the head-rope. If the mesh comes in a longer bale than the permitted net length and the full bale is used, it will be “baggy” and have greater chance of causing entanglement.

Soak times (length of time the net is set) have also decreased in some areas. Commonwealth fishers working out of Robe now usually set for 4-6 h. In the past, they often set for 8-10 h. This decrease in soak time was to improve the quality of product, but has probably also benefited captured white sharks as they are more likely to be found alive (and thus released). One of these fishers caught four white sharks between December 1998 and June 1999 and was able to release all four alive. However, not all fishers follow these shorter soak times. Longer set times appear more common in WA.

Changes to fishing gear (within management constraints) are often implemented by individual fishers, usually, to improve the catch of target species or to reduce by-catch. This can include changing the way gear is configured. In some cases, this has had direct benefits towards reducing incidental mortality of white sharks. For example, one snapper long-liner has increased the distance between snoods and uses heavier gear to reduce entanglement of larger sharks. The heavier main line and heavy anchors keep the gear more rigid. Increasing the distance between snoods enables a hooked shark to swim around without tangling or being foul-hooked on adjacent hooks. The heavier gear enables a large shark to exert pressure to straighten the hook instead of pulling the gear along.

Changes in the Marine Scale-fish Fishery in South Australia have probably also had some benefits. These changes have included reductions in long-line and handline effort since the 1980s. In 1987/88, gear restrictions were imposed on the long-line fishery with a maximum of 400 hooks per licence being permitted (McGlennon and Jones 1999).

4.4.2 Legal protection

The specific protection of white sharks in Australia was initiated in 1995. White sharks were protected from intentional capture in all Australian waters (excluding beach protection programs in NSW and Queensland) by 1999. Although incidental captures still occur, the banning of intentional capture and killing of white sharks has reduced intentional take and resulted in more white sharks being released after capture. However, the number of white sharks that continue to be taken by people prepared to break the law is unknown.

There has been a closure to shark gill-netting and shark long-lining within 3 nautical miles of the Victorian coast in ocean waters since 1988. Small white sharks occur reasonably frequently in some coastal areas of Victoria and this closure may provide a refuge for them at a size when they may be most susceptible to capture in nets. This closure also includes areas around fur seal colonies where large white sharks aggregate to feed. However, small white sharks are still caught by other (non-net) methods in Victorian waters.

Monofilament gill-nets are banned in NSW which has reduced incidental white shark captures in that state. Shark fishing is prohibited in WA from Shark Bay to NW Cape to protect breeding stocks of whaler sharks. However, white shark abundance in this area is probably low.

Taking white sharks for commercial purposes was banned in some areas prior to overall protection. In 1994, SA Fisheries removed the white shark from the list of species that commercial marine scale-fish fishers could take (Presser and Allen 1995). The ban on taking a number of shark species in Victoria (1985-1992), as a response to high mercury levels, would also have provided some protection to the white shark.

4.4.3 Changes in community attitudes

Even prior to protection, intentional killing had decreased from previous decades when community attitudes were primarily negative towards sharks. The change in community attitudes was also reflected, in part, by the change in game-fishing emphasis to tag release. Prior to the 1990s, a considerable number of white sharks were captured and killed by game-fishers in Australian waters. Tag-release subsequently became more common in Australia, although ‘trophy’ sharks were still occasionally killed up until protection.

4.5 Environmental factors influencing abundance

As with all species, white sharks are subject to inter-annual variations in abundance. In 1990 and 1995 abundance appeared to be higher in the GAB. In 1999-2001, white sharks appear to have been sighted more regularly in South Australia. While some sightings, may have been triggered by the wide media coverage of the three fatal white shark attacks (two in SA, one in WA) during 2000, cage dive operators at the Neptune Islands also reported a good year for shark sightings in 2000. However, a high proportion of the sharks sighted at the Neptune Islands, where operators work, were already tagged, suggesting more of the population was locally available rather than there being an increase in overall numbers.

Shifts in the distribution of white sharks may occur between years in response to environmental factors or the distribution of prey, or both. Some shark fishers reported that snapper as well as other species of shark (e.g. sevengill shark, *Notorynchus cepedianus*) were also unusually abundant in their catches in SA during 2000.

The links between these factors are still poorly known and worthy of continued study. Inter-annual differences in distribution make assessing abundance indices difficult. A significant time series of data from various sites will be necessary before indices can be used to assess overall population trends and status.

4.5.1 Water temperature

White sharks can tolerate a broad temperature *range* as indicated by their distribution (tropical to cool temperate). However, they appear to have a narrower temperature *preference* that may be related to the distribution of their main prey.

The occurrence of white sharks in NSW often seems to be associated with colder pulses of water. Several captures in 1999 occurred in water temperatures of 15 –18°C. In September 1999, five white sharks were captured over one weekend in central NSW in different beach protection nets. This was associated with water temperatures dropping from 18°C to 15.3°C due to a cold water plume or possible upwelling. In these examples, however, it is difficult to establish whether white shark movements were a direct response of temperature or if the temperature change influenced the availability of prey in the area. All five sharks were juveniles of 175-220 cm TL. A demersal long-liner in NSW reported catching white sharks when cold, “dark green” water was present. This fisher caught two in 1999 when the water temperature was 18°C, which was about 2°C cooler than normal.

White sharks are endothermic or warm-bodied (Carey *et al*. 1982) enabling them to function efficiently in cold water. Stomach temperatures of white sharks have been recorded as high as 14.3°C above ambient water temperature (Goldman 1997). Stomach temperatures were shown to vary within a narrow temperature range while ambient temperature fluctuated widely, suggesting that white sharks may be capable of regulating their body temperature.

4.5.2 Food resources

Marine mammals

It is common to find adult white sharks in the vicinity of pinniped colonies in southern Australia and their movements may be linked to pinniped distribution and behaviour. However, adult white sharks also occur in areas where there are no pinniped colonies, so this association is not an obligate one.

Adult white sharks also feed on cetaceans, including neonate whales, and their movements in the GAB and up the east and west coasts of Australia may be linked to whale migrations and calving events. They will also scavenge on whale carcasses when the opportunity arises, and may stay with a carcass for a number of days. From 1999-2001, there were at least 8 incidents of white sharks scavenging on large floating whale carcasses in Australia.

Seasonal fish migrations

There is an association between white shark and snapper distribution and movements. Some adult white sharks are associated with snapper in the SA Gulfs, and juvenile white sharks are associated with snapper in Victoria. There are probably linkages with the movements of other fish including Australian salmon, trevally (*Pseudocaranx spp.*), tailor (*Pomatomus saltatrix*) and mulloway (*Argyrosomus hololepidotus*) as well as school and gummy sharks that are referred to in previous sections.

5. CONCLUSIONS

White sharks are caught incidentally in a number of Australian fisheries and this will continue in the foreseeable future. However, widespread discussion about their vulnerable status and protection in Australia has had a tangible and positive benefit for this species in recent times. It has reduced the intentional take of white sharks and has increased the release rate of incidentally caught specimens. It has also promoted the value of this species and increased public perception that white sharks have an important role in our marine environment as an apex predator.

Refinement of by-catch estimates, further biological information and long-term regional abundance indices are required to provide a more adequate assessment of population status. A number of mechanisms to facilitate this have been initiated during this study, and these should be continued and expanded in the future.

There is no evidence to suggest that white sharks should be upgraded from vulnerable to endangered under protective legislation. There are strong indications that the current protection is of benefit and should be maintained.

6. FURTHER DEVELOPMENT

The identification of white sharks in some areas (e.g. small white sharks in eastern Victoria) and under some circumstances (e.g. illegally processed/marketed carcasses and fins) is still posing problems in Australia. Further information in the form of simple guides that identify internal and external characters is required.

Further work on movement patterns of white sharks is required to define site fidelity, home range and seasonal movement patterns and to identify critical habitat areas. An NHT funded study (2000-2002) using automated acoustic listening station technology, and further planned work on satellite tracking will address some of these questions.

Necropsies of white sharks captured as by-catch should be continued so that basic biological information on the species can be improved.

Further population modelling is required to determine population status and help monitor recovery and establish biologically meaningful recovery targets.

Levels of by-catch of white sharks in some Australian commercial fisheries have yet to be adequately assessed (e.g. tuna industry, various NSW commercial line fisheries).

Analysis of historical game fishing data sets and monitoring sightings frequency by game fishers may provide further insights into the species ecology and an additional useful index of white shark activity/abundance.

Continued tagging and monitoring of white sharks at the Neptune Islands in co-operation with the cage-dive industry will provide a useful index of abundance in future and should be maintained. Monitoring of shark bites on seals should also be continued at selected sites as a possible index of white shark abundance.

Sightings and interactions from other areas are required to compare with the Neptune Island Index as a means of monitoring white shark activity-abundance in Australian waters. Apart from those mentioned above, sightings by abalone divers, sightings in specific areas where white sharks are more commonly seen (e.g. west coast SA) and sightings-interactions by the tuna farming industry would provide useful indices.

A continued commitment by State and Commonwealth agencies is required to continue data collection.

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