Sawshark and elephant fish assessment and bycatch evaluation in the Southern Shark Fishery

Terence I. Walker and Russell J. Hudson

Project No. 1999/103
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July 2005

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Published by Primary Industries Research Victoria, Marine and Freshwater Systems, Department of Primary Industries, Queenscliff, Victoria, 3225.

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ISBN 1 74146 416 1

Formatted/designed by Primary Industries Research Victoria Queenscliff
Printed by PIRVic Queenscliff, Victoria
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NON-TECHNICAL SUMMARY

1999/103 Sawshark and elephant fish assessment and bycatch evaluation in the Southern Shark Fishery

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Objectives:
1. Determine population parameters required for fishery stock assessment of the non-target species common saw shark, southern saw shark and elephant fish.
2. Provide stock assessment of each of these three non-target species in Bass Strait.
3. Provide data for assessment of bycatch, discards and damaged shark in the shark fishery of southern Australia (part of Gillnet Hook and Trap Fishery).

Non Technical Summary:
This project investigated the fisheries population biology of two sawshark and one elephant fish species and evaluated target catch, byproduct catch, bycatch and damaged shark in the shark gillnet and shark hook sectors of the Gillnet Hook and Trap Fishery (GHATF). The species investigated were common sawshark (Pristiophorus cirratus), southern sawshark (P. nudipinnis), and elephant fish (Callorhinchus milii).

In addressing the three project objectives, data were used from field studies undertaken during 1973–76 and 1986–87 as part of earlier projects and from field studies undertaken during 1998–01 as part of the present project. Determination of population parameters (Objective 1) was based on data from all three periods. Stock assessment of sawshark and elephant fish (Objective 2) was based on these parameter values and several other data sets. The other data sets include length-frequency data from all three periods and time series of commercial catch (1950–03), fishing effort (1976–03), and catch per unit effort (1976–03) data for shark longlines and for each mesh-size of shark gillnets. The assessments also included catch for Danish seine (1950–03) and demersal trawl from the South East Trawl Fishery (1985–03) and Great Australian Bight Trawl Fishery (1988–03). The first stock assessment for each of common sawshark, southern sawshark, and elephant fish covering only the Bass Strait region was undertaken and presented to the 20–21 May 2004 SharkRAG meeting. These assessments were subsequently reviewed and extended to include Bass Strait, Tasmania and South Australia and, for elephant fish only, New South Wales, and were then presented to the 9–10 September 2004 SharkRAG meeting. Target catch, byproduct catch, bycatch and damaged shark evaluation in the shark fishery (Objective 3) was based on data collected during 1973–76 and 1998–01. All three objectives of the project were met completely.

Determination of population parameters
The gillnet selectivity parameters, von Bertalanfify growth parameters, and reproductive parameters for each of common sawshark, southern sawshark, and elephant fish were determined and applied for stock assessment undertaken through SharkRAG during 2004. New methods for estimating the values of reproductive parameters were developed and applied to new and available data on school shark.
reproduction. Descriptions of the structure and function of some of the reproductive structures of the elephant fish were also made.

The elephant fish belongs to the small taxonomic group known as holoccephalans or chimaeras, which form part of class chondrichthyes (sharks, rays and chimaeras) and which has received limited scientific attention in the past. This presented major challenges for the present project when investigating the elephant fish. To address basic biological uncertainties, several small-scale sub-projects were parcelled out to university postgraduate students supervised by the Principal Investigator and by Professor William C. Hamlett, of the University of Indiana, Indiana, USA to investigate the microanatomy, structure, and function of some of the male and female genital ducts. Similar more limited sub-projects were undertaken for common sawshark and southern sawshark. Although this work is not central to the objectives of the present project, it provides a basis for better understanding the reproductive biology of these species and determining maturity, maternity, and timing of mating and egg laying in elephant fish or birth in sawshark.

The at-sea, sampling component of the present project enabled opportunistic collection of data on the reproductive biology of school shark (*Galeorhinus galeus*) and gummy shark (*Mustelus antarcticus*) at no extra cost. The additional data sets for school shark and gummy shark augment earlier data sets and enable addressing certain uncertainties about their reproductive biology evident from the earlier data sets. The results for school shark are incorporated into the special book chapter on reproduction methodology and the gummy shark results are presented in a manuscript currently in preparation (excluded from the present report).

**Sawshark and elephant fish stock assessments**

The data sets for common sawshark, southern sawshark, and elephant fish off southern Australia are limited and stock assessment would be not be possible, had the present project not been undertaken. The only monitoring data on which an assessment of sawshark (species combined) and elephant fish can be based are catches and catch-rates. The types of long time series of catch length-frequency data and tag release-recapture data available for gummy shark and for school shark are not available for sawshark or elephant fish. Although most of the catch is from Bass Strait and there are generally low catches in waters off Tasmania and South Australia, the assessments undertaken apply to this entire region of waters on the continental shelf and slope for sawshark and to New South Wales for elephant fish. Catch-rate indices for these species were developed on the assumption that the effort estimated to be targeted at gummy shark is also targeted at sawshark and elephant fish. Catches of sawshark are distinguished between common sawshark and southern sawshark on the basis of catches recorded as scientific observations during 1973–76, 1986–87 and 1998–01. The assessments are based on a non-spatial, and age- and sex-based population dynamics model similar to that used for the 1996 stock assessment of school shark (*Galeorhinus galeus*) (Punt and Walker 1998). The results of the base-case assessments indicate that both sawshark and elephant fish are depleted to below 40% of the 1950 pup production level but that the rate of decline in the size of these resources has decreased substantially since the mid-1980s. Sensitivity tests indicate that the uncertainty range of depletion levels is less for elephant fish (14–22%) than for sawshark (17–39%). Pup production is assessed at 32% for common shark, 26% for southern shark, and 20% for elephant fish of the 1950 levels.

**Evaluation of target, byproduct, bycatch and damaged catch**

Catches were evaluated using data recorded during 1973–76 as part of a population study of gummy shark (*Mustelus antarcticus*) on the continental shelf of south-eastern Australia and data recorded during 1998–01 on commercial vessels as part of the present study. During 1973–76, catches of all species taken in gillnets of eight mesh-sizes 2–9 inches and on longlines were recorded; this provides valuable baseline data of the relative abundance of fish at that time. Comparing catch rates of all species by gillnets of 6-inch mesh-size between 1973–1976 and 1998–01 provides a basis for evaluating potential changes in the abundance of each species impacted by commercial fishing.

During 1973–1976 and 1998–01, a much higher number of animals and a higher number of species were caught by gillnets (mesh-sizes 2–9 inches) than by longlines (hook-sizes Mustad 2/O–11/O). Several important conclusions can be made about the catch rates of gillnets and longlines deployed on the continental shelf in the depth range 9–130 m. Shark gillnets and shark longlines are both much more

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**Sawshark, elephant fish and SSF bycatch**
effective at catching chondrichthyan species than at catching teleost species, and catches of species of cephalopoda, bivalvia, gastropoda, mammalia, aves and reptilia are negligible. The effect of gillnet mesh-size on catch rates is strong, whereas the effects of gillnet hanging ratio, hook size, hook shank length, and hook space are weak. Overall catch rates of chondrichthyan and teleost fishes by mesh-size are very different. For chondrichthyns, the modal catch rate is by 4-inch mesh-size with decreasing catch rates for both increasing and decreasing mesh-size, whereas for teleosts the modal catch rate is by 2-inch mesh-size with decreasing catch rates as mesh-size increases.

For chondrichthyes, the top four species taken by gillnet across 8 mesh-sizes—Squalus megalops, Mustelus antarcticus, Heterodontus portusjacksoni, and Galeorhinus galeus—are similar to the top four species taken by longline across 8 hook sizes—Squalus megalops, M. antarcticus, Cephaloscyllium laticeps, and G. galeus. The only difference is that H. portusjacksoni is more prevalent than C. laticeps in the gillnet catch, whereas the converse occurs for the longline catch. For teleostei, Platycephalus bassensis is the most prevalent species caught by both gillnets across 8 mesh-sizes and longlines across 8 hook sizes. Neosebastes scorpaeoides is the second most prevalent species caught by longline and the third most prevalent species caught by gillnet. The second most prevalent species taken by gillnet—Trachurus novaezelandiae—is not caught by longline.

For chondrichthyes in Bass Strait, there has been about a one-third overall reduction in abundance across all species combined between 1973–76 and 1998–01. About half of this reduction is attributable to an 87% reduction in the catch per unit effort (CPUE) of Galeorhinus galeus and a 54% reduction in the CPUE of Cephaloscyllium laticeps.

Only small proportions of the commercial catch of chondrichthyan (3%) and teleost (2%) animals taken by demersal gillnets of 6-inch and 6½-inch mesh-size coming on-board dead are discarded. The discarded animals are mostly Cephaloscyllium laticeps, Heterodontus portusjacksoni, Squalus megalops, and Myliobatis australis, which come on-board live.

Wildlife interactions occur occasionally with Australian fur seals (Arctocephalus pusillus dorfer) and common dolphin (Delphinus delphis). Of ten chondrichthyan species on the continental shelf and continental slope identified by the IUCN Shark Specialist Group as threatened, two are identified by the present study as caught by shark fishing. White shark (Carcharodon carcharias) is taken occasionally and Galeorhinus galeus, once the primary target species, is presently taken as significant byproduct catch (195 t during 2002). Both these species are now carefully managed.

Damage to shark carcasses from predation by invertebrates, fish and mammals to sharks landed on-board from gillnets of 6-inch or 6½-inch mesh-size was investigated on-board nine vessels operating under normal commercial fishing conditions. ‘Lost carcass mass’ from predation for gummy shark and school shark combined is estimated at 4.9% (4.7% for gummy shark and 6.9% for school shark); it is slightly higher in South Australia (5.3%) than in Bass Strait (4.7%). ‘Lost carcass mass’ for common sawshark and southern sawshark combined is estimated at 2.3% (2.1% for common sawshark and 3.5% for southern sawshark) and for elephant fish is estimated at 3.4%. ‘Devalued retained carcass mass’ from major damage is estimated at 9.2% for gummy shark and school shark combined (9.0% for gummy shark and 12.8% for school shark), 4.2% for common sawshark and southern sawshark combined (4.0% for common sawshark and 5.5% for southern sawshark), and 6.1% for elephant fish.

**OUTCOMES ACHIEVED**

All three objectives of the project were met completely and there are several important outcomes.

All basic gear selectivity parameters, von Bertalanffy growth parameters, and reproductive parameters required for appropriate fishery stock assessment are available for ongoing assessments. Available catch (1950–03), effort (1976–03), and catch per unit effort (1976–03) data for sawshark and elephant fish have been assembled in a secure and accessible SAS database and have been appropriately extracted and used for stock assessment.

The first stock assessment for each of common sawshark, southern sawshark, and elephant fish was undertaken and presented to 20–21 May 2004 SharkRAG meeting. These assessments were subsequently
reviewed and extended and then presented to the 9–10 September 2004 SharkRAG meeting. These full assessments provided a basis for setting sawshark and elephant fish total allowable catches for the entire Southern and Eastern Scalefish and Shark Fishery. Whereas there are not the rich data sets that underlie the renowned gummy shark and school shark assessments, there are now sufficient data to provide defensible assessments for the sawshark and elephant fish. Gummy shark and school shark also have long-term length-frequency and tag release-recapture data sets, which contribute markedly to reducing the bounds of uncertainty in those assessments.

Evaluating target catch, byproduct catch, and bycatch in the shark fishery of southern Australia has met a first step data requirement for several important processes presently under way and these results form an important part of legislatively prescribed documentation associated with these processes. One of these processes is strategic assessment of fisheries under the Australian Environment Protection and Biodiversity Conservation Act 1999 and AFMA has drawn heavily on the results of the present project in its documentation. As part of an independent process, AFMA has also drawn on these results for preparation of the Bycatch Action Plan for the Gillnet Hook and Trap Fishery required legislatively under the Australian Fisheries Act 1991. Catch evaluation in the shark fishery meets one of the requirements of Australia’s National Plan of Action for the Conservation and Management of Sharks launched 26 May 2004. The results were a crucial input for Ecological Risk Assessment for the Effects of Fishing for scoping and a level 1 assessment for each of five components (target species, byproduct and bycatch species, threatened and protected species, habitats, and communities) associated with the use of shark gillnets and shark longlines. The catch evaluation data now available on shark fishing has reduced uncertainty about the impacts of shark fishing (see section Further Development). Most bycatch comes on-board live and can be discarded live and there is negligible bycatch discarded dead. The results dispel myths and beliefs that shark gillnets and shark longlines have high bycatch. Industry, fishery managers, scientists and other beneficiaries find the data and results extremely informative and valuable.

**Keywords:** Gillnet Hook and Trap Fishery, sawshark, elephant fish, bycatch, and stock assessment

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Sawshark, elephant fish and SSF bycatch
Note: Outcomes are the results, impacts or consequences of actions by the FRDC and its R&D partners on the fishing industry and Australia’s economic, environmental and social resources.

Outputs are the goods and services (mainly knowledge, processes and technology) that the FRDC and its R&D partners produce for external organisations and individuals.

Acknowledgments

Acknowledgment is due to the many people who during 1998–01 participated in collection of sawsharks or elephant sharks at sea, in recording of targeted catch, byproduct catch, and bycatch at sea, in laboratory dissection and ageing of sharks, and in providing statistical advice for analysis of the data. Capture of the animals was undertaken by professional fishers Ron Anthony, Ron Atterton, Stephen Brockwell, Rod Casement, Mick Cook, Harry Ferrier, Jon Gazam, Mark Goulden, Neil Hosking, Peter Riseley, Adrian Rodgers, Arthur Sifford, and Robert White. These fishers made the animals either available for dissection at sea or returned them to port for dissection in the laboratory. Lauren Brown of the Marine and Freshwater Systems, Primary Industries Research Victoria Queenscliff Centre (PIRVic) and Dr Jeremy Prince of Biospherics Pty Ltd participated in monitoring bycatch and dissecting sharks at sea during 1998. Postgraduate students Justin Bell, Jessica Creek, Stephen Dwyer, Jessica Whitlock, Amy Beck, Tracey King, Stephen Leporati, Rachel Smith, Matthew Reardon, Megan Storrie, and Stephanie Van’t Hoff assisted with the laboratory dissections. Corey Green and Thérèse Stokie of the Central Ageing Facility at PIRVic undertook laboratory ageing of animals. Anne Gason of PIRVic provided advice on statistical methods for analysis of the data using the statistical package SAS. Professor William C. Hamlett of the Department of Anatomy and Cell Biology, Indiana University School of Medicine, and Dr Rob W. Day of the Department of Zoology, University of Melbourne, served as academic supervisors of students participating in the project.

Acknowledgment is also due to the former technical staff of PIRVic and the many professional fishers who participated in field sampling of sharks during 1973–76 and 1986–87. Collection of data during these two earlier periods was funded from the former Australian Fishing Industry Research Trust Account and the Victorian Treasury. Collection of data during 1998, as part of the Pilot Fixed Site Stations Survey, was funded by the Australian Fisheries Management Authority. Collection of data during 1999–01 and subsequent analysis and reporting of the data were funded by the Australian Fisheries Research and Development Corporation (FRDC) as part of FRDC Project 1999/103. Catch and effort data used for stock assessment of sawshark and elephant fish were sourced from the fisheries agencies of Victoria, Tasmania, and South Australia and from AFMA and were assembled as part of the AFMA funded Southern Shark Fishery Monitoring Project. Species names were based on the Codes for Australian Aquatic Biota (www.marine.csiro.au/caab/caabsearch). Dr André Punt of CSIRO Marine Research and University of Washington is acknowledged for applying available computer software for stock assessment to the sawshark and elephant fish data collated and made available as part of the present project. This software was originally developed for school shark and gummy shark through SharkRAG processes. SharkRAG is acknowledged for its ongoing specification, advice and scrutiny of the sawshark and elephant fish assessments.
Background

Acronyms

AFMA Australian Fisheries Management Authority
CSIRO CSIRO Marine Research
FIRTA Fishing Industry Research Trust Account
FRDC Fisheries Research and Development Corporation
GHATF Gillnet Hook and Trap Fishery
IPOA-Sharks International Plan of Action for the Conservation and Management of Sharks
NPOA-Sharks National Plan of Action for the Conservation and Management of Sharks
PIRVic Primary Industries Research Victoria
SharkRAG Southern Shark Resource Assessment Group

Structure of report

The present project investigates the population dynamics of two sawshark and one elephant fish species and evaluates target catch, byproduct catch, and bycatch taken by shark gillnet and shark longline in the Gillnet Hook and Trap Fishery (GHATF). The species investigated were common sawshark (*Pristiophorus cirratus*), southern sawshark (*P. nudipinnis*), and elephant fish (*Callorhinchus milii*). The report has all the prescribed sections of a standard FRDC report, but, because of the diverse range of subjects, much of the detailed information is presented in separate appendices prepared as ten manuscripts and two reports. These follow the standard Appendix 1 (Intellectual Property) and Appendix 2 (Staff). Appendices 3a–3g provide details relating to determination of population parameters (gillnet selectivity, length at-age, and reproduction) for common sawshark, southern sawshark, and elephant fish (Objective 1). Appendix 4 provides details of stock assessment of these three species (Objective 2). Appendices 5a–5b provide details of evaluation of catches of target, byproduct and bycatch species taken by shark gillnets and shark longlines and details of catch evaluation of damaged shark taken by shark gillnets in the Gillnet Hook and Trap Fishery (Objective 3).

Of the ten manuscripts, nine were prepared for internationally reviewed journals and one in a chapter of a book on chondrichthyan reproduction. The book chapter and four of the nine manuscripts are published, five manuscripts are in preparation. The manuscripts and reports are referenced as follows.


Sawshark, elephant fish and SSF bycatch


Walker TI (in prep) Gillnet selectivity for four chondrichthyan species harvested off southern Australia. (Prepared for Marine and Freshwater Research).


Walker TI, Hudson, RJ (2005) Predation damage rates to shark in the Gillnet Hook and Trap Fishery. 10 pp. Primary Industries Research Victoria, Queenscliff, Victoria, Australia. (Prepared for SharkRAG.)

Walker TI, Hudson RJ, Bell JD, Reardon MB, Smith RM, Hamlett WC (in prep) Reproductive biology of elephant fish (Callorhinchus milii) harvested off southern Australia. (Prepared for Marine and Freshwater Research).


Walker TI, Hudson RJ, and Green C (in prep) Age and growth studies of two sawshark and one chimaera species harvested off southern Australia. (Prepared for Marine and Freshwater Research).

In addition to preparing these 10 manuscripts for scientific papers and two reports, the following five theses were prepared on two sawshark and one elephant fish species.


The species

Three endemic species of sawshark whose distributions have not been described precisely occur off southern Australia. Common sawshark (Pristiophorus cirratus) is reported to range from Jurien Bay in Western Australia to Eden in New South Wales, including Tasmania, to depths of 310 m. Southern sawshark (P. nudipinnis) is reported to range from the western region of the Great Australian Bight to eastern Gippsland in Victoria, including Tasmania, to depths of 70 m. Eastern sawshark (Pristiophorus sp. A) is reported to range from about Lakes Entrance in Victoria to Coffs Harbour in NSW at depths of 100–630 m (Last and Stevens 1994). For assessment purposes, all sawsharks south of the Victoria–NSW border are assumed to be common sawshark and southern sawshark, whereas those north of this border are assumed to be eastern sawshark.

The elephant fish is distributed from Esperence in Western Australia to Sydney in New South Wales, including Tasmania, at depths to at least 200 m. Elephant fish also occur in New Zealand, but are assumed to be a separate stock from the population in southern Australia (Last and Stevens 1994).

Although these species have wide distributions off southern Australia, ~90% of the sawshark catch in the Gillnet Hook and Shark Fishery (GHATF) is taken in Bass Strait and ~99% of the elephant fish catch is taken in Bass Strait and off the eastern and south-eastern coasts of Tasmania. Most of the sawshark catch is not distinguished between the three species of sawshark; it is simply reported as ‘sawshark’ in their catch and effort logbooks. Of the total sawshark catch of 284 tonnes reported for 2002, the GHATF took 59%, the South East Trawl Fishery took 24%, the Great Australia Bight Trawl Fishery took 7%, Tasmanian state fisheries took 5%, and NSW state fisheries took 5%. Of the total elephant fish catch of 71 tonnes reported for 2002, the GHATF took 57%, the South East Trawl Fishery took 21%, Tasmanian state fisheries took 18%, and Victorian state fisheries took 4% (Walker, Taylor et al. 2003).

It is uncertain whether each of these species form single stocks or multiple stocks. Limited tag and release data provide evidence of movement within Bass Strait for P. cirratus, and of movement between Bass Strait and southern Tasmania for P. nudipinnis and C. milii. Neither species of sawshark appears to move into distinct pupping grounds, but each year mature elephant fish migrate into large estuaries and inshore bays to lay their eggs (unpublished data).

Previous research

Most previous research of sharks in the GHATF was focused on gummy shark (Mustelus antarcticus) and school shark (Galeorhinus galeus), but some biological data on reproduction, morphometrics, and gillnet selectivity were collected opportunistically for common sawshark, southern sawshark, and elephant fish during 1973–76 and 1986–87. In addition, small quantities of tag data were collected for these species during 1973–76 and 1990–01. However, it was not until undertaking the present project that there have been sufficient data to determine all the basic fisheries population parameters required for stock assessment of these species.

The present report draws both on data collected as part of the present project (1998–01) and on the earlier data collected opportunistically. The earlier biological data came from four projects: ‘Investigations of the Gummy Shark from South-eastern Australian waters’ (FIRTA 1973–76), Southern Shark Assessment (FIRTA 1985–88), ‘Southern Shark Tagging’ (FRDC Project 93/066), and ‘Southern Shark Tag Database’ (FRDC Project 96/162). In addition to the present project, available byproduct and bycatch data are from the FIRTA...
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1973–76 Project and the ‘Pilot Fixed Site Station Survey (AFMA 1998). Fishers logbook catch and effort data, which are used for the sawshark and elephant fish stock assessments in the present study, were during 1973–88 compiled as part of the four earlier FIRTA and FRDC projects and during 1988–03 compiled as part of an ongoing project. The ongoing project, presently referred to as the GHATF Monitoring Project, was initially funded by the former Australian Fisheries Service and, then subsequently, by AFMA.

The present project is the first study to investigate any species of sawshark worldwide. There have been previous studies of the elephant fish in southern Australia and New Zealand, but this is the first attempt to assemble all the data appropriate for a detailed stock assessment. Taxonomically, the elephant fish is a holocephalan species, for which less than 40 species are described worldwide. Hence, when the present project began, the male and female reproductive systems had not been described for any species of sawshark (family Pristiophoridae) (7 species described worldwide) and had not been well described for any species in the holocephalan group. Hence, description of the reproductive systems for *P. cirratus*, *P. nudipinnis*, and C. *milii* was addressed through collaboration with William C. Hamlett, Professor of Anatomy and Cell Biology at the Indiana University School of Medicine. Professor Hamlett is an authority on the structure and function of the reproductive systems of sharks and other chondrichthysans. This collaboration involved several projects undertaken by students for B.Sc. (Hons) degrees at the Zoology Department of the University of Melbourne. Through the involvement of Professor Hamlett and these projects, several journal papers have been published or are presently in the process of publication. These papers provide descriptions of the structure and function of the reproductive tracts of these three species (Beck, Walker *et al.* submitted; Bell 2003; Hamlett, Reardon *et al.* 2002; Reardon, Walker *et al.* 2002; Smith, Walker *et al.* 2004).

Need

The present project addresses three items listed as high priority in the Southern Shark Fishery Five Year Strategic Research Plan 1998; these items are under the key area ‘resource status’ of FRDC’s program ‘resources sustainability’. The three items are (1) investigation of non-quota species, (2) analysis of bycatch, and (3) effect of high grading through discarding on the TAC setting process.

The shark component of the GHATF presently targets mainly gummy shark and has almost completely phased out the targeting of school shark, and takes a range of chondrichthyan and teleost species as byproduct and bycatch. The most important by-product species are common saw shark, southern saw shark, and elephant fish. There are occasional interactions with the white shark (*Carcharodon carcharias*), mammals and sea birds, which are protected species. Apart from the need to evaluate bycatch, there is the need to address public perceptions of discards associated with the use of demersal gillnets, which are sometimes confused with surface-set driftnets.

The shark fishery is based on several species of temperate-water sharks inhabiting the continental shelf and slope, with most of the catch is taken in waters less than 75 m deep. The total annual catch ranged 2305–4226 t during 1970–2002 and had an annual value at first sale of $14.2 million ($559,000 for sawshark and $101,000 for elephant fish) during 2002. The catch during the 23-year period 1970–2002 comprised 50% gummy shark, 37% school shark and 13% by-product species. The 13% of byproduct catch comprised 7% sawshark, 2% elephant fish, 1% dogfish, and 3% ‘other species’. A total of 159 vessels licensed with Commonwealth Shark Permits and 460 vessels with State-only licences took shark during 2001 using bottom-set gillnets and longlines. Most of the catch is consumed in Victoria (Walker, Taylor *et al.* 2003).

Stock assessments of gummy shark and school shark are periodically updated and refined through SharkRAG, but, prior to the present study, fully quantitative assessments had never been made for any of the non-target species. Current assessments for the GHATF indicate that the stocks of gummy shark are sound, but those of school shark are markedly depleted (Punt, Pribac *et al.* 2000). Catch quota management, adopted for gummy shark and school shark on 1 January 2000 and for sawshark and elephant fish on 1 January 2001, is designed to reduce the catch of school shark and prevent escalation of the catches of the other species. During 2002, gummy shark provided 73% of the catch, with school shark at 10%, sawshark at 8%, elephant fish at 2%, and other shark species at 7%. There is a need to ensure that the byproduct species
are harvested sustainably and that the stocks of bycatch species (discarded species) are not depleted. It is therefore essential to provide the basic data needed for assessment of byproduct and bycatch species (Walker, Taylor et al. 2003).

Catches of the two species of sawshark combined from the GHATF rose from 52 tonnes during 1970 to reach a peak of 359 tonnes during 1995, before declining to 167 tonnes during 2002. Catches of elephant fish rose from 4 tonnes during 1971, peaked at 118 tonnes during 1985, and then declined to 40 tonnes by 2002. Sawshark and elephant fish catches have not been reliably monitored in the South East Trawl Fishery or in the Great Australia Bight Trawl Fishery prior to 2001. The reported demersal trawl catches for sawshark and elephant fish during 2002 were 88 and 15 tonnes, respectively. This gives total catches of 284 tonnes for sawshark and 71 tonnes for elephant fish across all fisheries during 2002 (Walker, Taylor et al. 2003).

Several initiatives taken in recent years have created a requirement to better evaluate catches in Australian fisheries. The requirement applies to both targeted and non-targeted species, and, of the non-targeted species, both the retained species (byproduct) and discarded (bycatch) species.

Australia’s Commonwealth Fisheries Management Act 1991 requires management arrangements to “ensure that the exploitation of fisheries resources and the carrying on of related activities are conducted in a manner consistent with the principles of ecologically sustainable development and the exercise of the precautionary principle, in particular the need to have regard to the impact of fishing activities on non-target species and the long-term sustainability of the marine environment”. Hence, in accordance with these legislative obligations and Commonwealth Government policy prescribed under Australia’s Ocean Policy regarding the impact of fishing activities on non-target species and the environment, the Australian Fisheries Management Authority developed bycatch action plans for major Australian fisheries.

More recently, the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC) 1999 requires fisheries managed under Commonwealth jurisdiction or fisheries producing products for export to be ‘strategically assessed’. This process involves assessing each fishery for ecological impacts on (a) target and by-product species, (b) bycatch species, (c) threatened, endangered and protected species, (d) marine habitats, and (e) marine food chains. The process requires collection of appropriate data, risk assessment, and appropriate management responses.

At a world level, concern for the condition of the stocks of chondrichthyan species led to the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks), developed recently by the Food and Agriculture Organisation of the United Nations. The IPOA-Sharks recognises that the life-history characteristics of chondrichthyan species can make for low ‘biological productivity’ and cause these animals to be generally more susceptible to overexploitation from fishing than teleost and invertebrate species. The IPOA-Sharks also recognises that these species require special management, research, and monitoring if they are to be harvested sustainably (Anon. 2000). As a signatory to the IPOA-Sharks, Australia has developed a National Plan of Action for the Conservation and Management of Shark (NPOA-Sharks), which has been ratified by the Commonwealth, Territory and State Governments and was launched 26 May 2004.

The catches of most chondrichthyan species have not been reported and it is likely that many species, particularly those taken as bycatch, are already at high risk without it being recognised (Walker 1998). ‘Critical bycatches’ are bycatches of species or populations that are in danger of extinction, and ‘unsustainable bycatches’ are bycatches of species or populations that are not currently at risk but will decline at current levels of bycatch (Hall 1996).

The present study is designed to evaluate the catch composition and catch rates in the gillnet and longline components of the GHATF. The catch of each species was evaluated in terms of whether the animals were landed on-board ‘live’ or ‘dead’ and whether they were ‘retained’ or ‘discarded’. The study addresses catches taken both by demersal monofilament gillnets and demersal longlines from data available for the two periods of 1973–76 and 1998–01. The study also addresses the effects of mesh-size and hanging ratio of gillnets and hook-size, hook-shank length, and hook-spacing on catch.

In the GHAT, a carcass in the catch is graded and valued according to its size and to the extent of damage to it. Damage to sharks captured in the gear from several sources can markedly reduce their value. Sharks that
die in gillnets are susceptible to being partly or totally eaten by sea lice, seals, teleosts, and other species of shark.

With the introduction of quota management in the GHATF, there is uncertainty on the quantities of shark that are damaged at sea and how much is discarded at sea. Lower valued gummy shark, school shark, common sawshark, southern sawshark, and elephant fish might be discarded at sea for higher graded carcasses. From on-board observations there is a need to provide estimates of (a) quantities of sharks damaged and marketed, (b) quantities of sharks damaged and discarded, and (c) quantities of undamaged sharks discarded because of lower prices.

Objectives

1. Determine population parameters required for fishery stock assessment of the non-target species common saw shark, southern saw shark and elephant fish.

2. Provide stock assessment of each of these three non-target species in Bass Strait.

3. Provide data for evaluation of bycatch, discards and damaged shark in the Southern Shark Fishery (now Gillnet Hook and Trap Fishery).

Methods

The methods are referred to briefly under three separate headings, one to address each of the three project objectives. Full details of the methods are contained in the various manuscripts presented as appendices to the main report.

Determination of population parameters

Determination of population parameters for gillnet selectivity, von Bertalanffy growth, and reproduction (Objective 1) was variously based on data from three separate periods: 1973–76, 1986–87, and 1998–01.

Gillnet selectivity

Full details of the methods are published for gummy shark (Kirkwood and Walker 1986) and given for sawshark, elephant fish and school shark in Appendix 3a. Gillnet selectivity was investigated for sawshark and elephant fish using data collected during two separate experiments when gillnet selectivity parameters for gummy shark were investigated. The first experiment was undertaken during 1973–76 on-board research vessels and the second 1986–87 on-board vessels engaged in commercial fishing. For each of these two periods, experimental gillnets were standardised by constructing them with identical length of net, diameter of headline and footline, number of floats attached to the headline and number of lead weights attached to the footline. Height of net varied slightly to standardise hanging coefficient at 0.60. In all cases, the monofilament polyamide webbing was double-knotted and double-selvedge, but during 1973–76 the thickness and breaking strain of the webbing varied with increasing mesh-size. The nets were set on the seabed at least 100 m apart and not joined to avoid the potential effect of nets of small mesh-size herding fish to nets of larger mesh-size. The fishing times of the different gillnets were controlled to ensure that their fishing times were similar. The species, sex and total length of each shark caught was recorded from each gillnet during field operations.

During 1973–76, eight gillnets had mesh-sizes ranging 2–9 inches (51–229 mm), in steps of 1 inch (25 mm). Each net had a standard length of 250 m and height of ~1.7 m. The eight nets were set at 73 sites on the continental shelf off south-eastern Australia at depths of 9–79 m. The number of meshes deep, the thickness
of the filaments of the webbing and the breaking strain of the filaments varied with mesh size. The gear was set before sunrise and hauled after sunrise with a mean fishing time of 5.8 h (Kirkwood and Walker 1986; Walker, Hudson et al. in press). During 1986–87, four gillnets had mesh-sizes ranging 5–8 inches (127–203 mm), in steps of 1 inch (25 mm). Each net had a standard length of 500 m and height of ~1.7 m. The number of meshes deep varied with mesh-size, but the thickness and breaking strain of the webbing filaments for all mesh-sizes were standardised at 0.90 mm and 359 N, respectively. The four gillnets were set 144 times on the continental shelf off south-eastern Australia at depths of 17–130 m. The gillnets were set, usually twice a day, at various times throughout the day and night, depending on stage of the tidal cycle. Mean fishing time for the gillnets was 4.8 h.

Relative selectivity, \( \mu_i \), expressed as a function of length of fish, \( l \), and mesh-size, \( m_i \), is given by

\[
\mu_i = (l / \alpha_i \beta_i)^{\theta_i} e^{(\alpha_i - \beta_i)}
\]

where \( \alpha_i \) and \( \beta_i \) are specified in terms of the mesh-size, \( m_i \), and length \( l \), and the length at maximum selectivity for gillnet \( i \) is proportional to the mesh-size such that

\[ \alpha_i \beta_i = \theta_i m_i \]

where \( \theta_i \) is a constant and the variance \( \theta_2 \) is constant over different gillnets. These assumptions lead to a quadratic equation for positive \( \beta_i \) such that

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

The maximum likelihood estimates of the main parameters of interest, \( \theta_1 \) and \( \theta_2 \), were estimated using the Nelder–Mead simplex algorithm (Nelder and Mead 1965). Standard errors for each of \( \theta_1 \) and \( \theta_2 \) were estimated according standard methods (Venzon and Moolgavkor 1988).

**Length-at-age**

Full details of the methods are presented in a manuscript in preparation (Appendix 3b). Stained whole vertebrae of sawsharks and sectioned dorsal spines of elephant fish were used for estimating the age of common sawshark, southern sawshark and elephant fish. Ages were estimated by assuming counted growth-increment bands are deposited annually.

The length-at-age data were fitted to the von Bertalanffy growth (VBG) model reparameterised by the Francis method (Francis 1988a; Francis 1988b) and adapted to correct for sampling bias caused by length-specific gillnet selectivity (Dow 1992). The VBG model has the equation

\[ l_a = L_\infty \{1 - e^{-K(a-a_0)}\} \]

where \( K \), \( L_\infty \) and \( a_0 \) are the VBG parameters and \( l_a \) is the length of a shark at age \( a \). For length-at-age data, these parameters are replaced by \( l_\phi \), \( l_\chi \) and \( l_\psi \), the mean lengths of fish estimated by the model at the arbitrary ages of \( \phi \), \( \chi \) and \( \psi \), respectively, where

\[ \chi = (\phi + \psi) / 2 \]

and \( \phi \) and \( \psi \) are chosen to represent the range of the data.
Reproductive biology

A full description of the methods adopted for determining the reproductive parameters required for fishery stock assessment are described in detail in each of three quantitative reproductive papers in preparation attached for common sawshark (Appendix 3c), southern sawshark (Appendix 3d), and elephant fish (Appendix 3e). A more general paper in press develops methods for application to chondrichthians in general, which are applied to school shark (Appendix 3f). Parts of work associated with preliminary investigation of the peculiarities of the structure and function of various reproductive organs and tissues of elephant fish have been published in scientific journals (Appendix 3g).

The total body mass, $w$, to total length (TL), $l$, relationship was determined using the power curve

$$w = acl^b,$$

where $a$ and $b$ are parameters determined by linear regression of the natural logarithm of $w$ against the natural logarithm of $l$, and $c$ is a factor correcting for biases caused by natural logarithmic transformation (Beauchamp and Olson 1973; Walker in press).

The linear relationship between the number of macroscopically visible in utero embryos, $p$, and maternal TL, $l$ is given by

$$p = a + bl,$$

where $a$ and $b$ are parameters estimated by linear regression.

The period of gestation and growth of embryos were determined by plotting mean TL of embryos observed in pregnant females with in utero embryos and mean TL values of 0 for in utero eggs observed in pregnant females against month and then evaluating the seasonal pattern.

The ovarian cycle was investigated by examining the ovary and measuring the diameters of the largest follicles in animals caught throughout the year. The largest follicle diameter (LFD) varied widely between individual animals and varied depending on uterus condition, so seasonal pattern in LFD for each of the six uterus conditions was examined separately. Pregnant females with macroscopically visible in utero embryos provided the least ambiguous basis for determining seasonal growth rates of follicles. Annual growth rate of follicles for pregnant females with macroscopically visible embryos was determined by the linear relationship between LFD, $o$, and Julian day, $t$, given by

$$o = a + bt,$$

where $a$ and $b$ are parameters estimated by linear regression. Scattergrams of LFD against Julian day for each uterus condition were compared with the regression line and its and 95% prediction intervals used as a basis for distinguishing between annual, biennial, and longer ovarian cycles.

Size-at-maturity and size-at-maternity were determined as the proportion of the population of animals mature at any TL by classing each animal as in mature condition or immature condition and applying logistic regression for females and males separately. Similarly, for females, the proportion of the population of animals in maternal condition at any TL can be determined by classing each animal as in maternal condition or non-maternal condition and applying logistic regression. A female was classed as in mature condition if the largest ovarian follicle was $>3$ mm in diameter (size at first yolking); otherwise it was classed as in immature condition. Given uncertainty of the best indicator of maturity of males, the results from methods based on alternative criteria for assuming the mature condition and the immature condition were compared. Males were classed as mature or immature on the basis of testis development, seminal vesicle condition, and clasper calcification. A female was classed in maternal condition at the time of capture, if, had it survived, it would have given birth to young before or soon after the following 1 January; all other females were classed in non-maternal condition.

Logistic regression was adopted to determine the proportion of females in mature condition, the proportion
of males in mature condition, and the proportion of females in maternal condition as a function of TL. Females or males in mature condition were assigned a maturity condition value of 1, whereas those in immature condition were assigned a maturity condition value of 0. Similarly, females in maternal condition were assigned a maternal condition value of 1, whereas females in non-maternal condition were assigned a maternal condition value of 0.

The logistic equation adopted to express \( P \) as a function of \( I \) is given by

\[
P = P_{\text{max}} \left( 1 + e^{-\ln(19) \left( \frac{I - I_{50}}{I_{95} - I_{50}} \right)} \right)^{-1},
\]

where \( P_{\text{max}} \) is the maximum proportion of animals in mature condition or maternal condition, and \( I_{50} \) and \( I_{95} \) are the lengths at which 50% and 95% of the maximum proportion of animals in mature condition or maternal condition (Walker in press). The parameters \( P_{\text{max}}, I_{50} \) and \( I_{95} \), with 95% confidence intervals, were estimated by the method of maximum likelihood using the probit procedure (Proc Probit) of the computer statistical package SAS (SAS Institute, Cary, North Carolina, USA). This applies a modified Newton–Raphson algorithm for estimation. \( P_{\text{max}} \) normally has a value of 1.00 except when parturition frequency is biennial (\( P_{\text{max}} = 0.500 \)), triennial, (\( P_{\text{max}} = 0.333 \)) or some other period (Walker in press).

Stock assessment

Full details of the assessments are presented in Appendix 4. Stock assessment (Objective 2) was based on the parameter values and length-frequency data from all three periods and time series of catch (1950–03), fishing effort (1976–03), and catch per unit effort (1976–03) data for shark longlines and for each mesh-size of shark gillnets. The assessments also included catch for Danish seine (1950–03) and demersal trawl from the South East Trawl Fishery (1985–03), and Great Australia Bight Trawl Fishery (1988–03). The first stock assessment for each of common sawshark, southern sawshark, and elephant fish covering only the Bass Strait region was undertaken and presented to the 20–21 May 2004 SharkRAG meeting. These assessments were subsequently reviewed and extended to include Bass Strait, Tasmania and South Australia and, for elephant fish only, New South Wales and then presented to the 9–10 September 2004 SharkRAG meeting.

The data sets for common sawshark, southern sawshark, and elephant fish off southern Australia are limited and stock assessment would be not be possible, had the present project not been undertaken. The only monitoring data on which an assessment of sawshark (species combined) and elephant fish can be based are catches and catch-rates. The types of long time series of catch length-frequency data and tag release-recapture data available for gummy shark and for school shark are not available for sawshark or elephant fish. Although most of the catch is from Bass Strait and there are generally low catches in waters off Tasmania and South Australia, the assessments undertaken apply to this entire area of waters on the continental shelf and slope for sawshark and also includes New South Wales for elephant fish. Catch-rate indices for these species are developed based on the assumption that the effort estimated to be targeted at gummy shark is also targeted at sawshark and elephant fish. Catches of sawshark are distinguished between common sawshark and southern sawshark on the basis of catches recorded as scientific observations during 1973–76, 1986–87 and 1998–01. The assessments are based on a non spatial, and age- and sex-based population dynamics model similar to that used for the 1996 stock assessment of school shark (Galeorhinus galeus) (Punt and Walker 1998). The results of the base-case assessments indicate that both sawshark and elephant fish are depleted to below 40% of the 1950 pup production level but that the rate of decline in the size of these resources has decreased substantially since the mid-1980s. Sensitivity tests indicate that the uncertainty range of depletion levels is less for elephant fish (14–22%) than for sawshark (17–39%). Pup production is assessed at 32% for common shark, 26% for southern shark, and 20% for elephant fish of the 1950 levels.
Evaluation of target, byproduct, bycatch and damaged catch

Full details of the methods on evaluation on target catch of shark, byproduct species of shark, and bycatch are presented in Appendix 5a. The present study is designed to evaluate the catch composition and catch rates in the shark fishery of southern Australia. The catch of each species was evaluated in terms of whether the animals were landed on-board ‘live’ or ‘dead’ and whether they were ‘retained’ or ‘discarded’. The study addresses catches taken both by demersal monofilament gillnets and demersal longlines from data available for the two periods of 1973–1976 and 1998–2001.

Data used for catch evaluation were collected opportunistically during three separate investigations. Data from the first of these investigations were collected on two research vessels during 1973–1976. Data from the second of these investigations were collected on two commercial fishing vessels during 1998 as part a pilot fixed-station fishery-independent survey designed to determine survey intensity for monitoring abundance of harvested species. Data from the third investigation were collected on eight fishing vessels during 1999–01 when collecting biological samples of common sawshark, southern sawshark, and elephant fish as part of the present study.

During 1973–1976, most of the research sampling was undertaken in Bass Strait, with a small amount of sampling undertaken in waters off the east and south coasts of Tasmania and in waters off South Australia. Five separate experiments were undertaken to test for the effects of gillnet mesh size, gillnet hanging ratio, hook size, hook shank length and hook spacing on catch rate. During 1998–2001, sampling was undertaken during normal commercial fishing operations in Bass Strait and South Australia. For Bass Strait, comparisons of catch rates from gillnet with 6-inch mesh-size were made between 1973–1976 and 1998–2001. Other than recording mesh size of gillnets, it was not possible to control the design of the fishing gear or undertake experiments during the second period. Catch rates for gillnet 7-inch mesh-size and longlines with Mustad 11/O long-shank hooks during 1973–1976 are also presented for Bass Strait, because these gears were used extensively by the fishing industry during that period. For Tasmania, similar data were presented for 1973–1976, but there are no data for 1998–2001. For South Australia, there are insufficient data for 1973–1976, but data for gillnets with 6-inch and 6½-inch mesh-size are presented for 1998–2001. During 1998–2001, most of the fishing gear deployed in South Australia and Tasmania was gillnets with 6½-inch mesh-size and most of the fishing gear deployed in Bass Strait was gillnets with 6-inch mesh-size.

Catch rates were statistically tested for each of the five experiments separately and for each of three regions adopted for comparisons of the fishing gears used most widely in the shark fishery during 1973–1976 and 1998–2001. For each experiment, the data were pooled over all fishing sites, whereas, for inter-period and commercial gear comparisons, the data were separated into the three regions Bass Strait, Tasmania, and South Australia. A one-way analysis of variance was applied to test for the effect of each of several explanatory (independent) variables on catch rate (dependent variable) separately for each species and each major taxonomic group. For each analysis separately, the variance was tested for homogeneity and, where this was true, the following model was applied.

\[
\text{Catch rate} = \text{Explanatory variable(s)} + \varepsilon.
\]

For Bass Strait, the unit of fishing effort applied was ‘metre-lift-hours’, and, for longlines, the unit of fishing effort applied was ‘hook-lifts’ (number of hooks). The explanatory variable in the model varied depending on experiment or on region for the inter-period or gear comparisons. The explanatory variable was mesh size for Experiment 1, hanging ratio for Experiment 2, and hook size for Experiment 3, and the three explanatory variables were hook size, hook shank-length, and hook-space for each of Experiments 4 and 5. For inter-period comparisons, the explanatory variable was sampling period for gillnet with 6-inch mesh-size in Bass Strait and, for commercial gear comparisons, the explanatory variable was mesh size for gillnet with 6-inch and 6½-inch mesh-size in South Australia during 1998–01. No statistical test was applied to the data presented for Tasmania during 1973–76.

Full details of the methods for determining levels of damage to carcasses of gummy shark, school shark, common sawshark, southern sawshark and elephant fish from the effects of predation are presented in...
Appendix 5b. ‘Shark carcass’ refers to a beheaded and eviscerated shark with the tail, all fins, and, for males, the claspers, attached, and a ‘damaged carcass’ consists of two portions: the ‘lost damaged portion’ and the ‘retained damaged portion’. The two damaged portions contribute to loss of income to the fishing industry in two ways. There is loss of income through the ‘lost damaged portion’ being unavailable for marketing, and there is loss of income through the ‘retained damaged portion’ being devalued on the market through a reduced price per kilogram. For the purpose of this report, there are an ‘undamaged catch’ (sum of all the sharks with zero damage to the carcasses), a ‘lost catch’ (sum of all the ‘lost damaged portions’ from the ‘damaged shark carcasses’), and ‘devalued catch’ (sum of all the ‘retained damaged portions’). Several steps were required to calculate ‘lost carcass mass’ and ‘devalued retained carcass mass’. The ‘total mass’ and ‘carcass mass’ (i.e. expected mass assuming no damage) were estimated for each shark from TL and the masses of the ‘lost damaged portion’ and the ‘retained damaged portion’ were estimated for each damaged shark from its TL and %-loss value. For each species separately, ‘lost carcass mass’ of each animal was estimated by calculating the mass of the ‘lost damaged portion’ as carcass mass x %-loss/100’. Similarly, ‘devalued retained carcass mass’ of each animal was estimated by calculating the ‘retained damaged portion’ as carcass mass x (1 – %-loss)/100’. Then total ‘lost carcass mass’ was determined by summing ‘lost carcass mass’ over all individual animals in the catch and total ‘devalued retained carcass mass’ was determined by summing ‘devalued retained carcass mass’ over all individual animals in the catch.

Results/Discussion

Determination of population parameters
The gillnet selectivity parameters (Appendix 3a), von Bertalanffy growth parameters (Appendix 3b), and reproductive parameters (Appendices 3cde) required for fishery stock assessment of each common sawshark, southern sawshark, and elephant fish have all been determined and applied through SharkRAG for stock assessment undertaken early 2004. The parameter values are presented as a summary in Table 1 of this overview report and applied in the three preliminary fishery stock assessments (Appendix 4).

Stock assessment
The stocks of each of common saw shark, southern sawshark, and elephant fish are depleted to below 40% of the levels in the early 1970s (Appendix 4) and although not severely depleted will need careful monitoring. The species have medium productivity. Although neonate and juvenile stocks appear to be distributed away from the main shark fishing grounds, the selectivity characteristics of gillnets of 6–6½-inch mesh-size are such that they mainly catch mature animals and pregnant females. Modelling of gummy shark and school shark indicate that shark stocks are most secure when the mid-sized sharks are harvest by gillnets through creating a gauntlet effect (Prince in press; Walker 1998), where pre-recruits and breeding fish receive minimum impact.

Through SharkRAG, these assessments will be markedly upgraded over the next few months to include estimates of catch from the South East Trawl Fishery and Great Australian Bight Trawl Fishery from logbook effort and catch per unit effort recorded by observers from the Integrated Scientific Monitoring Program in this fishery.

Evaluation of target, byproduct, bycatch and damaged catch
The extensive results from analyses of catches from the various experiments are presented in Appendix 5a. In summary, for 1973–1976 and 1998–2001 combined, a much higher number of animals and a higher number of species were caught by gillnets (22 918 animals, 124 species) than by longlines (4 006 animals, 54 species). The wider range of gillnet mesh sizes and longline hook sizes deployed caught both a higher number of animals and higher number of species during 1973–1976 (16 657 animals, 112 species) than during 1998–2001 (10 267 animals, 65 species), despite a much lower fishing effort during 1973–1976. Some of the differences in numbers of animals and numbers of species caught between the two periods can be explained...
by longlines being used only during 1973–1976 (4,006 animals, 54 species). However, most of the differences in the numbers caught is explained by eight mesh sizes (2–9 inch) used during 1973–1976 (12,651 animals, 104 species) and only two mesh sizes (6 and 6½ inch) during 1998–2001 (10,267 animals, 65 species). The catch comprised mostly chondrichthyans (21,633 animals, 33 species) and teleosts (5,118, 87), with small quantities of cephalopoda (26, 4), bivalvia (14, 1), gastropoda (9, 1), crustacea (121, 3), and mammalia (3, 2).

Ten important summary points can be made about the catch rates of gillnets and longlines deployed in the shark fishery of southern Australia on the continental shelf in the depth range 9–130 m.

1. Both gillnets and longlines are much more effective at catching chondrichthyan species than at catching teleost species, and catches of species of cephalopoda, bivalvia, gastropoda, mammalia, aves and reptilia are negligible.

2. The effect of gillnet mesh size on catch rates is strong, whereas the effects of gillnet hanging ratio, hook size, hook shank length, and hook space are weak.

3. Overall catch rates of chondrichthyan and teleost fishes by gillnet mesh size are very different. For chondrichthyans, the modal catch rate is by 4-inch mesh-size with decreasing catch rates for both increasing and decreasing mesh size, whereas for teleosts the modal catch rate is by 2 inch mesh-size with decreasing catch rates as mesh size increases.

4. For gillnets, there is linear increase in the ratio of the number of chondrichthyan fishes divided by the number of teleost fishes with increasing mesh size, whereas for hooks the ratio is approximately constant with increasing hook size.

5. For chondrichthyes, the top four species taken by gillnet across 8 mesh sizes (Experiment 1), *Squalus megalops*, *Mustelus antarcticus*, *Heterodontus portusjacksoni*, and *Galeorhinus galeus*, are similar to the top four species taken by longline across 8 hook sizes (Experiment 3), *Squalus megalops*, *M. antarcticus*, *Cephaloscyllium laticeps*, and *G. galeus*. The only difference is that *H. portusjacksoni* is more prevalent than *C. laticeps* in the gillnet catch, whereas the converse occurs for the longline catch.

6. For teleostei, *Platycephalus bassensis* is the most prevalent species caught by both gillnets across 8 mesh sizes (Experiment 1) and longlines across 8 hook sizes (Experiment 3). *Neosebastes scorpaenoides* is the second most prevalent species caught by longline and the third most prevalent species caught by gillnet. The second most prevalent species taken by gillnet—*Trachurus novaeezelandiae*—is not caught by longline.

7. For chondrichthyes in Bass Strait, there has been about one-third overall reduction in abundance across all species combined between 1973–76 and 1998–01. About half of this reduction is attributable to an 87% reduction in the catch per unit effort (CPUE) of *Galeorhinus galeus* and a 54% reduction in the CPUE of *Cephaloscyllium laticeps*. The decline in CPUE for *Cephaloscyllium laticeps* might partly be attributable to avoidance of high densities of this species by fishermen during 1998–01, but the marked reduction in CPUE for *Galeorhinus galeus* is consistent with trends evident in fishermen's logbook data.

8. Only small proportions of the commercial catch of chondrichthyan (3%) and teleost (2%) animals taken by demersal gillnets of 6 in and 6½ in mesh size coming on-board dead are discarded. The discarded animals are mostly *Cephaloscyllium laticeps*, *Heterodontus portusjacksoni*, *Squalus megalops*, and *Myliobatis australis*, which come on-board live.

9. Wildlife interactions occur occasionally with the Australian fur seal (*Arctocephalus pusillus doriferus*) and common dolphin (*Delphinus delphis*).

10. Of ten chondrichthyan species on the continental shelf and continental slope identified by the IUCN Shark Specialist Group as threatened, two are identified by the present study as caught by the fishery. White shark (*Carcharodon carcharias*) are taken occasionally and *Galeorhinus galeus*, once the primary target species, is presently taken as significant byproduct (253 t during 2000).

Damage to shark carcasses from predation to sharks landed on-board from gillnets of 6-inch or 6½-inch mesh size would normally be minimal.
mesh-size was investigated on-board nine vessels operating under normal commercial fishing conditions (Appendix 5b). The work was undertaken during November 1998–February 2001 at 153 fishing sites (91 sites in Bass Strait and 62 sites off South Australia). Of 3187 gummy sharks (*Mustelus antarcticus*), 145 school sharks (*Galeorhinus galeus*), 1099 common sawshark (*Pristiophorus cirratus*), 315 southern sawshark (*P. nudipinnis*), and 916 elephant fish (*Callorhinchus milii*) examined for carcass damage; 42% of the animals were landed on the deck alive without damage. Part of the catch of animals landed on-board dead had damage to carcasses resulting in ‘lost carcass mass’ and ‘devalued retained carcass mass’. ‘Lost carcass mass’ from predation for gummy shark and school shark combined is estimated at 4.9% (4.7% for gummy shark and 6.9% for school shark); it is slightly higher in South Australia (5.3%) than in Bass Strait (4.7%). ‘Lost carcass mass’ for common sawshark and southern sawshark combined is estimated at 2.3% (2.1% for common sawshark and 3.5% for southern sawshark) and for elephant fish is estimated at 3.4%. ‘Devalued retained carcass mass’ from major damage is estimated at 9.2% for gummy shark and school shark combined (9.0% for gummy shark and 12.8% for school shark), 4.2% for common sawshark and southern sawshark combined (4.0% for common sawshark and 5.5% for southern sawshark), and 6.1% for elephant fish.

**Benefits and Adoption**

Benefits from the present project are allocated as 98% to the Commercial Sector (90% Commonwealth, 5% Victoria, 2% Tasmania, 1% South Australia) and 2% Recreational Sector (1% Victoria and 1% Tasmania). Benefits from stock assessment of common sawshark, southern sawshark and elephant fish will flow to the GHATF, SETF, GABTF, and coastal fisheries of Victoria, Tasmania, and South Australia, which all take these three species. Evaluation of catches of byproduct and bycatch species will benefit the shark gillnet sub-fishery and longline sub-fishery directly and other fisheries indirectly. Published survey catch rates of the byproduct and bycatch species provide baseline abundance estimates that can be used for future monitoring of abundance of these species. Knowledge of these trends is not only relevant to the shark fishery but to other Commonwealth and state fisheries that impact these species.

Following documentation of the results from the present project, most future work will relate to ongoing stock assessment and harvest strategy evaluation. All data are managed in accessible databases in SAS. As these data sets are updated they will be made available to SharkRAG as required. Additional work has begun to also include data sets on sawshark and elephant fish from the ongoing Integrated Scientific Monitoring Programs for each of the South East Trawl Fishery and Great Australia Bight Trawl Fishery.

The results for catch evaluation were a crucial input for Ecological Risk Assessment for the Effects of Fishing for scoping and a level 1 assessment for each of five components (target species, byproduct and bycatch species, threatened and protected species, habitats, and communities) associated with a sub-fishery. Where a level 1 assessment identifies hazards judged to have moderate or higher consequences, there is a need to progress to a level 2 assessment or adopt a Risk Management Response to avoid or reduce the consequence of each hazard posing risk. Similarly, where a level 2 assessment identifies a medium, high or extreme risk, there is a need to progress to a level 3 assessment or adopt an appropriate Risk Management Response.

Level 1 assessment (Scale Intensity and Consequence Analysis) is complete for each of the Shark Gillnet Sub-fishery and Shark Longline Sub-fishery of the Gillnet Hook and Trap Fishery (GHATF). For the Shark Gillnet Sub-fishery, of 21 impact-causing activities internal to the fishery, only 2 internal activity-impact combinations were identified as having a moderate (score 3) or above impact. For the Shark Demersal Longline Sub-fishery, 31 of 32 activities were identified as leading to some form of impact (Hazard Identification). Of 25 ‘impact causing’ activities internal to the fishery, only 1 internal activity-impact combination was identified as having an impact of moderate or above. The level 1 assessment indicated that the only activity internal to the fishery to have a consequence score above 2 is ‘capture fishing’. Of the five components of ERAEF, this occurred for each of three components (target, byproduct and bycatch, and TEP species), but not for the other two components (habitat and community). All other activities internal to the fishery had a consequence score of 1 (negligible) or 2 (minor). Having completed stock assessments for common sawshark, southern sawshark, and elephant fish mean that level 3 assessments were complete for...
These species.

Further Development

The present project has provided the basic demographic and gear selectivity parameters required for stock assessment of common sawshark, southern sawshark, and elephant fish. The project provided the basis to undertake the first stock assessment for each species and provides a basis for ongoing assessments through SharkRAG. The assessments will be periodically undertaken with updated monitoring data and modelling enhancements. In addition, the project has provided a description of catch rates of byproduct and bycatch species from the shark component of the GHATF, which will be monitored through the AFMA funded Fixed Site Monitoring Program. Further monitoring can be compared with assembled baseline catch rate data provided by the present project for the periods 1973–76 and 1998–01.

To ensure the scientific defensibility of the results produced from the project and defensibility of future stock assessments dependent on the project outputs, the work is being prepared for publication in internationally reviewed scientific journals. To date three manuscripts have been published in scientific journals and five student B.Sc. (Hons) theses have been submitted and assessed. These papers mainly deal with uncertainty of the basic reproductive biology of the elephant fish, which belongs to the poorly understood chondrichthyan group know as the holocephalans. A fourth paper is in press in a scientific journal; this describes the results of evaluation of target catch, byproduct and bycatch from the shark component of the Gillnet Hook and Trap Fishery. A fifth paper in press is a chapter of a book on the reproduction of chondrichthyans; the chapter describes the methods applied to the quantitative approach adopted in the present project, much of which is new. These five papers have all passed through peer review processes. Seven other manuscripts are in preparation and not yet submitted for publication. These include three manuscripts on reproductive biology, one on each of the three species, a fourth on age and growth of the three species, a fifth on gillnet selectivity of the three species, a sixth on sawshark stock assessment, and a seventh on elephant fish stock assessment. During the months ahead these manuscripts will be refined and submitted for scientific review.

Reduction of uncertainty in the assessments will require investment in initiating time-series of additional data sets such as catch length-frequency, catch length-at-age composition, and tag release recapture. An uncertainty recently identified is that of the effects of fishing mortality on female breeding elephant fish entering inshore shallow waters during March–May to lay their eggs in soft-sediment areas.

Over the next year or two it is expected that these assessments will lead to management actions designed to improve the sustainability of byproduct and bycatch species and reduce environmental impacts of shark fishing.

Planned Outcomes

Outcomes from the project include accessibility of basic selectivity parameters, biological parameters and monitoring data sets for ongoing stock assessment and fishery management advice. Both the basic biological data and catch and effort, length-at-age and length-frequency data sets are secure and readily accessible from SAS databases. Steps are being taken to incorporate into the assessments, data on sawshark and elephant fish from the ongoing Integrated Scientific Monitoring Programs for each of the South East Trawl Fishery and Great Australia Bight Trawl Fishery. The data will be made available to scientists for ongoing assessment of sawshark and elephant fish as required.

Data and advice will continue to be provided for refining strategic assessment, bycatch action plans, ecological risk assessment, and initiatives associated with Australia’s National Plan of Action for the Conservation and Management of Sharks.
All results from the project will become available to scientists, fishery managers, industry personnel, and other beneficiaries in the form of the present report final to FRDC and ten scientific papers and two reports as they are published.

Conclusion

All gillnet selectivity parameters (Appendix 3a) and basic biological parameters required for age-based stock assessment models associated with Objective 1 are now available for common sawshark, southern sawshark and elephant fish (Table 1). The required biological parameters prescribe the von Bertalanffy length–age (Appendix 3b), logistic maternity–length, logistic maturity–length, linear litter-size–maternal length, and power mass–length (Appendices 3c–e) relationships. The project provided the opportunity to develop new methods for better determining the reproductive parameters required for stock assessment (Appendix 3f). Using data collected opportunistically during field operations, the project also provided the opportunity to provide better estimates of these reproductive parameters for school shark (Appendix 3f) and gummy shark (manuscript in preparation).

In addition to the required biological parameters, all available catch and effort, length-at-age, and length-frequency data required for fishery stock assessment as part of Objective 2 are secure and readily available for each of common saw shark, southern sawshark, and elephant fish from southern Australia. The stocks of each of these species are depleted to below 40% of the levels in the early 1970s and although not severely depleted will need careful monitoring and management. The species have medium productivity. Although neonate and juvenile stocks appear to be distributed away from the main shark fishing grounds, the selectivity characteristics of gillnets of 6–6½-inch mesh-size are such that they mainly catch mature animals and pregnant females (Appendix 4). Modelling of gummy shark and school shark indicate that shark stocks are most secure when the mid-sized sharks are harvest by gillnets through creating a gauntlet effect, where pre-recruits and large breeding fish receive minimum impact.

Apart from impacts on target and byproduct species, shark gillnets and shark longlines on the present fishing grounds of the continental shelf estimated as part of Objective 3 have minimal impact on other chondrichthyan and teleost species. Most bycatch species come on-board in live and vigorous condition; there is negligible discard of species dead and the level interactions with protected fauna is comparatively low (Appendix 5a). There is some damage to shark carcasses from predation by invertebrates, fish and mammals to sharks landed commercial vessels from gillnets of 6-inch or 6½-inch mesh-size. ‘Lost carcass mass’ from predation is estimated at 4.9% for gummy shark and school shark combined, 2.3% for common sawshark and southern sawshark combined, and 3.4% for elephant fish. ‘Devalued retained carcass mass’ from major damage is estimated at 9.2% for gummy shark and school shark combined, 4.2% for common sawshark and southern sawshark combined, and 6.1% for elephant fish (Appendix 5b).

References


Beck ALN, Walker TI, Hamlett WC (submitted) Histology of the testis, male genital ducts and spermatozeugmata formation in the Southern sawshark, Pristiophorus nudipinnis. Marine and Freshwater


Last PR, Stevens JD (1994) 'Sharks and rays of Australia.' (CSIRO Australia: Melbourne)


Walker TI (1998) Can shark resources be harvested sustainably? A question revisited with a review of shark


Walker TI, Taylor BL, Gason AS (2003) 'Southern shark catch and effort 1970–2002 report to Australian Fisheries Management Authority.' Marine and Freshwater Resources Institute, Queenscliff, Victoria, Australia.
Table 1 Biological and gear selectivity parameter values for common sawshark, southern sawshark and elephant fish required for stock assessment

Selectivity parameters were determined using the 8 mesh sizes 2 – 9 inches during 1973-76; common sawshark and southern sawshark data pooled.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Common sawshark</th>
<th>Southern sawshark</th>
<th>Elephant fish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>von Bertalanffy growth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_infty$ (mm)</td>
<td>1165</td>
<td>1502</td>
<td>971</td>
</tr>
<tr>
<td>$K$ (year$^{-1}$)</td>
<td>0.309</td>
<td>0.149</td>
<td>0.575</td>
</tr>
<tr>
<td>$t_0$ (year)</td>
<td>-1.00</td>
<td>-1.76</td>
<td>-1.00</td>
</tr>
<tr>
<td>Mass (kg) – TL (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non pregnant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$ (se range) ($\times 10^{-9}$)</td>
<td>1.520 (0.991–2.330)</td>
<td>0.990 (0.824–1.190)</td>
<td>0.078 (0.035–0.172)</td>
</tr>
<tr>
<td>$b$ (se)</td>
<td>3.015 (0.062)</td>
<td>3.292 (0.062)</td>
<td>3.450 (0.115)</td>
</tr>
<tr>
<td>Pregnant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$ (se range) ($\times 10^{-9}$)</td>
<td>0.423 (0.163–1.100)</td>
<td></td>
<td>354.0 (80.80–1550.0)</td>
</tr>
<tr>
<td>$b$ (se)</td>
<td>3.281 (0.134)</td>
<td></td>
<td>2.252 (0.214)</td>
</tr>
<tr>
<td>Litter size – TL (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a$ (se)</td>
<td>-14.52 (2.79)</td>
<td></td>
<td>-8.36 (4.63)</td>
</tr>
<tr>
<td>$b$ (se)</td>
<td>0.0205 (0.0022)</td>
<td></td>
<td>0.0184 (0.0045)</td>
</tr>
<tr>
<td>Maturity – TL (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{max}$</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>$l_{50}$ (mm)</td>
<td>1128 (1116, 1138)</td>
<td>866 (827, 892)</td>
<td>607 (585, 624)</td>
</tr>
<tr>
<td>$l_{95}$ (mm)</td>
<td>1383 (1362, 1407)</td>
<td>1056 (1037, 1083)</td>
<td>659 (636, 678)</td>
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<tr>
<td>Maternity – TL (mm)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$P_{max}$</td>
<td>0.50</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>$l_{50}$ (mm) (95% CI)</td>
<td>1156 (1155, 1157)</td>
<td>944 (836, 846)</td>
<td>659 (636, 678)</td>
</tr>
<tr>
<td>$l_{95}$ (mm) (95% CI)</td>
<td>1239 (1238, 1241)</td>
<td>954 (890, 896)</td>
<td>888 (871, 910)</td>
</tr>
<tr>
<td>Gillnet selectivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>237.91</td>
<td></td>
<td>237.91</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>185075</td>
<td></td>
<td>185075</td>
</tr>
</tbody>
</table>

Equations as in Punt and Walker (1998), except fecundity is different: Fecundity = $a + b$ TL
Appendix 1: Intellectual Property

No intellectual property has arisen from the research that is likely to lead to significant commercial benefits, patents or licences. Intellectual property associated with information produced from the project will be shared equally by the Fisheries Research and Development Corporation and by the Victorian Department of Primary Industries.

Appendix 2: Staff

Organisation, position, period on the project and percentage of time each year on the project are listed for each staff member at the Marine and Freshwater Resources Institute.

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Periods</th>
<th>Percentage of Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terry Walker</td>
<td>Principal Investigator</td>
<td>1 Jul 99–30 Jun 00</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Jul 00–30 Jun 01</td>
<td>10%</td>
</tr>
<tr>
<td>Russell Hudson</td>
<td>Fisheries Scientist</td>
<td>1 Jul 99–30 Jun 00</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Jul 00–30 Jun 01</td>
<td>60%</td>
</tr>
<tr>
<td>Lauren Brown</td>
<td>Fisheries Scientist</td>
<td>1 Jul 99–30 Jun 00</td>
<td>10%</td>
</tr>
<tr>
<td>Corey Green</td>
<td>Technical Officer</td>
<td>1 Jul 99–30 Jun 00</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Jul 00–30 Jun 01</td>
<td>15%</td>
</tr>
<tr>
<td>Thérèse Stokie</td>
<td>Technical Officer</td>
<td>1 Jul 00–30 Jun 01</td>
<td>5%</td>
</tr>
</tbody>
</table>
Appendix 3a: Gillnet selectivity

This appendix contains a manuscript in preparation which includes the results of gillnet selectivity trials for common sawshark, southern sawshark and elephant fish.
Appendix 3b: Age and growth

This appendix contains a manuscript in preparation of the results of age and growth studies for common sawshark, southern sawshark and elephant fish.
This appendix contains a manuscript in preparation, which presents the results of a study of the reproduction of common sawshark (*Pristiophorus cirratus*) required for fishery stock assessment.
Appendix 3d: Southern sawshark reproduction

This appendix contains a manuscript in preparation, which presents the results of a study of the reproduction of southern sawshark (*Pristiophorus nudipinnis*) required for fishery stock assessment.
Appendix 3e: Elephant fish reproduction

This appendix contains a manuscript in preparation, which presents the results of a study of the reproduction of elephant fish (*Callorhynchus milii*) required for fishery stock assessment.
Appendix 3f: Chondrichthyan reproduction

This appendix contains a chapter from a recently published book, which describes the methods required for determining information on reproduction of chondrichthyan species required for fishery stock assessment or ecological risk assessment. In this manuscript, the methods are demonstrated by applying them to school shark (*Galeorhinus galeus*) off southern Australia, using data collected opportunistically during the present project and during earlier projects.
Appendix 3g: Elephant fish papers

This appendix contains three papers published in scientific journals, which provide valuable descriptions of the reproductive structures of male and female elephant fish to better understand their structure and function.
Appendix 4: Stock assessments

This appendix contains a report initially prepared for SharkRAG
Appendix 5a: Catch evaluation

This appendix contains a manuscript in press, which evaluates catches of target, byproduct and bycatch species taken by gillnets and longlines in the shark fishing component of the Gillnet Hook and Trap Fishery.
Appendix 5b: Damaged catch evaluation

This appendix contains a report prepared for SharkRAG, which determines damage levels caused by the effects of predation from invertebrates (sea-lice), other fish and mammals on target and byproduct shark species taken by gillnets in the Gillnet Hook and Trap Fishery.