Investigation of school and gummy shark nursery areas in south-eastern Australia

J. D. Stevens and G. J. West

Project 93/061

Principal Contributors

Terry Walker	**MAFRI**
Lauren Brown	**MAFRI**
Natalie Bridge	**MAFRI**
Bruce Barker	**CSIRO Marine Research**
Stephanie Davenport	**CSIRO Marine Research**
Mark Green	**CSIRO Marine Research**

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1. NON-TECHNICAL SUMMARY

93/061 Investigation of school and gummy shark nursery areas in south-eastern Australia

Principal Investigator: Dr John Stevens
Address: CSIRO Division of Marine Research
PO Box 1538
Hobart TAS 7001
Telephone: 03 62 325353 Fax: 03 62 325000

Objectives:

(1) Identify pupping and nursery grounds of school and gummy sharks in southern Australia.

(2) Determine the distribution, size structure, residence time and movements of new-born and juvenile sharks in nursery areas.

(3) Attempt to develop recruitment indices for school and gummy sharks.

(4) Determine pre-recruit mortality from tagging experiments.

(5) Determine relative catch rates of juveniles by commercial and recreational fishers.

Non-Technical Summary:

Several school shark pupping areas in inshore waters of Tasmania and Victoria identified by Olsen in the 1940s and 1950s were re-sampled from 1991-97. Current catch rates are much lower at all sites and pups are apparently no longer present at some sites (Georges Bay, D'Entrecasteaux Channel). Additional sampling of mainly inshore embayments in Tasmania and Victoria failed to locate significant new pupping grounds of school shark. Limited sampling in South Australia and Western Australia failed to catch school shark pups. Rough calculations suggest that known pupping areas in Tasmania and Victoria are not sufficient to sustain the stock. Ocean beach habitats (such as Ninety Mile Beach) were not sampled in this study and represent an unknown source of recruitment.

Relatively few gummy shark pups were caught anywhere in this study; no significant pupping grounds were located and pupping appears to take place over scattered locations in inshore waters.

The size distribution of gillnet and longline caught school shark in inshore embayments was dominated by 0+ and 1+ juveniles; few mature fish were caught and they are probably not present in these areas for most of the year. In contrast, the catch of gummy shark comprised relatively few 0+ and 1+ juveniles, with the bulk of the catch being adolescent and mature fish. Adult gummy shark appear to use certain estuarine embayments as rich feeding grounds for crustaceans. Tagging and tracking work suggests that new-born school shark normally remain in their inshore pupping grounds during summer. Based on results from Pittwater, all age-classes of

school and gummy sharks move out of shallow inshore areas in winter, either migrating further afield or moving into deeper adjacent bays. During this project, 1228 gummy shark and 397 school shark were tagged in inshore Tasmanian waters; 12.1% of gummies and 12.3% of school sharks have been recaptured to date. The average distance moved by each species increases with increasing size and age.

Growth rates of 0+ school shark in Pittwater (and perhaps in Port Phillip Bay and Westernport Bay) have increased significantly from the 1940s and 1950s. Change in growth rate may be a density-dependent response to reduced population sizes in these areas.

Of tagged school and gummy sharks, significantly more recaptures came from commercial (school 48%, gummy 63%) compared to recreational (school 12%, gummy 9%) fishers in Tasmania.

Proton-probe microanalysis of vertebrae from two 0+ school shark from Upper Pittwater gave encouraging results. Strontium/calcium ratios converged strongly to a common level at the outer margin of the vertebrae, which is interpreted as a response to a common nursery area environment. This suggests that it may be possible to identify the area in which larger, older sharks were pupped by analysing that portion of the vertebrae laid down soon after birth.

Teleost fish, cephalopods and crustaceans were of equal importance in the diet of new-born school sharks; in older juveniles crustaceans were less important. Almost all (99%) 0+ school shark had food in their stomachs, suggesting that food is not limiting despite potential competition with abundant teleosts, such as flathead, in the pupping areas. Sevengill shark appear to be the only major potential predator of juvenile school shark in Tasmanian pupping areas. However, we found no evidence of high predation by sevengills on juvenile school shark. The level of competition and predation has implications for the level of natural mortality experienced by juvenile school shark.

One of the objectives of this study was to assess the feasibility of developing abundance or recruitment indices for new-born sharks. Gummy shark pups were not caught in sufficient numbers at any site to make this practical, while our results suggest that Upper Pittwater is the logical site to monitor 0+ school shark both in terms of catch rates and logistics. However, given the small area of this site, the small numbers of sharks involved (we calculate a population size of some 1100 pups) and the inherent variability of the catches, the value of such an index must be questioned. In addition, statistical analysis of our recruitment index from the seven years of sampling could detect no year trend in the data. While this might mean that recruitment at this site is stable it may also be a reflection of the inherent variability of the data masking any annual trend. Because school shark pups were not caught in sufficient numbers at sites other than Pittwater, we did not maintain a long enough time series to monitor numbers of larger juveniles elsewhere. Of the sites we sampled, Frederick Henry Bay would be a logical site to monitor both juvenile school and gummy sharks.

Keywords

Pupping areas, sharks, *Galeorhinus*, *Mustelus*, tagging, catch rates, recruitment, growth.

2. BACKGROUND

School (*Galeorhinus galeus*) and gummy (*Mustelus antarcticus*) sharks form the basis of one of Australia's oldest fisheries - the Southern Shark Fishery, which dates back to the late 1920s. This fishery is currently worth some $15 million to fishers in Victoria, Tasmania and South Australia. Initially the bulk of the catch was school shark taken by demersal longline, but gummy shark are now the main species and demersal gillnetting is the main fishing gear. Catches reached an all-time high of 3826 tonnes carcass weight in 1969 but are currently much lower, partly as a result of a management plan introduced in 1988; the 1994 catch was 956 tonnes of school shark and 1803 tonnes of gummy shark. Catches of gummy shark are considered to be sustainable but there is considerable concern over school shark, which are generally considered to be over-exploited.

In Australian waters, school shark have been recorded from southern Queensland to Perth, but are most abundant from eastern Victoria and Tasmania to the western side of the Great Australian Bight. They are mostly found near the bottom on the continental shelf, and sometimes on the upper slope (Last and Stevens 1994). School shark are thought to comprise a single genetic stock in southern waters. Tagging studies have shown some mixing with New Zealand fish across the Tasman Sea, although genetic studies suggest little interbreeding between Australian and New Zealand sharks (Ward and Gardner 1997).

Gummy shark, which are endemic to Australia, are most common from southern New South Wales to Bunbury, Western Australia; they are demersal on the continental shelf from nearshore to about 80 m, and are also found on the upper slope (Last and Stevens 1994). Gummy shark are thought to comprise three genetic stocks: one along the southern Australian coast from Bunbury in the west to Eden in the east, a second off New South Wales from Newcastle to Clarence River, and a third off Townsville, Queensland (Ward and Gardner 1997).

The biology of both species has been relatively well studied (Olsen, 1954, 1984; Walker 1992, Walker *et al*. 1995). Both sharks produce live young. The neonates and small juvenile school shark live in well-defined inshore nursery areas separate from the adult sharks; gummy shark nursery areas are thought to be less specific.

School shark were studied during the 1940s and 1950s by Olsen (1954, 1984). He noted that they gave birth mainly during November and December in protected bays and channels on low-energy coastlines in Victoria and Tasmania. From March onwards, juveniles move out of inshore bays into deeper waters (Olsen 1954, FRDC 91/23). Olsen (1984) stated that " no known nursery areas occur in South Australia". Olsen selected three estuarine nursery areas in Tasmania (Port Sorell, Georges Bay and Pittwater) and one in Victoria (Port Phillip Bay), where he studied and tagged juvenile school shark; these areas were chosen for "the availability of material". The four estuaries supported different size (age) classes of juvenile school shark. Using a standard fishing technique, Olsen (1954) documented catch rates in two nursery areas between 1948 and 1952. He attributed an apparent decline in catch rates to a decline in stock size resulting from heavy fishing pressure. Olsen (1984) commented that "This work has not been repeated (since) and hence no recent data are available for comparison".

Currently, there is considerable debate between scientists and industry on whether school shark pup only in Victoria and Tasmania or whether, as claimed by some sectors of industry, pupping also occurs in South Australia or even Western Australia.

At the September 1992 Scientific Industry Research Liaison Committee (SIRLC) workshop, scientists and industry agreed that research into shark nursery areas was a priority. The February 1990 Southern Shark Fishery Management Advisory Committee (SSFMAC) had recommended that “comprehensive information be sought from fishermen and scientists on the location of pupping grounds in each State with a view to improved controls over such areas”. The report from the 5th Southern Shark Stock Assessment Workshop (SSSAW) stated that “the vulnerability of juvenile sharks to capture by professional and recreational fishermen in Tasmanian inshore waters is of concern to the research group”. In addition to recommending that nursery areas be delineated to protect juveniles, the workshop recognised that monitoring recruitment in these areas could provide a means of assessing the health of the fishery independent of the commercial catch and effort data.

The development of recruitment indices for shark is of potentially great value to industry for two reasons. First, early warning of major changes in year-class strength could be used to ‘tune’ management measures aimed at maximising the productivity of the fishery while minimising the risk of recruitment overfishing. If the indices prove insensitive to relatively minor (less than 50%) variation in year-class strength they could still be immensely valuable indicators of continuing ‘normal’ recruitment, or, as a worst case scenario, of recruitment failure such as occurred recently with gemfish. Because of the close stock-recruitment relationship in sharks, high mortality in the pupping and nursery areas as a result of fishing or habitat degradation will translate more directly into a reduction in adult stock size than in scale-fish fisheries. Increased recruitment through improved management of nursery areas would promote stock recovery and complement the current management plan aimed at stabilising catches by reducing effort in the fishery.

In 1991, CSIRO carried out a 12 month netting survey (FRDC 91/23) to estimate the relative abundance of new-born and juvenile school and gummy sharks in a study site in south-eastern Tasmania. These estimates were used to establish whether pupping and nursery grounds were confined to inshore sheltered habitats within the study site. Within the study site of Pittwater, Frederick Henry Bay and Storm Bay, new-born school shark were essentially found only in the inshore sheltered habitat of Pittwater during the summer. However, the actual number of new-born pups caught in Pittwater was low: 66 in 113 gillnet sets (November-May). The results suggested the abundance of school shark pups in Pittwater over the last 45 years had changed dramatically. While Olsen (1984) could handline up to 80 juveniles a day in the period 1948-1952, in 1992 no school shark were caught in 23 h fishing in the same position and using the same technique. The relatively few new-born gummy shark were caught not only in sheltered inshore waters but also throughout the study site. School shark of 1–3 years old were relatively abundant in Frederick Henry Bay but not in Storm Bay, whereas 1–3 year old gummy shark were relatively abundant throughout the study site.

The current study aimed to locate and examine pupping and nursery areas in Tasmania and Victoria. Initially, a number of inshore sites around Tasmania and Victoria were sampled by CSIRO and the Marine and Freshwater Research Institute (MAFRI), respectively. To examine the possibility that school shark pupping areas exist in South Australia, and to sample other sites thought by industry to be important for pupping, we provided fishers with nets to use on a voluntary basis. We hoped to use the 1994 Industry Pupping Workshop (Prince 1996) to identify potential sites. Based on this initial survey, some of the main pupping areas would then be monitored annually in an attempt to develop recruitment indexes that could be used to assess the health of the stocks.

3. NEED

The Southern Shark Fishery Management Advisory Committee (SSFMAC) recommended in February 1990 that "comprehensive information should be sought from fishermen and scientists on the location of pupping grounds in each State with a view to improved controls over such areas". At the September 1992 Scientific Industry Research Liaison Committee (SIRLC) workshop it was agreed by scientists and industry that research into shark nursery areas was a priority. In addition to delineating nursery areas with an aim to protecting juveniles it was recognised that monitoring recruitment in these areas could provide a means of assessing the health of the fishery that was independent of the commercial catch and effort data. The apparently limited size and number of school shark nursery sites make them vulnerable to fishing pressure and environmental change. Information suggests that, over the last four decades, both fishing and habitat degradation have dramatically reduced the numbers of new-born and juvenile school sharks in these sites.

4. OBJECTIVES

The original objectives of this study were to:

(1) Identify pupping and nursery grounds for school and gummy sharks in southern Australia.

(2) Determine the distribution, size structure, duration time and movements of new-born and juvenile sharks in nursery areas.

(3) Attempt to develop recruitment indices for school and gummy sharks.

(4) Determine pre-recruit mortality from tagging experiments.

(5) Determine relative catch rates of juveniles by commercial and recreational fishers.

5. METHODS

5.1 Site Selection & Sampling Strategy

5.1.1 Tasmania

A total of 26 sites were sampled around Tasmania (Fig. 1) from a 5.5 m fibreglass 'Sharkcat'. The sites included several fished by Olsen from 1948–1952, some of which he recorded as school shark nursery areas. The previously unsampled sites were in sheltered estuarine habitats, non-estuarine embayments and shallow open coastal areas. Bathurst Harbour was sampled in 1992 during a collecting trip for the Port Davey skate. Logistical difficulties and time constraints prevented us from sampling the north west coast and Flinders and King Islands. Sampling consisted of monthly sampling during the pupping season, and special-purpose sampling; all figures and tables are based on monthly samples unless otherwise indicated, to avoid possible confusion over the different sample sizes involved.

Monthly sampling involved fishing each site initially once a month between December and March (the pupping season); if few sharks were caught the site was abandoned and, sometimes, a different site selected. The time period (months and years) over which each site was sampled, and the gear used, are shown in Appendix A, Tables A1 and A2. A total of 628 gillnet and 114 longline stations were made over the five years of the study. Only monthly sampling was used for any of the catch per unit effort (cpue) analyses.

Special-purpose sampling was additional fishing carried out to achieve various objectives (tag-recapture experiment, acoustic tracking etc). The results are shown in Table A3. The size distributions of captured sharks are based on monthly as well as special-purpose sampling.

The location of stations, by gear type, at each sampling site is presented in Appendix A, Figs. A1-A7. Station position was obtained from a JRC Global Positioning System (GPS). The number of stations was allocated according to the area of the site, but their location was usually arbitrary. In the larger and deeper Norfolk Bay, station positions were assigned randomly; in Great Oyster Bay only the shallow depths along Nine Mile Beach were sampled. An LED echo sounder was used to record depth. The nets and longlines were set around dusk and hauled as soon as possible after dawn. Within the limitations of the sampling logistics, we attempted to standardise fishing time of individual gear. The average fishing time was about 14 h. Fishing time was recorded as the time from the end of the set to the end of the haul.

5.1.2 Victoria

Three bays were sampled in Victoria (Fig. 2), including Port Phillip Bay which was recognised by Olsen as an important school shark nursery area. The time period over which each site was sampled, and the gear used, are shown in Tables A4 & A5. Sites, selected after consulting local commercial and recreational fishers, were concentrated on seagrass beds and channels. Particularly in Westernport Bay, fishers considered that the best catches would be made during falling tides, when pups were thought to retreat to the channels. Sampling gear generally consisted of longlines with baited hooks, provided by the fishers chartered at each bay, and bottom-set monofilament gillnets.

Sampling gear was set before dawn for four days around the full moon in Port Phillip Bay, and before the change of tides around the new moon for three days in Westernport Bay and for two days in Corner Inlet. Westernport Bay, unlike the other two areas, was sampled throughout the day, although sampling was concentrated in the early morning and evening. Sampling during

January-April 1996 in Port Phillip Bay and Westernport Bay was delayed by two weeks due to bad weather (i.e. half a moon cycle). The average duration of the sets was 4.0 h (range 0.8 to 10.6 h

5.1.3 Industry sampling

The original intention was to provide five industry volunteers with a 600 m long small-mesh net for sampling areas they thought were important nursery grounds. It was hoped to link this sampling in with the results from the 1994 industry survey on pupping and nursery areas (Prince 1996). Research permits would be provided by AFMA and the relevant States, and the industry members would be responsible for recording and measuring the catch; where possible, a biologist would be on board. As offers of help were made at the 1992 SIRLC workshop, no money was allocated to compensate fishermen for their efforts. However, this strategy proved largely unsuccessful, and in the 1995-96 season FRDC granted permission to divert money saved by not constructing all the nets into compensating fishermen for sampling nurseries. Despite this, only limited sampling was accomplished (Fig.3).

5.1.4 Previous studies on school shark; CSIRO (1947-56)

Tagging data collected by Olsen from 1947-56 (Olsen 1954, 1984) were re-examined and updated with later recaptures. Olsen made an intensive study of four estuaries that he identified as school shark nursery areas. In three Tasmanian areas — Port Sorell, Georges Bay (St. Helens) and Pittwater — juvenile sharks were sampled each month from 1947-54 and as many as possible tagged and released. From 1947-51, Port Phillip Bay, Victoria, was sampled for one week each year when fishermen reported the presence of large numbers of juveniles. Olsen chose these locations for the availability of material.

5.2 Fishing Gear

5.2.1 Gillnets

The bottom-set monofilament gillnets used by CSIRO and MAFRI in Tasmania and Victoria were 75 m long, made up of 25 m panels of 50, 76 and 102 mm stretched mesh which were 50, 34 and 25 meshes deep, respectively. The sequence of the different mesh panels was randomised between nets. These mesh sizes were required to adequately sample the 0+ to 4+ year old fish (Kirkwood and Walker 1986). All nets had hanging ratios of 0.5, hanging coefficients of 0.87 and a depth of 2.2 m. The monofilament gauge diameter was 0.40-0.45 mm; the gauge was not constant throughout the survey, as extensive damage to the nets, particularly to the fine-gauge 50 mm panels, led us to increase the strength of mesh when repairs were required. The headline was made of 6 mm diameter blue polypropylene rope, with 1 Y3 float (40 g upthrust) per 80 cm, giving 94 floats per net (3 kg upthrust). The leadline was made of 6 mm diameter blue polypropylene rope, with 50 g leads every 40 cm, giving 188 leads per net (9.4 kg). The nets were anchored with 5 kg weights at either end and marked with a 20 cm diameter polystyrene float attached by a float line to each weight.

The bottom-set monofilament gillnets supplied to industry were 600 m long, made up of 200 m panels of 50, 76 and 102 mm stretched mesh. The monofilament diameter was 0.52-0.57 and the 50, 76, and 102 mm mesh panels were 50, 34 and 25 meshes deep, respectively. The sequence of the different mesh panels was randomised between nets. All nets had hanging ratios of 0.5, hanging coefficients of 0.87 and a depth of 2.2 m. The headline was made of 8 mm diameter blue polypropylene rope, with 216 Y5 floats per net. The leadline was made of 8 mm diameter blue polypropylene rope, with 80 kg of leads per net

5.2.2 Longlines

The bottom-set longlines used by CSIRO in Tasmania had 50 hooks (Mustad number 8260; size 5/0) on 27 kg breaking strain monofilament snoods 0.5m long. Each snood was attached to the mainline with a 75 mm stainless steel sharkclip; snoods were 4 m apart. The mainline of 4.6 mm leadcore rope (tuna branchline) was 250-300 m long. Each end was anchored with a 5 kg weight and a Danforth number 4 anchor and was marked with a 20 cm polystyrene float attached by a float line to each weight. The hooks were baited with squid.

In the last year of the project some heavier longlines were used to target broadnose sevengill sharks (*Notorhynchus cepedianus*) which are potential predators of juvenile school and gummy sharks. These bottom-set lines had 50 hooks (Japanese tuna hooks, No 328-4, gape 2.5 cm, shank 5 cm) on 1 m long snoods made from 2 mm diameter multistrand galvanised wire. Each snood was attached to the mainline with a 150 mm sharkclip; snoods were 4 m apart. The mainline of 8 mm leadcore rope was 210 m long. Each end was anchored with a 5 kg weight and a Danforth number 4 anchor and was marked with a 20 cm diameter polystyrene float attached by a float line to each weight. Two or three similar float lines were also clipped at intervals along the main line. Baits included mullet, Australian salmon, jack mackerel and shark.

Longlines in Port Phillip Bay were constructed of 3 mm diameter monofilament mainline with 4/0 Mustad stainless steel longshank hooks attached to 1 m long, 3 mm diameter monofilament snoods. Frozen octopus, squid or barracouta were used for bait. A 6 mm diameter nylon rope mainline was used in Westernport Bay, with 5/0 Mustad stainless steel longshank hooks tied to 3 mm diameter monofilament snoods. Fresh mullet, octopus or squid were used for bait. Each longline set had about 200 hooks, was anchored at either end with approximately 5 kg weights, and marked above water with a dahn pole and flag.

5.2.3 Previous studies on school shark; CSIRO (1947-56)

During Olsen’s 1947-53 study of juvenile sharks in inshore Victorian and Tasmanian embayments (Olsen 1954, 1984) sharks were caught mainly by single-hook handlines, although 70-114 mm mesh gillnets were also used, particularly in Georges Bay.

5.3 Data Collection

The date and time of setting and hauling the fishing gear were recorded, together with its position (JRC GPS) and water depth (JRC LED echo sounder). The number, length (fork length for teleosts; total length for elasmobranchs) and sex (for elasmobranchs) of each species in the catch was recorded for each station. Mesh size was noted for each gillnet catch. Live school and gummy sharks (and a number of other shark species) in a suitable condition were tagged and released (see next section). School and gummy sharks that were dead in the net were dissected to remove their stomachs and a section of their vertebral column. Stomachs were removed by cutting anteriorly at the junction of the oesophagus and posteriorly at the junction with the spiral valve, and fixed in 10% formalin for dietary analysis. The vertebrae were taken from beneath the first dorsal fin, and frozen for micro-chemical examination.

5.4 Assignment of Age-from-Length Data

We used the length data to assign ages to the first two year-classes of juvenile school shark. Newborn school shark first appeared in Tasmania in December-January, although small numbers were occasionally caught in late November. Small numbers of newborn gummy shark pups were caught over the period October to February which suggests their pupping period is less well defined than for school sharks. To assign ages to Olsen's 1947-56 school shark length data, we used the same technique.

5.5 Tagging Experiments

5.5.1 Conventional tagging

School and gummy sharks smaller than about 800 mm TL were tagged with 90 mm long plastic-headed dart tags (HallPrint). The tag was inserted in a hollow stainless steel tagging needle and applied at an angle below the first dorsal fin so that the tag head locked in the basal fin rays. Larger sharks were tagged in the first dorsal fin with plastic Rototags (Daltons, Henley-on-Thames, England) as described in Stevens (1976, 1990). Sharks were injected with oxytetracycline hydrochloride (mixed with seawater) at a dose rate of 25 mg/kg body weight, for age-validation studies currently being undertaken by MAFRI in Queenscliff. Until the final year, very few new-born pups (300–450 mm) were tagged because of concerns over their subsequent survival. The fins of some school shark pups were clipped, and then in the final year tagging was re-initiated with discovery of a suitable 20 mm long 'mini' Rototag (Daltons). All broadnose sevengill sharks were tagged with Jumbo Rototags.

To estimate population numbers of juvenile sharks from tag-recapture experiments, a model was developed (Yongshun Xiao, CSIRO Division of Marine Research, Hobart) in a system of differential equations. Details of the model are given in Appendix C. The model uses a series of continuous tag-and-recapture data together with catch-and-effort information; tag shedding is incorporated. A special case of this model was used to analyse data for age 0+ school shark in Upper Pittwater, Tasmania.

5.5.2 Acoustic tagging

Two 0+ school sharks were tracked in Upper Pittwater on 22 December 1992 and 14 March 1994. The sharks were tracked from a 4.3 m inflatable boat, which was rowed (when close to the shark to minimise disturbance) or powered by a 6 hp outboard motor. Tracking gear consisted of Vemco 65.5-76.8 KHz transmitters (20 mm long, 5 mm diameter), a VR-60 receiver and V-11 hydrophone, and a Garmin 100 GPS. The GPS position was recorded at 3 second intervals; shark location and swimming speed were assumed to be the same as that of the tracking vessel. The tags had a battery life of 12 days and a range of about 200 m. The hydrophone was mounted on a pole and rotated by hand to locate the target in relation to the vessel. Sharks were captured by longline or gillnet, a tube inserted into the stomach through the mouth, and the tag pushed gently into the stomach.

5.5.3 Previous tagging studies on school shark; CSIRO (1947-56)

Between 1947 and 1956 Olsen (1953, 1954) tagged 6502 school and 587 gummy sharks in south-east Australia. Most of the school shark were tagged in inshore bays and estuaries, notably Port Phillip Bay, Port Sorell, Georges Bay and Pittwater. Most of the gummy shark were tagged in inshore areas around Flinders Island and the north coast of Tasmania. Sharks were tagged either with Petersen discs (grey or white) attached through the first dorsal fin with stainless steel wire, or with white plastic internal tags (35 mm long by 10 wide or 50 mm long by 23 wide). The internal tags were implanted in the body cavity through an incision in the body wall. Relatively few sharks were single-tagged with either the fin or internal tags; most were double-tagged with various combinations of fin and internal tags. Further details are given in Olsen (1953, 1954).

5.6 Stock Discrimination

Electron-probe microanalysis (EPMA) and proton-probe microanalysis (micro-PIXE), were used to analyse the concentration and ontogenetic variability of constituent chemical elements in school shark vertebrae, for possible use in stock discrimination. Two vertebrae from below the first dorsal fin of 0+ school sharks caught in Pittwater, south-east Tasmania, in 1993, were cleaned of all adhering tissue and dried. They were attached on their side to the base of an embedding mould with a drop of 5-min Araldite. The mould was filled with a harder-setting resin (Araldite D). After hardening, the vertebrae were sectioned longitudinally with a diamond-edged saw blade (350 µm thick) on a rotary saw. Grinding to the plane of the centrum nucleus was done by hand on a horizontal grinding wheel, using 600 grade silicon carbide wet/dry paper. Final polishing was done with progressively finer grades of diamond paste (6, 3 µm) and aluminium oxide powder (Linde B) on a lapping machine. After polishing, the section was ultrasonically cleaned and stored in a moisture-free environment.

For probe microanalysis, the section was heated on a hot-plate at 80°C for 10 minutes to remove any residual moisture, sputter- coated with a 250 to 300 Å (measured by colour on brass) coat of carbon, and then stored under vacuum until insertion into the probes.

Electron-probe microanalyses (EPMA) were done on a Cameca Camebax-Micro electron X-ray microprobe at CSIRO Division of Minerals, Port Melbourne, using procedures developed for otolith analyses (Gunn *et al*. 1992). The Cameca Camebax has three wave-length dispersive detectors. Damage to specimens was minimised with a defocused beam and a beam-power density of 2.4 µW μm^{-2} (15 kV accelerating voltage, 25 nA beam current, 14 µm beam diameter), for a total acquisition time of 3.7 minutes per point. The concentrations (weight-fractions) of S, Cl, K, Ca and Na were calculated from the count rates measured for their respective K_a lines, and for Sr, the L_a line. S and Cl were measured on Spectrometer 1 (PET crystal), K and Ca on Spectrometer 2 (PET crystal), and Na and Sr on Spectrometer 3 (TAP crystal). Matrix corrections were made with the “PAP” (Pouchou and Pichoir 1984) matrix conversion software supplied by Cameca. Minimum detection limits and confidence intervals for the concentration estimates are based on equations provided by Ancey *et al*. (1978).

Proton probe microanalyses (Micro-PIXE) were done with the proton probe at CSIRO Division of Exploration Geoscience (North Ryde, NSW), following procedures similar to those described by Sie and Thresher (1992). The analysing beam had a diameter of 50 µm and a current of 0.1 nA, which was accumulated for a total charge of 0.025 µC for each point. The X-rays were detected by energy dispersive spectrometry [Si(Li) detector], subtending a 50 milli steradian solid angle at the target. A 125 µm berylium filter was used in all measurements. Concentrations (weight-fractions) and minimum detection limits were calculated based on Ryan *et al.* (1990). Analyses were attempted by PIXE for P, S, K, Cl, Ca, Sr, Cr, Mn, Fe, Ni, Cu, Zn, Pb, Hg, Cd, Se, Co and Ba.

5.7 Growth Rates

The growth rates of 0+ school sharks in Pittwater in the periods 1947-53 and 1991-97 were examined by monthly length-frequency data grouped by 1 cm length intervals. Fish in the 0+ age-class were clearly identifiable from the monthly length data. The birth period in Pittwater varied between late November and January. The birth month in any particular year was assumed to be the month in which pups were first caught, except for a small number caught in late November which were given a December birth date. A linear regression model was fitted to the 1947-53 and 1991-97 sets of age-length data. A more limited set of length-frequency data on 0+

and 1+ school sharks from Port Phillip Bay and Westernport Bay, Victoria, for the periods 1947-51 and 1993-96 was also examined.

5.8 Diet

Stomach contents were mostly collected from dead animals. In the laboratory, each stomach was opened lengthways and the contents washed into a petri dish. In the last year of the project a number of live school shark were examined by flushing out their stomach contents with sea water before tagging and releasing the sharks. Individual prey items, or portions of prey, were sorted, counted, given a digestion stage, blotted dry and weighed to 0.01 g. Any remaining stomach content debris was washed through a 1 mm sieve and the retained portion blotted dry and weighed. Stomachs that contained only general debris such as isolated vertebrae, otoliths or fragments of muscle or crustacean exoskeleton (but which were not weighable to 0.01 g) were classed as empty. Prey items were identified to the lowest possible taxon. Identifications were based on both intact items and remaining hard parts such as cephalopod beaks. Results were expressed in terms of the number of stomachs containing a particular prey item among those stomachs that contained food, the number of individuals of a particular prey item, and the total weight of individuals of a particular prey item.

5.9 Predation Studies

The most likely predator of juvenile school and gummy sharks in Tasmanian inshore bays and estuaries is the broadnose sevengill shark (*Notorhynchus cepedianus*). From January 1996 to March 1997, 33 overnight sets were made with longlines specifically designed to catch these sharks (see section 5.2.2); the distribution of sets by month and area is shown in Table A3.

The sharks were landed through a removable “gate” in the side of the Sharkcat and restrained upside-down on the deck. The jaws were held open and a plastic tube was inserted into the stomach, which was irrigated with seawater by an electric pump. Any matter subsequently flushed out was collected in a sieve and analysed in the laboratory (see section 5.8). To check the method was successfully removing stomach contents, some sharks were also examined by inserting a hand into the stomach through a thick section of plastic pipe placed in the jaws. The sharks were then tagged and released.

5.10 Hydrography

To provide a basic description of the study sites, temperature and salinity profiles were taken with a Platypus submersible data logger (SDL). The SDL was lowered to the bottom, allowing the entire water column to be sampled. Some bottom temperatures were also taken with a reversing thermometer.

6. DETAILED RESULTS

6.1 Assignment of Age-from-Length Data

The length-frequency data were used to assign ages to the first two year-classes so that we could express our catch data in terms of age as well as length. The discrete pupping period for school shark produced clear separation of the first two size classes in plots of our Tasmanian length-frequency distributions by month, although in one area, Great Oyster Bay, the modal sizes were larger than at comparable times for other sites. The size limits used to assign ages to our Tasmanian school shark data are shown in Appendix B, Fig. B1. The length-frequency distributions from Victorian bays are based on fewer data but separation of the first year-class is relatively clear. The size limits used to assign ages to these data are shown on Fig. B2. School shark length-frequency data from Olsen's 1947-53 study was treated in the same way (Fig. B3), although it was found necessary to distinguish between southern, eastern and northern Tasmania, as well as Victoria (Table B1).

With gummy shark, separation of the first two modes was possible for the Victorian data, although modes were less clear than for school shark (Fig. B4). However, for the Tasmanian gummy shark data it was not possible to assign age from length-frequency distributions. There was a distinct mode of pups in summer, but it was not possible to trace it through the year. The progression of larger size-classes was equally confusing. We grouped the juveniles into three size-classes, based on the approximate sizes of 0-3 year old gummy shark, (<450, 450-629, 630-799) using the 1973 growth curves for Bass Strait from Moulton *et al.* 1992.

6.2 Analysis of Catch-and-Effort Data

6.2.1 Tasmania

Gillnet sampling

Monthly gillnet sampling was carried out at 25 sites between November 1992 and March 1996 (Fig. 1). A total of 628 nets were set (Table A1), resulting in a catch of 569 school shark and 999 gummy shark. Special-purpose gillnet sampling resulted in an additional 10 school shark and 5 gummy shark from 15 sets. The size distributions of gillnet-captured sharks are shown in Fig. 4. Of the 579 school shark, almost all belonged to the first three year-classes (0+, 1+ and 2+ fish) and were clearly separable into three length modes (Fig. 4a). Of the 1004 gummy shark, most were between 500 and 1000 mm TL; clear length modes were not apparent but these lengths correspond to the 1+ to 4+ age-classes (Fig. 4b). The gillnet catch of school and gummy sharks (0+, 1+ and total catch) and the cpue by site are shown in Tables 1 & 2. The distribution of effort and the cpue for 0+, 1+ and total school and gummy sharks, by site, are shown in Figs. 5 & 6.

School shark

School shark were caught at 9 of the 25 gillnet sites, with pups caught at 6 of these sites (Table 1 & Fig. 5). The size distribution of school shark caught by site, given in Fig. B5, shows that different size and age-classes of sharks were caught at different sites. For example, at Port Sorrel only 0+ fish were caught, while this age-class was not represented in the catch from Ralphs Bay and Isthmus Bay. Upper Pittwater had the highest catch rate of pups (0.97 sharks per 75 m net set) and produced consistent catches of pups from year to year (Table 1, Fig. 5). Great Oyster Bay and Norfolk Bay had the highest total catch rate of school shark (cpue 2.29 and 2.13, respectively) with both 1+ and 2+ fish well represented (Table1, Fig. B5).

Fig. 7, which includes data from a 12 month study in 1991-92 (FRDC 91/23), shows the summer distribution of age-classes for school shark in an extensive area of bays and inlets in south-east Tasmania, bounded by the D'Entrecasteaux Channel in the west and Marion Bay (Tasman Peninsula) in the east. New-born pups are essentially restricted to Pittwater, close inshore along the Seven Mile Beach area of Frederick Henry Bay, and to Norfolk and Blackman Bays. Pups are born in Pittwater between November and January, where they remain until autumn when they move into deeper water (Olsen 1984, FRDC 91/23).

Because school shark pups could be caught consistently in Upper Pittwater, this site was sampled each month during the summer from 1992-96, as well as throughout the year in 1991-92 (FRDC project 91/23). Monthly variations in cpue by age-class, together with the distribution of effort, are shown in Fig. 8 for this period.

Since the birth of school shark is normally complete by January, we initially tried using only the catch data (monthly sampling only) from January and February as a recruitment index for school shark pups in Upper Pittwater. This was also the most consistent data set, and avoided the problems of zero catches in December in some years, when, presumably, pupping was later. We investigated the effect of year and month on our gillnet catches in upper Pittwater by analysis of variance (Minitab Inc.). We analysed the average catch in each month (based on 8 to 10 sets) rather than the individual catches, which were highly skewed — the distribution of the means is closer to normal. The year effect was partitioned into single degrees of freedom polynomial components, from linear to quartic. With only one observation per year*month cell, we could not fully test the interaction. Instead, we tested only the linear component of year*month interaction. We found no significant effect (F = 0.00, 1,3 df, p = 0.990), and so the interaction was ignored. The resulting model was:

av catch = month + yr linear + yr quadratic + yr cubic + yr quartic;

Analysis of Variance table

Source	DF	Adj MS	F	P
month	1	0.3706	2.69	0.176
yr linear	1	0.5310	3.85	0.121
Y quadratic	1	0.9654	7.01	0.057
Y cubic	1	0.2000	1.45	0.295
Y quartic	1	0.9862	7.16	0.055
Error	4	0.1377		
Total	9	0.1377		

No term was significant at the 5% level, but the quartic term was sufficiently close to deter us from eliminating it to simplify the model. Consequently, we carried out an additional analysis, this time based on the individual catches for each net, over the months December to March (141 observations) (Fig. 9). The square root of the number of pups caught was used to reduce the problem of non-normality. The season*month interaction could not be fully tested because not

all months were sampled each summer. However, a partial test with 10 df instead of 12 df showed no significant interaction ($F = 1.303$, df = 10,123, $p = 0.236$). The model chosen included year and month as main effects, but with no interaction term. There was no significant year effect ($F = 1.61$, df = 4,133, $p = 0.175$) but the month effect was significant ($F = 4.82$, df = 3,133, $p = 0.003$). The adjusted values of catch (square root) were lowest in December, highest in January, then declined slowly until March. The levels in December were significantly less than the other months ($F = 12.44$, 1,133 df, $p = 0.001$) while levels in the other months were not significantly different from each other ($F = 1.01$, 2,133 df, $p = 0.366$).

Gummy shark

Gummy shark were caught at 18 of the 25 gillnet sites, with pups taken at 5 sites (Table 2 & Fig. 6). The size distribution of gummy shark caught by site is shown in Fig. B6. Few gummy shark pups were caught at any of the sites; the highest cpue's were recorded from Southport Lagoon (0.38), Port Sorell (0.26) and Upper Pittwater (0.06). However, the catches at Southport Lagoon were based on a small sample size. Great Oyster Bay and Marion Bay had the highest total catch rate of gummy shark (4.96 and 5.0 respectively), although Marion Bay had only limited sampling effort. Catches of 1+ fish in Great Oyster Bay were, however, very low. Monthly variations in cpue by age-class, together with the distribution of effort, are shown for Upper Pittwater in Fig. 10 for the period 1991-96. Insufficient numbers of either 0+ or 1+ gummy shark were caught at this site for use in a recruitment index.

Longline sampling

Monthly longline sampling was carried out at 13 sites between November 1992 and March 1996. A total of 114 longlines were set, resulting in a catch of 152 school shark and 158 gummy shark (Tables 1 & 2). Longline effort was concentrated in Upper Pittwater, and to a lesser extent at Great Oyster Bay. Special-purpose sampling resulted in an additional catch of 93 school shark and 162 gummy shark in 88 longline sets. The size distribution of sharks caught by longline is shown in Fig.11. An additional 71 sets (48 in Upper Pittwater) were made during 1996 as part of a tag-recapture experiment to estimate population numbers of school shark pups in Upper Pittwater (Table A3). An additional 71 school shark (67 pups) and 139 gummy shark (24 pups) were caught in this experiment (Table B2). The longline catch of school and gummy sharks (0+, 1+ and total catch), the effort and the cpue by site are shown in Tables 1 & 2 and Figs. 12 & 13. Monthly longline cpue (November to March) for Upper Pittwater is shown by age-class for each year in Figs. 14 & 15.

Only limited longline sampling was undertaken during 1992 and 1993. In 1994, and particularly in 1995 and 1996, longlining techniques were improved and sampling effort was intensified in Upper Pittwater. Increased emphasis on longlining during the program was to enable better comparison with Victorian data (which used longlines as the primary sampling gear) and in response to the relatively high mortality of school shark (69%) and the large teleost bycatch in our gillnet sampling. During the 1994-95 season, longlining in Upper Pittwater caught 62 school shark at a cpue of 3.9 (catch per 50 hook set) while gillnetting caught 37 school shark at a cpue of 1.2 per 75 m set. In the 1995-96 season, longlining caught 63 school shark at a cpue of 1.6 per 50 hook set while gillnetting caught 16 school shark at a cpue of 0.5 per 75 m set. Higher catch rates from longlining together with a lower shark mortality and reduced bycatch suggest that longlining (at least in Pittwater) is a better option for future long-term recruitment monitoring of 0+ and 1+ school shark. However, the effectiveness of longlining at other sites may be affected by the activity of sea lice which can quickly destroy the bait (for example at Great Oyster Bay).

Because of the changes in longline technique and effort levels before 1996, comparisons of catch rates between gillnet and longline fishing gears in Upper Pittwater were not possible and no statistical analysis was attempted. The results can be compared in Figs. 8 & 14 for school shark, and Figs. 10 & 15 for gummy shark.

6.2.2 Victoria

A total of 384 nets and 191 longlines were set at the eleven sites within the three Victorian embayments (Tables A4 & A5). The total gillnet and longline catch of school and gummy sharks, the catch of 0+ fish and the catch per unit effort (cpue) by site are shown in Table 3. The size distribution of these sharks by site and fishing method are shown in Figs. 16 & 17.

School shark were caught at 8 of the sites with pups also caught at 8 sites, although only one individual was caught at Corner Inlet in 17 longline and 34 gillnet sets. The South site in Western Port Bay had the highest cpue of school shark pups (longline 0.79 sharks per 50 hook set; gillnet 0.18 sharks per 75 m set) and the highest total cpue of school shark (longline 1.08; gillnet 0.20) (Table 3).

Gummy shark were caught at 10 of the sites with pups caught at 9 of these. The South site and Reef Island site in Western Port Bay had the highest cpue of gummy shark pups caught by longline (0.13), while Queenscliff in Port Phillip Bay had the highest cpue of pups (1.35) caught by gillnet. The highest total cpue of gummy shark caught by longline was at the Central site in Westernport Bay (1.65), while the highest total cpue of gummy shark caught by gillnet was at Queenscliff in Port Phillip Bay (1.82).

6.2.3 Industry sampling

Three out of the total of five small-mesh nets to be used by industry volunteers were constructed and supplied for use. The three nets were supplied to Rob Wilson and Peter Risely (South Australia) and the Western Australian Marine Laboratories in Perth. Data on seven sets made by Rob Wilson in the head of the Great Australian Bight (Fig. 3) in 6-22 m of water were received (three in 1994 and four in 1995); three school shark were caught (128-154 cm TL) but none were pups or juveniles. Two trips with Rob Wilson were made in 1996 with an observer on board, but because of unsuitable weather conditions, the small-mesh nets were not deployed. The Western Australian Marine Laboratories set their net 11 times in the Great Australian Bight in depths from 35-73 m; no school or gummy sharks were caught.

6.3 Tagging Experiments

6.3.1 Conventional tagging; releases

Current Tagging (1991-97)

Between October 1991 and March 1997, 404 school and 1254 gummy sharks were tagged mainly in inshore waters of Tasmania (Table 4); the size distributions of these fish are shown in Fig. B7. The numbers tagged with the three tag types are shown in Table 5. The size distributions of school and gummy sharks tagged with each of these tag types are shown in Figs. B8 & B9. Sharks tagged with dart tags were generally between 400-800 mm TL, those with Rototags were about 600-1200 mm, and those with ‘mini tags’ were less than 400 mm TL. The majority of school sharks were released in the south east in the area between the D’Entrecasteaux Channel to the west and Blackman Bay to the east, and centred on the Pittwater, Frederick Henry Bay, Storm Bay system. A few school sharks were also released on the east coast at Great Oyster Bay. The distribution of gummy shark releases was similar with the addition of some releases on the north coast between Port Sorell and Ringarooma Bay.

Previous tagging studies on school shark; CSIRO 1947-56

Olsen tagged 6502 school shark and 587 gummy shark between 1947 and 1956, using a variety of tag types (Table 6). The number of releases by age-class are shown in Table 7. Most releases were made in Port Phillip Bay, Port Sorell, Georges Bay and Pittwater.

6.3.2 Conventional tagging; recaptures

Current Tagging (1991-97)

Up to February 1997, 50 school shark (12.4%) and 160 gummy shark (12.8%) had been recaptured. The recapture rate for dart, Rototags and 'mini tags' for school shark was 10.5, 13.4 and 14.9%, respectively, and for gummy shark was 9.0, 16.2 and 0%, respectively (Table 5). The lower recapture rate of dart tags compared to Rototags ('mini tags' were only used in the last year of the project) probably results from the dart tags having a higher shedding rate (a Chi-square test on the number of recaptures from dart and Rototags was highly significant ($p > .001$, 1 d.f.). If this is the case, the number of dart tags returned in successive years from release might be expected to decline more abruptly than for Rototags. However, Chi-square tests on the number of recaptures by year at liberty and tag type (Table 8) did not show any evidence of differences in the pattern of recoveries for either school shark ($\chi^2 = 0.95$, 2 d.f., $p = 0.62$) or gummy shark ($\chi^2 = 5.97$, 5 d.f., $p = 0.66$). When the recaptures were examined by the gear type on which the sharks were originally caught, there was no significant difference for school shark ($\chi^2 = 0.22$, 1 d.f., $p = 0.64$). However, with gummy shark, there were far fewer recaptures from longline releases than expected ($\chi^2 = 10.5$, 2 d.f., $p = 0.005$) (Table 9). There was a very high (20%) recapture rate for the gillnet-released gummy sharks tagged with Rototags.

Some 0+ school shark had their stomachs flushed with seawater to remove the contents for dietary analysis, before being tagged and released. To examine the effects of flushing on subsequent shark survival the recapture rate of sharks that had been flushed (10.8%) was compared to those that were not flushed (22.5%). These differences were not significant ($\chi^2 = 2.35$, 1 d.f., $p = 0.13$).

Of the school shark recaptures, 48% came from commercial fishers, 12.0% from recreational fishers and 40.0% from research fishing; for gummy shark these figures were 63.3%, 9.5% and 22.8%, respectively (Table 10). The higher proportion of gummy shark caught by commercial fishers relative to school shark probably reflects the generally larger size of tagged gummy shark, and their greater mobility. Much of the tagging effort was in Pittwater where the small school shark tend to remain during summer resulting in a higher availability to research fishing and a lower availability to commercial fishing.

Previous tagging studies on school shark; CSIRO (1947-56)

Up to May 1997, 594 school shark (9.1%) and 60 gummy shark (10.2%) had been recaptured. Returns of tagged school shark continued up until August 1993, while gummy shark returns ended in April 1969. The recaptures for the various types and combinations of tags used are shown in Table 6.

School shark

The most conspicuous feature for the school shark recaptures is the very low return rate for fin-tagged fish (2.1%). A Chi-square test on the numbers recaptured for each tag combination was highly significant ($\chi^2 = 595.6$, 4 d.f., $p < 0.001$). Olsen (1954) noted a high shedding rate for the fin tags; when they were excluded from the analysis, the Chi-square value fell to 71.4 (3 d.f., $p < 0.001$), but was still highly significant. Most of the deviation from expected values was with the double-tagged fish that were returned in higher than expected numbers.

The lower return rate for fish tagged with small internal tags (applied to smaller fish) led us to analyse the recaptures by age-class (Table 7). The highest recapture rates were for the oldest double-tagged fish, and the lowest for the fin-tagged 0+ fish. The return rate for (single) fin-tagged fish was low for all three age-classes, but when this group was analysed separately, there was still a strong association between age-class and numbers returned ($\chi^2 = 33.7$, 2 d.f., $p < 0.001$). Fewer 0+ fish, and more 1+ fish than expected, were recaptured. This is consistent with higher tag-shedding rates in smaller fish because of their more delicate fins.

When the numbers of recaptures of double tagged fish, and those tagged with only an internal tag, were compared, the results were highly significant ($\chi^2 = 63.2$, 5 d.f., $p < 0.001$). There were far more recaptures for the oldest double-tagged fish, and far less for the 0+ class, than expected. The probable reason is higher tagging mortality in the smaller fish, and the better detection of tags in the larger fish afforded by the fin-tag in the early years at liberty (Olsen 1953, Stanley 1988).

The recapture rate of school shark tagged at the major release sites of Port Phillip Bay, Port Sorell, Georges Bay and Pittwater is shown in Table 11. The recapture rate of fish tagged at Georges Bay was much higher ($\chi^2 = 278.1$, 3 d.f., $p < 0.001$) than at any of the other sites; Olsen (1954) found that, unlike other bays, the juveniles remain in Georges Bay throughout the year. Table12 shows that of the large numbers of juvenile school sharks tagged at these four sites, very few were recaptured at the same site relative to recaptures made elsewhere.

Gummy shark

Most of the gummy shark were tagged with either large internal tags, or these tags in combination with a fin-tag (Table 6), and these two groups accounted for most of the recaptures. In contrast to the results for school shark, double-tagged sharks had a lower recapture rate than fish tagged with only an internal tag.

When the releases are considered by age-class (Table 7), it is apparent that most of the releases were of the >1+ age class. A Chi-square test restricted to this group, indicated that the differences in the numbers of recaptures for the internally tagged and double-tagged fish was significant ($\chi^2 = 6.34$, 1 d.f., p 0.012). We have no explanation why the number of recaptures was lower from the double-tagged fish.

6.3.3 Conventional tagging; movements

Current tagging (1991-97)

Movements of school and gummy sharks tagged in this project are shown in Figs 18 & 19; short-distance movements are shown in Figs 20 & 21. The average distance moved by school shark recaptured in this study was 227 nm while the average distance moved by gummy shark was 63 nm. Of the school shark recaptures, 69% were made within 50 nm of the tagging site, 22% moved distances greater than 200 nm and 2% moved more than 1000 nm from the tagging site (Fig. 22). There was no significant difference between the distances moved by male or female school sharks (Mood median test: $\chi^2 = 0.02$, 1.d.f., $p = 0.88$). Gummy shark were somewhat less mobile than school shark; 82% of gummies were recaught within 50 nm of the tagging site, 11% travelled more than 200 nm and no fish moved more than 600 nm from the tagging site. Female gummy shark moved significantly greater distances than males (Mood median test: $\chi^2= 6.81$, 1.d.f., $p = 0.009$). There was an increase in the distance moved with time at liberty for both school and gummy sharks (school, $r = 0.46$, 32 d.f., $p < 0.01$; gummy, $r = 0.41$, 124 d.f., $p < 0.01$). To examine whether the distance moved increased with age of the shark, the average distance moved by 0+ and 1+ school shark was examined at yearly

increments from release (Table 13). The data were very limited but showed an increase in the average distance moved by 1+ fish from 62 nm in the first year after release to 271 nm in the second year after release.

Previous tagging studies on school shark; CSIRO (1947-56).

The average distance moved by school shark recaptured from Olsen's tagging study was 162 nm while the average distance moved by gummy shark was 62 nm. There was no significant difference between the distances moved by male (127 nm) or female (188 nm) school shark (Mood median test: $\chi^2 = 0.47$, 1.d.f., $p = 0.49$). The average distance moved by female gummy sharks was 96 nm, which compared to 29 nm for males. These differences for gummy shark were not significant (Mood median test: $\chi^2 = 2.49$, 1.d.f., $p = 0.115$), however, the sample size was small. Olsen's data was used to obtain further information on the movement of school shark with age. The distance moved by 0+ and 1+ school shark was examined at yearly increments from release (Table 13). The average distance moved by 0+ fish up to three years from release was 5.4 nm while at four, five and six years after release the average distance moved was 166, 350 and 417 nm. For the 1+ fish, the average distance moved up to one year after release was 13 nm, but some fish had moved over 100 nm. At up to two years after release some fish had made extensive movements of over 500 nm. This suggests that the new-born pups generally remain close to their birth area for the first few years and then as they get older they tend to move greater distances. However, some individuals can make substantial movements as early as their second year.

6.3.4 Conventional tagging; population estimates

A tag-recapture experiment to estimate the population size of 0+ school shark in Upper Pittwater was carried out between December 1995 and March 1996. Of 100 0+ school shark tagged during this period with 'mini tags', 18 were subsequently recaptured. The number of fish tagged in December, January, February and March were 5, 84, 8 and 3, respectively, while the numbers recaptured in these same months were 0, 9, 6 and 3, respectively. The output of the population model is shown in Table 14; natural mortality (M) was fixed at 2.1 yr $^{-1}$, the value used for 0+ school shark by the Southern Shark Fishery Assessment Group. Population numbers calculated for different periods of the experiment varied from 1084-1446. High rainfall between about 20th January and 13th February in the Pittwater area resulted in lowered salinities and was associated with reduced catches of school shark. Since this suggested possible emigration of some sharks from Pittwater around this period, the first two estimates (50-51 days from the start of the experiment) of about 1100 sharks are probably the most reliable.

6.3.5 Acoustic tagging

On the 22nd December 1992, a 306 mm TL female school shark in a lively condition was captured by gillnet in Upper Pittwater. The shark was tracked from 0852 h on the 22nd until 1000 h on the 23rd when the track was terminated. During this time the shark remained in a relatively restricted area of Upper Pittwater (Fig. 23a).

A second school shark of 430 mm TL was captured by longline on 14th March 1994 and tracked from 1400 h on that day until 1400 h on the 15th March. After terminating the track on the 15th the shark was subsequently relocated on the 16th at 1438 h and followed until 1600 h. This shark also remained within a restricted area of Upper Pittwater (Fig. 23b).

6.4 Mesh Selectivity Characteristics

The size distributions of school and gummy sharks caught in the 50, 76, and 102 mm mesh panels are shown in Figs. B10 & B11. Kirkwood and Walker (1986) estimated that the peak selectivity for a gummy shark in a 100 mm mesh is about 750 mm TL, which is supported by our data. School shark have a more pointed snout than gummy shark and it might be expected that the length at peak selectivity for school shark in a 100 mm mesh would be greater than for gummy shark. However, the modal length of school shark caught in our 100 mm mesh net was about 650-700 mm TL. The explanation is probably that larger school shark are not generally present in the inshore areas where we sampled. The bi-modal length distributions for both school and gummy sharks caught in the 50.8 mm mesh net are interesting. The monofilament gauge for this mesh was very fine (particularly at the start of the study) and was easily broken. The mode at 350-400 mm TL in the catch data for both species represent new-born fish in the 0+ age-class and probably approximates peak selectivity for this net. The larger mode in the catch data probably represent larger fish which have been caught in broken meshes. The seasonal availability of these 0+ fish may also affect the distribution.

6.5 Stock Discrimination; Vertebral Microchemistry

Electron-probe microanalysis (EPMA)

EPMA requires that specimens for analysis have a flat, highly polished surface. Even in the relatively small vertebrae from the juvenile sharks there was substantial curvature in the centrum surface, to the extent that a single section, encompassing the full growth axis, could not be obtained. Surface curvature is more severe in centra of adult shark vertebrae. In addition, the ridges and grooves that form the growth markings on the centra surface provide too much relief for EPMA analysis. We expended considerable time and effort in attempts to prepare a section from the vertebral centrum of southern bluefin tuna that would allow EPMA across the surface of the centrum, as per the method employed by Calliet and Radtke (1987), but these attempts were unsuccessful. We decided that similar attempts on shark vertebrae were also likely to prove unsuccessful, and therefore prepared longitudinal sections that exposed the layers of tissue underlying the centrum surface.

Five EPMA analyses were done on vertebra SV#1 (Table 15, Fig. 24 a & b). The elements measured, Na, Sr, K, S, Cl, and Ca are the six elements routinely measured by EPMA in otoliths. The intention was to do a series of test analyses along the growth axis, close to the centrum surface. The first two analyses (Points 1, 2) were done close to each other and close to the centrum nucleus. The variability in the concentration of all six elements for these two points was high; variability almost certainly due to the vacuoles in the cartilaginous tissue (see Fig. 24 b) and subsequent absorption artefacts imposed on the X-rays generated. Three more analyses were carried out in other areas of the section (Points 3, 4, 5). Difficulty was experienced in finding smooth areas on which to target the beam, due to the high density of large and small vacuoles in all tissues. Even using a relatively mild beam power density, ‘burning’ by the beam was significant and pitting was severe. For this reason, and because of the insurmountable problems associated with specimen topography, no further EPMA analyses were done.

Table 15. Concentration of constituent elements measured by EPMA on school shark, *Galeorhinus galeus*, vertebra SV#1.

Point #	Na ppm	Sr ppm	K ppm	S ppm	Cl ppm	Ca %
1	5010	980	490	4860	990	29.71
2	1380	590	230	6510	1830	9.85
3	1500	820	140	3690	320	24.76
4	1150	420	130	3980	250	20.7
5	3020	680	490	2950	320	33.09

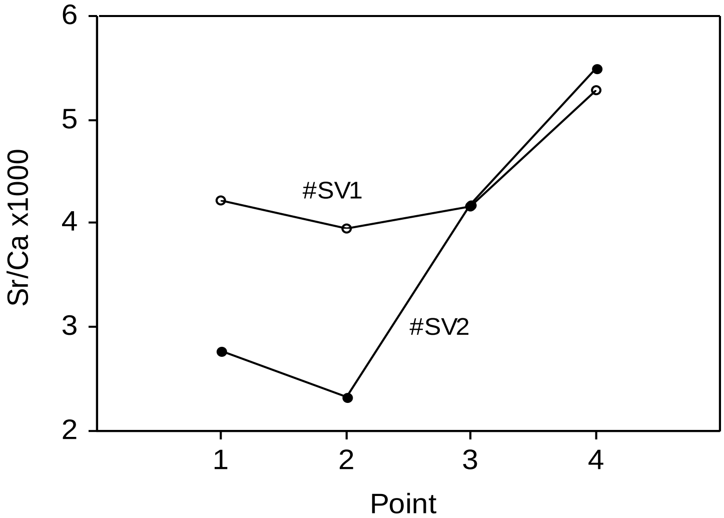
Proton-probe microanalysis (PIXE)

PIXE analyses were carried out at four points (Fig. 24 a) on both vertebrae (#SV1 and #SV2); the first analysis close to the centrum nucleus, a second and third on the layer underlying the centrum surface, and a fourth at the centrum margin (ie. four points which should be in ontogenetic sequence). The concentration of all elements at these points are detailed in Table 16**.** Some of the element concentrations were below minimum detection limits, and are shown as "0".

Some of the high concentrations for some elements, most notably Fe, Cr, Mo, and Ni should be viewed with suspicion, as these elements are characteristic of stainless steel contamination. We use stainless steel "chucks" in our grinding/polishing procedure, and there is a high probability that stainless steel residues could accumulate in the vacuole spaces of the vertebrae. There are several 'unusual' features among the PIXE data eg. the high Cu concentrations at point 3 on both vertebrae, and "0" levels at the other points.

Sr/Ca ratio in the two school shark vertebrae converged strongly to a common level at the outer margin of the section (Point 4, Fig. 25), which we interpret as a response to a common nursery area environment.

Fig 25. Strontium/ calcium ratio as measured by PIXE on tissue underlying the centrum growth axis of vertebrae from two school shark (*Galeorhinus galeus*) juveniles.



Point 1 was close to the centrum nucleus and Point 4 at the centrum margin.

Table 16. Concentration of elements as measured by PIXE on vertebrae of school shark, *Galeorhinus galeus*. Values are all ppm, except Ca which is %, and Sr/Ca which is a ratio

Specimen/ Point	P	S	K	Cl	Ca	Cr	Mn	Fe	Ni	Cu
#SV1/1	3340	153	40	117	5.68	419	35	409	0	0
#SV1/2	2580	106	22	115	4.82	467	48	1070	101	0
#SV1/3	3640	213	32	159	5.82	1080	66	2430	281	1950
#SV1/4	3460	317	23	106	5.53	1180	84	2920	423	0
#SV2/1	3810	249	88	88	6.14	642	57	1080	117	0
#SV2/2	3900	138	86	68	6.85	572	78	238	0	0
#SV2/3	3130	79	51	32	5.15	414	24	143	0	3270
#SV2/4	2640	108	22	42	4.43	321	0	129	0	0
	Zn	Br	Sr	Sr/Ca	Mo	Hg	Cd	Se	Co	Ba
#SV1/1	37	0	239	4.21	48	0	0	20	0	0
#SV1/2	29	0	190	3.94	0	41	0	18	0	0
#SV1/3	42	0	243	4.17	89	0	0	25	0	0
#SV1/4	38	0	292	5.28	172	0	0	20	0	0
#SV2/1	42	25	171	2.78	0	0	0	1990	18	0
#SV2/2	45	0	160	2.34	0	0	0	35	0	0
#SV2/3	17	0	215	4.18	64	0	0	1600	0	0
#SV2/4	38	0	244	5.50	0	19	0	11	0	0

6.6 Growth Rates

Length-at-age data for 0+ school shark from Pittwater captured during two different time periods, 1947-53 and 1991-97, are plotted in Fig. 26, and linear regression models fitted. Regressions of total length on age (in months) for the combined data set (1947-53 and 1991-96) showed differences in the intercept and the slope. Growth rates have increased from 12 to 17 mm/month ($F = 67.03$, 1,1052 df, $p <.001$) and size at birth has increased from 318 to 334 mm ($F = 35.33$, 1,1052 df, $P <.001$).

Length-frequency data for the periods 1947-51 (Olsen) and 1993-96 (MAFRI) from Port Phillip Bay and Westernport Bay, Victoria, are shown in Fig. 27. Data were only available between December and March. It appears that the 0+ and 1+ age-classes are larger now than they were previously, and that growth has increased. No analysis of the data was attempted because the limited seasonal coverage precluded determination of the birth month in each year, which meant that age in months could not be assigned.

6.7 Diet

School shark

The stomach contents of 484 school shark ranging in total length from 286-1401 mm were examined; these comprised 139 0+ fish (63% of which were from Pittwater), 168 1+ fish (73% from Frederick Henry Bay) and 177 >1+ fish (85% from Frederick Henry Bay). Of the 0+ fish, 0.8% had empty stomachs, while 2.3% of the 1+ fish and 2.8% of the >1+ fish had empty stomachs. The percentage occurrence, number and weight of prey items recorded for 0+, 1+ and >1+ sharks are shown in Table B3, and the analysis by site in Table B4.

The contribution to the diet of the major prey categories by age-class and site are shown in Figs. 28 & 29. In 0+ school shark, teleost fish, cephalopods and crustaceans were of similar importance in the stomach contents while in older sharks crustaceans were less important. The cephalopod component in the diet also declined with increasing age-class, but this was mainly a reflection of relatively high predation of 0+ sharks on the inshore loliginid *Loliola noctiluca* in Pittwater. Of the identifiable teleost prey, the most important species were school whiting *Sillago bassensis*, sand flathead *Platycephalus bassensis*, anchovy *Engraulis australis*, cod *Pseudophycis bachus* and (particularly in 0+ sharks from Pittwater) bridled goby *Arenigobius bifrenatus.*

Gummy shark

The stomach contents of 425 gummy shark ranging in total length from 358-1223 mm were examined; these comprised nine 0+ fish (56% of which were from Frederick Henry Bay), 112 1+ fish (71% from Frederick Henry Bay) and 304 >1+ fish (45% from Pittwater). Of the 0+ fish, none had empty stomachs, while 4% of the 1+ and 5% of the >1+ fish had empty stomachs. The percentage occurrence, number and weight of prey items recorded for 0+, 1+ and >1+ sharks are shown in Table B5, and the analysis by site in Table B6.

The contribution to the diet of the major prey categories by age-class and site are shown in Figs. 30 & 31. Of the identifiable prey items, crustaceans were the only component in the diet of the limited sample of 0+ fish; crustaceans were also the dominant prey item in the diet of 1+ and >1+ sharks but teleosts, cephalopods and sipunculids were more prevalent in the larger sharks. However, this may also be a function of the greater availability of these prey items in Frederick

Henry Bay and Storm Bay. Of the identifiable crustacean prey, the crab *Paragrapsis gaimardi* is

particularly important in the diet of >1+ gummy shark in Pittwater and *Paridotea munda* appears to be relatively important in 0+ gummy shark, although the sample size is small. Among the other identifiable prey categories, sipunculids are relatively important in 1+ sharks and *Octopus* sp.1 in gummy shark from Storm Bay.

6.8 Predation Studies

Twenty one bottom longline sets of 50 hooks each were carried out between January and March 1996 and 102 broadnose sevengill shark were caught; in 1997, 12 sets were made in February and March and 27 sevengill shark caught.

In 1996, four sets were made in Upper Pittwater and the cpue was 0.5 sharks per 50 hooks. In Norfolk Bay, 13 sets were made (cpue: 7.5 sharks per 50 hooks).

In 1997, 12 sets were made in Norfolk Bay (cpue: 2.3 sharks per 50 hooks).

Sharks ranged in size from 1250-2800 mm TL; of those which could be sexed 57 were female and 58 were male. One hundred and eleven sharks were examined for stomach contents, the majority by flushing their stomachs with seawater after which they were tagged and released. In 10 sharks, the stomach was everted while a further 52 had empty stomachs and a further eight contained only the bait. Of the 41 sharks containing food, fish occurred in 98%, elasmobranchs in 80% and teleosts in 22% of stomachs. Sharks and rays occurred in about equal numbers (34% and 32% of stomachs, respectively) but about half of those containing sharks had been predated on the longline. Urolophids were the most frequently identified elasmobranch prey. The only school sharks identified from the stomachs of the sevengills had been attacked while on the longline.

Of 113 sevengill shark tagged and released, six were recaptured close to their release point in Norfolk Bay (two a year later), a seventh shark was recaptured on the New South Wales coast the following July, and an eighth was recaptured off St. Helens on the Tasmanian east coast the following January.

6.9 Hydrography

In Upper Pittwater, the site where most 0+ school shark were caught, temperature and salinity near the bottom was generally in the range of 14-21°C and 34-37‰ between December and March. During the wet summer of 1995/96 bottom salinities were 25.5-28‰ in February, at which time the catch rate of 0+ school shark was very low— the lowered salinity may have caused the pups to move out of Pittwater into deeper water.

Bottom temperatures and salinity at other sites where 0+ school shark were caught in summer ranged from 16-21°C and 34-36.5‰ at Blackman Bay, 15.5-18°C and 34.5-35.5‰ at Great Oyster Bay and 17-20.4°C and 31-35‰ at Port Sorell. The sites at which no 0+ school shark were caught had similar temperature/salinity values of 14-19°C and 27.8-35.5‰, respectively.

7. DISCUSSION AND CONCLUSIONS

7.1 Analysis of Catch-and-Effort Data

Catch rates from this study suggest that juvenile school shark have a relatively specific distribution in inshore waters of Tasmania and Victoria. Fairly intensive sampling, particularly around south-east Tasmania, showed that the occurrence and abundance of juveniles varied considerably between bays and estuaries which were often of similar appearance. Additionally, as also noted by Olsen (1954, 1984), there were often site-specific differences in length and age structure between areas where juvenile school shark did occur. New-born pups were caught at six of the nine Tasmanian sites at which school shark were captured during this study, but they were caught most consistently at Upper Pittwater. Pups were caught at the two additional sites sampled in our earlier study (FRDC 91/23) but in the deeper and more exposed Storm Bay they were only caught during winter (when they had presumably moved out of their shallower summer area). In Frederick Henry Bay they were only caught at the northern end along Seven Mile Beach, close to the entrance to Pittwater. Olsen also caught school shark pups in Tasmania at Georges Bay, the Tamar River, Ralphs Bay (Derwent) and on the north-west coast, near the Hunter Group; from 1-5 pups were also caught at Flinders Island, Bicheno, Coles Bay and the D'Entrecasteaux Channel **(**Fig. 32)**.** We caught no school shark pups at Georges Bay, the Tamar River, Ralphs Bay, Coles Bay or the D'Entrecasteaux Channel. We were unable to sample Flinders Island or the north-west coast.

Results from our two studies on the distribution of pups generally confirm Olsen's (1954, 1984) findings that school shark give birth between November and January in protected environments on low-energy coastlines in Tasmania and Victoria, but that not all such areas that appear suitable are utilised. There have also, not surprisingly, been changes in the abundance of juveniles at sites sampled by Olsen in the 1940s and by our study in the 1990s. Indeed, as noted by Olsen (1984), his data indicate a decline in catch rates during the period that he sampled Pittwater and Port Sorrel, although no decline was apparent in his other primary sites at Port Arlington (Port Phillip Bay) and Georges Bay (Table 17).

Table 17. CPUE (sharks per trip between December and March) of juvenile school shark in four embayments, by year (CSIRO 1947-56 tag data)

Year	Port Phillip Bay		Port Sorell		Georges Bay		Pittwater	
	Mean	St. error	Mean	St. error	Mean	St. error	Mean	St. error
1947	123.6	37.6						
1948	64.5	33.5	52.8	12.3			38.5	17.6
1949	41.6	10.0	59.7	17.5			31.9	5.1
1950	126.2	37.5	33.3	11.6	11.0	1.7	18.4	5.2
1951	114.0	38.8	8.6	5.0	15.8	3.6	16.5	4.1
1952			15.8	9.1	5.5	2.5	10.3	2.6
1953			9.5	6.5	16.0	5.5	7.7	6.7
1954							4.0	

While direct comparisons are complicated by the different gears used there is no doubt that current catch rates at these sites are much lower than when Olsen started his work. We caught no school shark at Georges Bay while catch rates at Port Sorrel and in Port Phillip Bay were low, although set times by MAFRI at the latter site were relatively short. In a direct comparison of catch rates in Pittwater where we used the same gear (handlines) and fished the same location as Olsen we were unable to catch any school shark. However, as noted in FRDC 91/23 it is possible that changes in behaviour have accounted for some of these differences (Anon 1993). During a tag-recapture experiment in 1996 in Upper Pittwater to estimate population size, 100 0+ school shark were tagged and 18 subsequently recaptured (18%). During Olsen's tagging program from 1947-56, 1170 juvenile school shark were tagged in Pittwater; only 0.3% were recaptured at the same site compared to 4.2% recaptured from elsewhere. Results from Port Phillip Bay, Port Sorrel and, to a lesser extent, Georges Bay were similar (Table 12). While there are other explanations, this suggests that the population sizes at that time were much higher.

We attempted some order-of-magnitude calculations to see if the abundance levels of school shark pups we were recording in Tasmania and Victoria were sufficient to sustain the adult stock. We used our population estimate for Upper Pittwater together with relative indices of abundance (average gillnet catch x area of bay) for other sites at which pups occurred. By assuming that the relationship between population size and abundance index at Pittwater was the same at all other sites, we estimated annual pup numbers at known pupping sites in Tasmania as approx 10500, for a total area of approximately 330 km2. With an average litter size of 30, it would take only about 350 females to produce this number of pups. If we assume that the current stock size is around 9,000 tonnes total weight (a speculative best estimate), half are females, one third of these are mature, and one third breed every year, the current biomass of breeding females would be about 500 tonnes. At an average weight of 15 kg the number of females pupping each year would be about 33,000, and the number of pups about 1 million. Our estimates of 10,000 pups per year for known pupping areas in Tasmania seems trivial (1%) by comparison, and this would hold even if the present stock size was much smaller. Port Phillip and Westernport Bay have an area of approximately 2400 km2, more than seven times the area of known pupping grounds in Tasmania (although the pupping areas, particularly in Port Phillip Bay, may be relatively restricted in extent). On this basis, at best, the known pupping grounds in Victoria and Tasmania could be considered to produce a minor component (less than 10%) of the total pup production. However, it may also be that these areas are particularly favourable for the survival of school shark pups, in which case their value could be much higher.

Currently, there is considerable debate between scientists and some industry members about whether school shark pupping areas are restricted to Tasmania and Victoria. Prince (1996) hypothesises that the south-eastern pupping grounds are depleted and that recruitment is being maintained primarily from other (currently unidentified) areas throughout the species range. Some industry members believe that pupping also occurs in southern New South Wales and South Australia, notably around Beachport and Robe, the Coorong, south coast of Kangaroo Island and Yorke Peninsula, south-western Eyre Peninsula and the head of the Great Australian Bight (GAB) (Prince 1996). Olsen (1984) was unable to confirm the existence of pupping areas in South Australia; in recent discussions with Olsen, who has maintained an interest and involvement in the fishery, he is still of the same opinion. Our intention was to provide selected industry members with small-mesh nets to sample proposed pupping areas in South Australia identified through the 1994 Southern Shark pupping workshop (Prince 1996). Unfortunately, this proved largely impractical although limited sampling was carried out in the head of the GAB both off South Australia and Western Australia — no school shark pups were caught. We also sampled a large recreational fishing competition around the Coorong asking participants to retain any small school shark, but none were reported. In the absence of a dedicated sampling program in South Australia, we cannot exclude the possibility of pupping occurring there although our numerous inquiries and our (albeit limited) sampling carried out in this study provide little evidence to support it.

Another possibility is that the ‘missing’ pupping grounds are located along protected ocean beach environments in Victoria and Tasmania. Research cruises by MAFRI in the period 1973-76, and by CSIRO in 1994-96 have found pups in open coastal waters (Fig. 33), some of which (Ninety Mile Beach in Victoria, for instance), coincide with areas considered by industry to be pupping grounds. While the density of pups at these sites may be lower than in embayments and estuaries, the greater area they occupy may lead to an overall greater contribution to recruitment.

Very few gummy shark pups were caught in the Tasmanian sampling (this study and FRDC 91/23) although relatively high catch rates of gummy shark pups were caught at some sites in Port Phillip Bay and Westernport Bay in Victoria. The data are too limited to determine anything about specific pupping grounds for gummy shark. However, gummy shark were caught at more sites than school shark and had a higher total catch rate. Most of the gummy shark catch were fish of 700-1100 mm TL, mainly adolescent and mature fish. Stomach content analysis carried out on gummy shark in this study suggest that these larger fish are exploiting rich crustacean feeding grounds in inshore embayments and estuarine areas such as Pittwater. In contrast, adolescent and mature school shark were virtually absent from our catches in this study. While this could be a function of mesh selectivity, it would be expected that, if present, a proportion of larger sharks would be caught by rolling in the nets. Longlines set for sevengill shark also caught no large school shark.

One of the objectives of this study was to assess the feasibility of developing abundance or recruitment indices for new-born sharks. Gummy shark pups were not caught in sufficient numbers at any site to make this practical, while our results suggest that Upper Pittwater is the logical site to monitor 0+ school shark both in terms of catch rates and logistics. However, given the small area of this site, the small numbers of sharks involved and the inherent variability of the catches the value of such an index must be questioned. In addition, statistical analysis of our recruitment index from the seven years of sampling could detect no year trend in the data. While this might mean that recruitment at this site is stable it may also be a reflection of the inherent variability of the data masking any trend. Because school shark pups were not caught in sufficient numbers at sites other than Pittwater, we did not maintain a long enough time series to monitor numbers of larger juveniles elsewhere. Of the sites we sampled, Frederick Henry Bay would be a logical site to monitor both juvenile school and gummy sharks.

We initially used gillnets to sample juvenile sharks. However, as a result of the large bycatch of teleosts and the higher mortality of sharks in gillnets we subsequently switched to longlines. Of gummy sharks, 55% were alive on longlines compared to 21% in gillnets; for school shark these figures were 69% and 29%, respectively. While the capture of sharks on longlines depends on attraction to the bait and thus on whether they are actively feeding, the chances of capture by gillnet is also presumably higher when the sharks are actively searching for food and thus more likely to encounter the net.

7.2 Tagging Experiments

A comparison of the nylon-headed dart tags and Rototags used in this project suggests that Rototags have better retention qualities; this supports similar results from other studies (Davies and Joubert 1967; Carrier, 1985). However, for at least the first year of this work the dart tags were inserted into the muscle rather than being locked into the base of the fin rays of the first dorsal fin. Shedding rates are likely to be higher when these tags are inserted into the muscle. While the ‘mini tags’ were suitable for short-term tagging experiments on 0+ sharks no suitable tags were found which were externally visible and would be retained by the sharks for periods in excess of several years. The internal tags used by Olsen (1954) have good retention qualities but may be overlooked on recapture and also appear to cause higher tag mortality on 0+ sharks.

The recapture rate of both school and gummy sharks was higher from commercial rather than recreational fishers. Recreational gillnets are allowed in Tasmania and net fishing occurs in most inshore waters. Some designated shark nursery areas are closed to net fishing while in others fishing is allowed but school and gummy sharks cannot be retained (Williams and Schaap 1992). However, most recreational net fishers target reef and hard-bottom areas (Williams and Schaap 1992) which tend to have lower catch rates of juvenile school and gummy sharks (FRDC 91/23). Commercial fishing effort in some of the deeper embayments in south-east Tasmania is relatively high with a number of licensed net fishermen operating in these areas. The higher return rate of gummy relative to school shark by commercial fishers is probably because more large gummy shark were tagged; these larger fish are more mobile and would be immediately vulnerable to the commercial fishing gear.

Both the 1947-56 and 1991-97 tagging data show that the average distance moved between release and recapture increases with size and age for school shark (there were insufficient data to examine this effect for gummy shark). New-born school shark are essentially restricted to their inshore pupping grounds during their first summer, before moving into adjacent deeper water during winter. Generally, it is not until their third or fourth year that they move distances in excess of 100 nm.

Results from the 1947-56 and 1991-97 tagging suggest that school shark, on average, move bigger distances than gummy shark. This is what we might expect on eco-morphological grounds (Last and Stevens 1994). Data from both studies show no significant difference in the distances moved by male or female school sharks, while female gummy shark appear to move greater distances than males. This is probably a reflection of the larger number of mature gummy shark tagged compared to school shark. The distance moved increases with age and size of the shark and any differences between the sexes in distance travelled are likely to be associated with reproduction.

7.3 Stock Discrimination; Vertebral Microchemistry

Of all the elements analysed from the school shark vertebrae in this study, the Sr/Ca ratio is probably the most interesting. It is now universally regarded as an element ratio in bone structures of marine organisms that is closely linked to environment, and most commonly linked to physical factors such as water temperature and salinity. Sr/Ca ratio in the two school shark vertebrae (Fig. 25) converged strongly to a common level at the outer margin of the section (Point 4), which we interpret as a response to a common nursery area environment. This suggests that similar convergence on different mean concentrations may occur in other nursery areas, that would allow positive identification of nursery area of origin for larger, older individuals (based on analysing that portion of the vertebra laid down during the nursery area stage of development).

7.4 Growth Rates

The finding in this study that the growth rate of 0+ school shark in Pittwater (and possibly in Port Phillip Bay and Westernport Bay) has increased significantly over the last 40 years is of considerable importance. There has been a dramatic reduction in catch rates (presumably reflecting population numbers) in Pittwater over this period and it is tempting to link increased growth rates to a density-dependent change in population size. There is little evidence for density-dependent population change in elasmobranch stocks although some workers have postulated that such mechanisms are most likely to operate through changes in natural mortality or fecundity (Holden 1974; Wood et al. 1979). However, at this stage it is not possible to exclude other possible causative factors which might affect growth rate such as increases in water temperature in the area. Irrespective of the cause, if growth changes have also taken place on older year-classes a general increase in growth rate could have implications for the stock assessment process.

7.5 Diet

School shark

Olsen (1954) noted that the fish and cephalopod component was lower in the diet of 3–4 year old juvenile school shark (88%) than in adults (98%), and that juveniles supplemented their diet with annelids, molluscs, and crustaceans. The diet of small sharks which he examined in Pittwater included sandworms, crabs, shrimps, small fish, and cephalopods. Walker (1997 in review) reported smaller quantities of cephalopods (notably *Octopus* spp.) and fish (notably *Thyrsites atun*) in small sharks (less than 900 mm TL) than in larger sharks. In this study, the most notable difference in the diet of the first three age-classes was the decline in importance of crustaceans with increasing age. In 0+ sharks, fish, cephalopods and crustaceans were of similar importance while in 2+ sharks crustaceans were a negligible component of the diet. The cephalopod component in the diet also declined with increasing age-class but this was mainly a reflection of relatively high predation of 0+ sharks on the inshore loliginid *Loliola noctiluca* in Pittwater.

Gummy shark

In our study of gummy shark diet we found that crustaceans were the dominant prey group in all age-classes of sharks we examined from Pittwater, Frederick Henry and Storm Bay. Teleosts, cephalopods and sipunculids became more important in the larger sharks from Frederick Henry and Storm Bay. *Octopus* spp., in particular, increased in importance in the diet of larger sharks taken from the more offshore and exposed Frederick Henry, and in particular, Storm Bay. Our sample of 0+ sharks was limited, but *Paridotea* spp. contributed most to their diet. Walker (1997 in review) examined the stomach contents of 497 gummy shark caught mainly on the continental shelf off southern Victoria and in Bass Strait. He found that cephalopods contributed most weight (36%) to the stomach contents of these sharks with crustaceans contributing 24%, teleosts 11% and sipunculids 1% by weight. The larger sharks tended to feed on bigger prey, notably *Octopus* spp., *Jasus novaehollandiae, Leptomithrax gaimardii* and *Sepioteuthis australis.* Smaller species of prey such as *Macropipus corrugatus* and *Themiste dehamata* were more frequently preyed on by smaller sharks. Results from these two studies suggest that larger gummy shark tend to take larger prey such as octopus which are more available in deeper inshore areas. However, large gummy shark also utilise shallow inshore estuarine areas such as Pittwater as rich feeding grounds for crustaceans such as *Paragrapsis.*

7.6 Predation Studies

Natural mortality is an important parameter in stock assessment models but is difficult to estimate, and it's value is often assumed. For viviparous school and gummy sharks natural mortality is assumed to be highest on the youngest age-class. The main causes of natural mortality are presumably competition and predation. New-born school sharks are about 300 mm TL at birth; in the Tasmanian inshore pupping grounds they would have few natural predators. The most likely predator is the broadnose sevengill shark and we selectively fished for these sharks in the school shark pupping grounds of Upper Pittwater and Norfolk Bay. School shark, gummy shark and *Squalus* were identified from sevengill stomachs but no school or gummy shark pups were found, and all school sharks identified from the stomachs had been predated while on the longline. Our results show that elasmobranchs were the most frequent prey occurring in 80% of the stomachs of broadnose sevengill shark that we captured in two Tasmanian school shark nursery areas. Sharks and rays were represented in about equal proportions with urolophids the most frequent of identifiable elasmobranchs. Chondrichthyans were also the major prey group in dietary studies of this shark from South Africa (Ebert 1991) and triakid sharks (the family to which the school and gummy shark belong) were among the most frequent chondrichthyan prey. Triakids were also important prey of sevengill sharks examined from California and Uruguay (Ebert 1989, Praderi 1985).

8. BENEFITS

The successful development of recruitment indices that are independent of the fishery is of great potential value to the Southern Shark Fishery, as a means of monitoring the health of the stocks. The index that we have developed for 0+ school shark in Pittwater appears to indicate that recruitment there is currently stable. However, it is possible that the inherent variability of the data may be masking any trends in abundance. The data need to be used with caution as pupping areas in Tasmania and Victoria are clearly depleted compared with levels observed in the 1940s and may no longer be representative of the stock. Our data on pup abundance in Victoria and Tasmania over the time period of this study will certainly provide a level against which abundance can be measured in the future.

The apparently low numbers of school and gummy shark pups in any of the areas sampled in this study suggest that the current main pupping areas have yet to be identified. Since these are almost certainly in inshore waters, any future management decisions affecting these areas could have important consequences for shark recruitment and this should be taken into consideration.

Information provided by this study on the current distribution of different age-classes of school and gummy sharks in inshore waters of Victoria and Tasmania, and their capture rates by commercial and recreational fishers, can be used to refine the present regulations on shark nursery areas. Greater protection of juveniles will result in enhanced recruitment to the stock which will assist in stock recovery and result in more economically efficient utilisation of the resource.

This study has generated considerable data on movement rates of school and gummy sharks from tagging, and has identified changes in growth rate with time which may be a density-dependent response to reduced population size. This information will be incorporated in the current spatial and age-structured population models. Refining stock assessments of Southern Shark have obvious benefits in terms of the sustainability of the SSF.

9. INTELLECTUAL PROPERTY

No commercial intellectual property arose from this work

10. FURTHER DEVELOPMENT

One interpretation of the current low catch rates of pups is that known south-eastern pupping grounds are depleted, that numbers there are not sufficient to support the stock, and that the stock must be sustained by recruits from elsewhere. In 1994, an industry questionnaire identified a number of areas thought to be important school shark pupping grounds, including locations in South Australia such as the head of the Great Australian Bight, the Coorong and around Kangaroo Island. During this study some limited sampling was carried out in these areas but no pups were caught. Another possibility is that pupping occurs at low levels over a large area of inshore habitat in Tasmania and Victoria, such as along ocean beaches, in depths from the surfline out to about 25 m. While the density of pups may be much lower than in estuaries and embayments, the much larger area would provide a larger overall biomass.

Future research and management of school shark nursery areas is largely dependant on determining which of the three following general areas contribute the greatest biomass of pups and juveniles to the adult stock: (1) semi-enclosed estuaries and embayments in Tasmania and Victoria, such as Port Phillip Bay, Westernport Bay and Pittwater (2) other inshore habitats in Victoria and Tasmania, such as ocean beaches, from the surfline to about 25 m depth (3) areas in South Australia such as the Coorong, and Western Australia (head of the Great Australian Bight).

Until this has been determined, the validity of recruitment monitoring sites for 0-3+ age-classes set up in Victorian and Tasmanian estuarine embayments may be questionable, as may management measures protecting current designated nursery areas. SharkMAC 25 noted that the States had agreed to further area closures if these areas could be proven to be pupping grounds. Furthermore, detailed studies of particular pupping and nursery grounds may not be justified unless they can be shown to be critically important areas.

Future work should examine the hypothesis that ocean beach habitats and/or certain inshore habitats in South Australia are important pupping grounds for school shark. If pups are found in these areas then their distribution should be mapped and the contribution of the different pupping habitats quantified. The use of microprobe techniques could play an important role in this work.

11. STAFF

John Stevens	CSIRO CSOF7
Grant West	CSIRO CSOF5
Bruce Barker	CSIRO CSOF3
Stephanie Davenport	CSIRO CSOF5
Joel Scott	CSIRO CSOF3
Mark Green	CSIRO CSOF3
Terry Walker	MAFRI Principal Fisheries Scientist
Lauren Brown	MAFRI Fisheries Scientist
Natalie Bridge	MAFRI Technical Officer

12. FINAL COST

XXX HAVE TO GET FIGS FROM GREG ON THE FINAL BUDGET BREAKDOWN

13. ACKNOWLEDGEMENTS

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15. APPENDICES

15.1 Appendix A

15.2 Appendix B

15.3 Appendix C

Tag-recapture model used to estimate the number of school shark pups in Upper Pittwater