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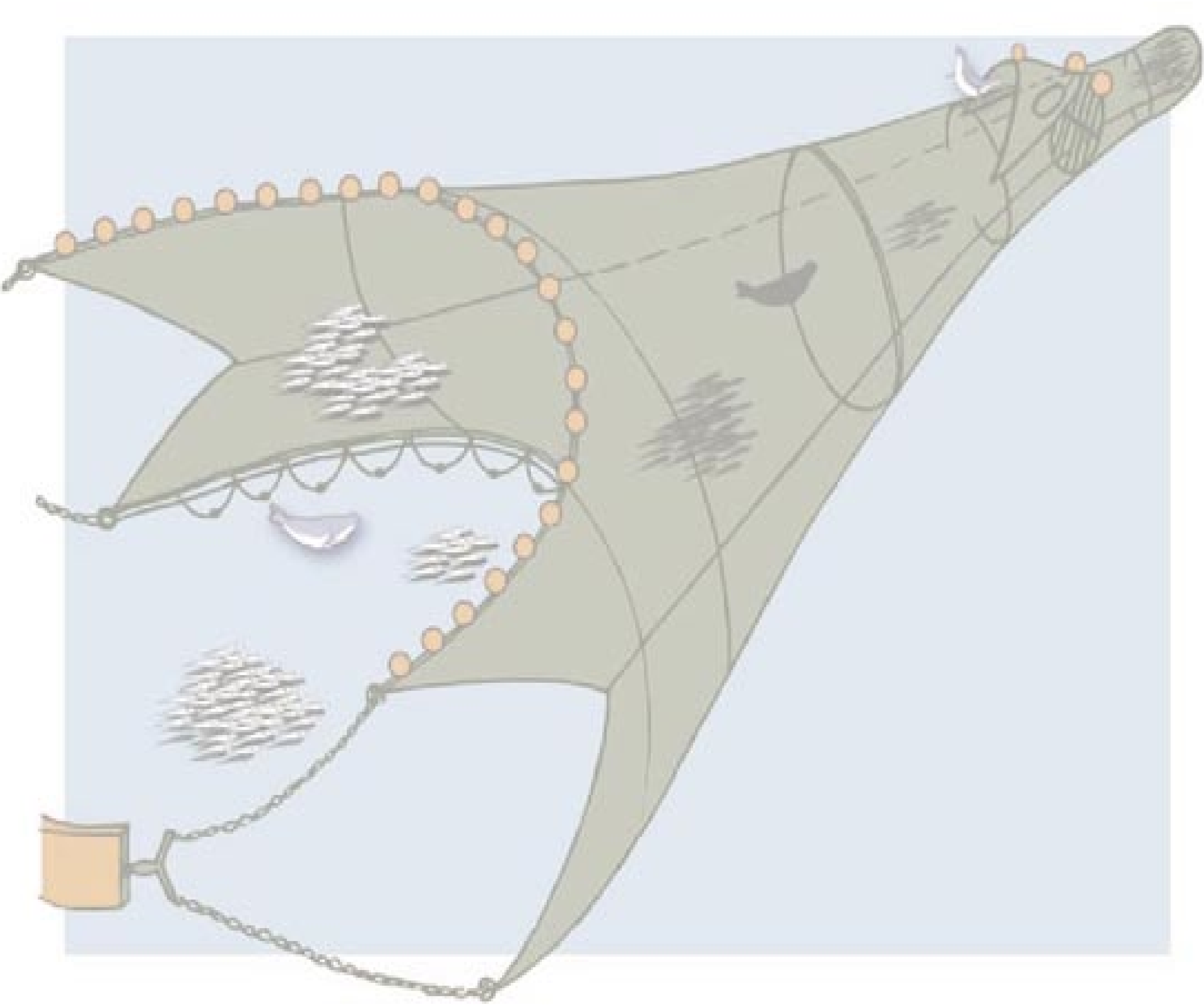
Seal-fishery interactions in the winter blue grenadier fishery

Assessment of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers



Assessment of seal–fishery interactions in the winter blue grenadier fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers

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2001/008	Assessment of seal-fishery interactions in the winter blue grenadier fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers

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OBJECTIVES

1. To improve the effectiveness of Seal Exclusion Devices (SEDs) in blue grenadier trawl nets in reducing seal mortalities and minimising losses of fish.
2. To assess the effectiveness of fishing techniques aimed at minimising seal bycatch.
3. To gather biological information from all seal fatalities.
4. To achieve full observer coverage of freezer-trawler activities during the 2001 and 2002 winter grenadier fishery and monitor seal numbers around vessels and all seal-trawl interactions.
5. To gather information on seal movement/residence-time in the winter grenadier fishery.

NON-TECHNICAL SUMMARY

Background and resourcing: The winter trawl fishery for blue grenadier off west Tasmania is now the most valuable in the South East Fishery. Freezer trawlers entered this fishery in 1997 and seal bycatch by three such vessels in 1999 caused the observed deaths of an estimated 83 seals. Under the *Environment Protection and Biodiversity Act 1999* it is the responsibility of fishers to operate in a manner that will minimise the risk of such accidental bycatch. The 1999 seal deaths prompted the development of a program to mitigate seal bycatch in this fishery, the principal components of which were a Code of Fishing Practice aimed at avoiding seals and conducting trials of Seal Exclusion Devices (SEDs) in trawl nets. During the 2000 fishing season the program was funded by the fishing companies operating the freezer trawlers, Petuna/Sealord and OceanFresh/Simunovich, under a joint venture agreement. These fishing companies, the Fisheries Research and Development Corporation (FRDC) and the Bureau of Rural Sciences (BRS) funded the program during the 2001 to 2003 seasons. Fishing operations were conducted under a permit issued by the Australian Fisheries Management Authority (AFMA) and the Department of the Environment and Heritage (previously Environment Australia, EA) that limited seal deaths to 30 a season, i.e., two permits issued, one for each of the vessels operating in the blue grenadier sector of the South East Trawl Fishery, that allowed 15 seal deaths per vessel. However, seal bycatch during SED trials was not debited against this total. Permit conditions for the winter blue grenadier fishery also stipulated full and independent onboard observer coverage during 2000 to 2002. SED trials were conducted on the only two large freezer trawlers in the fishery during 2000 to 2003, the *FV Aoraki* and *FV Ocean Dawn.*

Code of Fishing Practice: Major components of the Code of Fishing Practice were: actively steaming away from seals before shooting the trawl net; removing meshed fish (‘stickers’) from the net prior to use; and no discarding of unwanted fish or offal on the fishing grounds. The fishing permit limit on seal deaths prevented quantitative assessment of the Code’s components. However, comparison between fisheries data for the 1999 season and equivalent data for the 2000 to 2003 seasons indicated that adopting the Code had halved the incidence of seal bycatch per trawl shot.

2000 SED trials: The initial SED design used in 2000 had much in common with the Turtle Exclusion Devices used in prawn fisheries, with a square, backward-sloping exclusion grid and a backward facing escape hatch on top of the net sleeve. Fish loss of blue grenadier via the escape hatch was significant. Forty out of 453 trawl shots contained seal bycatch. The incidence of seal bycatch in nets with a SED was about double that for nets without a SED, suggesting that seals were entering the net via the escape hatch. The

survival rate for seal bycatch in SED nets was 66%, compared with 22% for nets without a SED. Seal bycatch in bottom trawl nets was low compared with that for the larger midwater trawl nets.

2001 SED trials: Trials were conducted with several SED designs in 2001. All had forward facing escape hatches to minimise fish loss and larger square grids. Two basic design features were either a top mounted, or a bottom mounted, escape hatch. Closed SEDs ('grid-only') were also used to assess if denying seal access to the net's codend sufficed to reduce seal bycatch mortality. SED trials were confined to midwater trawls from 2001 onwards. Seal numbers on the fishing grounds were comparatively low and only 26/511 trawl shots contained seal bycatch. The bycatch survival rate (8%) was also low. The incidence of seal bycatch in SED nets was again about double that for nets without a SED. Fish loss via open SED escape hatches appeared to be minimal, but problems were experienced with fish building-up and blocking the SED grid.

2002 SED trials: One vessel conducted trials with a 'top-hatch' SED and the other vessel with a 'bottom-hatch' SED throughout the 2002 season. Substantial improvements to the SED grid structure, notably a threefold increase in area and a near-circular shape, were made for both designs. Seal numbers on the fishing grounds were greater than in 2001 and 41/557 trawl shots contained seal bycatch. The bycatch survival rate was moderate (24%). With the 'bottom-hatch' SED seal bycatch in nets with a SED (12.3%) was again greater than that for nets without a SED (3.9%). With the 'top-hatch' SED the incidence of seal bycatch in nets with a SED (3.1%) was much lower than that for nets without a SED (20.7%), indicating that this improved design was successfully expelling seals and denying seals access to the net via the escape hatch.

2003 SED trials: One vessel again used the 'top-hatch' SED design from the 2002 trials. The other vessel used a closed 'grid-only' SED, as the 2001 results from this design were ambiguous. Seal numbers on the fishing grounds were comparatively low and only 19/483 trawl shots contained seal bycatch. Bycatch survival was moderate (32%). SED results were ambiguous because of the low incidence of seal bycatch. Although the 'top-hatch' SED again had a low incidence of seal bycatch (3.0%), the overall incidence was also low (3.9%). There was little difference between the seal bycatch of nets with or without a closed SED.

Overall SED performance: Whereas general additive model (GAM) analyses clearly showed that the 2002 'top-hatch' SED had a significantly lower occurrence of seal bycatch than other SED designs and nets without a SED, SED performance remains largely unquantified. The actual total numbers of seals interacting with the trawl net and seals successfully exiting the net via the SED escape hatch during this study are unknown because underwater video footage was limited. Many more direct observations using improved underwater camera equipment are needed to quantify such interactions. Obtaining significant results on SED performance by comparing replicate sets of trawl shots with and without a SED is confounded by the low level of seal bycatch and the complex suite of factors influencing seal interactions with the trawl net. The use of SEDs clearly enhances the survival rates of seal bycatch by preventing entry into a net's codend where most seal drownings probably occur. An overall (2000 to 2003) seal bycatch survival rate of 48% occurred in midwater nets with an open SED as against zero for nets without a SED. The *FV Aoraki* will conduct more trials of the 'top-hatch' SED in 2004, as this design merits further appraisal.

Factors affecting seal bycatch: Comparative seal abundance on the fishing grounds, as determined from observer counts and bycatch incidence, varied from year to year. GAM analyses factored in this variation and found the following parameters to significantly affect the probability of seal bycatch: trawl shot position (latitude and proximity to seal colonies or haul-out sites); time of day (seal bycatch peaked during the late morning); and catch composition (seal bycatch increased with higher spotted warehou bycatch). Other factors influencing seal counts around the trawlers included vessel speed, number of vessels within 2 nautical miles, swell height and visibility.

Net entry by seals: Mechanical problems were experienced with underwater camera use throughout this project, largely because of the depths fished and the rigours of commercial fishing activities. Hence direct video observations of seal behaviour were fragmented. Surface counts of seals indicated most net foraging to occur when a trawl was being hauled. However, limited video footage showed that some seals entered the net when it was being shot, despite the seal avoidance aspects of the Code of Fishing Practice. If a seal became entrapped soon after the net was shot, it would certainly drown. However, a large proportion of seals that were caught during hauling survived. More direct underwater observations with better camera equipment are needed to more fully understand where and when seals enter trawl nets.

Seal biology: All bycatch seals unambiguously identified were Australian fur seals. The great majority (94%) of seals caught were males. Most age classes contributed to the seal bycatch, including juveniles (2–4 years), subadults (5–7 years) and adult males (8+ years), with the majority of bycatch being composed of sub-adult males. Stomach analyses showed bycatch seals to have been foraging almost exclusively on trawl caught fish.

Seal movements: A novel, crane-operated dip-net was used to capture adult seals prior to attaching satellite tags. Tag-life varied widely, but all tagged seals actively foraged on the blue grenadier fishing grounds during the fishing season. Seals that hauled-out at Reid Rocks or Hibbs Point returned straight to the fishing grounds after resting. At the end of the fishing season seals generally dispersed southwards. The tracking study demonstrated the habitual nature of seals foraging on the fishing grounds. The seal population interacting with the fishery is probably comparatively small and intransient during the fishing season.

OUTCOMES ACHIEVED

Introducing a Code of Fishing Practice aimed at avoiding seals appeared to halve the incidence of seal bycatch in this fishery. In SED trials, the problems of fish-loss via the SED escape hatch and net blockage via the SED grid were solved by changes in SED design. Although the effectiveness of most SED designs in reducing seal bycatch could not be quantified, the forward facing, ‘top-hatch’ SED design used in 2002 significantly lowered the incidence of seal bycatch in midwater trawl nets. Trials with this design are continuing. Some of the major factors that influence the probability of seal bycatch occurring in this fishery were delineated. Biological sampling of seal fatalities showed the dominant seal bycatch to be sub-adult male Australian fur seals habituated to foraging from trawl nets. Seal tracking studies developed a novel method of tagging seals at sea and indicated that a comparatively small and intransient sub-set of their population interacted with this fishery.

The following recommendations were made *in the winter grenadier fishery:* use open, forward-facing, ‘top-hatch’ SEDs (or a more effective design if one is developed) in all midwater net shots (or as directed for research purposes); continue the Code of Fishing Practice; continue the shot-by-shot recording of seal bycatch in the SEF1 logbook and maintain a level of scientific observer coverage and biological data collection; and, continue trials of the ‘top-hatch’ SED and gather more information by using underwater filming on the timing and depth–frequency of net entry by seals, and the circumstances of net entry that place seals at risk.

The following recommendations were made *in the rest of the SEF trawl fleet:* Priority should be given to assessing the nature and extent of seal-fishery activities across the fishery; The Code of Fishing Practice should be followed where practicable; and, At this juncture, SED use should be confined to large midwater trawl nets in areas where seals are known to be common, as more assessment of SED effectiveness is needed before extending their usage.

Project results also assisted the goal of obtaining accreditation for the SEF under a Section 33 determination under this Act.

KEYWORDS: Blue grenadier trawl fishery, seal bycatch mitigation, Seal Exclusion Devices, Australian fur seal biology

ACKNOWLEDGEMENTS

The joint-venture companies Petuna/Sealord and Ocean Fresh/Simunovich, respectively operating the *FV Aoraki* and *FV Ocean Dawn* invested a considerable amount of time and money in this seal bycatch mitigation project. Both vessels should be congratulated for their cooperation. The skippers and crews responded admirably to the needs of this project. The time consuming insertion and removal of SEDs in nets, the repair and modification of SEDs and the rigging and operation of underwater camera gear were carried out efficiently and congenially midst the many demands of commercial fishing activities. The accommodation and hospitality afforded scientists and observers were of a high order. The vessels' crews are thanked for their considerable assistance, in particular skippers Gary Courtney, Keith Fowler, Lance Heger, Isabella Lang, Arve Lauten, Jostein Sando, Arve Skjong and Egil Smenes.

The following are also thanked for their contributions to the project: Les Scott and Gerry Geen who co-ordinated the joint venture involvement and input; Bob Stanley and Jack Woods who co-ordinated and carried out onboard observer duties; the shore-to-ship co-ordinators Tony Bewley, Tim Hess and Angus Nichols; Roger Kirkwood for assisting in satellite tagging operations; Steve Eayrs, Ian Knuckey and Crispian Ashby for facilitating and assisting underwater camera work; and James Larcombe and Patty Hobsbawn for creating some of this report's figures. AGSO kindly provided the image used as Figure 1 and Richard Parker the SED illustrations used on the cover and as Figure 25.

Petuna/Sealord and Ocean Fresh/Simunovich funded all work in 2000. The 2001 to 2003 work was funded by this joint venture, the Fisheries Research and Development Corporation and the Bureau of Rural Sciences.

1. BACKGROUND

Interactions between seals and commercial fishing operations are a common occurrence in temperate and polar latitudes around the globe (e.g. Pemberton *et al.* 1994; Wickens 1996; Read and Wade 2000; Baird 2001; Bjorge *et al.* 2002). Operational interactions occur in a great variety of capture fisheries, as well as with aquaculture facilities. For example, Kirkwood *et al.* (1992) recorded operational interactions between fur-seals and purse seine, rock lobster, gill net, drop line, troll and trawl fisheries in Tasmanian waters. The (Tasmanian) Marine and Marine Industries Council (2002) and Shaughnessy *et al.* (2003) recently reviewed operational interactions between pinnipeds and Australian fisheries. Such interactions may result in seal mortality.

In Australian waters, seals and other marine mammals were protected in Commonwealth waters under the *National Parks and Wildlife Conservation Act 1975*. The *Endangered Species Protection Act 1992* provided additional protection, but no Australian seal species were listed as either endangered or vulnerable under this Act. These two Acts were repealed in July 2000 when the *Environment Protection and Biodiversity Conservation Act 1999*, came into force. Under this new Commonwealth legislation it is the responsibility of fishers to operate in a manner that will minimise the risk of accidental bycatch, and to release and return to the sea uninjured any live mammals taken. All incidents involving animals alive or dead must be reported to the Secretary, Department of the Environment and Heritage (previously Environment Australia, EA). The bycatch of any marine mammal during a licensed fishing operation is legal, provided the management plan for the fishery is accredited under a Section 33 determination, (EPBC Act) and such bycatch is reported to the appropriate authority within the time specified. Thus, an unreported seal bycatch in a licensed Commonwealth fishery is currently an offence under the Act. At the time this project commenced, no Commonwealth fisheries were accredited under the Act. Note that seals and other marine mammals are also protected in State coastal waters under relevant State legislation.

Three species of seal breed on the southern Australia coast—the Australian sealion (*Neophoca cinerea*), the Australian fur seal (*Arctocephalus pusillus doriferus*) and New Zealand fur seal (*A. forsteri*). Shaughnessy (1999) summarised their distribution ranges. The latter two species commonly occur on continental shelf and upper-slope fishing grounds within the South East Fishery (SEF). Australian populations of these two species have been recovering from over-harvesting (*note: commercial sealing ceased in Australia in 1949*). If they follow the pattern of recovering fur seal populations elsewhere, they are likely to reach pre-exploitation numbers within the next few decades (Goldsworthy *et al.* 2003). With rising seal numbers being accompanied by a gradual expansion in commercial fishing activity, interactions between fur seals and the Australian fishing industry are becoming more frequent. Because of the polygamous breeding behaviour of fur seals, large numbers of non-breeding males range considerable distances from established seal colonies. Female Australian fur seals also undertake foraging trips ranging up to 550 km distance from their colony (Littnan and Arnould 2002).

Until comparatively recently, direct interactions in the SEF were more commonly reported in hook and line fisheries, particularly drop-lining and long-lining. In these fisheries seals commonly ‘steal’ both bait and catch, but seal bycatch by hooking is rare. However, the development of southern trawl grounds has seen increasing interactions between seals and trawlers and seals are periodically caught in trawl nets. The Action Plan for Australian Seals (Shaughnessy 1999) reviewed available information on Australian seals and threats posed by commercial fishing, including by-catch and entanglement in discarded fishing gear. Circumstantial evidence indicated that seals had become habituated to feeding around trawlers. As well as ingesting non-commercial fish discards from trawlers, seals also attempt to take fish from the trawl net when it is being hauled.

Although Shaughnessy and Davenport (1996) described the capture of fur-seals during research trawling, the levels of fur-seal bycatch experienced in the SEF trawl fishery were unverified until the advent of an Integrated Scientific Monitoring Program (ISMP) in 1993 that regularly placed scientific observers onboard vessels. Whereas the primary aim of this program is to gather information on catch composition and discarding levels for all SEF fish species, some details of non-fish bycatch are also recorded. In 2001, following increasing concern about seal bycatch (see below), the Australian Fisheries Management Authority (AFMA) initiated an analysis of ISMP data to estimate the number of seals caught. This analysis found annual seal bycatch rates by SEF trawlers from 1993 to mid-2001 to vary greatly, with an estimated average of about 720 seals per year being caught across the fishery (Knuckey *et al.* 2002), of which about 490 drowned. This catch-rate equated to about one seal for every 50 trawl shots (i.e. gear operation), or 0.02 seals per shot. The SEF fleet from which these estimates were derived is comprised of so-called ‘wet’ boats, vessels with limited onboard processing/freezing capability that typically undergo comparatively short (<1 to 6 days) fishing trips and supply fresh chilled fish to market.

With the decline in SEF orange roughy (*Hoplostethus atlanticus*) populations, blue grenadier (*Macruronus novaezelandiae*) landings now comprise the highest volume of any species in the fishery. Blue grenadier aggregate to spawn off the west coast of Tasmania during winter (June–August) and most of the SEF catch is now taken from this fishery. Before 1997 landings from this spawning fishery were to some extent constrained by marketing requirements, as blue grenadier is a comparatively soft-fleshed fish needing careful handling after capture to retain marketable quality. New Zealand has a large blue grenadier (hoki) fishery, with the bulk of the catch being taken by ‘factory’ or ‘freezer’ trawlers that process the catch onboard immediately after capture. Since 1997, two or three of these vessels have fished in the winter grenadier fishery via joint ventures between Australian and New Zealand fishing companies. These vessels typically remain at sea for much longer periods (3–5 weeks) than ‘wet’ boats and seals appear to become habituated to feeding around them during fishing trips.

In 1999, the incidental captures of 87 fur-seals (averaging of 0.131 seals per trawl shot) and consequent observed death of an estimated 83 seals by the three freezer-trawlers in the fishery focussed attention on the seal bycatch problem. Following discussions between Environment Australia, AFMA and the fishing companies responsible for these vessels (Petuna/Sealord and Ocean Fresh/Simunovich) it was agreed that a pilot project centering on researching methods of reducing seal bycatch levels would take place in the 2000 winter grenadier fishery. It should be noted that industry agreed to fully fund research in 2000 (about A$160,000), but the onboard observer and research programs were administered, conducted and reported independently from these companies to comply with EA and AFMA requirements. It was further agreed that the conditions of the fishing permit would limit seal deaths to a maximum of 15 per vessel (30 overall) during the winter grenadier fishery. If these conditional limits were reached, the vessels concerned would cease fishing. However, an integral part of the research program was determining the effectiveness of Seal Exclusion Devices (SEDs) and EA agreed to issue scientific permits to cover periods when the vessels were actively experimenting with SEDs or other research methods. Any seals killed during the periods of these scientific experiments would not be debited against the 15 seal catch limit. All seal bycatch (alive or dead) had to be formally reported to EA and AFMA within 24 hours of the time of capture.

The initial SED design was based on the Sea Lion Exclusion Device (SLED) being developed in the New Zealand midwater trawl fishery for squid around the Auckland and Campbell Islands, where bycatch of the threatened Hooker’s sea lion (*Phocarctos hookeri*) constituted a major management problem (Woodley and Lavigne 1993). The New Zealand fishing industry has been actively using SLEDS in this fishery since 1997 (Wilkinson *et al.* 2003). A marine mammal scientist (Martin Cawthorn) involved in this SLED development was employed to oversee the initial SED trials in the Australian winter grenadier fishery.

Two freezer-trawlers (the *FV Aoraki* and *FV Ocean Dawn*) operated in the 2000 winter fishery. Initial results from the pilot project indicated that the use of modified fishing practices and SEDs were potentially effective tools for reducing seal bycatch mortality. The Fisheries Research and Development Corporation (FRDC) and industry then provided funding to conduct further studies in the 2001 and 2002 winter grenadier seasons, with the same two vessels trialling SEDs and collecting data. Following the development of a promising SED design, these vessels conducted further trials during the 2003 winter, with additional funding being provided by FRDC and industry. This report describes the results obtained during all four (2000 to 2003) winters.

The research program was approved by the CSIRO Sustainable Ecosystems Animal Ethics Committee.

2. NEED

With the continuing recovery in the size of Australian-based fur seal populations post-sealing, a corresponding increase in seal interactions with domestic fishing vessels is occurring and will continue. There is an urgent need to develop effective seal bycatch prevention procedures to prevent fishing operations from being severely curtailed, or closed down, under the *Environment Protection and Biodiversity Conservation Act 1999*.

Following the 1999 winter blue grenadier season, incidental seal mortalities emerged as a major issue that threatened the continuation of this fishery; at least that part of the fishery harvested by factory trawlers. These trawlers had successfully developed the fishery, increasing the total grenadier catch from about 3000 t in 1996 to over 9000 t in 1999. The processed value of the factory trawler catch is now around $20 million per year (ASIC 2003) at first sale. The seal deaths in 1999 resulted in significant pressure from some environmental groups to prevent factory trawlers access to this fishery in 2000. This action would have caused significant loss of income in this sector and possibly jeopardised the future participation of factory trawlers in the fishery. There is a strong need for such vessels to demonstrate that seal bycatch can be reduced by adopting appropriate fishing procedures and gears.

It is also likely that pressures will be brought to bear on the ‘wet boats’ fishing for blue grenadier and possibly the rest of the SEF trawl fleet to take measures to reduce incidental seal captures. The study by Knuckey *et al.* (2002) indicated seal bycatch to occur virtually across the whole multi-species trawl fishery. Some of the results of the development and testing of SEDs and other mitigation measures by the factory trawlers in the targeted ‘single-species’ fishery under this project may be transferable to other vessel operators in the wider multi-species fishery, helping them to avoid many potential operational problems and costs. Increasing the effectiveness of SEDs in both reducing seal mortalities and minimising fish losses would be an important step in helping to gain wider industry acceptance of the potential use of these devices.

3. OBJECTIVES

1. To improve the effectiveness of Seal Exclusion Devices (SEDs) in blue grenadier trawl nets in reducing seal mortalities and minimising losses of fish.
2. To assess the effectiveness of fishing techniques aimed at minimising seal bycatch.
3. To gather biological information from all seal fatalities.
4. To achieve full observer coverage of freezer-trawler activities during the 2001 and 2002 winter grenadier fishery and monitor seal numbers around vessels and all seal-trawl interactions.
5. To gather information on seal movement/residence-time in the winter grenadier fishery.

The above objectives apply to the two years (2001 and 2002) in which substantial FRDC and operator funding was provided. In 2000, the primary objective was to assess the potential usefulness of SEDs in reducing seal bycatch in this fishery, but objectives 2, 3 and 4 above were also pursued. In 2003, the major objectives were to: (a) further trial the most promising SED design; (b) further trial the use of only a grid to prevent seal access to the cod-end; (c) gather further information on seal movement/residence-time in the fishery; and (d) make further observations on when/how seals entered the trawl net.

4. GENERAL INFORMATION, DATA COLLECTION AND METHODOLOGY

The same two vessels, the *FV Aoraki* and *FV Ocean Dawn*, were used for research and monitoring purposes throughout this project (2000–2003). Both are stern trawlers with onboard fish processing and freezing facilities and a fish-meal plant to convert unwanted bycatch and waste from the processing deck. The *Aoraki* has a length of 69.5 m and 15.5 m beam. *Ocean Dawn's* respective dimensions are 64.0 m and 13.0 m.

Both vessels had full independent onboard observer coverage in the 2000, 2001 and 2002 seasons. In 2003, only partial (21% of vessel-days fished) observer coverage was considered to be necessary.

4.1. Fishing practices

Spawning blue grenadier aggregate off western Tasmania during June to early September, with most spawning occurring north of Macquarie Harbour. The continental shelf in this area abuts several canyons running down the slope (Fig. 1). The upper reaches of these canyons are spawning sites favoured by grenadier. Adults and spawners typically exhibit diurnal migration, rising into the water column at night and staying close to the bottom, mainly in depths between 300 m and 600 m, during the day. Thus, both bottom and midwater trawls were used. Whereas the overall use of each gear type was similar across the 2000 to 2002 seasons, bottom nets were used more frequently at the start and end of a season. Midwater shots comprised the bulk (84%) of 2003 shots. In general, mid-water trawls were more frequently fished in the water column during darkness, but were usually fished very close to the bottom during daylight hours. In general, the start and end of the fishing season were dominated by longer, more speculative trawl shots and the middle of the season (when spawning biomass peaked) by shorter targeted shots. Bottom trawl net types included a 'Selstar' and an 'Alfredo 3+', with footropes ranging from 22.4 to 45.8 m and headropes from 36.5 to 61.6 m. Midwater trawl net types included 'Motuekas', with head/foot-ropes ranging from 157.7 to 223.5 m. Codend mesh sizes were 100–103 mm.

The optimum daily production for each vessel was around 30 t of processed product. Hence, the daily catch target was around 80 to 100 t of fish. To maintain fish quality and a steady input to the processing deck, shots containing >30 t were avoided when possible. Net monitoring devices such as catch sensors were used to estimate the tonnage in the net. The number of shots per day (range 1 to 7) and the duration of shots (range 5 to 570 minutes) largely reflected comparative fish abundance and/or availability. The spawning biomass generally peaked in July, during which time large acoustic 'marks' could be targeted and fewer and shorter trawl shots were needed to catch the optimum tonnage. At the start and end of the spawning season 'marks' were fewer and many trawl shots were speculative hoping to catch dispersed fish. A few very long (>8 hr) shots occurred when a vessel was processing fish. When fish were abundant, fishing operations would cease until most of the day's catch had been processed.

For each trawl shot the following details were recorded on AFMA SEF1 logbook sheets: date, net-type, position – start/finish, time – start/finish, depth, shot validity, and estimated catch weights by species. Shot time/position details were also duplicated on standardized data sheets by the onboard observers to facilitate cross-referencing, with the following information being added: trawl speed, hauling rate, SED use, SED type, underwater camera use, seal numbers around vessel at shot start/finish and the number/proximity of other vessels, together with details of any seal bycatch. For each voyage, shots were sequentially numbered to further facilitate cross-referencing.

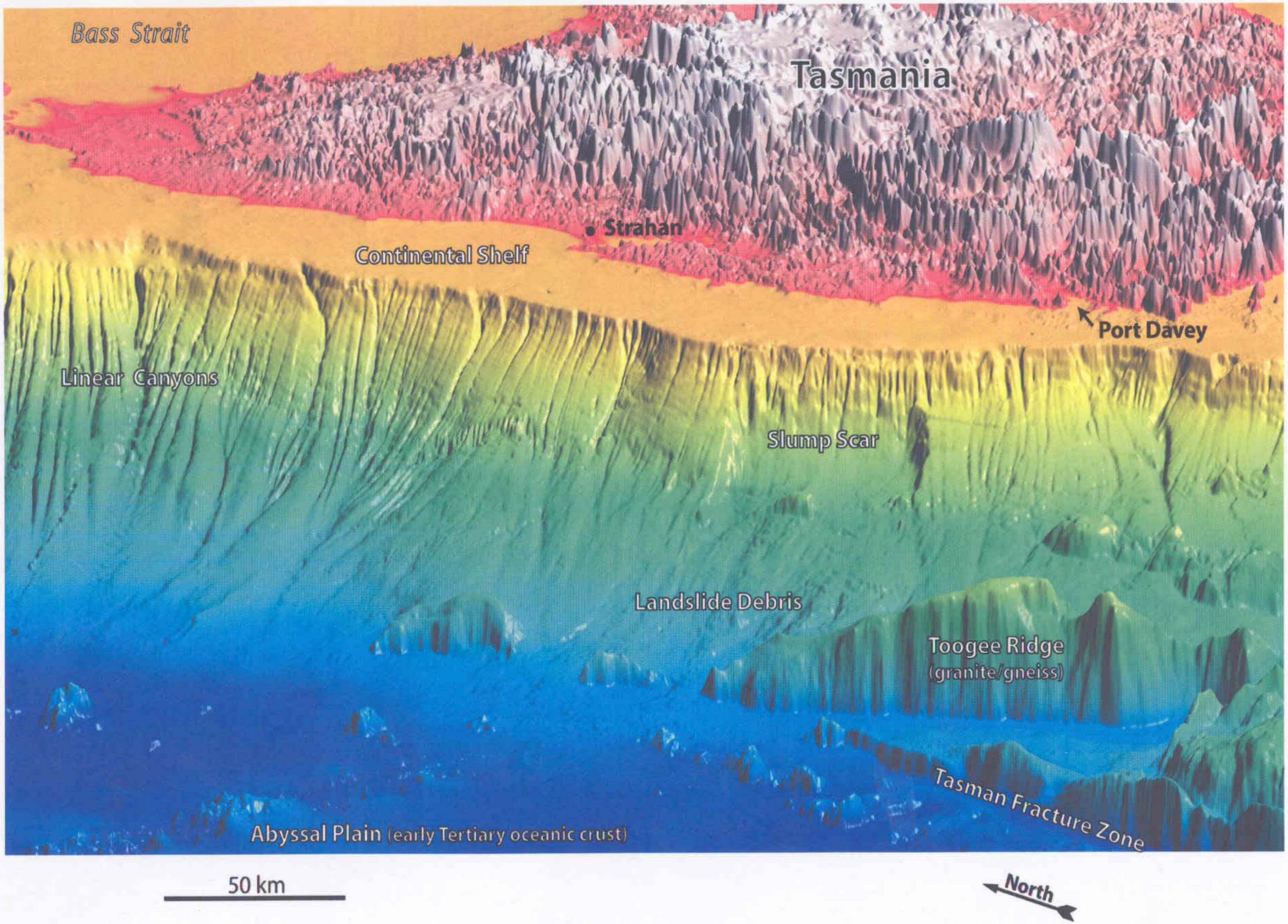


Figure 1. Exaggerated relief map of the bathymetry off the west coast of Tasmania

4.2. Seal avoidance practices

Following the 1999 winter, the joint venture companies developed a Code of Practice with the specific aim of reducing seal bycatch. The Code was derived from a New Zealand code of practice with the assistance of Australian seal scientists, Peter Shaughnessy and Bob Warneke. Both vessels adhered to the following practices throughout the 2000 to 2003 seasons, with one exception (see Section 5.2).

- The vessel steamed at an average speed of 10–12 knots for at least 40 minutes prior to shooting the gear regardless of the number of seals observed.
- If seals were still present, gear deployment was delayed and the vessel continued steaming at 10–12 knots for a further 20 minutes.
- Fish meshed in the net (stickers) were removed prior to shooting the gear.
- All shooting and hauling was carried out as rapidly as possible.
- The vessel often made a sharp turn when shooting the bottom trawl to keep the net closed on descent.
- During fishing the gear was not lifted into the top 150 m of the water column to make turns or a change in direction.
- After hauling the vessel turned 90–180 degrees immediately after the net was on deck.
- The vessel steamed away from the hauling area at an average speed of 10–12 knots for at least 40 minutes after hauling, regardless of the estimated time of the next shot.
- When fixing the net or streaming it for cleaning, the codend was always open and the SED escape hatch closed. The mouth of the trawl was always on board at this time.
- The discarding of fish, processing offal, or domestic waste on fishing grounds was rigorously avoided.

Before each shot, onboard observers recorded the following details of avoidance practices: date, course – before/during steaming, time – start/finish, speed (knots), seal number around vessel – start/finish, shot number and ‘sticker’ removal (yes/no). Additional notes were made of any additional manoeuvres or significant occurrences.

Because the two vessels were working under a permit that limited seal deaths to a maximum of 30 per fishing season, the need to minimize such deaths prevented estimating the effectiveness of avoidance practices through a structured program of comparisons between shots with and without these practices. The only comparative data available were the 1999 (no avoidance) seal bycatch data and equivalent 2000–2003 (avoidance) data for shots without a SED.

4.3. Daily seal counts

Counts of seal numbers around the vessel were conducted four times a day between dawn and dusk by the observers. In most instances these counts were distinct from the counts made during trawl operations. Each count was conducted using a set quadrant format. However, seals are often very mobile and it is possible that some seals were either counted twice or escaped detection as they moved between quadrants. The times of the daily count sequence were frequently interrupted by the observer’s other duties and could not be standardized. However, for most daily counts the ‘dawn’ (around 8 am) and ‘dusk’ (around 5 pm) counts were successfully achieved.

In the initial season (2000), some nocturnal counts were carried out in the visibility arc around the stern of the vessel created by the gantry lights. However, the visibility range of such counts was much smaller than daylight counts and this practice was discontinued towards the end of the season.

The following details were routinely recorded with each count: time, vessel position, wind strength (0–10), wave height (0–10), visibility (0–10), ship activity and net location. Although it was hoped to identify each seal to species level it proved extremely difficult to distinguish between Australian and New Zealand fur seals in the water and in most instances observers did not attempt to do so. An observer on the *FV Ocean Dawn* recorded a seal captured and released alive as being a New Zealand fur seal, but acknowledged that there was some uncertainty with the identification. All captured seals unambiguously identified were Australian fur seals and experienced seal scientists did not identify any New Zealand fur seals in the water during their time onboard. Hence, analyses of seal count data assumed that all seals were Australian fur seals.

The major objectives of these counts were to determine if there were any seasonal or diurnal (noting that counts could not be effectively made during darkness hours) patterns in seal numbers around the vessels and if comparative seal numbers were influenced by the parameters collected with each count and, most importantly, by fishing activities. If the latter proved to be an important parameter, fishing practices could possibly be further modified to reduce seal bycatch.

4.4. SED trials

***SED design*:** Prior to this project, exclusion devices to prevent pinniped bycatch by trawlers were being developed in the New Zealand midwater trawl fishery for squid (Wilkinson *et al.* 2003). Hence, the initial SED design used in 2000 was the (then) current design in that fishery which was, in many ways, similar to the Turtle Exclusion Devices commonly used in prawn fisheries (e.g. Tucker *et al.* 1997). The SED basically consisted of an angled grid set in a sleeve 'lengthener' in the throat of the net leading into the codend, that deflected large bycatch animals such as seals out of the net via a top escape hatch (Fig. 2). It was realized that this design would probably require significant modification to operate effectively in the grenadier fishery. The body-size of the major target species was much greater than arrow squid (*Nototodarus sloanii*) and the probability of fish loss via the SED escape hatch because of fish blocking the SED grid was a major concern. Hence, the SED design was progressively modified during this study. Both vessels had mechanical workshops, and modifications were sometimes made at sea.

Following the 2001 fishing season, two new SED designs were also subject to trials in the flume tank at the Australian Maritime College. The main objective of these trials was to assess water flows through the SED and the performance of forward facing escape hatch 'scoops' in the lengthener.

Throughout this report the term SED refers to the whole device, namely the grid, escape hatch, lengthener and any attachments made thereto to improve performance. The various SED designs are detailed later in this report, together with observations on their performance. The 'final' design is described in Section 6.3.

***SED effectiveness*:** Two methods were used to assess SED effectiveness: (a) comparison between sets of trawl shots with and without SEDS, and (b) using underwater video equipment to directly assess fish/seal movement and behaviour in the SED. Although the conditions of the fishing permit did not debit seal deaths incurred during SED experiments against the permit limit, the political need to keep such deaths to a minimum prevented the use of an external retention net over the SED escape hatch. This method had been successfully used to assess escapement of Hooker's sea lions from trawls in the New Zealand squid fishery (Wilkinson *et al.* 2003). In the current project, early attempts to monitor fish loss through the SED escape hatch via such a retention net were terminated when a seal drowned in this net.

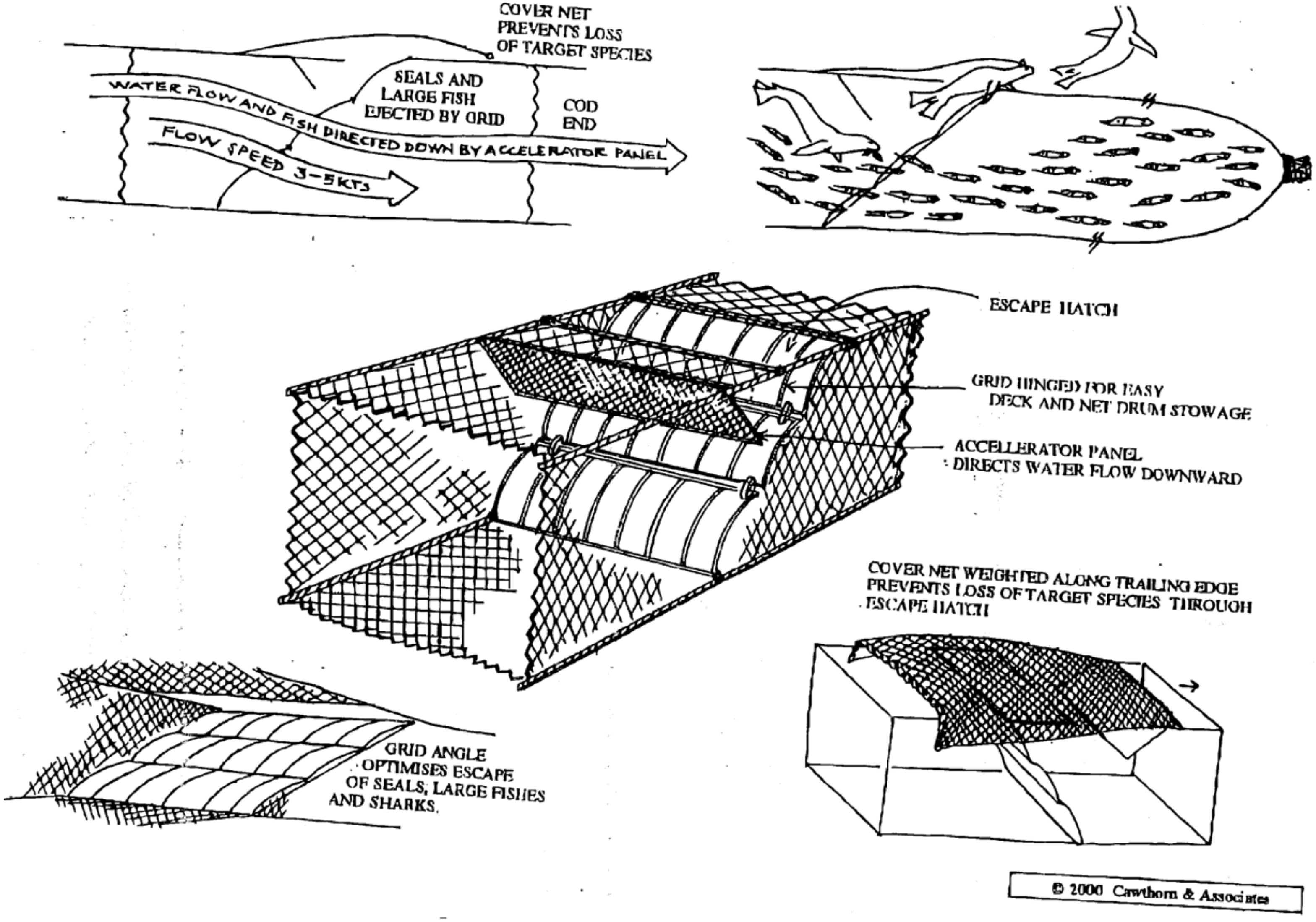


Figure 2. Initial (Type 1) SED design used during the 2000 fishing season

From the outset it was agreed that the experimental design of trawl shot sets would have to be structured to cause as little disruption as practicable to commercial fishing activities. Both vessels had large crews, high operating costs and comparatively tight fishing schedules. Although factory trawlers often have ‘processing’ periods when no fishing occurs and time is theoretically available to insert or remove a SED sleeve in the trawl net, the availability of such time is very variable. If fish are disaggregated and difficult to catch, a vessel might have to fish ‘around the clock’ to keep the processing deck active. Conversely, if dense spawning aggregations can be targeted, three 30 t shots will keep the processing deck active for most of the day, providing time for net/SED adjustments. Another important experimental design consideration was that the incidence of seal bycatch would probably be of a lower order than that experienced in 1999 (0.131 seals per shot). Comparatively small replicate sets of ‘with and without’ shots would inevitably have large coefficients of variation and it was probable that data would have to be aggregated to yield statistically significant results. Ongoing changes in SED design would also make obtaining replicate data sets more difficult.

It was also realised from the outset that there were many potential sources of error when comparing trawl shot sets. No one trawl shot is exactly the same as another, even when as many parameters as possible (e.g. vessel, net-type, speed, time, duration, location, depth, etc) are replicated for comparative purposes. Even on dedicated research vessels, it is virtually impossible to precisely replicate shots unless gear such as twin-rigs is used simultaneously. The probable major sources of variance in this project are listed below, together with the analytical approach taken.

Temporal differences: The year, month, time and duration of each trawl shot were recorded. Important parameters such as SED-type and seal abundance on the fishing grounds differed from year to year. SED types were treated separately. Comparative indices of annual seal abundance were derived from the respective incidences of seal bycatch in ‘no-SED’ shots and factored into the model.

Spatial differences: There is a seal breeding colony at Reid Rocks and a haul-out site at Hibbs Point, respectively to the north and south of the fishing grounds. The respective distances of each shot from these sites were also treated as parameters, together with the latitude and longitude of the end of the shot.

Operational differences: The same vessels fished in each year and data sets from each vessel were treated separately throughout. Data sets from bottom and midwater trawls were examined separately throughout. Final analyses were confined to midwater shots as SED use in bottom trawls was discontinued after the 2000 season. Catch composition and catch weight varied considerably and the estimated weights of blue grenadier, spotted warehou and other species for each shot were also incorporated as independent variables.

Model: A general additive model (GAM) approach to analysis was used with the parameters below being incorporated as independent variables. These standardisations using general additive models should be considered an exploratory analysis of the influence and significance of factors affecting the bycatch of Australian fur seals.

The factors considered were the:

- Year of the survey designated Year
- Month of the shot designated Month
- End latitude of the shot designated Endlat
- End longitude of the shot designated Endlong
- Duration (minutes) of the shot designated Duration
- End time of the shot designated Endtime
- SED design designated SED
- Depth (metres) of the shot designated Depth
- Distance from Reid Rocks (metres) designated DistA
- Distance from Hibbs Point (metres) designated DistB
- Estimated blue grenadier catch (kgs) designated Grenadier
- Estimated spotted warehou catch (kgs) designated Warehou
- Estimated catch (kgs) of all other species designated Other

GAMs were fitted using a logistic regression with a binomial response for the occurrence data. The form of the Presence-Absence (PA of a seal in a trawl shot) model was:

PA~Year+Month+s(EndLat)+s(EndLong)+s(Duration)+s(EndTime)+SED+s(Depth)+s(Dist A)+s(DistB)+s(log(Grenadier))+s(log(Warehou))+s(log(Other))

The GAM analyses were carried out using SPLUS (Insightful Corporation). Variable selection was performed using backwards elimination with the Akaike Information Criterion (AIC) statistic being used to differentiate between potential models. Continuous variables were considered for the model in three formulations either as smooth terms (using a cubic B-spline with default degrees of freedom in SPLUS), linear terms or null (*i.e*. excluded). Factor variables were either included as a factor or excluded if found not to be significant.

The main reason for standardising was an attempt to remove from the data any variation due to effects other than the occurrence of Australian fur seals in mid-water trawl nets. This usually involves a multivariate statistical technique with the occurrence of Australian fur seals in mid-water trawl nets as the dependent variable explained by a number of independent explanatory variables (Gavaris 1980, Kimura 1981, Olsen and Laevastu 1983). To the extent that the explanatory variables account for all the variation in occurrence of seals in mid-water trawl nets other than variation in abundance and random noise (*i.e.* catchability can then be assumed constant over time), the SED design variable estimates the effectiveness of the design. In addition, environmental variables may also be used as explanatory variables, although there is a danger that broader-scale environmental variables may affect the abundance of seals rather than their catchability.

Traditionally, standardised series are produced using generalised linear models (GLMs) (McCullagh and Nelder 1989). In this analysis a general additive model (GAM) technique was used (Hastie and Tibshirani 1990, Chambers and Hastie 1992). GAMs are a flexible class of models that can be used either as the main analysis tool (e.g. Kleiber and Bartoo 1998 and Fewster *et al*. 2000) or as an exploratory tool (e.g. Wise *et al*. 2002) before constructing more formal analysis using, for example, GLMs. The GAM technique allows numerical independent variables to have nonlinear effects on the dependent variable as determined by a smoothing algorithm (Cleveland 1979). Thus the effect of an independent variable is only constrained by the smoothing algorithm and is the major difference between the GAM and GLM techniques.

A distinctive feature of catch and effort data is that it is often “zero inflated”. That is, the data contain more zeros (i.e. in this case, the mid-water trawling operations for which no seals were caught) than might be predicted from standard error models used with GLMs (Ridout *et al*. 1998). If this feature is ignored there is a risk of overlooking important trends in abundance indicators. For example, it is possible that non-zero data may remain constant over time suggesting that the occurrence of seals is constant, but the actual number of zero catches is increasing over the time period, indicating that the occurrence is in decline (Stefansson 1996). In the analyses presented here we consider the occurrence or presence/absence of seal bycatch data to indicate the level of probability of catching the species, but due to data limitations we do not undertake analysis of presence-only data which indicates the level of non-zero captures (Barry and Welsh 2002). As SED use in bottom trawls was discontinued after 2000, the capture of Australian fur seals in this component of the fishery was not considered. The present analysis is limited to presence/absence data because the number of shots containing more than a single seal was only 13 (10.3 %) out of the 126 seal bycatch shots recorded.

***Underwater video observation*:** Video camera units were leased from the Australian Maritime College throughout the project. The depths fished (mainly 400 to 600 m) required robust housings for the camera, lights and power pack to resist water pressure. These units were usually mounted in a tubular aluminium frame for protection. Video camera observations were limited to the *FV Aoraki* throughout the project. The frequency of video observations is summarized in the following chronology.

Chronology of SED trials

2000: The SED used was similar to that shown in Figure 2, except the grid consisted of two (rather than 3) stainless steel sections with convex curved vertical bars hinged together at their margins and set into a tube (sleeve) of netting in four panels with a total circumference of 200 meshes (4.5" stretched mesh). The grid was inclined backward from the vertical at about 45 degrees, leading to an escape hatch cut into the top panel (Fig. 2). Two to three large spherical floats were attached to the upper margin of the SED, inside the net, to provide positive buoyancy. A cover-net was made fast to the upper panel ahead of the escape hatch and extended about 1.5-1.75 m aft of the hatch with the trailing edge weighted with chain to prevent it flying open. Ahead of the grid, a narrow panel of net, the "accelerator panel", extended from the top across the full width of the net and was sewn to each side with an adjustable zipper stitch. Its designed purpose was to direct the flow of water away from the SED escape hatch and prevent the escape of target species. Various adjustments to the SED and the surrounding net lengthener sleeve(s) were made during the season. Towards the end of the season, the SED was rotated 180 degrees so that the escape hatch opened on the underside of the (midwater) net. The chain on the cover net was then replaced with small floats.

A basic target of one week of 'SED' shots alternating with one week of 'no-SED' shots was set for each vessel. However, their actual timing and duration was largely left to the discretion of the skippers concerned. As the season progressed and the cumulative number of drowned seals increased, the number of SED shots in midwater nets greatly exceeded the number of 'no-SED' shots. Although seals caught when using a SED were theoretically not debited against the 30 seal limit imposed by the EA/AFMA permit, it was deemed politically expedient to try and keep seal mortality below this limit during this initial season of SED trials. The granting of such a permit was criticised by some environmental groups (e.g. Brand 2000) and both industry and scientists were well aware of the sensitive politics accompanying the seal bycatch issue.

The video camera was usually mounted inside the lengthener, pointing backwards towards the grid and escape hatch. Only 22 shots were successfully covered, with 34 hrs of footage being obtained. Several maintenance problems with the camera gear were encountered during the season, curtailing further coverage. A seal scientist (Martin Cawthorn) oversaw camera operations.

Following analysis of data from these initial trials and discussions on probable designs for future trials (including forward facing escape hatch 'scoops' to minimize fish loss), it was decided to limit future trials to midwater nets only. The reasons for doing this were: (1) seal bycatch in the smaller bottom nets was low compared with midwater nets; (2) SEDs with an escape hatch located on the underside could not be used in bottom nets; and (3) video observations could not be made when the net was on the bottom because of the poor visibility created by disturbed sediments.

2001: Two improved SED designs were initially used in 2001. Both had larger square grids hinged across the middle with vertical bars about 20 cm apart with forward facing escape hatches to reduce the problem of fish loss observed in the 2000 SED design. The 'top-hatch' SED (Fig. 3) had the escape hatch on top with floats keeping open a scoop net over the hatch. The 'bottom-hatch' SED (Fig. 3) was similar in design but had a bottom hatch and chain attached to the leading edge of the scoop net to keep it open. The accelerator panel was removed from both types of SED. Also, both open and closed SEDs were trialled. A closed SED had the escape hatch tied down and essentially comprised a fixed grid preventing access to the codend. In the absence of a SED drowned seals were retained in the codend. It is probable that most seal drownings take place in the codend where seal movement is constrained and seals may become disorientated by, or smothered by, incoming fish. The objective was to evaluate if just a simple barrier could enhance seal bycatch survival by preventing access to the codend. Such a barrier would eliminate the problem of fish-loss and possible seal entry via the escape hatch and would be logistically easier to use during fishing operations. A pre-season briefing with vessel skippers and operators stressed the need to have regular progressions of 'open-SED','no-SED', 'closed-SED', 'no-SED', 'open-SED', etc, shots. As in 2000, the actual timing/frequency was again left to the discretion of the skippers concerned. Both vessels achieved a good mix of shot types.

On 30 June the *FV Aoraki* narrowly escaped bursting a midwater trawl when fish blocked the SED grid and about 25 t of fish lodged in the throat of the net. This prompted the development of a 'hinged' SED (called the Fowler SED after the skipper who designed it) in which the top half of the grid was held in place by the drag resistance of trailing floats (Fig. 4) but folded back if a large build-up of fish occurred, spilling the fish into the codend. This design was used, with one modification, until 3 August when the SED was accidentally hauled over the net drum and destroyed. A 'bottom-hatch' SED was then used again.

There were fewer seals observed around vessels than in 2000 and only 26 shots contained seal bycatch. Data had to be pooled for analysis and no distinction was made between the different SED designs when comparing 'open-SED' and 'closed-SED' shots with shots without a SED.

The video camera was mounted in the same position used in 2000. Coverage was again less than planned because of problems with gear breakage/failure. Footage from bottom trawls in 2000 showed that visibility was of a very low order because of sediment being stirred-up by the trawl. Thus, the camera was confined to midwater trawl shots. A coverage of only 17 shots was achieved. The accident with the SED on 3 August also saw the camera cage irreparably damaged. A seal scientist (Martin Cawthorn) again oversaw camera operations.

2002: The 'top-hatch' and 'bottom-hatch' SEDs were again used in 2002. However, whereas their basic design was unaltered, substantial improvements to their structure were made. The shape of the stainless steel grid was changed from 'near-square' to 'near-circular' to more fully conform to the circular cross-section shape of the net sleeve during trawling. The area of the grid was increased approximately threefold to facilitate improved water flow and fish passage and more robust (i.e. thicker) steel rods were used for construction. As in earlier designs, the grid had a central horizontal hinge to facilitate handling. Two spacings (30 and 25 cm) between the vertical grid bars were initially trialled, but the grid with 30 cm bar spacing was replaced with a spare one of about 20 cm spacing, after 3 juvenile seals passed though it. SED trials were confined to midwater shots only, although near the end of the season a few (11) bottom shots also had SEDs because of concern about the cumulative total of seals drowning. Throughout the season the *Aoraki* used the 'bottom-hatch' SED and the *Ocean Dawn* the 'top-hatch' SED (Fig. 5), with both vessels alternating periods of around 20 SED and 20 'no-SED' shots. No major design changes occurred during the season other than replacing the 30 cm spaced grid.

Video camera use was confined to midwater trawl shots with a SED, with the objective of recording seal and fish passage through the escape hatch. To that end, the unit was mounted on the outside of the lengthener about 2 m ahead of the escape hatch. Further technical problems were experienced with camera equipment and the unit was only used in 14 shots. No useable footage was obtained from eight of these shots. A seal scientist (Peter Shaughnessy) oversaw camera operations.

The 2002 trials indicated that the 'top-hatch' SED used on the *FV Ocean Dawn* might have minimised one of the principal problems with other 'open-SED' designs, namely seals entering the net via the SED escape hatch. Hence, the project was extended for an additional year to further assess this design.

2003: The budget for 2003 was considerably less than in previous years and onboard observer coverage was reduced. SED trials were again limited to midwater nets. The 'top-hatch' SED was used by the *FV Ocean Dawn* throughout the season. However, because of a very hurried briefing (as the vessel departed) and consequent misunderstanding by the skipper, and the lack of an independent observer, alternating sets of 'no-SED' shots were not carried out. Thus no "control" data were obtained. As trials with 'grid-only' (i.e. closed SED) nets in 2001 were inconclusive because of low seal bycatch overall, this technique was again trialled by the *FV Aoraki*. This vessel alternated 20 'closed-SED' shot sets with 20 'no-SED' shot sets throughout the season.

Video camera equipment was only used on one trip (22/7/03 – 22/8/03) in which 26 midwater shots were covered, all successfully. The main objective was to monitor seal entry into the net. With 'no-SED' shots, the camera was attached facing forwards inside the net about 5 m ahead of the codend. When a (closed) SED was used the camera was attached to the lengthener in front of the grid. A seal scientist (Derek Hamer) oversaw camera operations.

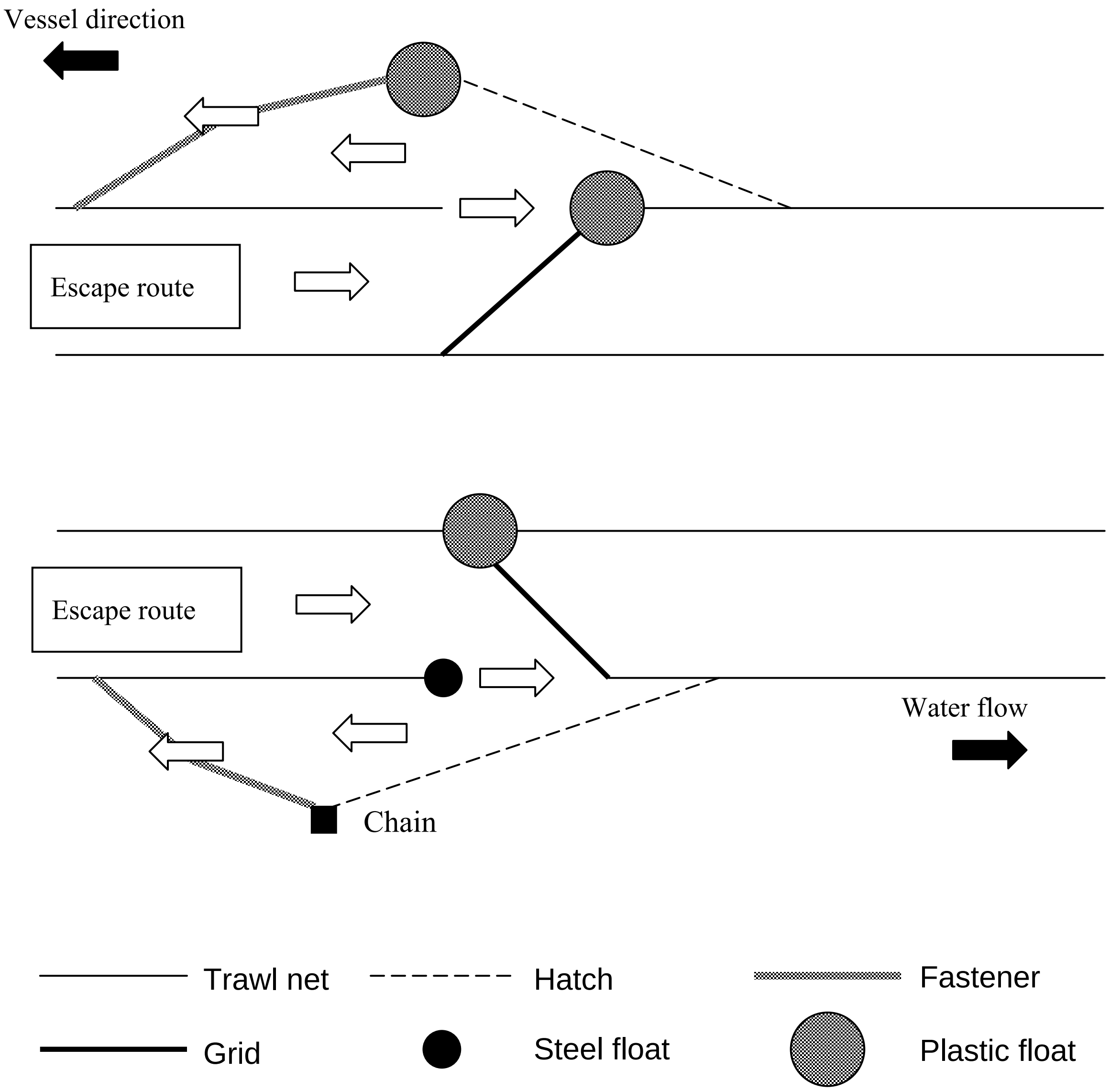


Figure 3. Diagrams of the 2 basic SED designs with forward facing 'scoop' escape hatches used in 2001. Improved versions of the same designs were used in 2002.

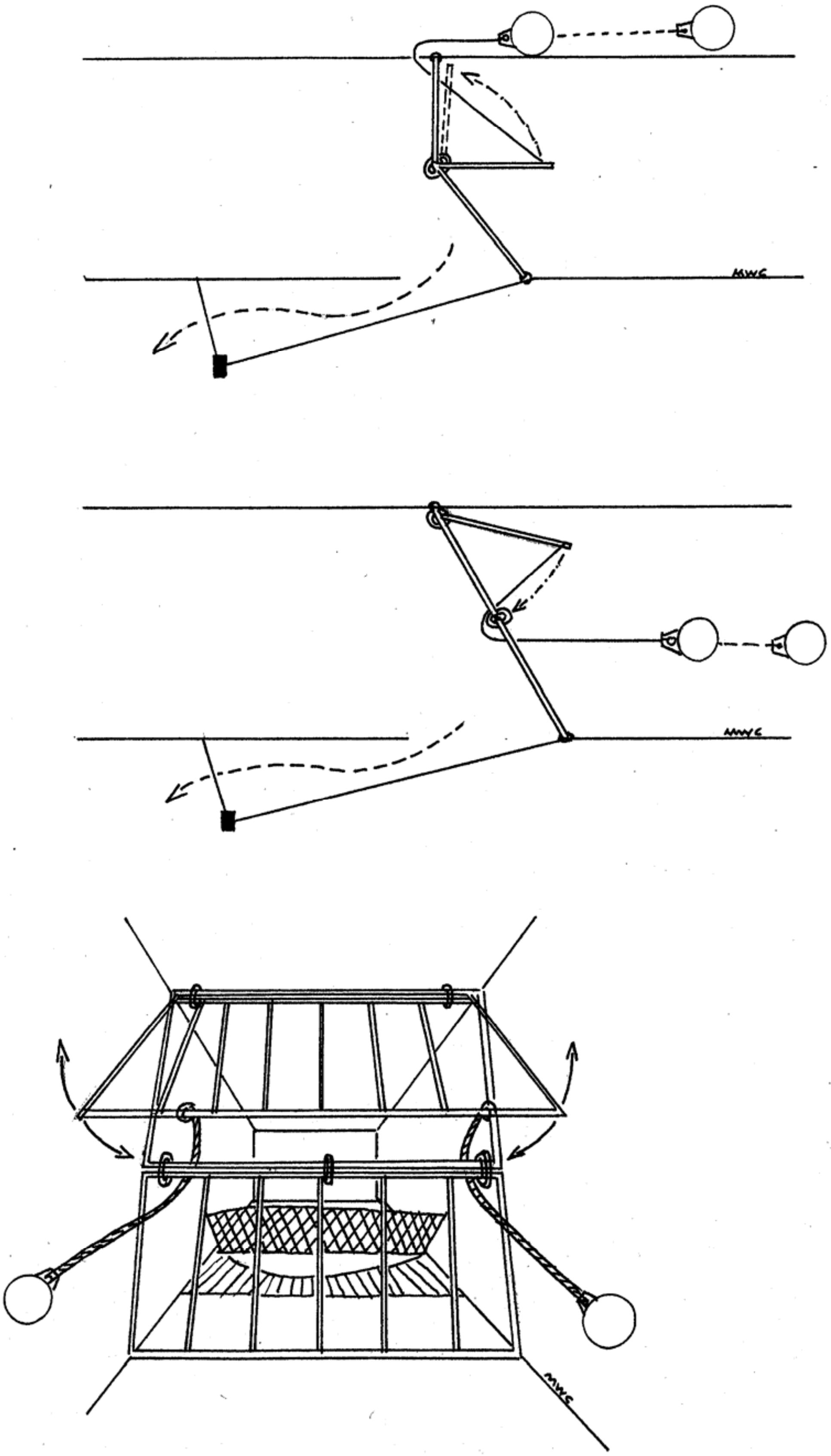


Figure 4. Schematic view of “Fowler” SED design with opening half grid

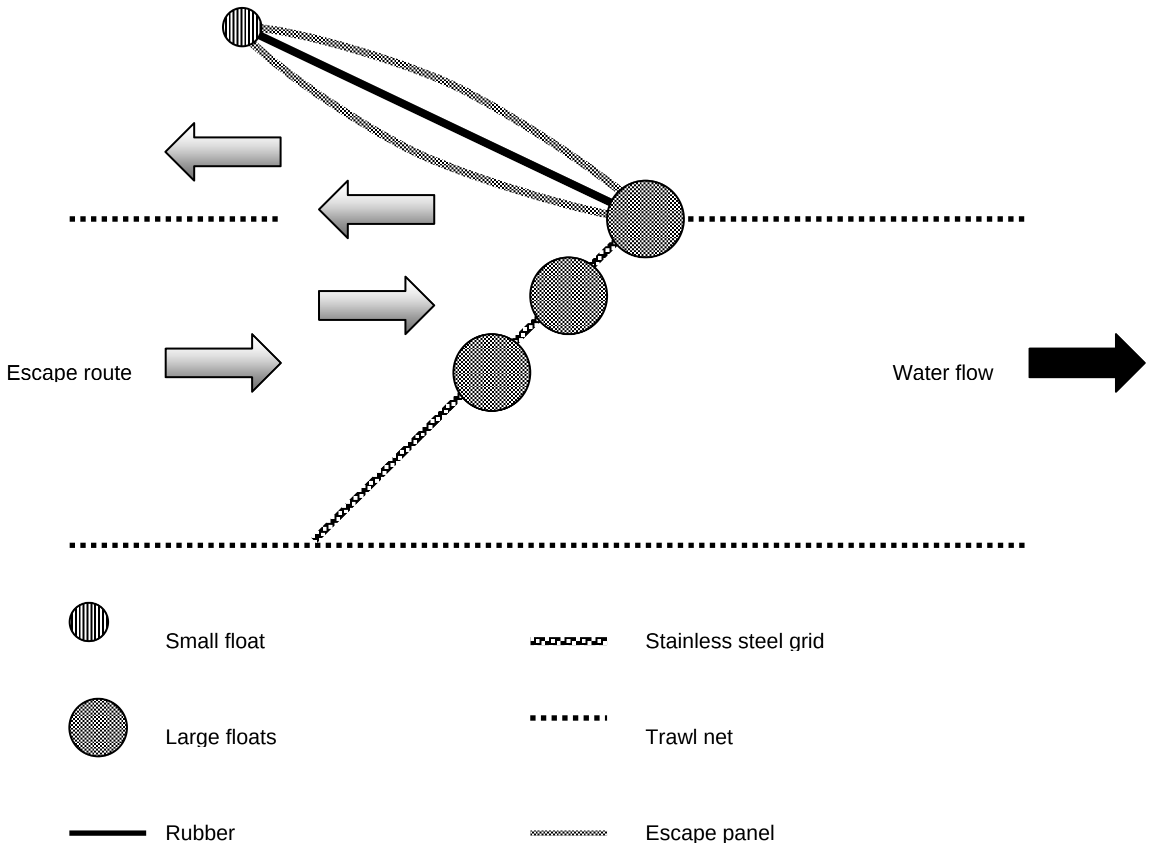


Figure 5. Diagram of improved 'top-hatch' SED trialled on the *FV Ocean Dawn* in 2002 and 2003

4.5. Seal biological data

For conservation and ethical reasons, biological information for fur seals in Australia is largely confined to data collected from live animals. Consequently, every seal carcass represents a valuable information source and each was subject to biological examination where possible. Dr Simon Goldsworthy supervised this section of the project. Such information provided important base-line information for the management of seal bycatch issues, and provided key insights into ways in which the fishery can be made less attractive and less profitable to seals, thereby reducing the number of seals interacting with the fishery.

The main objectives of this part of project were to:

- determine the species, sex and age composition of seal bycatch
- determine the nature of the biological interaction with the fishery, including identifying what aspects of the fishery are responsible for attracting seals.

These data will provide important information for management in terms of:

- assessing the impact of seal bycatch on seal populations
- determining what aspects of the fishery are attracting seals
- the importance of factors such as catch composition and discarding practices on seal bycatch rates.

Information collected included: core body temperature to ascertain the approximate time of death, species (DNA sampling, if necessary), sex, reproductive state, morphometric measurements, age (from tooth sections), stomach contents and, if required, other details such as pesticide residue levels. This information contributed to ongoing studies/analyses of fur seal demography in southern Australia. In 2000, whole seal carcasses were retained and frozen for later biological analysis onshore. The requisite landing and transporting permits were obtained from the pertinent wildlife authorities. Each carcass was labelled (shot reference, etc) and placed in a strong polythene bag to avoid any chance of contamination to fish product in the freezer hold. Several difficulties were experienced in transporting large (>200 kg) seal carcasses to below deck freezing facilities. The interim onshore storage and transportation of such large carcasses were also fraught with logistical problems. Hence, dedicated seal sampling/measuring stations were set up in allocated deck areas on both vessels in 2001. Seal carcasses were temperature-probed, weighed and measured and their heads and stomachs, only, were retained for onshore analysis. These samples were labelled and placed in polystyrene boxes in the vessel's freezer hold. At the end of each fishing trip the boxes were stored in a cold store prior to being shipped to LaTrobe University for analysis by Dr Goldsworthy's team. Both vessels followed this procedure in 2002 and the *FV Aoraki* continued in 2003. Unfortunately, 14 samples were lost in transit during 2001.

4.6. Satellite tracking of seal movements

Whereas seals appear to have become habituated to following vessels in the winter grenadier fishery, it is not known if such seals comprise a "resident" or "shifting" population. Is a sub-set of the seal population becoming increasingly habituated to feeding in trawl nets and following vessels throughout the season, or are seal-trawl interactions largely random and driven by seal population size and/or a vessel's proximity to seal colonies or haul-out sites? This is an important question when considering ways to minimise seal-fishery interactions. If the seals around a vessel constitute a "resident" group, they may become increasingly adept at entering nets to feed therein. If this is acquired behaviour by "resident" seals, different bycatch avoidance procedures other than SED-use may have to be employed. For example, such seals may respond to repeated "scare" tactics aimed at stopping them following a vessel. Conversely, if the seals comprise a transient population, current avoidance procedures may be adequate. Information on seal residency time and/or exchange rate on the fishing grounds will assist in answering these questions.

The decision to use satellite tags was made after considering other tracking methods. Whereas the use of conventional "flipper" tags throughout the season would provide some insight into seal movements if recaptures occurred, seal tagging can only be successfully carried out by skilled and experienced operators. Seals are typically aggressive after being caught in a net and tagging large animals is a dangerous exercise not to be done by inexperienced observers or crewmen. The cost of retaining skilled tagging operators onboard throughout the season would far outweigh that of using a few satellite tags. Also, conventional tags do not supply the detailed movement information provided by satellite tags. Consequently, six satellite tags were purchased and appropriate satellite time was booked. This tagging work also linked in with another satellite tagging program conducted by Dr John Arnould (Melbourne University) and Dr Rodger Kirkwood (Philip Island Nature Reserve), who were tagging female Australian fur seals at Bass Strait haul-out sites.

The principal objectives were to assess the duration of seals' foraging trips within the fishing grounds during the fishing season, and to gain some insight into the proportion of the seal population that is feeding within the fishing grounds and is vulnerable to bycatch. The primary aim of this work was to determine if these seals represent, either: (a) a large population of seals visiting and feeding in association with vessels for brief periods in between feeding bouts in other foraging grounds, or (b) a smaller population of seals that is habituated to the fishery, where seals remain feeding in association with vessels throughout the duration of the fishing season. Seal counts around the vessels and sightings/recaptures of tagged seals assisted interpretation of tagging data.

It was originally intended to carry out tagging during the 2001 season, with the two taggers (Drs Goldsworthy and Kirkwood) boarding the *FV Aoraki* for a brief trip when seal abundance appeared high. Healthy seals taken as bycatch were to be marked. However, the comparatively low incidence of seals and seal bycatch in this year led to tagging operations being postponed. It also became apparent that, even in a year with more seals on the fishing grounds, it was impractical to rely on bycatch for animals to tag as the tagging team may have to wait onboard for lengthy periods between captures.

During 2002, a novel method for capturing seals at sea was developed by skipper Keith Fowler, Martin Cawthorn and the crew of the *FV Aoraki*. This used a 'dip-net' that was suspended 1–2 m under the surface from a crane. Fish were thrown from the vessel into the net, in order to attract seals. When seals ventured into the net, the crane operator raised the net out of the water (Fig. 6). On most occasions, seals were quick enough to escape the net before it had cleared the water, but eventually one would be caught. Captured seals were lowered onto the trawl-deck, and given a 1.5 mg/kg intra-muscular injection of Zoletil, via a needle and syringe attached to a jab-stick while still in the capture net. Once the drug had taken effect, the seal was removed from the netting and laid-out on the flat base of a collapsible box (Fig. 7), where each was kept lightly anaesthetized on isofluorane administered via a portable gas anaesthetics machine, while a satellite transmitter was glued to the dorsal midline of the seal using fast setting epoxy (Fig. 7).

The catching technique readily enabled the deployment of satellite transmitters on seals directly interacting with the fishery. During late July 2002, Simon Goldsworthy and Roger Kirkwood spent about one week on *Aoraki*, with the aim of deploying six satellite transmitters on live Australian fur seals caught by the above method, in order to learn more about the foraging behaviour of seals feeding within the fishing grounds and their interactions with fishing operations. Using these methods, satellite transmitters were deployed on three male Australian fur seals, named *Sass* on 26 July, and *Jimmy* and *Jack* on 28 July. Due to presumed battery failures, two of the satellite transmitters only operated for a short time (10 and 25 days), while the third transmitter (*Jack*) operated for its expected battery life (109 days) (Fig. 24 on page 47). It was subsequently discovered that either *Sass* or *Jimmy* drowned in the trawl of a 'wet' boat targeting blue grenadier. The date of capture is unknown and the tag was not returned. The remaining three tags had their batteries rebooted prior to the 2003 season. As the initial budget covered 6 tags only, Petuna/Sealord kindly purchased an additional three tags to use during the 2003 season when all 6 tags were successfully deployed, giving a total of nine tagged seals for the project.

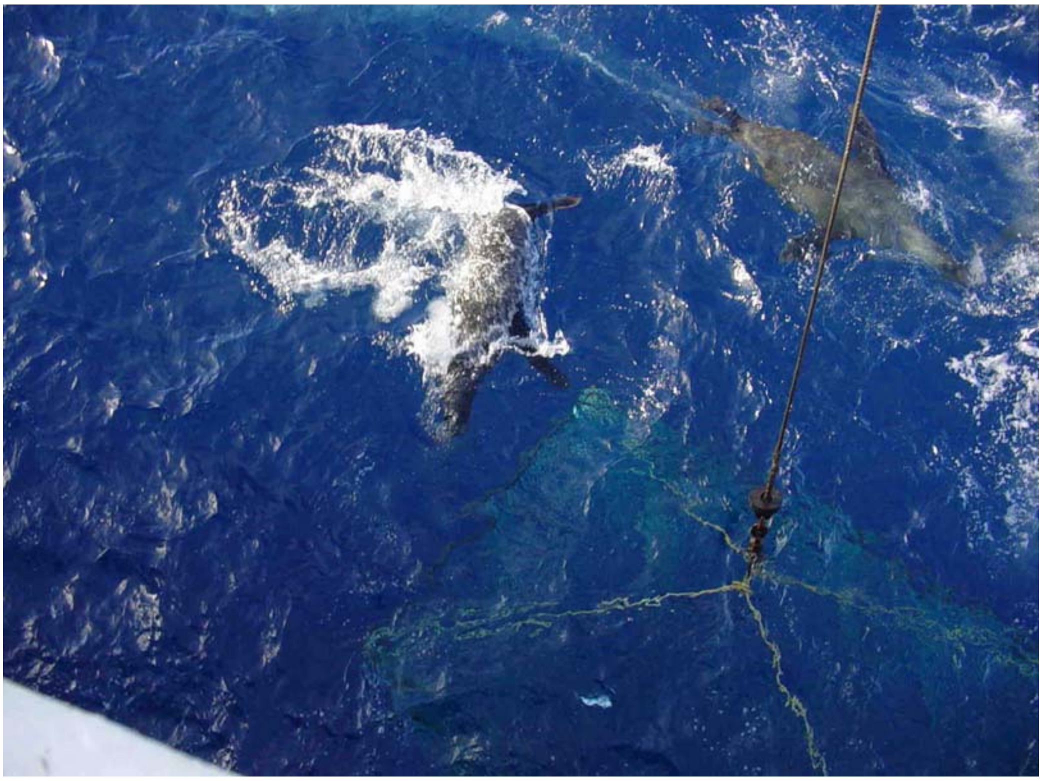


Figure 6. Seal 'dip-net' being used alongside *Aoraki* above, with interested seals, and below, capture seals being hauled onto the deck

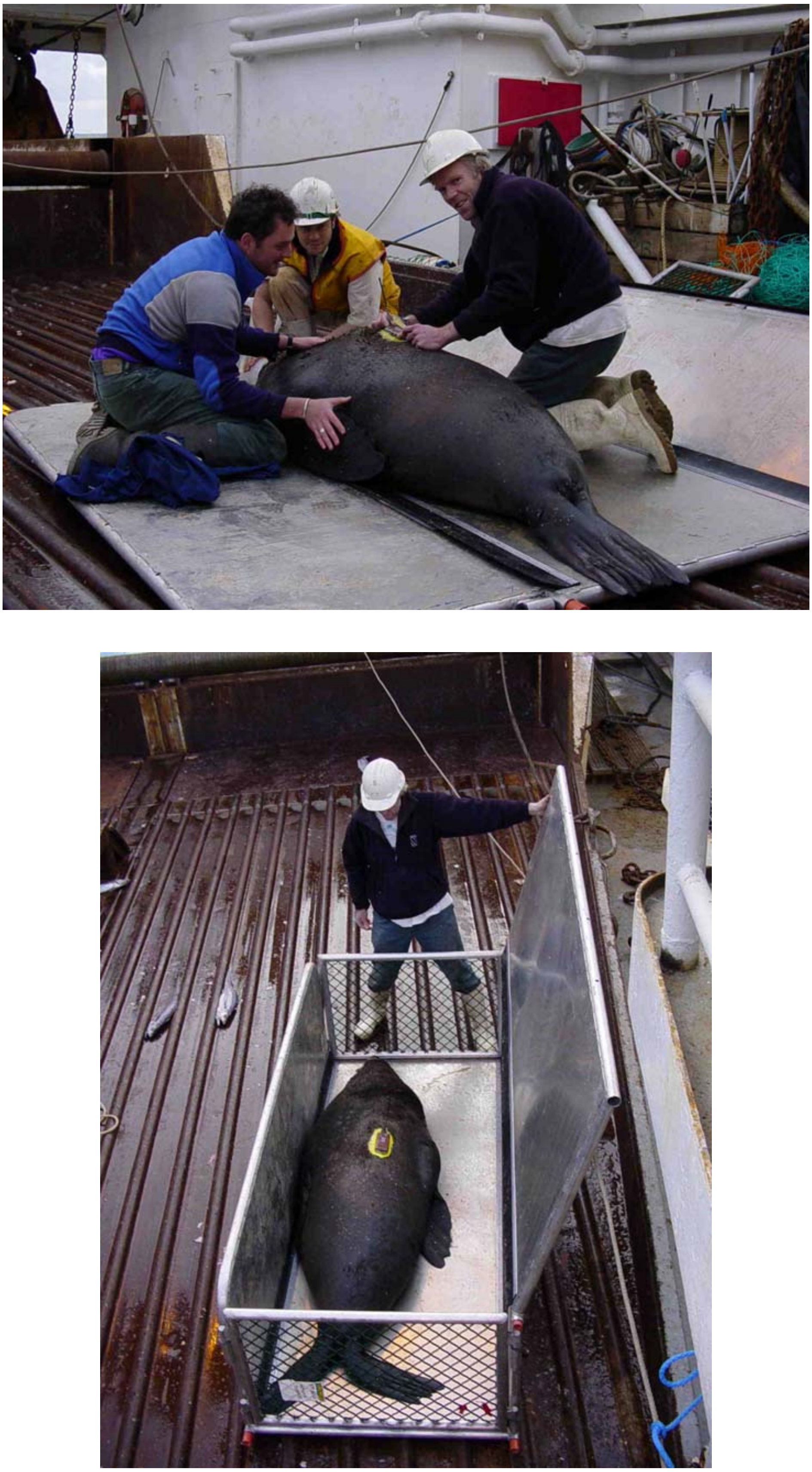


Figure 7. Anaesthetised seals being fitted with a satellite transmitter on collapsible box (above), and with box folded up to hold seals during recovery, prior to release

5. RESULTS

5.1. Fishing operations

Fishing operations for the period 2000 to 2003 are summarized in Table 1. Shot locations are shown in Figures 8 to 11.

Table 1. Summary of fishing operations, 2000–2003

Year	Boat	Gear	SED	Shots	Depth	Time	Gren.	War.	All sp.	T Catch
2000	A	B	NS	31	474	216	4522	409	5181	160625
			SO	94*	498	217	7050	2483	9717	908815
		MW	NS	7	514	322	5786	18	6562	45931
			SO	119	372	104	18022	2059	20108	2392859
	OD	B	NS	93	508	227	10149	2517	12968	1206066
			SO	28	511	173	6574	737	7373	206445
		MW	NS	16	462	146	19350	481	19866	317850
			SO	65	466	124	14211	448	14661	952950
2001	A	B	NS	51	456	133	7873	799	8834	450560
			SO	19	499	165	7956	556	8655	164448
			SC	42	486	141	7976	294	8418	353541
		MW	NS	79	354	91	19698	487	20217	1597125
			SO	21	327	85	23629	129	23811	500038
			SC	37	351	80	15601	106	15725	581814
	OD	B	NS	59	498	206	9711	1172	11011	649670
			SO	41	487	180	7588	2430	10151	416205
			SC	40	473	211	8356	1450	9926	397024
		MW	NS	34	423	91	15207	376	15616	530944
			SO	48	437	80	12864	2258	15142	726796
			SC	30	442	85	17107	1328	18454	553610
2002	A	B	NS	81	516	226	7514	1472	9503	769714
			SO	2	435	212	750	1250	3004	6008
		MW	NS	102	414	59	17940	1462	19426	1981457
			SO	81	403	51	14783	2047	16940	1372152
	OD	B	NS	125	489	248	4750	1995	6939	867353
			SO	10	480	275	310	4830	5496	54960
		MW	NS	58	414	66	14425	1453	15886	921380
			SO	98	431	114	13020	4547	17572	1722039
2003	A	B	NS	35	486	250	2787	1993	4990	174640
		MW	NS	106	412	61	16073	721	16803	1781105
			SC	101	416	59	14979	823	15827	1598574
	OD	B	NS	44	473	217	4829	1592	6503	286126
		MW	NS	0	-	-	-	-	-	-
			SO	197	417	103	19551	1568	21123	4161182

A=*Aoraki*; OD=*Ocean Dawn*; Gear – B=Bottom trawl, MW=Midwater trawl; SED status – NS=No SED, SO=Open SED, SC=Closed SED; Shots=Number of trawl shots; Depth=Mean shot depth (metres); Time=Mean trawl duration (minutes); Catch columns show mean estimated shot weights (kg) for; Gren=Grenadier, War.=Spotted warehou, All sp.=All species; T Catch=estimated weight of total season's catch of all species by each gear combination. See text for SED designs used; * 1 shot had a bag over the escape hatch.

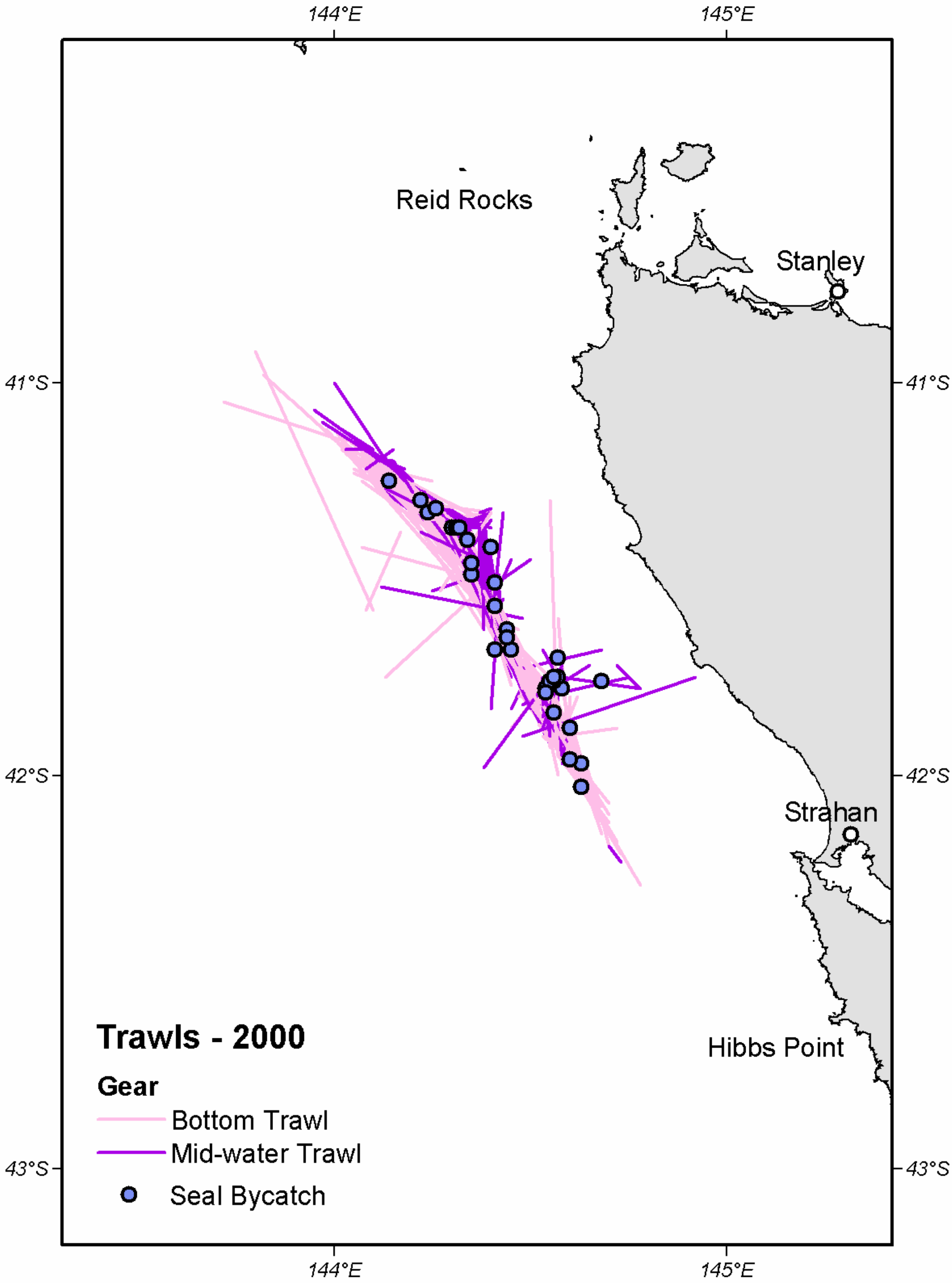


Figure 8. Map of all 2000 season trawl shots and shots containing seal bycatch

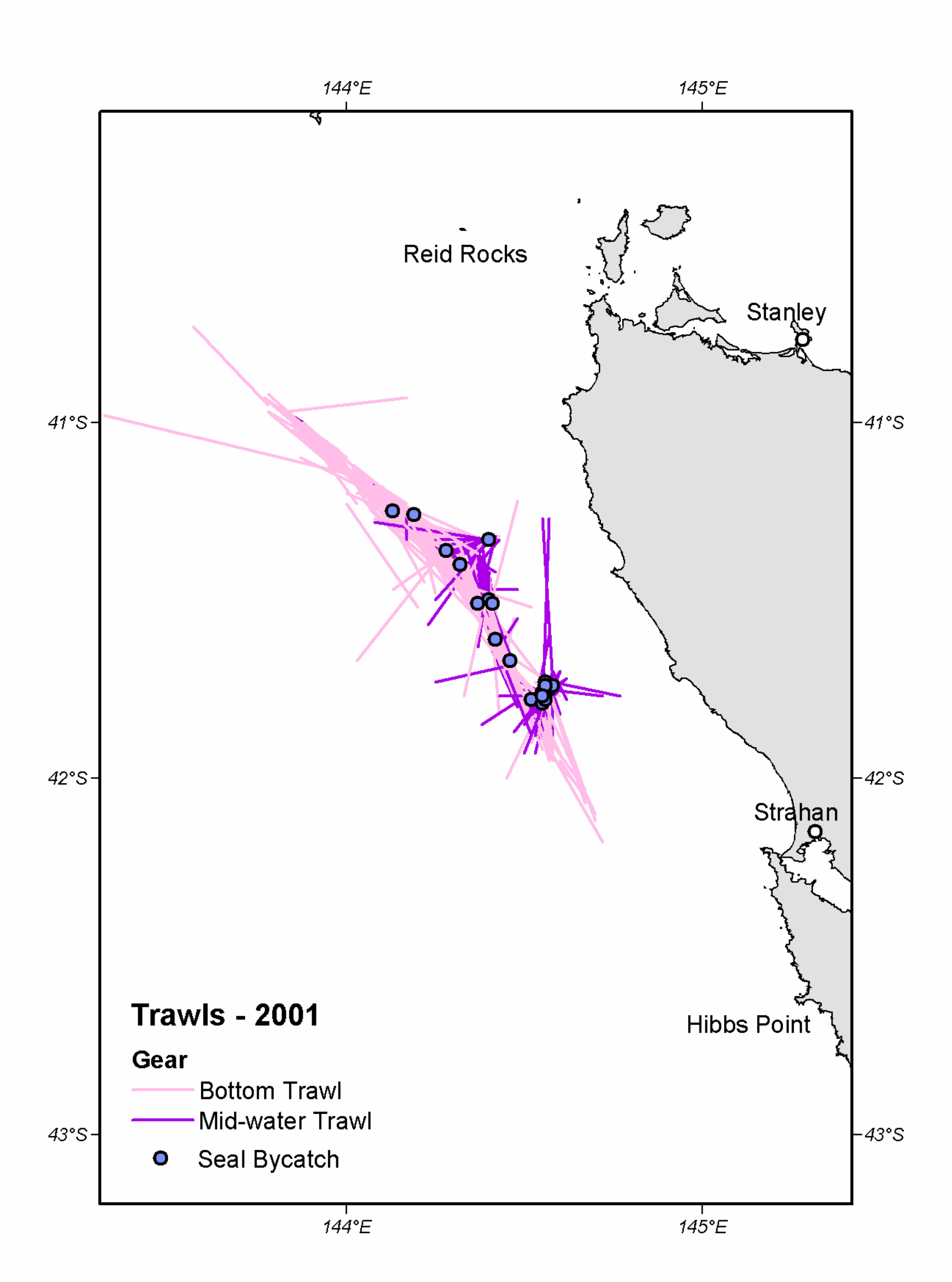


Figure 9. Map of all 2001 season trawl shots and shots containing seal bycatch

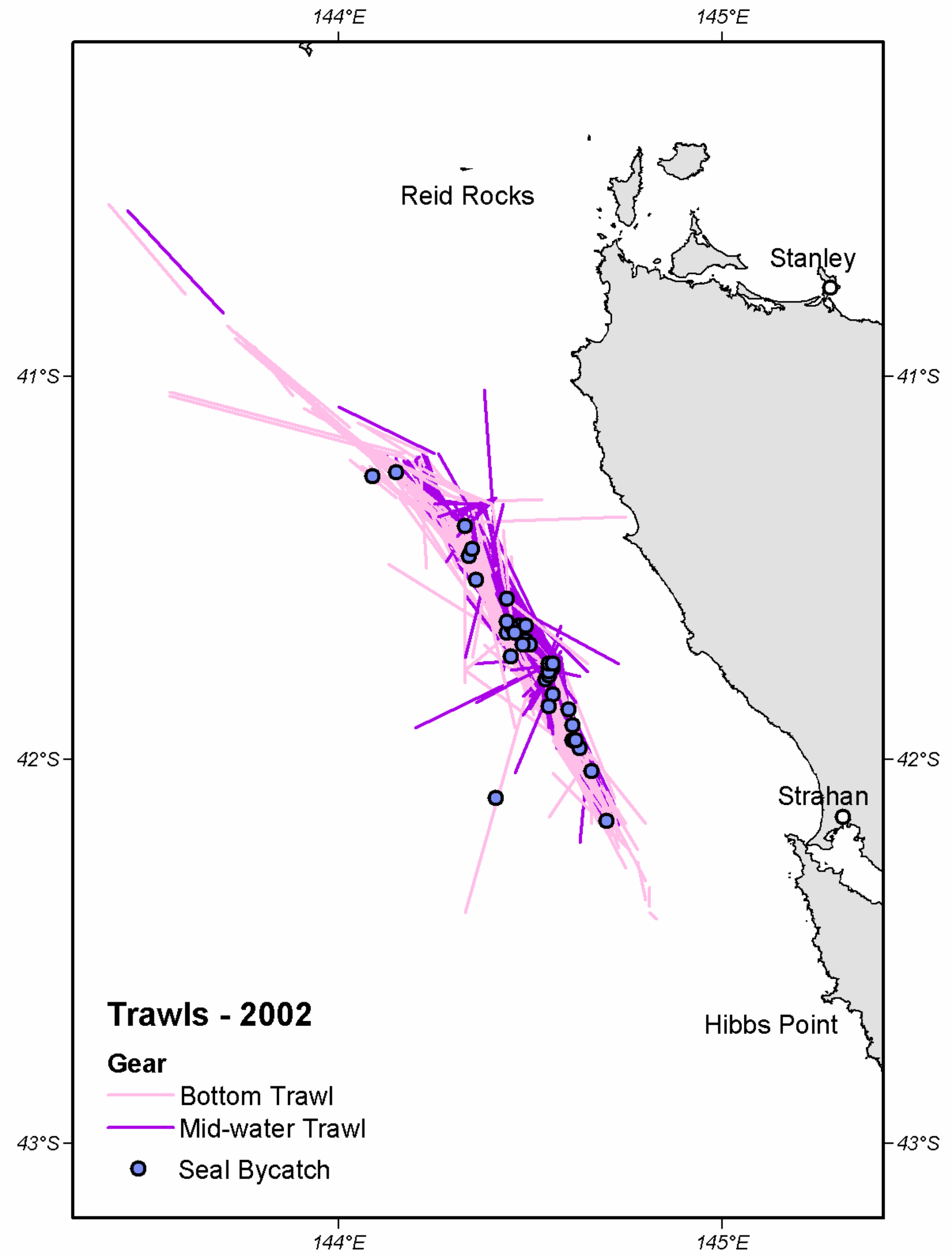


Figure 10. Map of all 2002 season trawl shots and shots containing seal bycatch

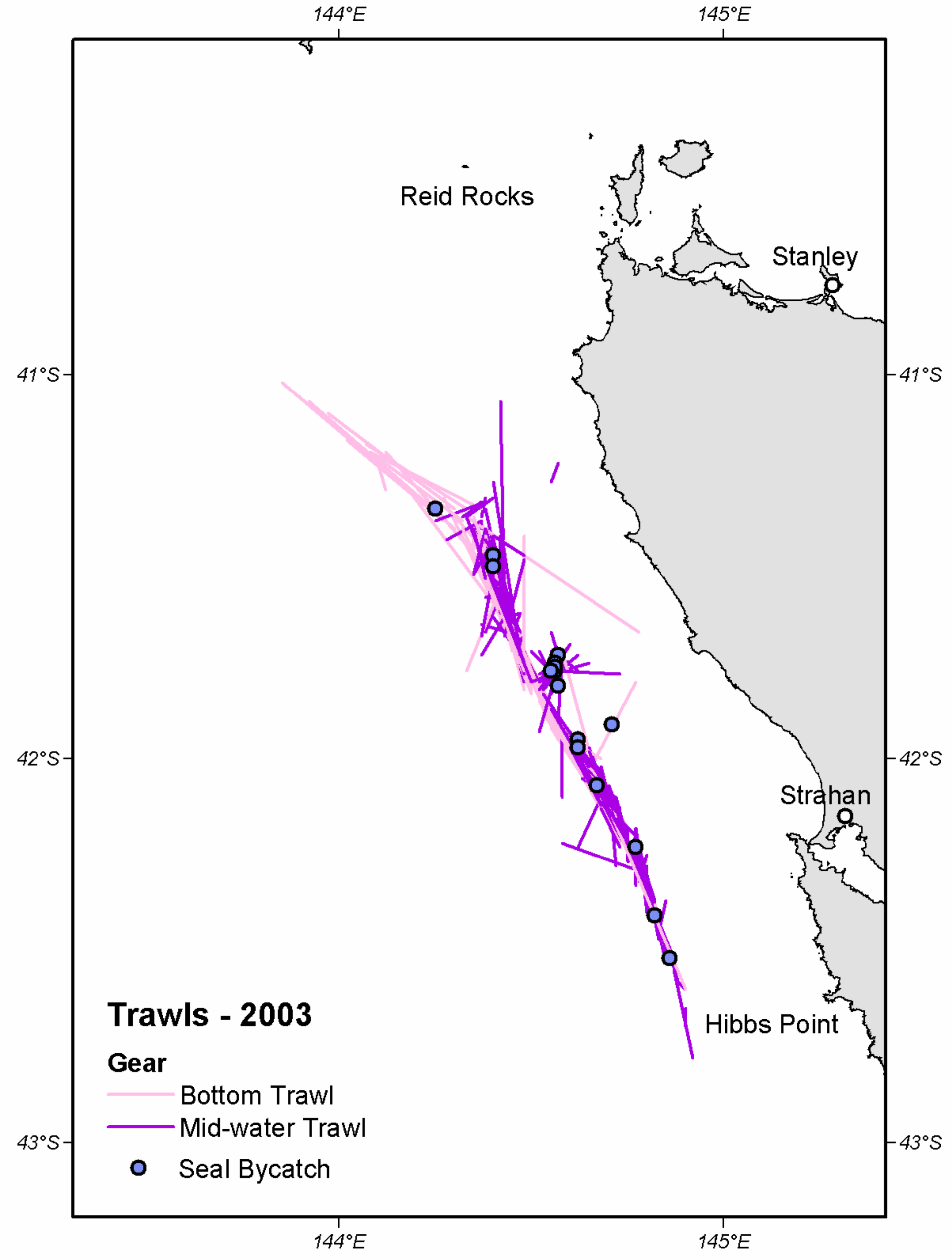


Figure 11. Map of all 2003 season trawl shots and shots containing seal bycatch

Early in the season (June) grenadier are more widely dispersed. As the season progresses the fish form large pre-spawning aggregations with groups of fish breaking away to spawn. Shot duration typically varies during the season, with shots targeting pre-spawning aggregations being much shorter than those targeting fish dispersed in the water column. Also, mean grenadier size decreases during the season, with the 'early' spawners usually being the largest fish. The major "bycatch" (it is occasionally targeted) species is spotted warehou (*Seriolella punctata*). In addition, small catches of blue warehou (*S. brama*), ling (*Genypterus blacodes*), blue-eye trevalla (*Hyperoglyphe antarctica*), silver dory (*Cyttus australis*) and frostfish (*Lepidopus caudatus*) are also periodically taken.

For the two vessels, the 2000 season began on 10 June and ended on 29 August. Respective start and finish dates for the following 3 years were 8/6/01 to 25/8/01, 13/6/02 to 19/9/02 and 11/6/03 to 26/8/03. The 2002 season extended into September because both vessels attempted to catch their entire grenadier quota, following AFMA's (2001) decision to abolish the carry-over of uncaught quota into the following year. Prior to 2002, up to 20% (by weight) of uncaught quota could be credited to an operator's quota holdings in the following year. In 2000, both vessels conducted 453 shots for a total of 1301 hours of actual fishing (i.e. bottom or midwater) time. Respective values for 2001, 2002 and 2003 were 501 shots and 1087 hrs, 557 shots and 1294 hrs and 481 shots and 850 hrs. Over the study period (2000–2003) there was a gradual shift by both vessels towards the increased use of midwater gear compared with bottom gear (Table 1). The mean duration of midwater shots also became shorter, indicating that both vessels became increasingly familiar with the fishing grounds and more adept at targeting grenadier. Most bottom shots occurred at the start of the season when vessels were 'searching' for fish and the mean duration of such shots stayed reasonably constant from year to year (Table 1).

In 2000 and 2001 the mean depths of midwater shots by *FV Ocean Dawn* were deeper than those by *FV Aoraki* (OD 465 and 434 m, A 380 and 349 m, respectively), but in 2002 and 2003 both vessels fished at similar depths (OD 423 and 417 m, A 409 and 414 m, respectively). There was little difference between the mean annual depths of bottom shots for each vessel. Both vessels fished essentially the same areas.

The fishery lies approximately midway between an Australian fur seal colony at Reid Rocks and an established haul-out site at Hibbs Point (Fig. 8). In 2000 and 2001, virtually all fishing occurred north of Strahan (Fig. 8 and Fig. 9). The 2002 and 2003 seasons saw fishing effort gradually extend southwards towards Hibbs Point (Fig. 10 and Fig. 11). However, in all 4 seasons the bulk of fishing effort occurred between latitudes 41.2°S and 42.0°S. The occasional shot extending into shelf waters occurred when the vessel concerned was picking up or dropping off an observer. The two most northerly shots in 2002 (Fig. 10) were targeting spotted warehou near the end of the season when grenadier were scarce.

To facilitate assessment of SED performance it was hoped that the characteristics of respective sets of SED and 'no-SED' shots would be similar, but differences inevitably occurred. In most instances there were relatively good matches between the mean durations and depths of the respective sets of SED and 'no-SED' shots (Table 1), the only exception being the mean duration of *FV Ocean Dawn* 2002 sets of midwater shots (NS = 66 min and SO = 114 min), or when one data set contained only a few shots. For example, the *FV Aoraki*, 2000 midwater net means for 'no-SED' shots (322 min and 514 m) were derived from only 7 shots whereas the respective SED-open means (104 min and 372 m) were derived from 119 shots (Table 1).

The use of catch-per-unit-effort (CPUE) to assess and compare the performance of factory trawlers can be misleading as such vessels limit their catch volume to their processing capacity. Both the *FV Aoraki* and the *FV Ocean Dawn* are capable of processing about 100 t of fish per day and try and maintain catches at around that level. Product quality is also an important marketing issue with blue grenadier and large (>30 t) 'bags' of fish are avoided because of damage/bruising occurring in the net. Nets are usually fitted with stretch sensors that provide timely indication of the volume of fish in the codend. Although again stressing that in this instance CPUE is only an arbitrary indicator, comparison between the catch rates of each vessel found the *FV Aoraki* to be the more efficient catcher (Table 2). Most fish were caught in midwater nets and midwater catch rates for the *FV Aoraki* were consistently higher than those for the *FV Ocean Dawn* (Table 2).

Table 2. Summary of vessel fishing performance, 2000–2003

Year	Boat	Gear	No.Shots	Tot. Time	CPUE 1	CPUE 2
2000	A	B	125	451.6	1778	2368
		MW	126	243.8	8963	10003
	OD	B	121	432.6	2607	3265
		MW	81	173.3	7117	7333
2001	A	B	112	264.0	3362	3669
		MW	137	198.9	13221	13469
	OD	B	140	466.2	2613	3138
		MW	112	158.1	10422	11457
2002	A	B	83	312.2	1954	2485
		MW	183	169.1	17902	19832
	OD	B	135	562.5	1060	1640
		MW	156	250.0	8450	10574
2003	A	B	35	145.8	669	1198
		MW	207	207.1	15532	16319
	OD	B	44	159.1	1335	1798
		MW	197	338.2	11388	12304

A=*Aoraki*; OD=*Ocean Dawn*; B=Bottom trawl; MW=Midwater trawl; No.Shots=Total number of trawl shots; Tot. Time=Total bottom/midwater time (hrs); CPUE 1= Mean catch per unit effort (kg/hr) for blue grenadier only; CPUE 2=Mean catch per unit effort (kg/hr) for all species

5.2. Seal avoidance practices

The Fishing Code of Practice was followed by both vessels throughout the 2000 to 2003 seasons, with one major exception. For most of the 2000 and 2001 seasons, spotted warehou (*Seriolella punctata*) heads were routinely discarded overboard from the processing deck, contrary to the stated practice of avoiding discarding of any offal on the fishing grounds. Warehou heads impart an undesirable colour and taint to fish-meal, lowering its market value. A stomach from one of the seals caught in 2001 was crammed with warehou heads, demonstrating that seals were actively feeding on such offal. From 2002 onwards, species or body-parts unsuitable for fish-meal were either macerated then discharged through the bilge pumps, or dumped away from the fishing grounds.

Observers recorded the number of seals around a vessel at the start of 524 (daylight) shots. Despite avoidance practices, seals were present at 10.9% (57) of these shots. In many of these instances seals appeared immediately after a shot had commenced. Groups of seals were regularly sighted on the fishing grounds and whereas the practice of steaming away from seals following a vessel was largely successful, chance encounters with roaming seals often occurred. In one instance, a group of 25 seals appeared off the bow of a vessel and made their way aft as the trawl doors hit the water. This was the highest seal count recorded when shooting the net, with most other counts being 1–3 seals only. It appears possible that seals can ‘hear’ or sense the sounds or vibrations associated with trawl operation and are attracted to a vessel when this occurs. Fishers speculated that seals “know when the (trawl) winches are being used”. The *FV Ocean Dawn* (2.5% seal occurrence when shooting) was much more effective at avoiding seals than the *FV Aoraki* (18.6%). Despite this difference, no relationship was found between the speed, direction or duration of avoidance movements and the incidence of seals when shooting the net. The overall effectiveness of avoidance movements can be measured against the much higher (79.4%) occurrence of seals when hauling the net.

The practices of steaming away from seals before shooting the net, and not discarding offal, effectively prevented ‘resident’ groups of seals building-up around the vessels. Most (95.2% in 2001 and 2002) of the daily seal counts (see Section 5.3) recorded at least one zero count during daylight hours.

As noted earlier, the need to work within the permits issued by EA/AFMA and minimize seal mortality meant that the effectiveness of avoidance practices could not be directly estimated by experimental procedure. However, some indication of the effectiveness of these practices can be derived from comparing the incidence of seal bycatch in 1999, when these practices were not in place, with that for 'normal' (i.e. 'no-SED') shots in 2000 to 2003. The seal bycatch in 1999 was not recorded against individual shot data, so bottom and midwater data have to be pooled for comparative purposes. Table 3 summarises these data. The fact that the 2000 to 2003 mean seal bycatch per shot (0.060) was 55% less than that in 1999 (0.131) indicates that avoidance practices have at least halved the incidence of seal bycatch.

Table 3. Comparison between 1999 and equivalent ('no-SED' shots) 2000–2003 seal bycatch data

Year	Shots	S.Shots	Incid	Dead	Alive	Surviv	Mean
1999	665	?	?	83	4	4.6	0.131
2000/03	921	50	5.4	46	9	16.4	0.060

Shots=No. of shots; S.Shots=No. of shots with seal bycatch; Incid.=Incidence (%) of seal shots; Dead=No. of dead seals; Alive=No. of live seals; Surviv.=Proportion (%) of seals released alive; Mean=Seal bycatch per shot.

5.3. Daily seal counts

Daily counts of seal numbers at the surface around vessels were successfully completed on 342 days during the 2000 to 2002 seasons. On each day counts were made in the morning (0800 hrs) and evening (1700 hrs) and on 93% of these days two counts around 1100 and 1400 hrs were also made. The remaining 7% of these days had one other count around either of these 1100 or 1400 hr times. Seal counts are summarized in Table 4. It should be noted that these counts were certainly influenced by the seal avoidance practices described above. For example, 95.2% of the 'count' days in 2001 and 2002 had at least one count when no seals were observed.

In all seasons there was wide variability in the number of seals observed around both vessels. As noted in Section 5.2, groups of foraging seals were frequently observed traveling across the fishing grounds and the seal avoidance practices effectively prevented a build-up of 'resident' seals around each vessel. Satellite tracking data (Section 5.6) also showed that individual foraging seals periodically left the fishing grounds to haul-out and rest at Reid Rocks or Hibbs Point. A relationship was also found between seal abundance around vessels and the proximity to these two haul-out sites. These factors should be borne in mind when examining seal counts for evidence of temporal variability or cycles.

***Diurnal variability**:* Fur seal species are primarily nocturnal feeders (Riedman 1990), but Australian fur seals forage during the day as well (S Goldsworthy, pers. com.). Attempts to conduct nocturnal counts were constrained by limited visibility, despite aft-deck lighting. Analysis of data for days on which all 4 counts were carried out found little evidence of any diurnal trends during daylight hours. The most complete continuous sets of counts were for the *FV Ocean Dawn* in 2001 and 2002 (Table 4) when 4 counts were completed on every day. The mean number of seals per count were as follows: 2001 (71 days – aggregate 578 seals) 0800 hrs – 1.77, 1100 hrs – 2.56, 1400 hrs – 2.11 and 1700 hrs – 1.69; 2002 (92 days – aggregate 1472 seals) 0800 hrs – 2.06, 1100 hrs – 2.24, 1400 hrs – 2.18 and 1700 hrs – 3.02. Whereas the 2001 data suggested that seal numbers peaked around noon, there was no such peak in the 2002 season when the highest numbers occurred around dusk. The overall (163 days – aggregate 2050 seals) means for both years were: 0800 hrs – 1.94, 1100 hrs – 2.38, 1400 hrs – 2.15 and 1700 hrs – 2.23. Note that avoidance procedures and fishing operations would have exerted strong influences on so-called 'diurnal' counts.

Table 4. Summary of seal counts around vessels, 2000–2002

Year	Month	Vessel	N	Min. 1	Max. 1	Min. 2	Max. 2	Mean	Zero
2000	June	A	22	0	16	0	22	6.1	?
		OD	0	-	-	-	-	-	-
	July	A	27	0	30	0	41	11.2	?
		OD	14	0	60	0	89	5.1	1
	Aug	A	27	0	30	0	35	14.1	?
		OD	4	0	10	0	10	4.7	1
2001	June	A	0	-	-	-	-	-	-
		OD	18	0	10	0	12	4.8	6
	July	A	20	0	12	0	15	4.2	5
		OD	29	0	15	0	22	5.3	9
	Aug	A	18	0	16	0	19	5.3	4
		OD	24	0	30	0	45	14.5	5
2002	June	A	0	-	-	-	-	-	-
		OD	17	0	15	0	23	7.2	5
	July	A	8	0	20	0	43	19.5	1
		OD	28	0	25	0	43	14.2	1
	Aug	A	28	0	23	0	49	10.0	6
		OD	28	0	25	0	39	10.0	8
	Sept	A	11	0	28	0	49	15.7	3
		OD	19	0	18	0	31	5.4	9

A=*Aoraki*, OD=*Ocean Dawn*, N=Number of days 3-4 counts were made, Min.1=Minimum single count, Max.1=Maximum single count, Min.2=Minimum cumulative daily total, Max.2=Maximum cumulative daily total[1], Mean=Mean total number of seals per day[1], Zero=Number of days when no seals were observed.

[1] Note that some seals may have been counted more than once during the day.

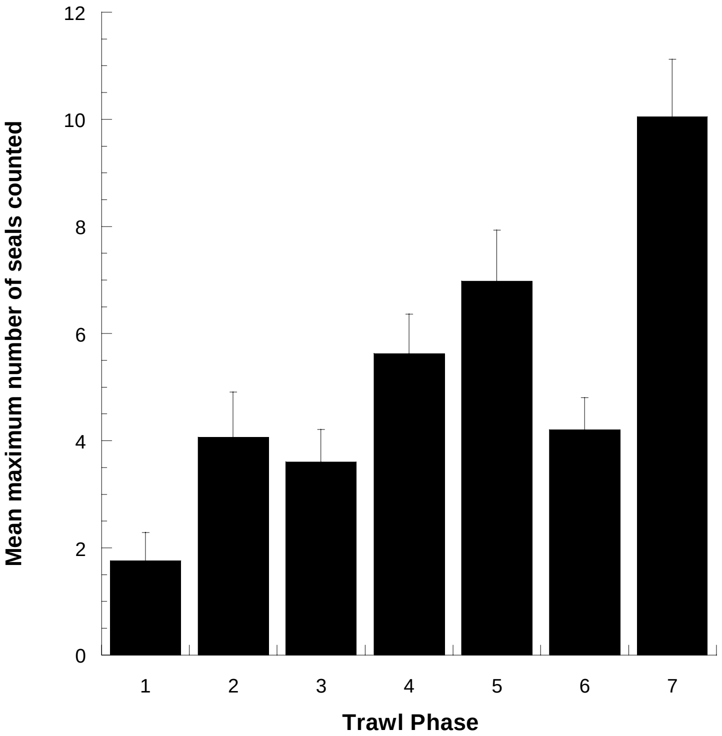
However, analysis of the variables influencing seal bycatch (Section 5.4) found shot end-time to be a significant factor, with the indicator of seal bycatch peaking at around mid-day for each vessel.

Seasonal variability: In all 3 seasons, seal counts were comparatively low in June. In 2000 and 2001 seal numbers increased as the season progressed, but in 2002 mean seal count values peaked in July (Table 4).

Inter-annual variability: If the counts were representative of comparative seal abundance, the number of seals on the fishing grounds did vary from year to year. Mean total daily seal count values for the 2000, 2001 and 2002 seasons were 16.1, 7.6 and 12.1, respectively. These comparative abundances were reflected in the incidences of seal bycatch in each year that were 0.117, 0.049 and 0.088 seals-per-shot, respectively (noting that SED effectiveness improved over this period, probably resulting in an increasing proportion of seal bycatch escaping the net unrecorded). Few seal counts were done in 2003, but the low (0.046) seal-per-shot value suggests that seal numbers were comparatively small during that season. The reason why seal numbers on the fishing grounds were comparatively low in 2001 (and probably 2003) is unclear. An observer noted that in late July and early August 2001 very large concentrations of redbait (*Emmelichthys nitidus*) were recorded at the heads of the canyons in depths of 160–180 m. As redbait are a preferred dietary item for Australian fur seals (Gales and Pemberton 1994, Goldsworthy *et al.* 2003), it is possible that foraging seals targeted these concentrations and did not venture out to the fishing grounds. Redbait were recorded in the stomachs of the limited seal bycatch in 2001 (see Section 5.5).

Influence of fishing operations: Whereas avoidance procedures minimized the number of seals around a vessel, fishing operations had the opposite effect and attracted foraging seals to a vessel. The number and timing of net shots would undoubtedly have influenced the number of seals counted during many ‘regular’ counts. This influence was strongest when the net was being hauled. As noted in Section 5.2, seals were recorded during 79.4% of hauling operations, as against only 10.9% of shooting operations.

During the 2003 season, seal numbers around the *FV Aoraki* were recorded more frequently by the observer (Derek Hamer) as part of his post-graduate study (Hamer 2004). Trawl operations were divided into 7 discrete phases and the maximum number of seals sighted at the stern of the vessel was recorded for each phase. Results are summarised in Figure 12.



Trawl phases; 1 Prior to net-shoot; 2 Net-shoot to doors released; 3 Doors released to start of trawl (net reaches trawl depth); 4 Trawling period; 5 Start of haul; 6 Haul to doors up; 7 Doors up to codend bag at surface.

Figure 12. Summary of seal counts during net operations

Seal numbers at the surface progressively increased during the trawl (Fig. 12) then declined sharply in phase 6, when the trawl doors came up to the stern of the ship. Seal numbers dropped during this phase, presumably because seals were diving to forage from the ascending net. Pemberton *et al.* (1994) also suggested that seals congregate some 200 m astern of the vessel and then dive prior to the net reaching the surface. This certainly occurred in the present study. The seals may be using visual or audio cues from the trawl doors (there is a lot of noise when the trawl doors hit the back of the ship) or winch operations. Phase 7 had the most seals present, which correlates with seals accompanying the codend to the surface prior to it being hauled up the stern ramp. Full analysis of the above graph, including ANOVA of mean maximums for each phase and multiple regression analysis to examine what factors contribute to seal numbers for each phase are described in Goldsworthy *et al.* (2003).

5.4. SED trials

SED use and seal bycatch are summarised in Table 5. The locations of shots containing seal bycatch are shown in Figures 8 to 11 (Section 5.1). Note that these locations have been placed in the centre of the trawl track concerned, irrespective of the time and place the seal actually entered the net. In virtually all instances seal bycatch would probably have occurred at the start or finish of the trawl track.

In 2001 the skippers of both vessels commented that a SED appeared to slow down the passage of fish into the codend. As the trawls have net-sensors that indicate the tonnage of fish caught, delays were experienced in the 'triggering' of such devices. This made it difficult to control the amount of fish entering the codend, particularly when targeting large schools ('marks') of fish. However, comparisons between the mean shot times for nets with and without a SED in 2000 showed little difference between *FV Aoraki* bottom shots and *FV Ocean Dawn* midwater shots (Table 1). The mean duration of *FV Ocean Dawn* bottom shots with a SED were actually 24% less than 'no-SED' shots. In 2001, the mean midwater (open) SED shot time was less than 'no-SED' shots for both vessels (Table 1). The greatest disparity occurred in 2002 when the mean time for *FV Ocean Dawn* midwater SED shots was 73% greater than that for 'no-SED' shots. However, there was little difference between respective *FV Aoraki* values in 2002. Comparisons between respective mean catch weights for SED and 'no-SED' shots (Table 1) also did not find any consistent differences during 2000 to 2003.

Table 5. Summary of seal bycatch, 2000–2003

Year	Boat	Gear	SED	Shots	S.Shts.	Incid.	Dead	Alive	Mean	Surviv.
2000	A	B	NS	31	3	9.7	3	0	0.097	0
			SO	94	7	7.4	4	5	0.095	55.6
		MW	NS	7	0	0	0	0	-	-
			SO	119	16[1]	13.4	7	20[1]	0.227	74.1
	OD	B	NS	93	3	3.2	1	2	0.032	66.6
			SO	28	5	17.9	1	4	0.179	80.0
		MW	NS	16	3	18.7	3	0	0.187	0
			SO	65	3	4.6	3	0	0.046	0
2001	A	B	NS	51	1	2.0	0	1	0.020	100.0
			SO	19	0	0	0	0	-	-
			SC	42	2	4.8	2	0	0.048	0
		MW	NS	79	4[2]	5.1	4[2]	0	0.051	0
			SO	21	0	0	0	0	-	-
			SC	37	4	10.8	4	0	0.108	0
	OD	B	NS	59	1	1.7	1	0	0.017	0
			SO	41	0	0	0	0	-	-
			SC	40	1	2.5	1	0	0.025	0
		MW	NS	34	2	5.9	2	0	0.059	0
			SO	48	8[3]	16.6	7[3]	1	0.166	12.5
			SC	30	3	10.0	3	0	0.100	0
2002	A	B	NS	81	4	4.9	2	2	0.049	50.0
			SO	2	0	0	0	0	-	-
		MW	NS	102	4	3.9	4	0	0.039	0
			SO	81	10[4]	12.3	7[4]	7	0.173	50.0
	OD	B	NS	125	6	4.8	5	1	0.048	16.7
			SO	10	2	20.0	0	2	0.200	100.0
		MW	NS	58	12	20.7	16	0	0.276	0
			SO	98	3[5]	3.1	3[5]	0	0.031	0
2003	A	B	NS	35	2	5.7	0	2	0.057	100.0
		MW	NS	106	4	3.8	5	0	0.047	0
			SC	101	6	5.9	5	3	0.079	37.5
	OD	B	NS	44	1	2.5	0	1	0.025	100.0
		MW	NS	0	-	-	-	-	-	-
			SO	197	6	3.0	5	1	0.030	16.7

[1] Not including an aborted shot which caught and released 6 seals [2] Not including an aborted shot which drowned 3 seals

[3] Including 2 shots with a seal that passed through a broken grid [4] Including 2 shots with a juvenile seal that passed through grid bars

[5] Including 1 shot with a juvenile seal that passed through grid bars

A=*Aoraki*; OD=*Ocean Dawn*; Gear – B=Bottom trawl, MW=Midwater trawl; SED status – NS=No SED, SO=Open SED, SC=Closed SED; Shots=No. of shots; S.Shts=No. of shots with seals; Incid.=Incidence (%) of seal shots; Dead=No. of dead seals; Alive=No. of live seals; Mean=Seals per shot; Surviv.=Percentage (%) of seals released alive.

Analyses of seal bycatch data in mid-water shots

The backward stepwise regression reduced the number of model variables (Figures 13–17). In a number of cases the need for a smoothing function to improve the fit was found not to be significant and a linear regression was fitted instead (Figures 13, 15 and 16). The final models (i.e. models resulting from the stepwise procedure) explained only a relatively small amount of deviance yet their statistical effect was significant (Table 6).

The relative effects of different variables and factors upon seal bycatch rates are presented in Figures 14 and 17. In each figure, the solid trend line represents the mean relative effect of the variable upon catch rates, while the dashed lines either side of the mean represent the margin of error or uncertainty. These error margins tend to increase or "fan out" when there is little underlying data upon which the mean line is calculated. Thus the following description of data trends only attempts to infer trends where these error bounds are small (i.e. close to the mean line).

The use of several SED designs (e.g. the 'Fowler' Mk 1 and 2) by *FV Aoraki* in 2001 led to high variance and uncertainty in the open SED (SO) data for 2001, so this data set was discarded in the final analysis for that vessel (Fig. 16 and Fig. 17).

Table 6. Comparison of the final backward stepwise regression with the null and full models (see Methods for full model) for *FV Ocean Dawn* and *FV Aoraki* midwater trawl shots (*Aoraki* open SED data for 2001 was removed).

	Residual degrees of freedom	**Residual deviance**	**Change in degrees of freedom**	**Change in deviance**	**P value of Chi test**
FV Ocean Dawn					
Null model	545.00	286.09			
Final model[1]	515.39	195.78	29.61	90.31	<0.001
Full model	496.23	183.38	19.15	12.40	0.87
FV Aoraki					
Null model	631.00	354.51			
Final model[2]	618.02	318.71	12.98	35.80	<0.001
Full model	584.38	291.67	36.63	27.04	0.88

Final model[1] is of the form:

PA~Year+EndLat+s(Duration)+s(EndTime)+SED+Depth+DistA+DistB+s(log(Warehou))+s(log(Other))

Final model[2] is of the form:

PA~s(EndTime)+SED+s(Depth)+s(log(Warehou))

The full model is presented in the methods (Section 4.4)

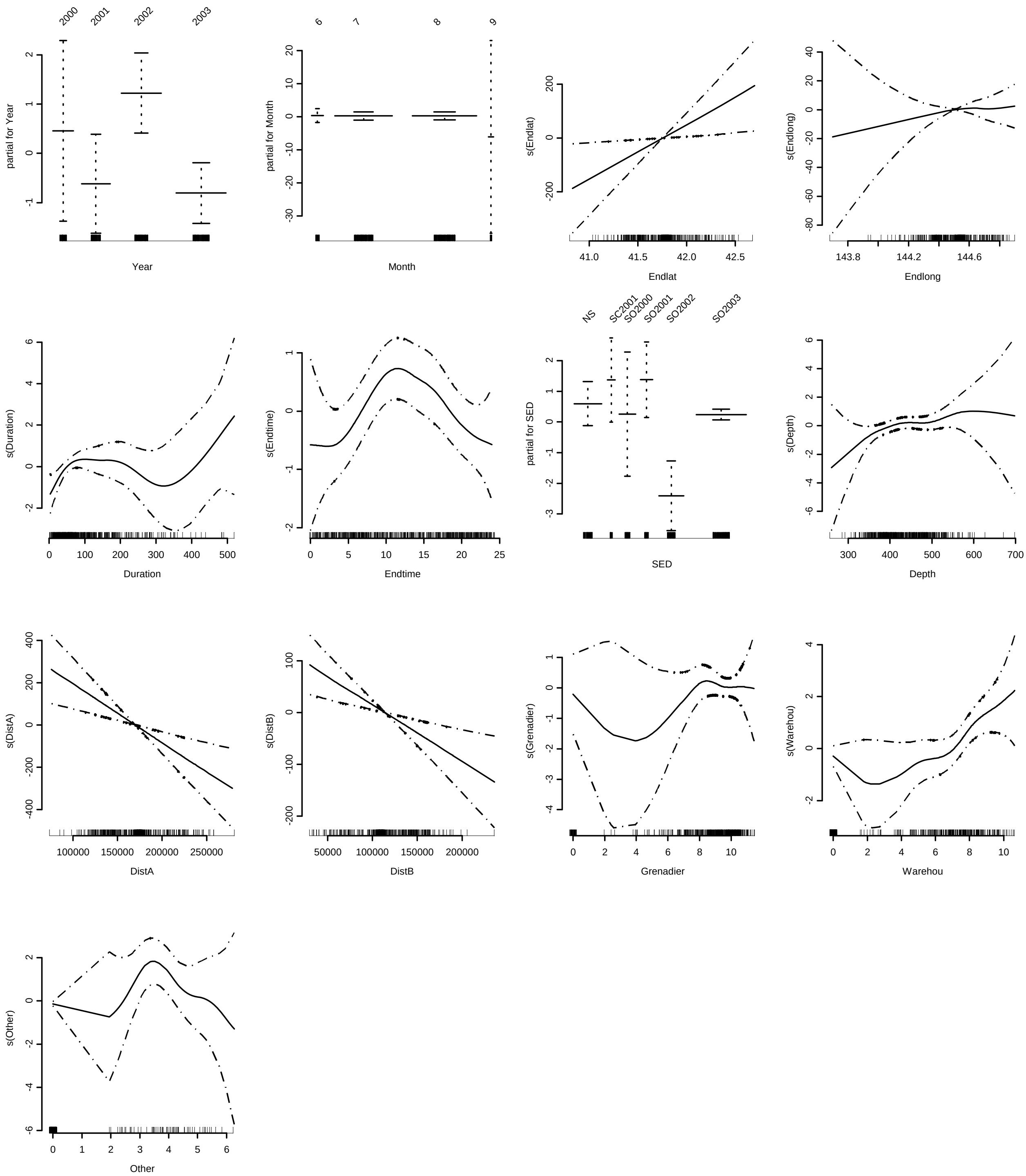


Figure 13. Full GAM model for occurrence of seals in mid-water trawls shot by *FV Ocean Dawn*

The strokes on the *x* axis represent individual shots. X axis units are as follows; Duration – minutes, Endtime – hours, Depth, DistA and DistB – metres, Grenadier, Warehou and Other (sps) – tonnes.

Refer to methods (Section 4.4) for full model.

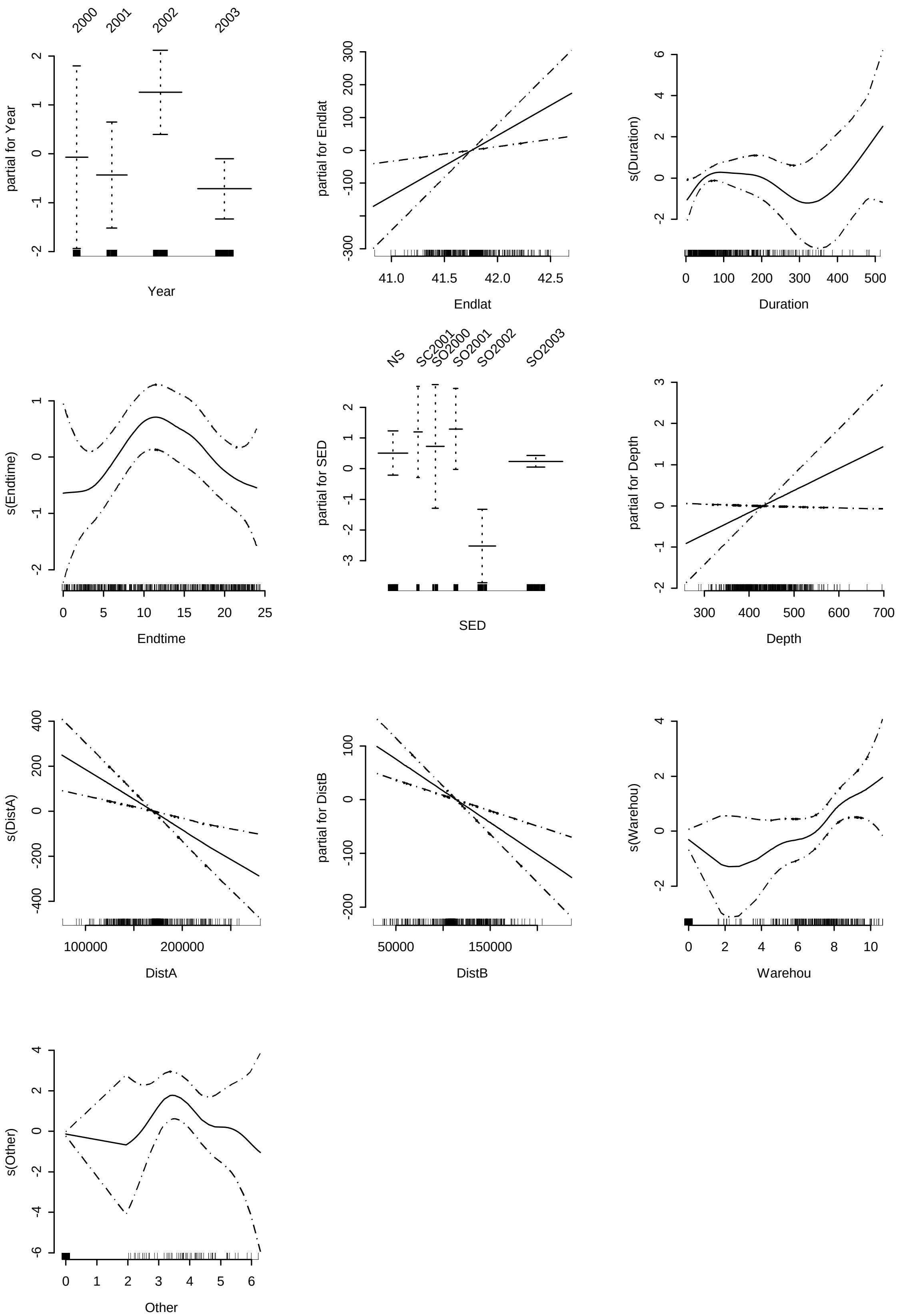


Figure 14. Final GAM model for occurrence of seals in mid-water trawls shot by *FV Ocean Dawn* (based on backwards elimination of variables shown in Figure 13 using SPLUS).

See Figure 13 for x axis values.

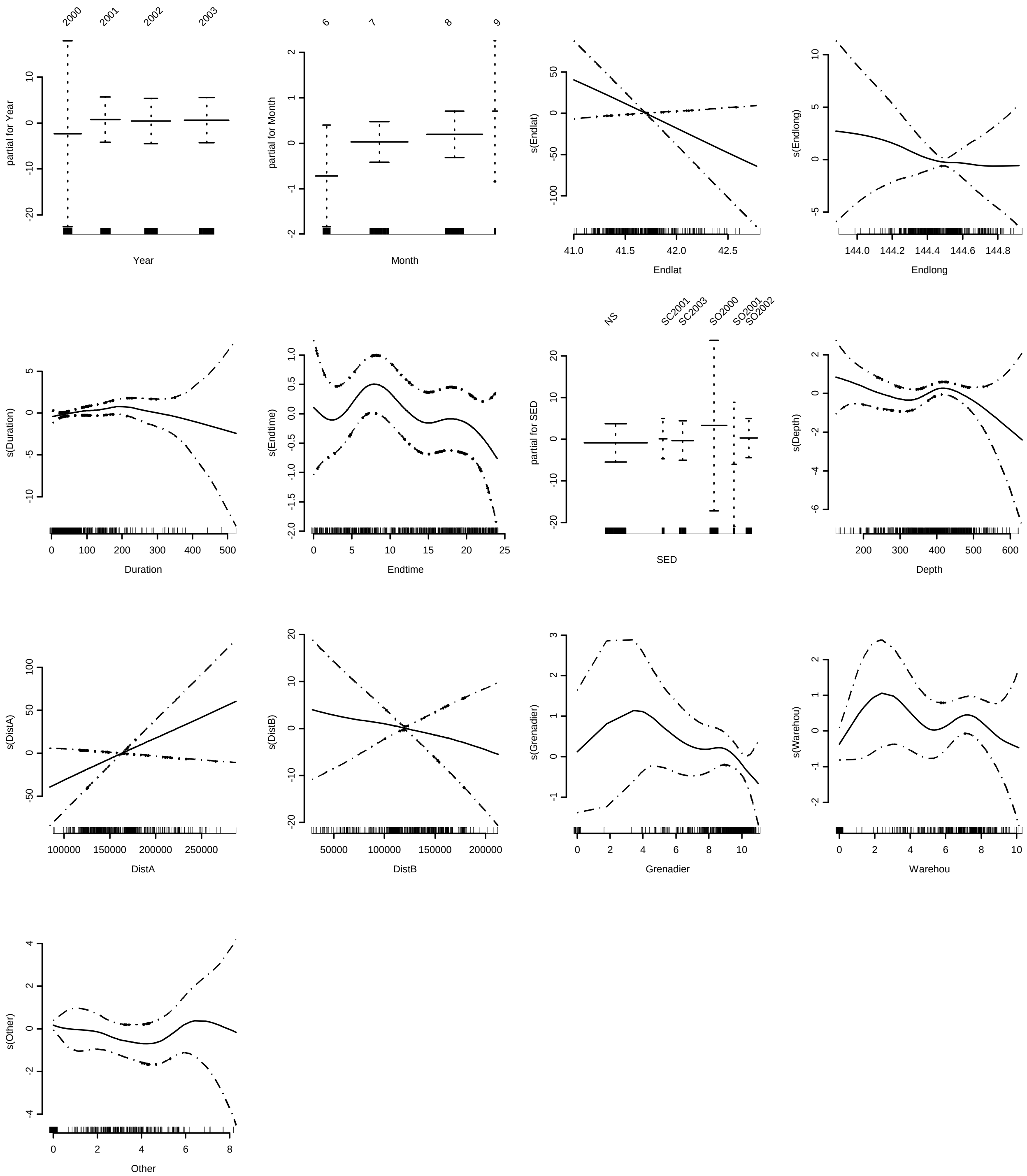


Figure 15. Full GAM model for occurrence of seals in mid-water trawls shot by *FV Aoraki*

See Figure 13 for x axis values.

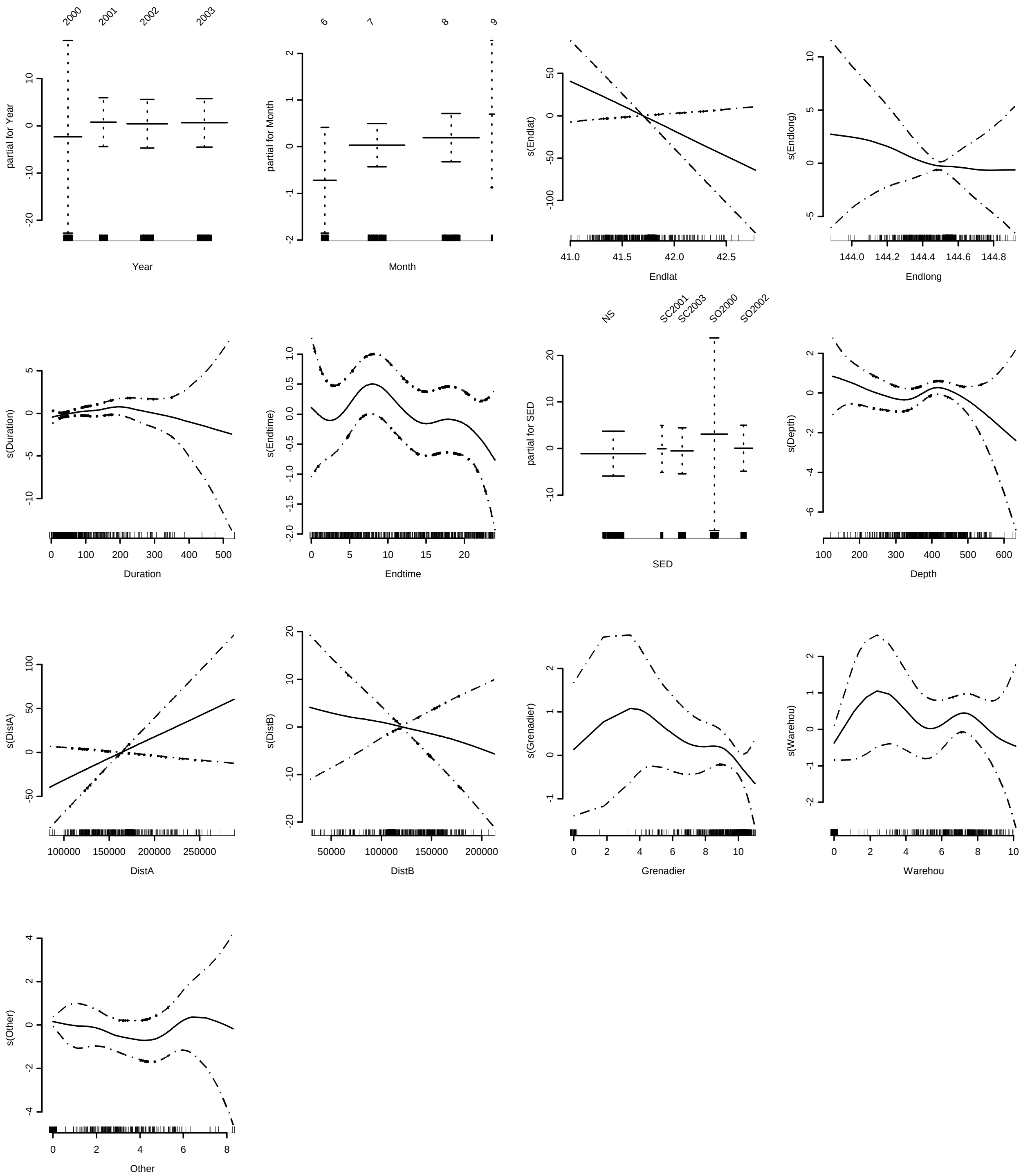


Figure 16. Full GAM model for occurrence of seals in mid-water trawls shot by *FV Aoraki* where the data for open SEDs in 2001 was removed.

See Figure 13 for x axis values

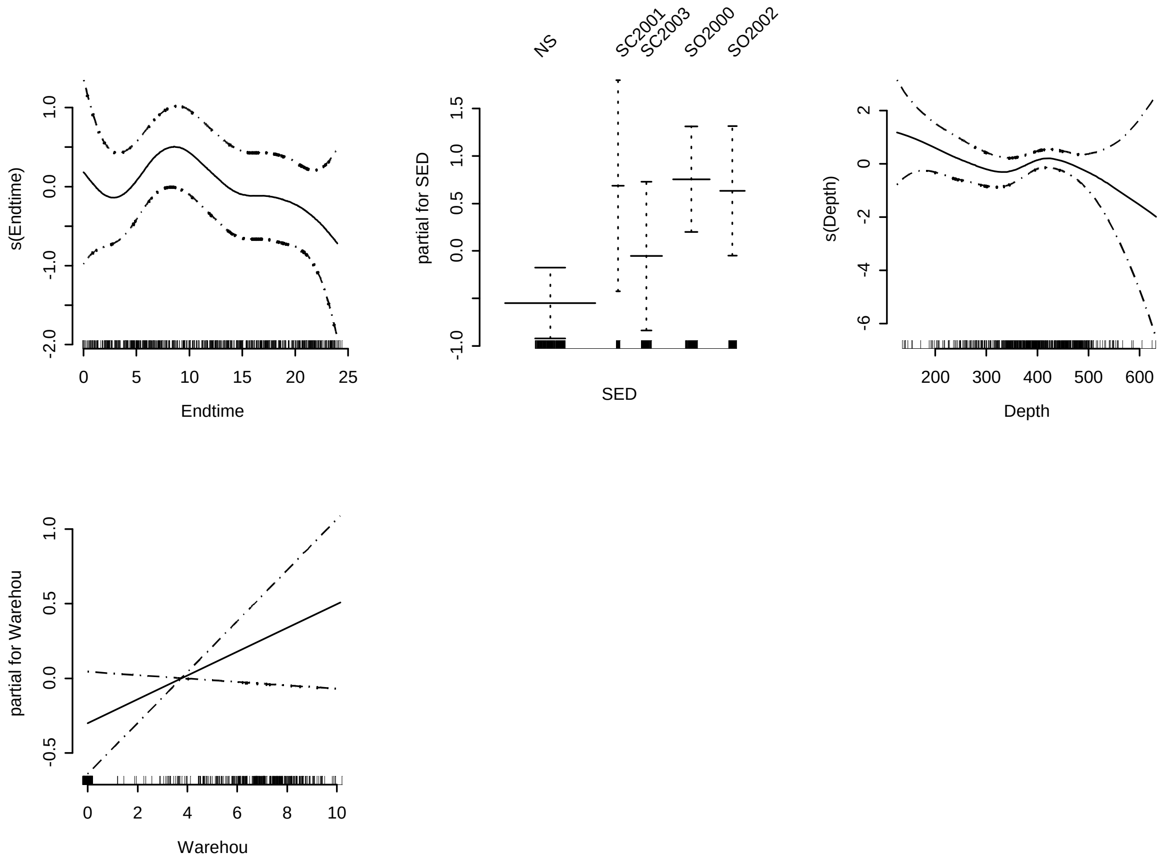


Figure 17. Final GAM model for occurrence of seals in mid-water trawls shot by *FV Aoraki* where the data for open SED design in 2001 was removed. (based on backwards elimination of variables shown in Figure 16 using SPLUS)

See Figure 13 for x axis values.

5.5. Seal biological data

This part of the report describes the biological data obtained from seal mortalities during the 2000, 2001 and 2002 seasons.

5.5.1. Species, sex and age-composition of seal bycatch

Table 7. details information collected from 88 seals drowned during the 2000–2002 seasons. Some biological samples (head and stomach) were lost in transit between Hobart and La Trobe University and these are shown in the final 'Missing' column.

Species

Table 7 includes information on the nominal species identification given to drowned seals. All were identified as Australian fur seals (*Arctocephalus pusillus doriferus*), although for two individuals there was some doubt. As species identification, especially of smaller seals, can be difficult (even for experts), it is possible that New Zealand fur (*A. forsteri*) seals could contribute to a small part of the bycatch. One seal, (live caught and released, *Ocean Dawn* 13 August 2001, shot 217), was believed to have been a male New Zealand fur seal.

Table 7. Summary of biological data obtained from seals drowned in the blue grenadier freezer-trawler fishery off western Tasmania during the 2000, 2001 and 2002 season

Date	Boat	Trawl type	Shot #	SED	Species	Sex	Length (cm)	Girth (cm)	Wt (kg)	Dead No.	Head	Stomach	Missing
17-Jun-00	A	MW	26		AFS	F	145		110	1	+	+	
18-Jun-00	A	BT	30		AFS	M	185	154	187	2			
20-Jun-00	A	BT	37		AFS	M	210	143	193	3			
20-Jun-00	A	BT	38	SED	AFS	M	167			4	+	+	
26-Jun-00	A	BT	61		AFS	M	244	151	220	5	+	+	
04-Jul-00	A	MW	88		AFS	M	200		192.5	6	+	+	
13-Jul-00	A	MW	121	SED	AFS	M	220			7			
14-Jul-00	A	MW	124	SED	AFS	M	191			8			
17-Jul-00	OD	MW	100		AFS	M	210	160	235	9	+	+	
17-Jul-00	A	MW	134		AFS	M	199			10			
18-Jul-00	OD	BT			AFS	M	204			11			
24-Jul-00	OD	MW			AFS	M	202			12			
29-Jul-00	A	BT	5	SED	AFS	M	165	135		13	teeth		
31-Jul-00	OD	BT		SED	AFS	-	162			14			
07-Aug-00	OD	MW		SED	AFS	F	155			15			
09-Aug-00	OD	MW		SED	AFS	F	136			16			
23-Aug-00	OD	MW			AFS	M	205			17			
24-Aug-00	OD	MW		SED	AFS	M	136			18			
24-Aug-00	A	MW	86	SED	AFS	M				19			
24-Aug-00	A	MW	86	SED	AFS	M				20			
24-Aug-00	A	MW	86	SED	AFS	M				21			
27-Aug-00	A	BT	97	SED	AFS	M	200			22	teeth		
22-Jun-01	A	MW	71	NS	AFS	F	158	116	110	1	+	+	+
23-Jun-01	A	BT	76	SC	AFS	M	201	151	210	2	+	+	
27-Jun-01	OD	BT	54	SC	AFS	M	184	148	220	3	+	+	+
02-Jul-01	A	MW	108	SC	AFS?	M	160	130	140	4	+	+	
06-Jul-01	OD	MW	86	SO	AFS	M	191	163	210	5	+	+	+
08-Jul-01	A	BT	132	SC	AFS	M	191	140	180	6	+	+	+
08-Jul-01	A	MW	133	SC	AFS	M	203	150	190	7	+	+	
08-Jul-01	A	MW	136	SC	AFS	M	206	163	190	8	+	+	
14-Jul-01	OD	MW	105	SO	AFS	M	179	128	170	9	+	+	
20-Jul-01	OD	MW	130	NS	AFS	M	182	134	185	10	+	+	
26-Jul-01	OD	MW	155	NS	AFS	M	222	164	260	11	+	+	
26-Jul-01	A	MW	21	SC	AFS	M	198	132	185	12	+	+	
30-Jul-01	OD	MW	175	SC	AFS	M	193	142	147	13	+	+	
30-Jul-01	A	MW	35	NS	AFS	M	157	111	95	14	+	+	
01-Aug-01	A	Abort	-	NS	AFS	M	213	176	265	15	+	+	
01-Aug-01	A	Abort	-	NS	AFS	M	213	165	270	16	+	+	
01-Aug-01	A	Abort	-	NS	AFS	M	198	137	210	17	+	+	
01-Aug-01	A	MW	41	NS	AFS	M	197	132	~195+	18	+	+	
06-Aug-01	OD	MW	192	SC	AFS?	M	171	134	155	19	+	+	+
08-Aug-01	OD	MW	196	SO	AFS	M	164	127	130	20	+	+	+

Date	Boat	Trawl type	Shot #	SED	Species	Sex	Length (cm)	Girth (cm)	Wt (kg)	Dead No.	Head	Stomach	Missing
10-Aug-01	A	MW	71	NS	AFS	M	168	130		21	+	+	
11-Aug-01	OD	MW	210	SC	AFS	M	197	176	270	22	+	+	+
14-Aug-01	OD	MW	220	SO	AFS	M	157	111	145	23	+	+	+
14-Aug-01	OD	MW	220	SO	AFS	M	195	153	190	24	+	+	+
15-Aug-01	OD	MW	223	SO	AFS	M	230	179	310	25	+	+	+
16-Aug-01	OD	BT	224	NS	AFS	M	211	215	320	26	+	+	+
16-Aug-01	OD	BT	224	NS	AFS	M	167	126	130	27	+	+	+
19-Aug-01	OD	MW	234	SO	AFS	M	153	108	130	28	+	Partial	+
24-Aug-01	OD	MW	252	SO	AFS	M	202	138	140	29	+	+	+
17/06/2002	OD	BT	16	NS	AFS	M	178	138	160	1	*	*	
19/06/2002	OD	BT	24	NS	AFS	M	208	142	250	2	*	*	
22/06/2002	OD	BT	33	NS	AFS	M	204	195	290	3	*	*	
26/06/2002	A	BT	46	NS	AFS	M	207			4	*	*	
27/06/2002	A	BT	50	NS	AFS	M	204			5	*	*	
04/07/2002	A	MW	72	NS	AFS	M	170		150	6	*	*	
18/07/2002	OD	MW	108	NS	AFS	M	187	165	250	7	*	*	
19/07/2002	OD	MW	110	NS	AFS	M	202	183	350	8	*	*	
19/07/2002	OD	MW	110	NS	AFS	M	179	143	195	9	*	*	
19/07/2002	OD	MW	111	NS	AFS	M	207	164	265	10	*	*	
26/07/2002	A	MW	4	NS	AFS	M	166	117	110	11	*	*	
27/07/2002	OD	MW	136	NS	AFS	M	215	161	225	12	*	*	
27/07/2002	OD	MW	136	NS	AFS	M	181	132	205	13	*	*	
27/07/2002	OD	MW	137	NS	AFS	F	169	129	185	14	*	*	
27/07/2002	OD	MW	137	NS	AFS	M	178	117	180	15	*	*	
28/07/2002	OD	MW	139	NS	AFS	M	191	150	295	16	*	*	
31/07/2002	A	MW	16	NS	AFS	M	180	130	140	17	*	*	
04/08/2002	A	MW	26	SO	AFS	M	173	125	130	18	*	*	
04/08/2002	OD	MW	154	SO	AFS	M	143	109	70	19	*	*	
06/08/2002	A	MW	33	SO	AFS	M	145	100	80	20	*	*	
08/08/2002	OD	MW	166	NS	AFS	M	189	145	190	21	*	*	
08/08/2002	A	MW	37	SO	AFS	M	170	118	120	22	*	*	
10/08/2002	OD	BT	176	NS	AFS	M	172	121	165	23	*	*	
10/08/2002	A	MW	44	NS	AFS	M	168	141	170	24	*	*	
13/08/2002	OD	MW	185	NS	AFS	M	142	136	105	25	*	*	
13/08/2002	OD	MW	187	SO	AFS	M	189	171	270	26	*	*	
18/08/2002	A	MW	76	SO	AFS	M	185	149	180	27	*	*	
18/08/2002	OD	MW	206	NS	AFS	M	191	147	255	28	*	*	
19/08/2002	OD	MW	210	NS	AFS	M	171	147	205	29	*	*	
19/08/2002	OD	MW	210	NS	AFS	M	186	179	255	30	*	*	
20/08/2002	OD	MW	213	NS	AFS	M	212	175	320	31	*	*	
21/08/2002	OD	MW	218	NS	AFS	M	183	138	185	32	*	*	
22/08/2002	OD	MW	221	NS	AFS	M	182	142	220	33	*		
26/08/2002	OD	MW	234	SO	AFS	M	186	134	215	34	*	*	
02/09/2002	A	MW	30	SO	AFS	M	202	142	230	35	*	*	

Date	Boat	Trawl type	Shot #	SED	Species	Sex	Length (cm)	Girth (cm)	Wt (kg)	Dead No.	Head	Stomach	Missing
03/09/2002	A	MW	32	SO	AFS	M	178	120	140	36	*	*	
03/09/2002	A	MW	32	SO	AFS	M	210	161	270	37	*	*	

Sex ratio

Of 87 seals caught over three fishing seasons, the majority were male (94%), with only 5 (6%) females being caught (Table 8). Although the strong bias towards male bycatch was highly significant (X^2 = 68.1, P<0.001), most (3 out of 5) of the females were caught in the 2000 season (Table 8). Despite this, the ratio of females to males in the bycatch did not differ significantly among the three years (G-test, G_{adj} = 2.6, P>0.05). Two females that were autopsied were pregnant (one in 2000 and one in 2002), and probably lactating with a dependent offspring at a breeding colony. These females most likely originated from the nearest Australian fur seal breeding colony at Reid Rocks (south-east of King Island, approximately 120 km from the main fishing ground).

Table 8. Details on the sex composition of Australian fur seal bycatch across three seasons in the winter grenadier fishery off western Tasmania

Year	Females	Males	Total sexed
2000	3 (14%)	18 (86%)	21
2001	1 (3%)	28 (97%)	29
2002	1 (3%)	36 (97%)	37
Combined	5 (6%)	82 (94%)	87

Length and age frequency

Standard length (straight-line measure from tip of nose to tip of tail) data are available for 85 drowned Australian fur seals from the 2000, 2001 and 2002 seasons (Table 7). The mean length was 185.9 cm (sd = 22.3). A length-frequency distribution for these seals from the three seasons is presented in Figure 18. There was no significant difference in the mean standard length of seals caught between seasons (ANOVA $F_{2,82}$ = 0.391, P = 0.678, all Fisher's pair-wise comparisons P>0.05; 2000 mean = 185.3 ± 30.7 n = 18, 2001 mean = 188.7 ± 21.1 n = 30, 2002 mean = 183.9 ± 18.6 n = 37).

Based on a logistic equation to convert standard length to age developed for male Australian fur seals developed by Arnould and Warneke (2002, based on data from known-age animals 1970–1972), the ages of caught seals were estimated from their standard length (SL) as follows:

$$Age = i + \frac{\ln(\frac{a}{SL} - 1)}{-k},$$

where i (theoretical age 0) = 0.88, a (asymptotic length) = 220.8 and k (rate of increase/change) = 0.3. For seals longer than 220.8 cm, their age was categorized as +20. Based on these estimates, the mean age of captured seals was 7.5 years (sd = 3.9, n = 85) (Fig. 19), and there was no significant difference between the estimated ages of animals drowned between years (ANOVA $F_{2,82}$ = 1.007, P = 0.370, all Fisher's pair-wise comparisons P>0.05). Most estimated ages ranged from 2–13 years, there were, however, a few animals with estimated age greater than 20 years (Fig. 19). As such, animals from most age classes contribute to the seal bycatch, including juveniles (2–4 years), subadults (5–7 years) and adult males (8+ years), with the majority of captured seals being composed of sub-adult males.

Canine teeth obtained from 17 seals caught during the 2000 and 2001 seasons were subject to a direct aging method based on counting tooth dentine growth layer groups (GLGs). Teeth were analysed at Massey University (Institute of Veterinary, Animal and Biomedical Sciences, New Zealand), via a sectioning and acid etching process (Fig. 20). The mean estimated age of these samples was 7.5 years (sd = 2.4). There was no significant difference between the mean estimated age of captured seals based on teeth and standard length measurements (t = 0.12, df = 100, P = 0.990).

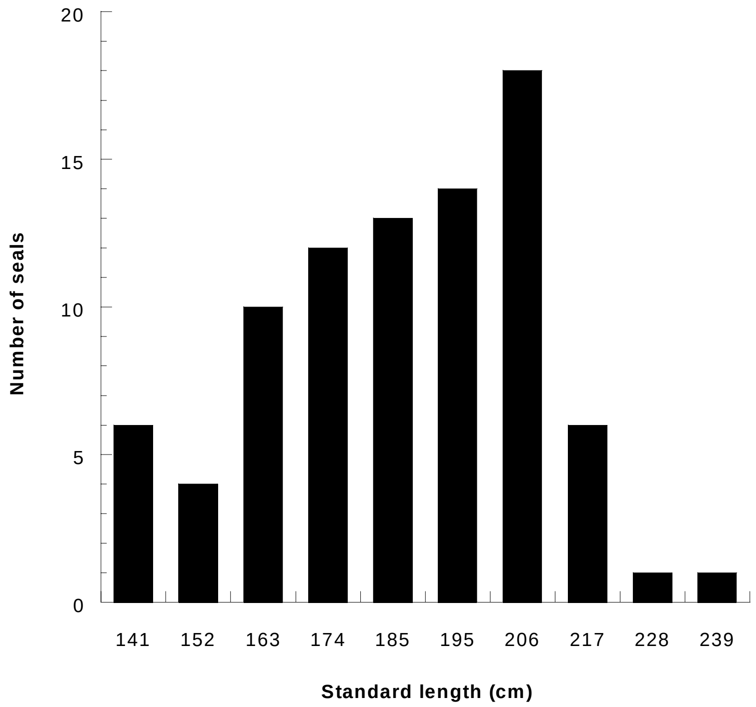


Figure 18. Length-frequency distribution of 85 Australian fur seals drowned during the 2000, 2001 and 2002 seasons

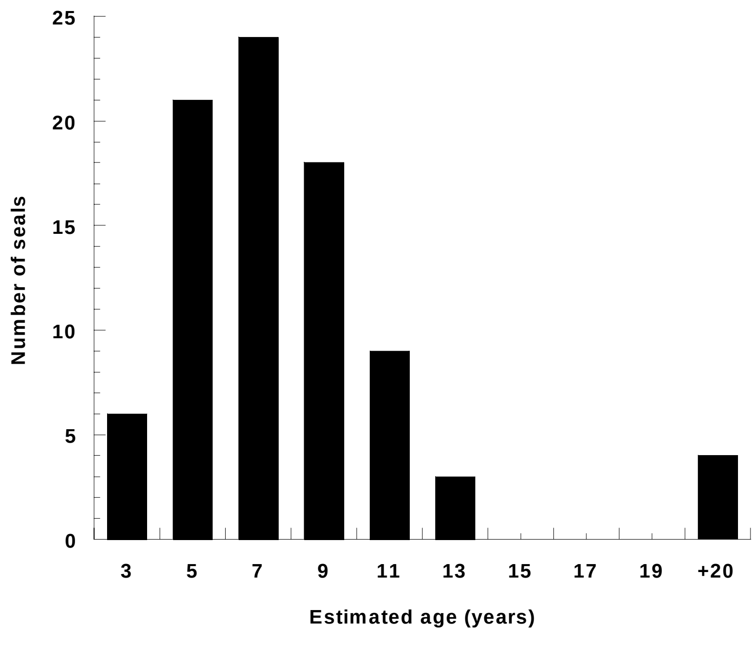


Figure 19. Estimated age frequency distribution based on the standard lengths of 85 Australian fur seals drowned during the 2000, 2001 and 2002 seasons

Figure 20. Section through a canine tooth of a bycatch seal after acid etching showing the contrasting dentine and cementum layers (see arrows) corresponding to growth layer groups that are used to estimate the age of seals

5.5.2. The diet of seals feeding in association with the fishery

A total of 50 stomachs recovered from drowned Australian fur seals from the 2000 (8), 2001 (17) and 2002 (25) seasons have been processed to examine their contents (Table 7). Stomach contents weighed on average 2.71 kg, but varied greatly from 0.07 to 16.39 kg (sd = 3.53). Prey remains varied in the extent of digestive state from fresh, to partial and complete digestion. According to their digestive state, fresh and undigested items within a stomach sample were categorised as *net* feeding, indicating prey items consumed in the net immediately before drowning. Those that were somewhat digested were catagorised as *prior*. The prey may have been consumed in *prior* trawls or independent of the fishery.

The most numerous prey species in terms of frequency of occurrence (FOO) and biomass was blue grenadier (66 and 55%, respectively), followed by four other species (spotted warehou, redbait (*Emmelichthys nitidus*), silver dory (*Cyttus australis*) and Gould's squid (*Nototodarus gouldi*)) that were periodically recovered (Table 9). The remaining three species (frostfish (*Lepidopus caudatus*), yellowtail mackerel (*Trachurus novaezelandiae*) and octopus (unidentified species)) were only incidentally recovered (Table 9).

Inter-seasonal differences

The variation in percentage biomass of prey species over three years is presented in Figure 21. Blue grenadier was the most numerous prey species in all years. Despite some variation in the prey biomass composition and the absence of some prey species in some years (eg. redbait and silver dory), there was no significant difference in prey biomass composition across years (analysis of similarity, ANOSIM, R = 0.058, P = 0.137), although pair-wise comparisons between years indicated a significant difference in diet between 2001 and 2002 (ANOSIM, R = 0.113, P = 0.015) (Fig. 21).

Net feeding and prior feeding

There was a significant difference in the prey biomass composition of *net* and *prior* samples (ANOSIM, R = 0.203, P = 0.004), suggesting that blue grenadier and silver dory were more prevalent in *net* samples and redbait and squid were more prevalent in *prior* samples (Fig. 22). However, grenadier was still the most abundant species in *prior* samples.

Results from dietary analysis indicate that seals feeding within the fishing ground are targeting the trawling operation to feed on commercially targeted species (blue grenadier, spotted warehou). The similarities between *net* and *prior* samples for these two species, gives strong evidence that seals attracted to the fishing grounds are there to feed principally on the contents of trawls. There is little evidence to support that any substantive foraging is undertaken away from trawling operations by bycatch seals, as the predominant prey item in both *net* and *prior* samples was blue grenadier, which can only be accessed by seals when brought into their diving range through net-feeding during trawling operations.

In contrast, dietary studies undertaken at Reid Rocks, the nearest breeding colony of Australian fur seals to the grenadier fishing grounds, have shown that leatherjackets, redbait, red cod and jack mackerel are the most important prey species (Hume *et al.* in press). Only redbait predominate in both fishery and land-based dietary analyses. Clearly, most prey species targeted by seals within the fishing ground are predominantly deep sea species, and these differ from the shallower pelagic and demersal species preyed on by Australian fur seals feeding on the continental shelf.

Table 9. Percentage frequency of occurrence (FOO) and reconstructed biomass of prey items recovered from the stomachs of Australian fur seals caught as bycatch in the 2000–2002 seasons

Prey species	% FOO	% Biomass
Blue grenadier	66.0	54.8
Spotted warehou	26.0	14.7
Redbait	14.0	11.7
Silver dory	14.0	8.6
Gould's squid	16.0	8.5
Frostfish	2.0	0.7
Yellowtail Mackerel	2.0	0.5
Octopus	2.0	0.5

One stomach examined from the 2001 season contained 36 spotted warehou heads (Fig. 23) indicating that the seals had fed on factory discards prior to drowning. Warehou heads impart a dark colouration to fishmeal, lowering its value, and were the only waste discarded. This is the first direct stomach evidence of seals feeding on discards within this fishery, although Cawthorn (pers com.) had reported surface feeding seals consuming warehou heads during the 2000 season. After 2001, warehou heads were retained onboard and discarded away from the fishing grounds.

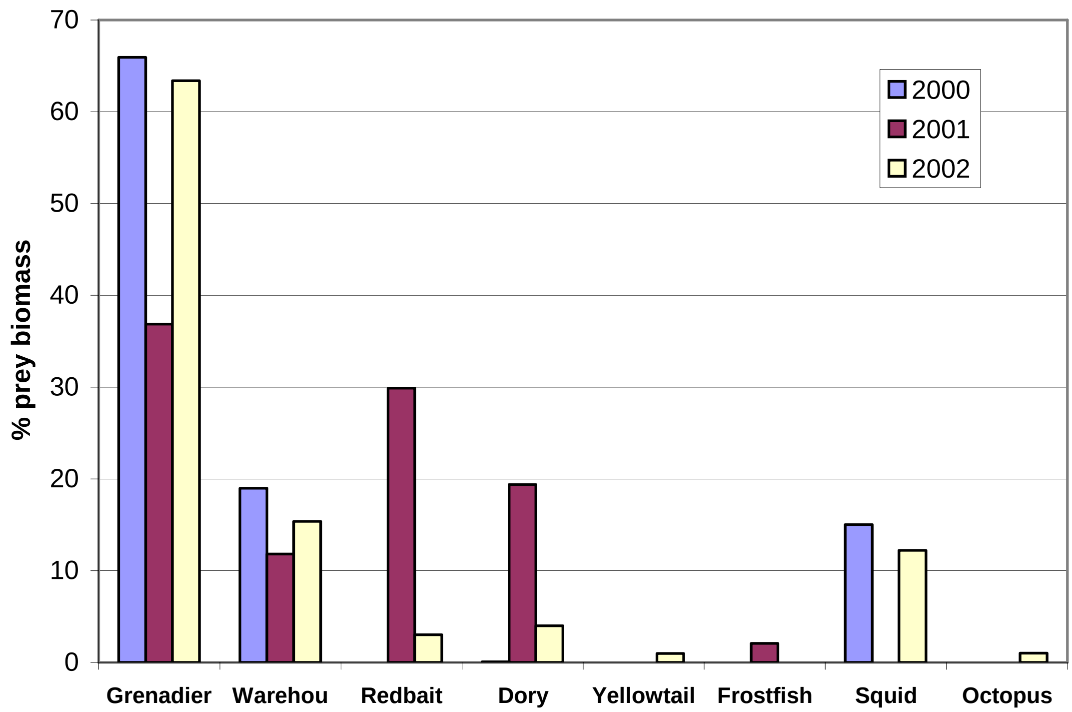


Figure 21. The estimated importance of prey species expressed as a proportion of total prey biomass, based on the presence of otoliths and cephalopod beaks obtained from the stomachs of Australian fur seals drowned in the 2000, 2001 and 2002 seasons

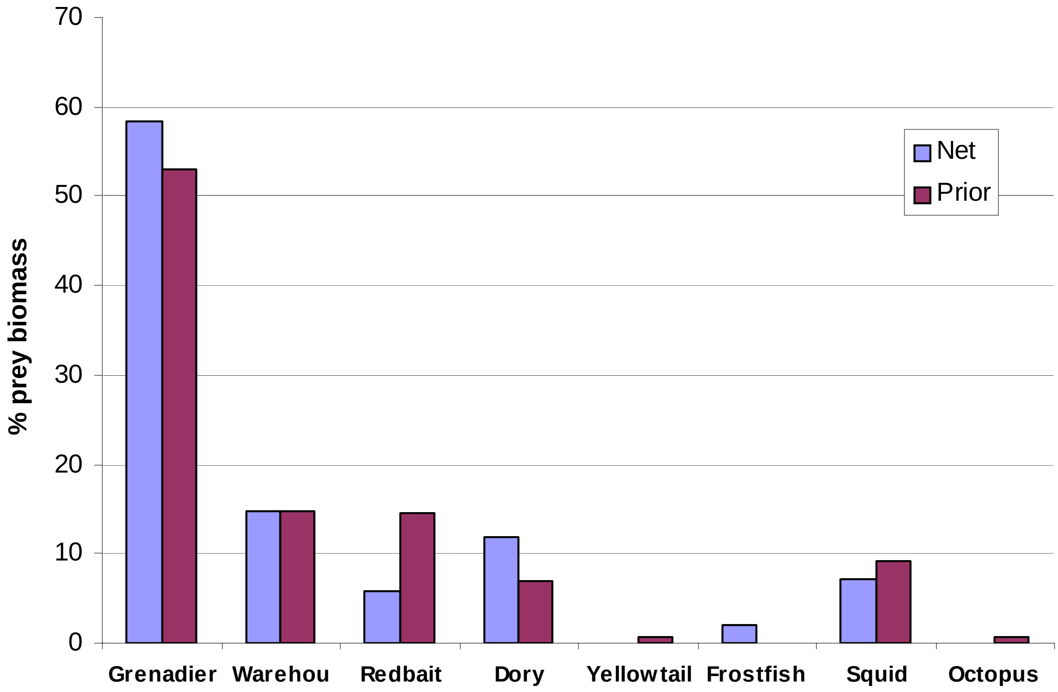


Figure 22. The estimated importance of prey species expressed as a proportion of total prey biomass, in net and prior samples from the stomachs of Australian fur seals drowned in the 2000, 2001 and 2002 seasons

Figure 23. Examples of stomach contents of bycatch Australian fur seals. Left, a stomach from the 2001 season containing 36 warehou heads, all neatly cut indicating that the seal had fed on factory discards prior to drowning. Right, more typical stomach containing fresh prey remains of blue grenadier and frostfish.

5.6. Seal movements

Nine satellite transmitters were successfully attached, three during the 2002 season and six during the 2003 season. Release dates and the size and age of tagged seals are summarised in Table 10.

Table 10 Summary of capture/release dates and the size (cm) and age (years) of tagged seals

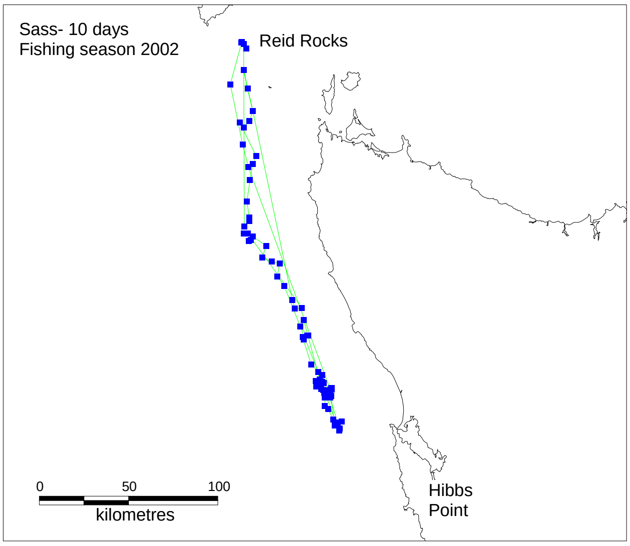
Capture date	Name	Length	Girth	Estimated age
26-Jul-02	Sass	192	148	7
28-Jul-02	Jack	177	127	6
28-Jul-02	Jimmy	208	152	10
20-Jul-03	Jayden	190	155	7
20-Jul-03	Ken	190	155	7
20-Jul-03	Pete	189	158	7
20-Jul-03	Neil	220	163	20
21-Jul-03	Dave	205	174	9
26-Jul-03	Garry	188	130	7

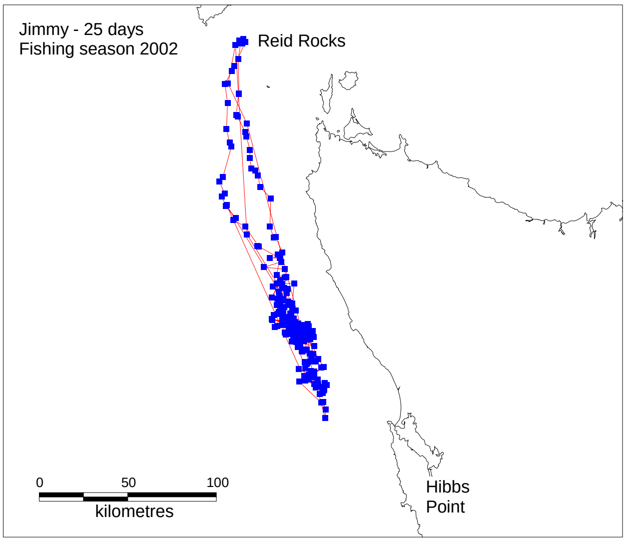
The durations that seals were tracked varied considerably from 10 to 223 days (at 1 March 2004). As noted earlier (Section 4.6), the short tracking durations were probably due to transmitter battery failure. All seals tracked foraged almost exclusively within the grenadier fishing grounds throughout the duration of the fishing season, and rested between foraging trips at either Hibbs Point or Reid Rocks. One seal (Jack in 2002) also rested at Seal Rocks in Victoria (Fig. 24).

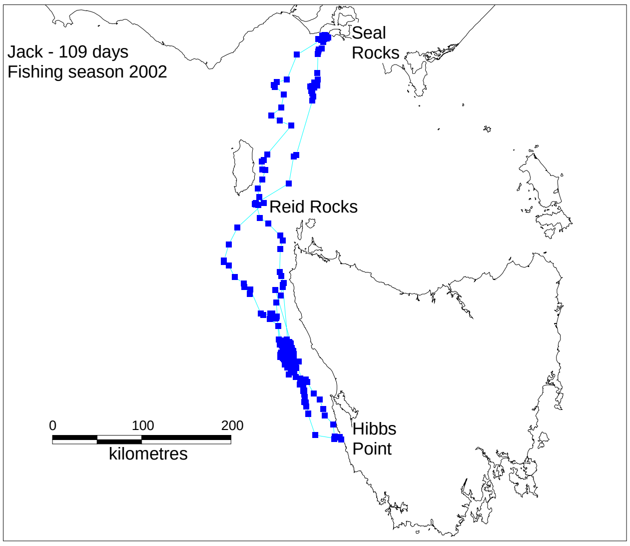
When leaving the fishing grounds, seals typically swam in a direct line towards haul-out sites, but on return, swam out to the edge of the continental shelf possibly to enhance the likelihood of intercepting fishing vessels. For seals that were tracked beyond the duration of the winter fishing season, there was a noticeable change in the focus of foraging effort. Most seals moved their foraging to areas south of the fishing ground, typically between Macquarie Harbour and Maatsuyker Island (SW Tasmania). One seal (Pete) foraged extensively over outer-shelf waters of southern Tasmania, as far north as Maria Island on the east coast of Tasmania, before returning to the west coast of Tasmania. At the start of November 2003, Pete was hauled-out at Seal Rocks off Phillip Island (Victoria) (Fig. 24). Another seal (Ken) headed north for the summer breeding season at the Lady Julia Percy Island colony (Victoria) then rapidly returned south and foraged extensively around southwest Tasmania (Fig. 24).

The tracking study demonstrated the habitual nature of seals feeding in the fishing grounds in between resting at nearby haul-outs. The number of direct resightings of tagged seals along-side fishing vessels (including one live capture and release) plus the intensity of movements to and from the fishing grounds between haul-outs suggests that the seal population interacting with the fishery may be relatively small and intransient during the period of the fishing season. More analysis could be undertaken at smaller spatial scales to examine the extent to which seals follow vessels within the fishing grounds.

Figure 24. Satellite tracks of tagged seals during and after the 2002 and 2003 fishing seasons. The left plot shows movements during the fishing season and the right plot movements after the fishing season.







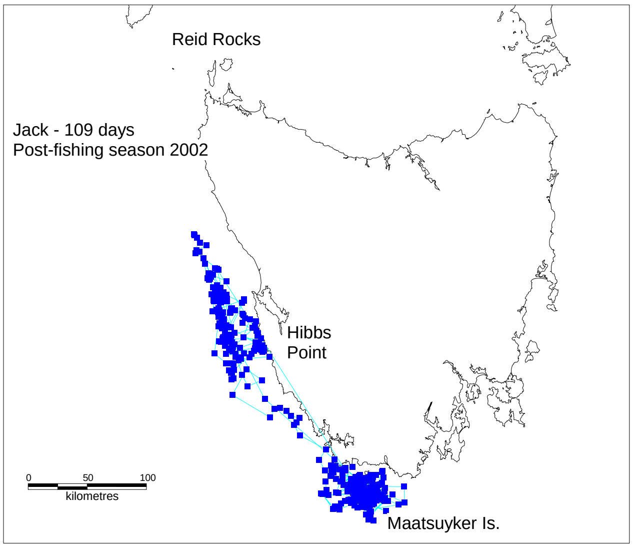
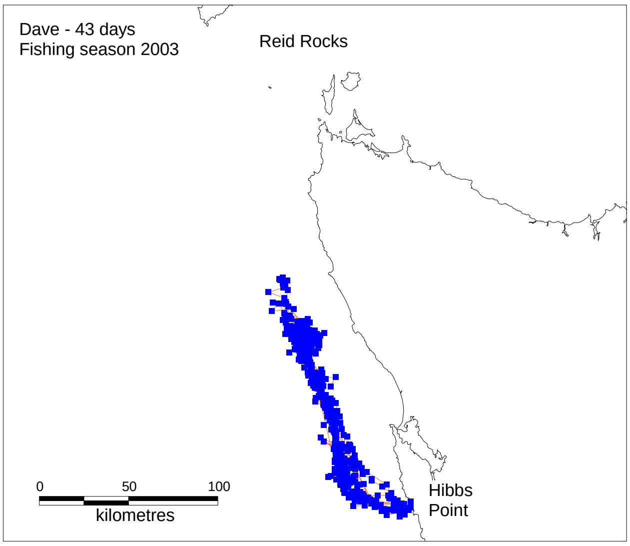
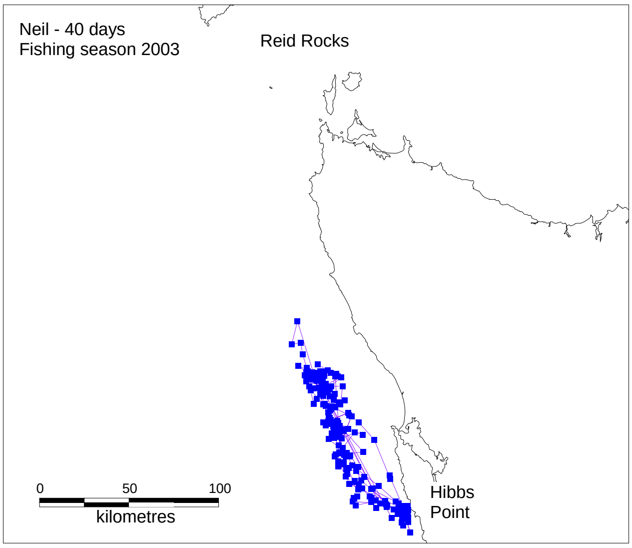
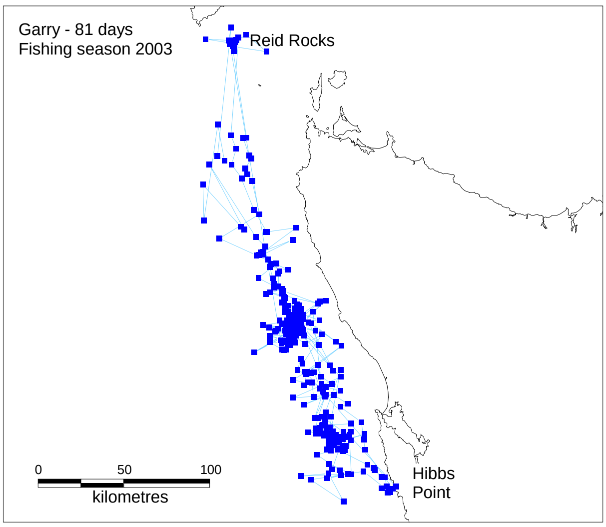


Figure 24 *continued*







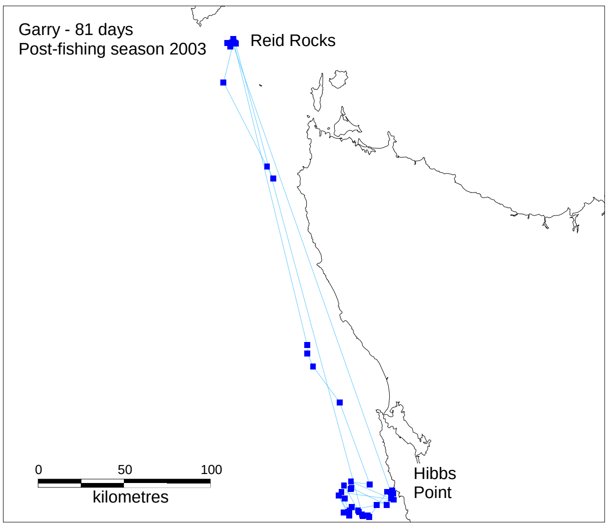
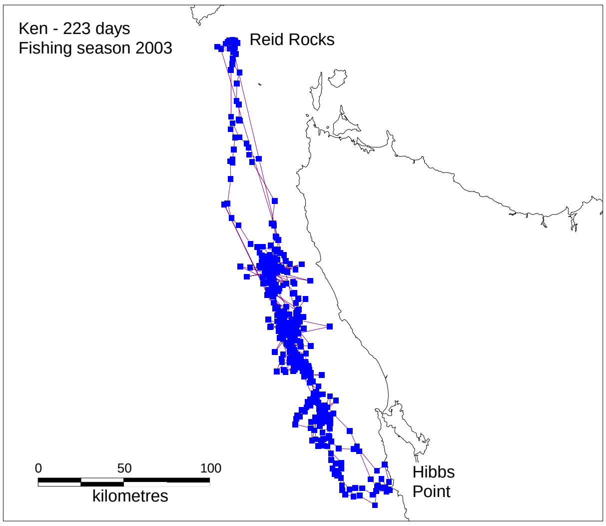
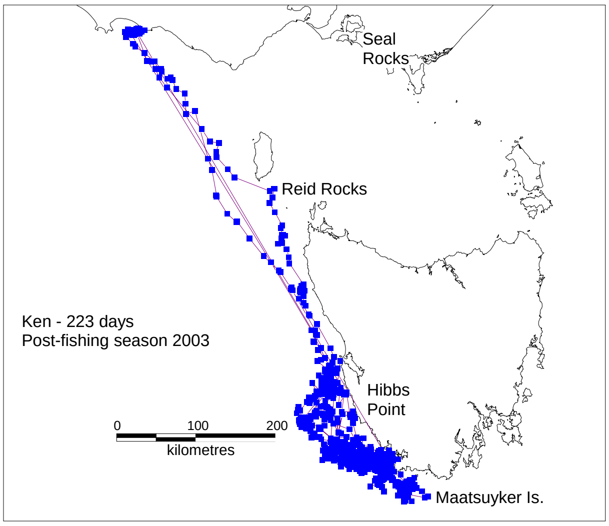
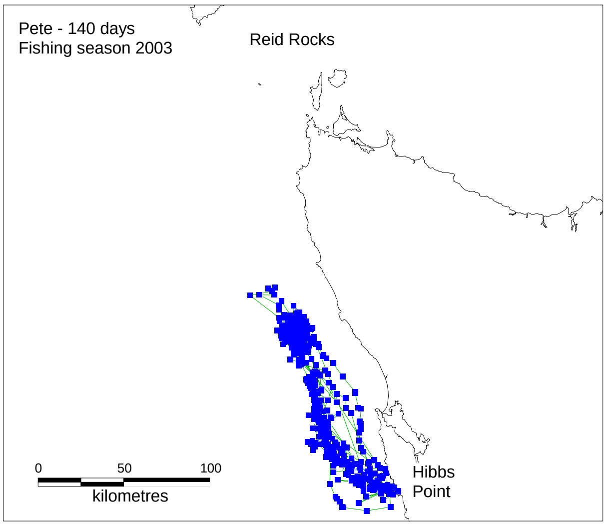
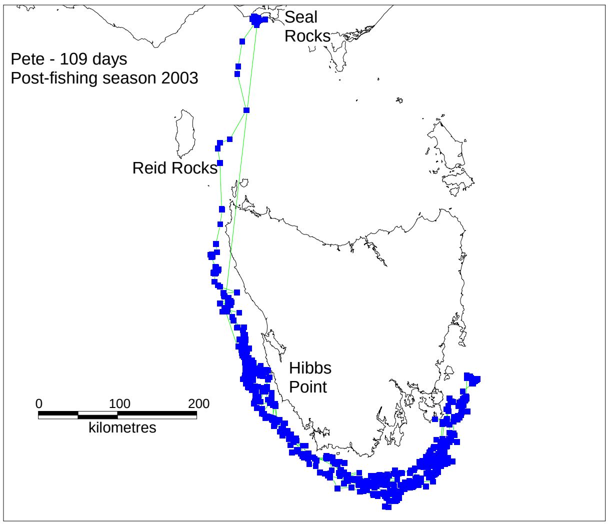


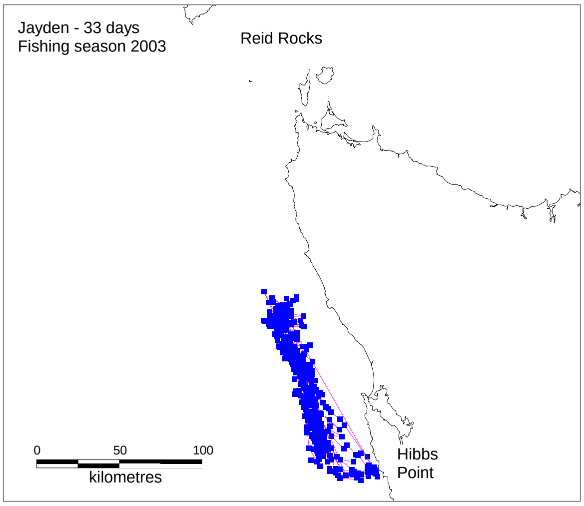
Figure 24 *continued*











6. DISCUSSION

6.1. Factors associated with seal bycatch

The GAM models were used in an effort to gain information on the following:

1. The effectiveness of the SED designs in reducing the bycatch of seals in mid-water trawl nets.
2. The factors affecting the variability in the occurrence of seals in mid-water trawl nets. What do these relationships imply about the catchability of seals?

A complex suite of factors is associated with seal bycatch in this fishery. Whereas the GAM analyses attempted to identify what factors are significant, differing results between data sets often occurred. As anticipated, there were several differences between the fishing behaviour/performance of the two vessels in this study and their respective data sets could not be pooled for analysis. Although the data sets for each vessel were analysed separately, there were often differences between GAM analysis results for the annual data sets for each vessel. Several factors that appeared to be significant in one year appeared of little significance in another year and vice versa. This led to the four (2000 to 2003) annual data sets being aggregated in the final analyses. In several instances there were contrasting results between vessels from the aggregated GAM analyses. Factors that were significant included time (year and time of day), spatial location and the species composition of trawl catches.

Annual factors

Seal counts around vessels during 2000, 2001, 2002 and 2003 (Section 5.3) found comparative annual abundance on the fishing grounds to vary, with a comparatively large number of seals being observed in 2002. Comparative annual seal abundance on the blue grenadier fishing grounds was reflected in the seal bycatch by the *FV Ocean Dawn* (Fig. 14) but not in the seal bycatch by the *FV Aoraki* (Fig. 16) and the GAM did not find this to be a significant factor for the latter vessel. Comparatively low seal counts in 2001 and 2003 were accompanied by a low incidence of seal bycatch by both vessels in these years.

Spatial and temporal factors

Trawl shot location was an important factor. Both vessels fished along a comparatively narrow strip of a NNW–SSE oriented upper slope, with most fishing occurring between 144.2 and 144.8^{0}E. End latitude was a significant factor and was almost certainly linked to the proximity of trawl shots to the seal breeding colony at Reid Rocks to the north (DistA), or the seal haul-out site at Hibbs Point to the south (DistB), of the fishing grounds. However, there were differences between the GAM analyses for each vessel. With the *FV Ocean Dawn*, the incidence of seal bycatch was greater with increasing proximity to these sites and the final GAM (Fig. 14) included both sites. With the *FV Aoraki*, a negative correlation occurred with Reid Rocks, there was little correlation with Hibbs Point (Fig. 16) and the final GAM rejected these factors (Fig. 17). It is logical to expect an increase in seal bycatch with increasing proximity to seal colonies. In this fishery, most fishing occurred in an area lying approximately equidistant from Reid Rocks and Hibbs Point and these two parameters probably pulled against each other in the majority of trawl shots. The final GAM for the *FV Ocean Dawn* (Fig. 14) included end latitude and the correlation between increasing seal bycatch and increasing latitude suggested that Hibbs Point had a greater influence than Reid Rocks. The end longitude for each trawl shot did not appear to be a significant factor.

GAM analyses did not find ‘month’ to be a significant factor although there was some evidence from seal counts around vessels (Table 4) of seal numbers gradually increasing as the fishing season progressed.

Trawl endtime was clearly significant for both vessels with a morning peak in seal bycatch occurring at around 1100 hrs for the *FV Ocean Dawn* (Fig. 14) and around 0900 hrs for the *FV Aoraki* (Fig. 17). Hamer (2004) also observed a 1000 hrs peak in seal numbers around the *FV Aoraki* during the 2003 season. Hindell and Pemberton (1997) and Arnould and Hindell (2001) found the foraging activity of Australian fur seals to be slightly higher in daylight hours. Seals are probably highly dependent upon visual cues for net entry and may be reluctant to enter nets during darkness hours. The comparatively high incidence of seal bycatch in nets with most SED designs compared with nets without SEDs suggested that the sighting of a SED grid may induce seals to enter a net with the expectation of easy escape or access. More information is needed to thoroughly explain this diurnal pattern of seal bycatch.

Operational factors

There were differing results from both vessels for trawl duration time. With the *FV Ocean Dawn*, the incidence of seal bycatch increased sharply in trawl shots exceeding 400 minutes (Fig.14). No relationship between trawl duration and seal bycatch occurred with the *FV Aoraki* (Fig. 16) and the final GAM (Fig. 17) did not attribute significance to this parameter. The comparatively low vessel speed during the trawling phase of fishing operations should theoretically enable seal numbers around the vessel to build up at this time. Seal counts typically peaked when a trawl was being hauled (Section 5.3). Hamer (2004) counted seal numbers around the *FV Aoraki* at 15 minute intervals from the start of trawling and found that, although seal numbers increased with trawl duration, their numbers fell slightly during the first 120 minutes of trawling. As 84% (174) of observed trawls (207) were 120 minutes or less, a non-significant correlation was obtained. Mean shot durations for the *FV Aoraki* were usually shorter than those for the *FV Ocean Dawn* (Table 1) and this may, in part, explain the absence of a relationship between trawl duration and seal bycatch with the former vessel.

Trawl depth was closely correlated with the duration of winch operation when hauling. The final GAMs for both vessels retained trawl depth as a parameter. However, differing results were again obtained from each vessel, with a positive correlation between depth and seal bycatch occurring with the *FV Ocean Dawn* (Fig. 14) and a weakly negative correlation occurring for the *FV Aoraki* (Fig. 17). As most fishing occurs at depths exceeding the Australian fur seal's known diving range, the duration of winch operation is probably the most important factor. Fishers held a strong opinion that seals recognised the sound of winch operation and were attracted to the vessel when this occurred. In general, the *FV Aoraki* was a more efficient vessel than the *FV Ocean Dawn* and hauled nets at a greater speed. This may in part explain why the *FV Aoraki* did not have a positive correlation between trawl depth and seal bycatch.

There was little correlation between the quantity of blue grenadier in the net and seal bycatch for both vessels (Fig. 13 and Fig. 16) and the full GAMs did not attach significance to this parameter. The same occurred for 'other species' although the final GAM for the *FV Ocean Dawn* (Fig. 14) retained this parameter. Both vessels showed a significant correlation between seal bycatch and the quantity of spotted warehou in the net (Fig. 14 and Fig. 17). Spotted warehou appear to be a preferred forage item for Australian fur seals and large catches were accompanied by increased seal bycatch. Spotted warehou flesh is denser and oilier than blue grenadier flesh and may be a more attractive dietary item for seals. Spotted warehou were observed to escape through the SED hatch and the possibility of such escapees attracting seals to enter the net via the escape hatch should not be discounted, although most fish escaped at depths beyond the seals' diving range. As most seal foraging appeared to occur when the net was being hauled, it is probable that seals were attracted to enter the net by the presence of warehou. Gales and Pemberton (1994) recorded blue warehou (*S. brama*) in the diet of Australian fur seals.

Vessel speed clearly impacted on the number of seals around a vessel between tows. Linear regression analysis showed vessel speed to be significantly negatively correlated with seal numbers. Steaming away from seals before shooting the net was an essential part of the

Fishing Code of Practice. Hamer (2004) noted that seal numbers dropped by more than 50% when the *FV Aoraki's* speed exceeded 4 knots.

Hamer (2004) found that as the numbers of vessels within 2 nautical miles of *FV Aoraki* increased, a corresponding increase in seal numbers occurred for hourly and trawl based observations. A greater number of vessels within a certain distance may become a greater attractant to foraging fur seals, because of the collectively improved foraging opportunities (Hückstädt and Antezana 2003). Under these conditions, seals may have been included in counts, even though they were actively following other vessels and effectively independent of the *FV Aoraki*. Alternatively, additional seals may have opted to follow the *FV Aoraki* in favour of other vessels once the vessels were sufficiently close enough to encourage the 'swap'. Some vessels appeared to make better foraging targets than others. On many occasions, groups of up to 6 seals left the stern of the *FV Aoraki* shortly after the FV Petersen (a smaller freezer trawler that entered the 2003 fishery for a short time) had passed within about 1nm. Hamer (2004) also noted that seals would often spend periods of time actively looking in the direction of other vessels that were relatively close.

Environmental factors

Hamer (2004) found swell height, visibility and barometric pressure to be significant factors in the number of seals present around the *FV Aoraki*. Although wind strength was not included in his final GLM, it exhibited a highly significant relationship with seal numbers observed during linear regression analysis. In general, seal numbers appeared to rise when the weather deteriorated, specifically when swell, visibility and wind increased and barometric pressure decreased. Improved visibility during rough conditions may be responsible for the apparent rise in seal numbers observed (Wilkinson *et al*. 2003). Animals at greater distances are visible during clearer conditions and thus included in counts, compared to observations undertaken during calm conditions when sea mist was more often enveloping the vessel. However, swell height and wind strength had little effect on seal counts around squid jig vessels in north-western Bass Strait (Arnould *et al*. 2003).

The results should be used as a basis for the development of further experimentally designed surveys using more formal quantitative analysis appropriate for that data. The results and analyses presented here should be treated as preliminary. Further exploration of the data could be carried out. While GAM analysis provides functional forms of the model terms, subsequent GLM analyses using polynomial approximations could be undertaken.

6.2. Net entry by seals

The question of when seals enter the net during a trawl shot remains largely unresolved. In this fishery, most of a net's fishing time is spent at depths in excess of the Australian fur seals' known diving capability. Seals almost certainly enter the net when it is descending or ascending the top 200 m of the water column. Observations of seal behaviour and counts of seal numbers during fishing operations strongly suggested that most seal bycatch entered the net during the latter stages of hauling. It is logical to expect this to occur, as the net then contains fish and presents the most favourable foraging opportunity. Seal counts showed that many seals dived to meet the net as it neared the surface. However, the limited underwater video observations made during the 2003 season showed an equal number of seals to enter the net when it descended as did when it ascended.

More underwater video observations are needed to resolve this matter. If a seal becomes trapped in a descending net it will certainly drown. Conversely, seals caught during the latter stages of hauling have a good chance of escaping drowning. Once the trawl doors are secured, the net is at the surface and a comparatively short time elapses before the net is winched onboard. The issue of net entry is probably of greater importance to studies of seal bycatch by SEF trawlers fishing in shallower shelf waters, where seals can theoretically dive and enter the net at any time during a fishing operation. Shallower waters facilitate the use of more compact underwater camera gear, such as the 'National Geographic' cameras used in the New Zealand SLED program (Wilkinson *et al.* 2003), to monitor seal bycatch. The camera equipment used on the *FV Aoraki* was bulky and difficult to successfully deploy. More sophisticated, robust and compact camera equipment is needed to expedite future studies on seal behaviour in and around trawl nets used in deeper slope waters.

6.3. SED effectiveness

The initial SED design used in 2000 had much in common with the Turtle Exclusion Devices (TEDs) used in Australian and American prawn trawl fisheries despite being modified for use in the New Zealand midwater trawl fishery for squid, in that the main design feature was a grid to deflect large animals out of the net via an escape hatch. However, seals are much more active and mobile than turtles and are more intelligent. With prawn trawlers, turtles and unwanted fish species are caught incidentally as 'passive' bycatch, whereas seals have become habituated to actively feed around vessels in the South East Fishery and often enter trawl nets to forage. In prawn and squid fisheries the target species are comparatively small and easily pass through exclusion grids. Blue grenadier range up to a metre in length and can block and damage exclusion grids, especially when dense spawning aggregations are targeted. A TED is, in essence, a straightforward deflection device with the exclusion grid acting as a deflector and the water flow/net velocity providing the turtle's deflection momentum out of the net. This research program found that the requirements for a SED design to successfully reduce seal bycatch in the blue grenadier fishery are by no means as straightforward. Significant problems with initial SED designs included fish-loss and seal entry into the trawl net via the SED escape hatch.

An effective trawl SED should satisfy the following criteria:

- Prevent seals from entering the net's codend where most seal mortality probably occurs;
- Facilitate seal passage out of the trawl net via the SED escape hatch;
- Discourage seal entry into the net via the SED escape hatch; and
- Not result in target fish-loss from the net, nor unduly impede fishing operations.

Both of the open SED designs used in 2002 and 2003 effectively prevented seals from entering the codend. The passage of three juvenile seals through the SED grid into the codend in 2002 was attributable to the increased (from 20 to 30 cm) gap between the grid bars. The optimum gap size for Australian fur seals is about 25 cm and this should be used for SEDs aiming to reduce the bycatch of this species. The more robust grid construction used in 2002 and 2003 worked well and there was only one instance of (submerged) grid damage, compared with several in 2000 and 2001.

Achieving criterion (b) appeared to jeopardise attaining criterion (c) and vice versa in early trials. An effective seal exit can also double as an entrance. Results from the 2000 and 2001 seasons showed that the incidences of seal bycatch in open SED shots were approximately double those in 'no-SED' shots. In 2002, the incidence of seal bycatch in the 'bottom-hatch' SED was almost three times that in comparable midwater 'no-SED' shots. As an unknown number of seals are thought to have exited the SED via the escape hatch, the actual incidence of seals in open SED shots was almost certainly higher. This strongly suggested that SEDs could be facilitating entry to the trawl net and providing a convenient 'feeding chamber'. Some underwater video footage of seals showed them to be actively feeding on fish within the SED. A SED is a 'convenient' feeding site as the net sleeve concentrates fish passing towards the codend and fish may bank-up in front of the SED grid.

With midwater nets, the distance from the headrope to the beginning of the codend is about 200 m, whereas the distance from the SED escape hole to the codend is only about 20–30 m (depending on sleeve length). Although underwater video footage was limited, seals were observed entering the net via the escape hatch on two occasions. The satellite-tagging movement data suggest that a sub-set of the Australian fur seal population is habituated to feeding on the grenadier fishery grounds and regularly return thereto during the winter fishing season. It is logical to expect some of these seals to become increasingly adept at foraging from trawl nets, including gaining entry via a SED hatch.

Table 11. Summary of SED results in midwater nets: 2000 to 2003

Year	SED	No.shots	Incidence (%)	Seals/shot	Survival (%)
2000	NS	23	13.0	0.130	0
	SO	184	10.3	0.163	66.6
2001	NS	113	5.3	0.053	0
	SC	67	10.4	0.104	0
	SO	69	11.6	0.116	12.5
2002	NS	160	10.0	0.125	0
	SO (bot)	81	12.3	0.173	50.0
	SO (top)	98	3.1	0.031	0
2003	NS	106	3.8	0.047	0
	SC	101	5.9	0.079	37.5
	SO (top)	197	3.0	0.030	16.7

NS = No SED, SO = Open SED (bot=bottom hatch, top=top hatch), SC = Closed SED, Incidence = Shots with seal bycatch, Seals/shot = mean no. seals per shot (includes multiple captures), Survival = Proportion of seals released alive.

The 2002 trials of the ‘top-hatch’ SED suggested that this design had made considerable progress towards facilitating seal exit and preventing seal entry via the escape hatch, as only 3.1% of SED shots caught seal bycatch (Table 11) compared with 10.0% of ‘no-SED’ shots (20.7% of respective *FV Ocean Dawn* shots). The lower incidence of seal bycatch in ‘top-hatch’ SED shots indicates that this design is effectively expelling seals and limiting access to the net via the escape hatch. Even when allowing for differences between vessel fishing practice/performance, the 2002 data indicate that the ‘top-hatch’ design is much more effective at minimising seal bycatch. This could be attributable to two reasons: (1) a ‘top-hatch’ better facilitates seal escape (it is logical to expect a seal to head for the surface after foraging), and/or (2) seal entry to the net via an escape hatch is less for a ‘top-hatch’ than for a ‘bottom-hatch’. Following the adoption of seal avoidance procedures before shooting the net, seal numbers around vessels typically peak when the net is being retrieved. A top hatch is probably accessible for a much shorter period than a bottom hatch at this critical time. Blue grenadier has a swim bladder and a net codend containing this species typically floats on the surface prior to being hauled up the stern ramp. Hence, a ‘top-hatch’ is inaccessible at this time. In 2003, the incidence of seal shots using a ‘top-hatch’ SED in midwater nets was again low (3.0%). However, in this season the overall (all bottom and midwater shots) incidence of seal bycatch was also low at 3.9% and was similar (3.8%) for midwater ‘no-SED’ shots (Table 11).

Although seals were observed entering the escape hatch in 2000 and 2001, it should be noted that the incidence of seal bycatch in ‘closed-SEDs’ was also greater than that for comparable ‘no-SED’ shots in 2001 and 2003. Seal numbers (counts) and bycatch were low in 2001 and 2003 and comparative bycatch values for all SED categories could well have been skewed by just a few seal captures. Nevertheless, this suggests that a SED structure with its associated grid and net lengthener, and presumed foraging opportunity, may also be enticing seals to enter the net via the net-mouth. More direct (camera) observations of seal entry behaviour are needed to resolve this issue.

Criterion (d) was not achieved by initial SED designs. Fish-loss via the backward facing escape hatches used in 2000 was not quantified, but appeared to be significant. Some video footage showed large numbers of moribund grenadier being ‘swept’ through the escape hatch. The forward facing escape hatches and larger SED grids appeared to have largely achieved criterion (d). Observed loss of the target species, blue grenadier, via the forward facing ‘bottom-hatch’ SED in 2002 was minimal (a few grenadier escaped on one occasion only), noting that only six shots were observed and there was no direct observation of the forward facing ‘top-hatch’ SED. Underwater video cameras have not been used on the Ocean Dawn and the extent of fish-loss via the ‘top-SED’ is unknown. However, as the major difference between the two SED designs is only the respective ‘vertical’ locations of the escape hatches and the associated inclination angle of the grid, fish-loss should have been similar to that experienced in a ‘bottom-SED’. With both vessels, there were no significant differences in mean catch weights between comparable SED and ‘no-SED’ shots. Cawthorn (2004) trialled a similar SED design in the New Zealand hoki fishery and reported no loss of fish.

The 2002 video footage observed significant numbers of spotted warehou to escape via the forward facing bottom escape hatch. It is probable that this also occurs in a top hatch SED. Thus, if more ‘active swimming’ species such as warehou are the target, as is the case in some other SEF trawl fisheries, the current SED design may not fulfil criterion (d). Piasente *et al.* (2004) used video cameras to observe fish behaviour in trawl nets and noted that spotted warehou escaped capture by swimming faster than the towing speed.

If a ‘grid-only’ SED proved effective for criterion (a), then criteria (c) and (d) would be satisfied and there is a greater likelihood of such a device being accepted by the wider SEF trawl fleet, should the need arise. The midwater closed SED trials conducted during 2001 and 2003 were inconclusive because of the low incidence of seal bycatch. However, in both seasons the overall incidence of seal captures was about double that for comparable ‘no-SED’ shots, suggesting that ‘grid-only’ devices are also ‘attracting’ seals. As seals cannot enter a closed SED via the escape hatch some other factor has to be causing this disparity. Perhaps seals experienced at net foraging see the grid in the net and enter the net mouth with the expectation of being able to escape via an open hatch. More direct (camera) observations are needed to resolve this issue.

The GAM analysis indicated that the probability of seal bycatch was slightly higher in nets with all open or closed SED designs other than the ‘top-hatch’ SED used by the *FV Ocean Dawn* in 2002. As the 2003 trials of this design were inconclusive because of a lack of control data, more trials are needed, preferably with adequate camera observation.

6.4. Seal bycatch mortality

The key issue with SEDs is: do they reduce seal bycatch mortality? The data gathered over the 4 years of SED trials provided mixed results. In the 2000 season, 40 shots caught seals and the overall (both vessels and all net types) survival rate was 58%. The survival rate of seals caught in nets with a SED (66%) was three times greater than that for nets without a SED (22%). Drowned seals were inevitably retained in the trawl’s codend and it appeared probable that most deaths actually occurred in the codend, where seals became entrapped and drowned. These early results indicated that preventing seals from entering this part of the net enhanced their chance of survival. However, the incidence of seal bycatch in nets with a SED was about double that for nets without a SED.

In the 2001 season, open and closed SEDs were trialled to examine if a grid preventing seals from entering the codend would be as effective as a SED with an open escape hatch. However, seal bycatch numbers were low throughout the 2001 season (26 seal shots only) and little could be inferred from comparisons between data sets. The use of three differing SED designs further complicated analysis. In midwater nets there was no significant difference between open (87.5% mortality) and closed (100% mortality) SEDs, but the incidence of seal shots in nets with a SED was again about double that for nets without a SED (Table 11). Overall (bottom and midwater nets) seal survival in 2001 (7.7%) was low for both SED (5.6%) and ‘no-SED’ (12.5%) seal shots.

In 2002, 41 shots contained seal bycatch and the overall seal survival rate was again low (24%). The two SED designs used in midwater shots throughout the season also provided contrasting results. With the ‘bottom-hatch’ SED used by the *FV Aoraki*, a seal survival rate of 50% was achieved (Table 11). However, the incidence of seal shots in SED nets (12.3%) was again higher than that for nets without a SED (10% overall, but 3.9% for the *FV Aoraki*). With the ‘top-hatch’ SED used by the *FV Ocean Dawn*, the seal survival rate was zero. However, the incidence of seal shots in ‘top-hatch’ SED nets (3.1%) was much lower than that for ‘no-SED’ nets (10% overall, but 20.7% for the *FV Ocean Dawn*), strongly indicating that seals were successfully exiting the ‘top-hatch’ SED design. The 3:1 ratio between the incidence of seal shots in ‘no-SED’ nets and ‘top-hatch’ SED nets indicates a survival (escape) rate of about 66%, similar to that experienced in 2000 when seal abundance on the fishing grounds was also comparatively high.

In 2003, the incidence of seal shots in midwater nets using the ‘top-hatch’ design was again low (3.0%), but no respective ‘no-SED’ data were obtained from the vessel concerned. The overall number of seal bycatch shots (19) in 2003 was very low, comprising only 3.9% of all shots. The overall survival rate for caught seals was 32%. These low seal numbers again largely thwarted trials with a ‘grid-only’ (closed SED), but a seal survival rate of 37% occurred in shots with a grid, compared with zero for ‘no-grid’ shots.

It should be stressed that the actual numbers of seals successfully passing through the escape hatch of open SEDs is unknown in all years. Thus the survival rate values for open SEDs in Tables 5 and 10 are undoubtedly conservative. In all four seasons, there was 100% mortality for seals caught in midwater nets without a SED, compared with survival rates ranging from zero to 66.6% for nets with an open SED (Table 11). For nets with the ‘top-hatch’ SED, the incidence of seal shots in 2002 was only about one-third of that for nets without a SED, indicating that this SED design significantly reduced seal mortality by both facilitating escape from the net and denying entry to the codend. The GAM analysis supported this deduction.

Available fisheries data indicated that adoption of fishing practices aimed at avoiding seals had halved the overall incidence of seal bycatch (Table 3).

It should be noted that in all four seasons very few (6% of overall bycatch) female Australian fur seals were caught. Given the polygamous nature of this species’ reproductive behaviour, seal mortality in the winter grenadier fishery is having minimal impact on the reproductive capacity of the Australian fur seal population. However, the incidence of female seal bycatch elsewhere in the South East Fishery is currently poorly documented.

It should also be noted that, in the short to medium-term, seal bycatch mortality in the winter blue grenadier fishery will probably be less, as fishing effort should decline as the TAC level for this species becomes progressively reduced. Blue grenadier recruitment is highly variable and recruitment success is probably driven by environmental factors that are, as yet, poorly understood. Most of the catch taken in recent years was composed of the 1994 and 1995 cohorts as major recruitment events occurred in both these years. There has been no major recruitment since 1995 and the spawning biomass is declining as the 1994 and 1995 cohorts pass through the fishery. Even in the absence of fishing, a decline would occur. The AFMA management target is to maintain spawning biomass at or above 40% of the average biomass before fishing commenced. Unless good recruitment occurs in the near future, TAC levels should continue to be reduced to attain this aim. As it takes about 4–5 years for a cohort to mature and enter the winter spawning fishery, TAC reductions will almost certainly continue until at least 2008. The recommended annual TAC for grenadier remained at 10,000 t between 1994 and 2002, but has since been reduced to 9000 t in 2003, 7000 t in 2004 and 5000 t in 2005. A reduction in fishing effort may partly be offset by the continuing increase in seal population number, but lower overall seal bycatch will probably occur (See Appendix A).

6.5. Current (2003/04) SED design

It should again be noted that the development of the current SED design has been a cooperative project involving the results from a project funded by the New Zealand fishing industry in their midwater trawl fisheries for grenadier (hoki) and squid. At the time of this report (April 2004), the following design is recommended for future use.

The two–piece grid used is made of 25 mm diameter stainless steel rod with the vertical bars at 250–300 mm centres (275 mm appears to be near optimal in the winter grenadier fishery). The two grid sections are hinged horizontally along the centre and held together with 'hammer–locks'. The rounded shape and size of the grid should conform as closely as possible to the corresponding cross-section dimensions of the net, noting that larger grids better facilitate fish passage into the codend. In the midwater nets used in the winter grenadier fishery, a near circular grid of 1.7 metre diameter appears to be near optimal. The SED lengthener section, can be inserted into a mid–water trawl net in 30 minutes or less using simple zipper stitches fore and aft. On recovery, the SED usually came to the stern properly orientated, unless the codend had rolled over during the haul. The grid folded easily around the net drum, although when stowing a midwater trawl on the net drum the deck crew often found it more convenient to fold the grid in half, securing the top and bottom bars with light twine, which would break open on shooting.

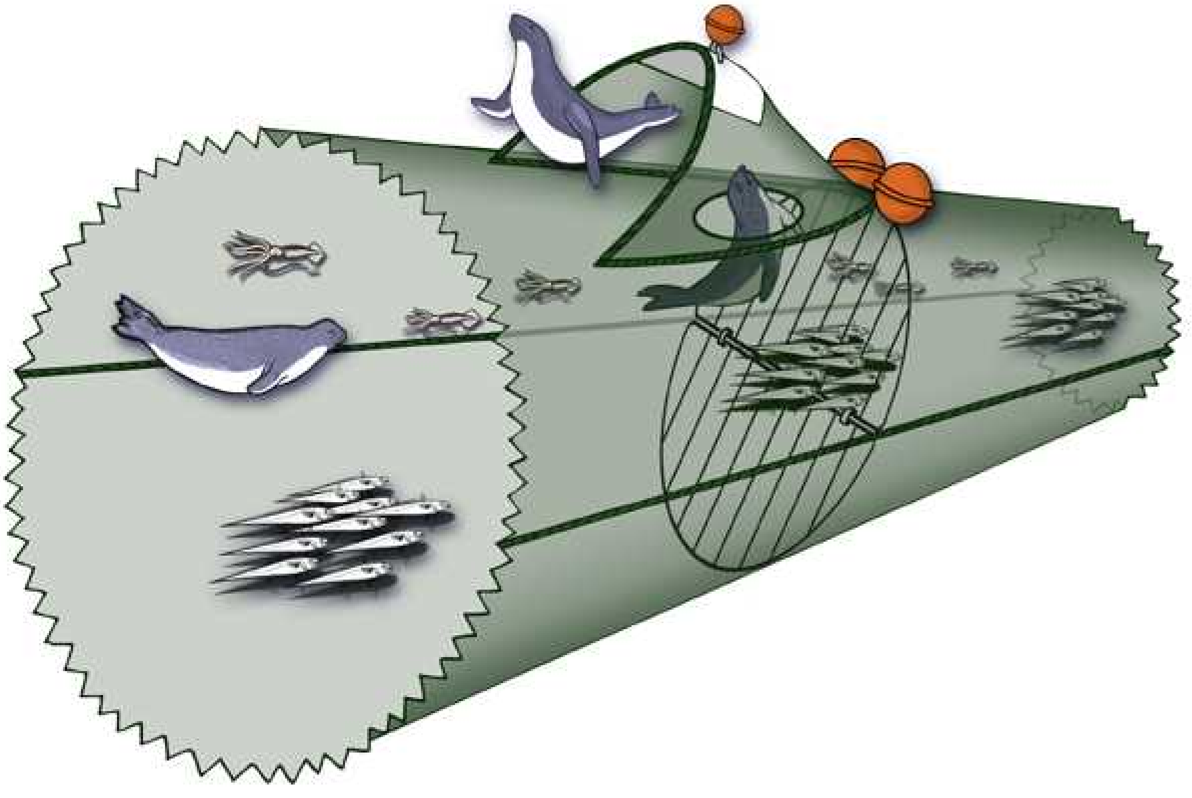


Figure 25. Artist's impression of 'top-hatch' SED used in 2002 and 2003. Note that the preferred shape of the escape aperture is now triangular, rather than the circular aperture shown here (see text).

On shooting, the SED worked well without the need for supplementary floats along the top bar of the grid. The 'scoop' net over the escape hatch opened fully very quickly, raised by the kite along the leading edge. Currently, the scoop is made of 100 mm mesh, the same size as the trawl, with a length of flexible conveyor belting attached to the leading edge as a kite. A single 20 cm diameter float is attached at the centre of the leading edge of the kite for initial flotation. Beneath the scoop, the triangular escape aperture (hatch) is cut into the top panel of the net with its base along the top edge of the grid. The distance from the grid to the apex of the hatch is about one metre. This triangular configuration is a definite improvement on a diamond shaped escape hatch used in earlier trials. The diamond shape sometimes caused fish to pile up in the back corners of the scoop reducing the hydrodynamic efficiency of the scoop. Fish ('stickers') meshing in the bottom of the scoop can be prevented by reducing the mesh size of the scoop. This will eliminate stickers and increase the speed of the water flow down through the hatch and grid reducing the chance of fish escaping via the hatch. A small mesh scoop should be standard in all SEDs.

At this juncture, the use of SEDs by the wider SEF trawl fleet is not recommended, except when large midwater nets are being used in areas frequented by seals. Whereas the current ('top-hatch') SED design appears to be working effectively, SED operation requires ample deck space aft of the net drum. Whereas the current SED grid can be wound on to the net drum, this usually cannot be done when the net is tensioned by a catch of fish. The pressures involved will inevitably result in damage to the grid. On the factory trawlers, fleeting winches are usually used to help bringing a large bag of fish onboard. Such winches are not normally used until the bag is touching the stern ramp. However, when a SED is in the net fleeting begins further up the net as the net winch operation ceases when the SED grid reaches the drum. The two vessels in this study have large fishing deck areas, but most SEF trawlers have comparatively limited deck space aft of the net drum. Extending the use of SEDs to smaller vessels will probably require further design development enabling the SED to be directly wound on the net drum during hauling operations.

6.6. Other seal bycatch mitigation methods

Stewardson (2004) summarised the technologies used to reduce seal-fisheries interactions and mortalities. Most such technologies have had equivocal success, even when applied to more sedentary methods of fishing such as gillnetting. In the South African hake (*Merluccius* spp.) trawl fishery an arc-gap transducer that generates shock waves simulating a bullet hitting the water had moderate success in trials. An acoustic deterrent device with a transducer mounted on a paravane towed in front of the trawl mouth was trialled in the New Zealand grenadier fishery, but was not found to be effective (Cawthorn 2004). In general, the use of 'seal-scare' devices has often been characterised by an initial 'fright' reaction by seals followed by their becoming increasingly familiarised with the device and ignoring it. In the winter grenadier fishery, the seal tagging data indicate that a semi-resident population seasonally forages on the fishing grounds. Thus there is an increased likelihood that seals would eventually ignore any such scaring devices.

In the winter blue grenadier fishery, possible methods of closing the net during its descent were discussed with fishers. The only practical method was to make a sharp turn when shooting the net, to bring the trawl doors closer together. This manoeuvre was possible with bottom trawl nets but could not be achieved with the much larger midwater trawl nets. Bottom nets were also shot using different warp lengths to attempt to 'close' them, but this method increased the chance of net malfunction. The hydrodynamic design of trawl doors is aimed at spreading the net. Possible methods of somehow linking the doors until a predetermined depth was reached were dismissed as impractical, largely because of the stresses involved, the associated operational dangers and the possibility of the doors malfunctioning. As it was, the doors of the midwater trawl very occasionally became twisted resulting in an aborted shot.

The higher incidence of seal bycatch during daylight hours suggests that fishing only during darkness hours might reduce seal bycatch in the winter grenadier fishery. However, this would unduly impede fishing operations as blue grenadier often migrate up into the water column during the night and can only be targeted by midwater trawls and not by bottom trawls. It is not known if the diurnal pattern of seal bycatch recorded in this fishery occurs elsewhere in the SEF trawl fishery.

7. BENEFITS AND ADOPTION

Following the large number of seal deaths during the 1999 fishing season there was considerable pressure from conservation groups and environmental agencies to ban freezer trawlers from the winter blue grenadier fishery. The development of a fishing Code of Practice, the commencement of this project and ongoing liaison with the conservation groups concerned enabled these vessels to continue fishing. This has been a major benefit as grenadier landings have been the highest volume and most valuable of the species caught in the SEF since 1999.

The fishing Code of Practice was adopted at the start of the 2000 fishing season and has continued since. Available data indicate that the adoption of these fishing practices halved the incidence of seal bycatch compared with that for the 1999 fishing season. Such practices are now being more widely promoted across the distribution range of seals in the SEF.

The biological data gathered from seal captures demonstrated that the great majority of bycatch seals were males. Thus bycatch mortality in this fishery was having no obvious impact on the reproductive capacity of the Australian fur seal population. However, the long term effects of changing the population structure (by removing predominately males ≥ 5 years from the population) are unknown.

Whereas the actual effectiveness of SEDs in expelling seals from nets was not quantified, advances in SED design appeared to have largely solved the problem of seals entering the net via the SED escape hatch; at least in this fishery. Top hatch SEDs are now in regular use in midwater trawls in this fishery. More information on SED performance and the nature of seal interactions across the whole SEF is needed before contemplating the wider adoption of SED use.

This project has been of substantial assistance in developing wider seal bycatch mitigation strategies (See Section 8 below). The SEF trawl fleet is now being actively encouraged to report seal interactions and collect biological samples from captured seals.

8. FURTHER DEVELOPMENT

SED development

This project has seen significant improvements in SED design. However, the number of seals that successfully passed through the escape hatches of the SEDs used during the project is unknown and the actual effectiveness of SEDs remains largely unquantified. The factors governing the likelihood of a seal being taken as bycatch are complex and often confound quantitative comparisons between 'replicate' sets of trawl shots with, or without, a SED. Data interpretation is further complicated by the low incidence of seal bycatch (about 2% of shots) inevitably leading to high coefficients of variation in analyses. The consequent need for a relatively large number of shots for comparative purposes heightens the chances of significant differences occurring between the parameters affecting the so-called 'replicate' sets. The GAM analysis has demonstrated the significance of several variables. A possible method of eliminating many potential error sources would be to use twin-rig trawl gear with one net having a SED and the other net acting as the 'control' (one large SETF vessel has recently been trialling twin-rig gear). However, a twin-rig project would probably require the chartering of a designated vessel at considerable expense.

A more effective method that could be carried out during normal commercial fishing operations would be to place a retention bag over the SED escape hatch to monitor seal numbers exiting the net. However, this method would obviously cause increased seal mortality in the short-term and fishing permit conditions would have to allow for this. Such a method was successfully used in SED trials in the Auckland Island squid trawl fishery where an ejection rate of 91% was achieved for Hooker's sea lions (Wilkinson *et al.* 2003).

At this juncture, the most practical and humane method of assessing SED effectiveness is by direct observation via underwater camera. More efficient camera gear than that available for this project is required. A compact camera that can be easily attached to net is essential to gaining voluntary assistance from fishers. Given the low incidence of seal bycatch, a camera will have to be frequently deployed to collect adequate information. The camera should use infra-red light and associated light-sensitive video tape, as fishers think that white light alerts fish to the approaching net and may reduce catches. Although no significant differences were observed between the catch weights of shots with and without the camera package, fishers remained convinced that the camera lighting adversely affected catches. Such lighting could also influence seal behaviour within the illuminated area. The infra-red camera package should contain a depth recorder and be able to withstand depths down to 600 m.

Policy development

Although seal-fishery interactions have been flagged as an important conservation issue for some time (e.g. Shaughnessy 1999), it is only recently that a focussed research effort has analysed this issue. The few mitigation actions and policies in place (e.g. seal capture and translocation in the Tasmanian mariculture industry) have mostly been confined to State wildlife agencies. There has been a paucity of information at the national level relating to the extent (magnitude) and nature (biological consequences) of seal bycatch in Commonwealth managed fisheries. Clearly, very limited progress will be made on the assessment of the issue, the development of management targets and application of mitigation strategies unless adequate information becomes available. Research initiatives to address critical information gaps are needed to provide an adequate base for policy development.

The seal deaths during the 1999 winter grenadier season focussed attention on the South East Trawl Fishery (SETF) and prompted the development of seal bycatch mitigation strategies. The fishing companies involved in the factory trawler sector of this fishery (i.e. Petuna/Sealord and Ocean Fresh/Simunovich) demonstrated their commitment to reducing seal bycatch by developing a Fishing Code of Practice and embarking on this SED project.

The South East Trawl Fishing Industry Association (SETFIA) has since done much to promote the Fishing Code of Practice across the SETF. Another step towards developing coordinated strategies to research/manage seal interactions in the SETF was a special meeting of the Southern and Eastern Scalefish and Shark Fishery Ecological Advisory Group (SESSFEAG) held in November 2003. This meeting involved a wide range of stakeholders including scientists, conservationists, fishers and NGO representatives and provided a good overview of the key issues and information gaps associated with seal interactions in the SETF (AFMA and BRS 2004). Funding has since been obtained to promote the collection of fishery-wide information on seal interactions with trawlers (Stewardson and Knuckey 2005).

The formation of the National Seal Strategy Group (NSSG) in late 2003 has seen the development of unified Australia-wide policies on seal issues. In February 2003, the Marine and Coastal Committee (MACC) of the Natural Resource Management Standing Committee identified the need to address the growing national issue of human–seal interactions. In turn, the MACC established a small inter-government working group —the National Seal Strategy Group (NSSG)—to initiate the development of a coordinated national approach to human–seal interactions.

The terms of reference for the NSSG are presented below:

The NSSG will consider current and emerging human–seal interaction issues with the view to developing strategies to mitigate adverse impacts on Australian seal populations (i.e., Australian fur seals, New Zealand fur seals and Australian sea lions), and on the fisheries, aquaculture and tourism sectors. Based on these considerations, the NSSG will develop the draft National Seal Strategy for consideration by MACC and in doing so will:

- Report to the Marine and Coastal Committee.
- Engage relevant stakeholders (including: industry, seal researchers and environmental non government groups) in the development of the National Seal Strategy to achieve commitment to the process.
- Develop a work program.
- Share information and experiences on the nature and extent of human–seal interactions and existing management responses, including research activities.
- Develop an Assessment Report on the nature and extent of human–seal interactions, identify issues and document existing management responses and relevant research.
- Develop a National Seal Strategy that identifies: key issues relevant to interactions between humans and seals; and actions that can be implemented to manage those interactions in a coordinated way.

9. PLANNED OUTCOMES

With respect to the winter blue grenadier fishery

All fishers should use open, 'top-hatch' SEDs (or a more effective design if one is developed) in all midwater net shots (or as directed for research purposes).

Continue the current Code of Fishing Practice, as available data indicate these seal avoidance procedures to have halved the incidence of seal bycatch.

Continue the shot-by-shot recording of seal bycatch in the SEF1 logbook and maintain a level of scientific observer coverage.

Develop a system of collecting/storing ear tissue from seal bycatch mortalities for subsequent DNA analysis to determine the species and sex of seals caught.

With respect to the rest of the SEF trawl fleet

The fishing Code of Practice aimed at reducing seal bycatch should be used by vessels fishing in areas where seals are commonly encountered.

This report presents information on seal interactions with freezer-trawlers operating in a seasonal fishery within a comparatively small area of the SEF. Given the complex suite of factors that appear important in determining the extent of seal activity around vessels, it is likely that the nature and extent of seal–fishery interactions elsewhere in the SEF will differ significantly from those observed in the winter blue grenadier fishery. Much more information is needed about the nature of, and problems associated with, seal interactions with 'wet–boat' trawlers across the SEF (and the Southern and Eastern Scalefish and Shark Fishery) before contemplating extending SED usage. A program has now been developed to collect such information and industry is being encouraged to record all seal interactions and collect tissue for DNA analysis when seal mortality occurs (Stewardson and Knuckey 2005).

10. CONCLUSION

Comparative seal abundance on the grenadier fishing grounds fluctuated annually and comparisons between years should be made with caution. Nevertheless, the adoption of fishing practices specifically aimed at avoiding seals appeared to half the incidence of seal bycatch from 2000 onwards. Such practices should be compulsory in this fishery.

SED trial results were largely ambiguous. In general, lower seal bycatch mortality rates were offset by higher incidences of seal bycatch in nets with a SED, indicating that seals were entering the net via the SED escape aperture. The top-hatch SED significantly reduced seal bycatch in the 2002 season and this SED design has been used in midwater trawl nets thereafter. However, further trials did not yield statistically significant results because of the low number of seals captured.

More trials of the ‘top-hatch’ SED are needed. However, the comparatively low incidence of seal bycatch militates against obtaining statistically significant information from comparisons between replicate sets of shots with different SED designs or deployments. More information should be gathered by using underwater filming on the timing and depth–frequency of net entry by seals, and the circumstances of net entry that place seals at risk. Further underwater filming will contribute greatly to the further assessment of SED effectiveness, as it will provide direct data on the incidences of net–entry and net-exit via SEDs. Such direct observation will more clearly assess the effectiveness of SEDs as a bycatch mitigation tool.

The current camera system is unsuitable for further monitoring of seal activity due to significant practical limitations that interfere with fishing operations and make voluntary frequent camera use an unpopular option. A smaller camera system using infra–red light (rather than white light) should be acquired for future use.

At this juncture, SED use in the SEF should be confined to large midwater trawl nets in areas such as the grenadier fishery where seals are known to be common. If the target species is an active swimmer such as warehous, or the trawler is fishing for a ‘mixed bag’ (as is usually the case in this multi-species fishery), further underwater camera observations will need to be carried out to assess if significant fish–loss via the SED escape hatch occurs.

GAM analyses showed that, even in the comparatively small area of this fishery, a complex suite of factors influence the likelihood of seals being caught. There should be a significant increase in independent observer coverage across the SETF in order to understand the spatial and temporal variability in bycatch rates, and collection of samples to enable the species, sex and age composition of seal bycatch to be determined both spatially and with respect to different fisheries. Such a data set would provide important insights to identifying the critical regions that need to be targeted for management, whether spatially or within particular fisheries. For example, where are bycatch levels highest, and/or where do female seals represent a significant part of seal bycatch? Suitable and representative platforms for research need to be identified, and relationships and arrangements fostered to enhance data collection and trialing of mitigation options. Factory freezer trawlers have played an integral role in enhancing our knowledge and in testing mitigation options. Clearly other vessels in other regional fisheries need to be utilised to ensure data are representative and that mitigation strategies/technologies that are developed are appropriate and practical in their application across the fleet.

11. REFERENCES

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12. APPENDICES

12.1 Intellectual Property

None of the technology and information generated by this project is considered to be patentable. Indeed, the project was largely facilitated by cooperation between the fishing companies involved and government fisheries and conservation agencies on both sides of the Tasman, and the free flow of information between same. The initial SED designs were derived from similar trials in the New Zealand squid fishery and many of the subsequent SED design developments were prompted by the fishers involved in the project.

As the major thrust of this project was to develop techniques to reduce seal bycatch by trawl nets, useful information and details of SED designs were made freely available on an ongoing basis.

12.2 Project Staff

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12.3 More Recent Observations

2004 SED trials: The *FV Aoraki* returned to the fishery during the 2004 winter and fished from 11/6/04 to 24/08/04. Trials of the ‘top-hatch’ SED continued and alternating sets of midwater shots with and without a SED were carried out. Fishing operations and seal bycatch are summarised in the table below.

Gear	SED	Shots	S.Shts	Incid.	Dead	Alive	Mean	Surviv
B	NS	22	1	4.5		1	0.045	100
MW	NS	109	6	5.5	5	1	0.055	17
MW	SO	108	5	4.6	3	2	0.046	40

B=Bottom trawl, MW=Midwater trawl; SED status – NS=No SED, SO=Open SED; Shots=No. of shots; S.Shts=No. of shots with seals; Incid.=Incidence (%) of seal shots; Dead=No. of dead seals; Alive=No. of live seals; Mean=Seals per shot; Surviv.=Percentage (%) of seals released alive.

Again, little information on SED performance could be derived from this series of midwater shots. Although the incidence of seal bycatch in shots with a SED was slightly lower and seal survival higher compared with no-SED shots, there was no statistical difference between these two sets of shots. The overall incidence of seal shots (12/239 = 5.0%) was identical to that for this vessel in 2003 (12/242 = 5.0%) when a closed-SED was used instead of an open-SED (Table 5). No multiple seal captures occurred in 2004 and the total number of seals caught by the *FV Aoraki* (12) was slightly lower than in 2003 (15). These comparatively low numbers of seal captures are certainly due in part to the seal avoidance fishing practices followed by this vessel.

The comparatively low incidence of seal captures in 2004 again illustrates the difficulty in obtaining statistically significant information from comparisons between replicate sets of shots with different SED designs or deployments. Direct observation via underwater video camera appears to be the most practical method of assessing SED effectiveness.

***Seal interactions in the small pelagics fishery*:** Problems with dolphin bycatch have recently (2004/05) been experienced in midwater trawl operations targeting small pelagics (principally redbait) off eastern Tasmania. A pilot study aimed at monitoring marine mammal interactions in this fishery used video cameras to assess such interactions and the effectiveness of a 'soft-mesh' exclusion device (Browne *et al*. 2005). Although no dolphins were observed or captured during this study, seals (probably all Australian fur seals) were observed in 89% of the shots monitored. Seals primarily interacted with the net near the exclusion device, feeding at the escape opening or entering/exiting the net via this opening. A total of 1864 seal interactions were recorded on video during the 19 shots monitored, noting that video footage per shot ranged from 2.73 to 2.93 hours whereas shot duration ranged from 3.08 to 11.50 hours. Seals were recorded as fully entering the net via the escape opening in over half the shots observed when this opening was recorded on camera and seals remained in the net for up to 8.66 minutes.

It should be noted that the small pelagics fishery occurs at much shallower (100 – 120 m) depths than that for blue grenadier. Midwater trawl shots targeting small pelagics usually lie well within the Australian fur seal's diving range and are thus accessible to seals throughout the shot. Nevertheless, the high level of net-entry by seals observed by Browne *et al*. (2005) strongly supports the assumption made in the grenadier fishery study that seals were entering trawl nets via the SED escape hatch. Furthermore, the observations of Browne *et al*. (2005) indicate that current SED designs will not reduce, and may increase, seal bycatch by trawlers in shelf waters. Some kind of 'one-way' (ie exit only) SED escape hatch is required.

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