Assessment of the implications of interactions between fur seals and sea lions and the southern rock lobster and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in South Australia

Photo: Nick Gales

Final Report to the Fisheries Research and Development Corporation

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1 NON TECHNICAL SUMMARY

2005/077	Assessment of the implications of interactions between fur seals and sea lions and the southern rock lobster and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in South Australia

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OBJECTIVES:

1. Synthesise and review the PIRSA and AFMA fishery logbooks for the SA Rock Lobster and Commonwealth shark fisheries for reports of interactions with seals
2. Undertake a desktop risk assessment of seal-fishery interactions in the SA Rock lobster and Commonwealth shark fisheries, based on distribution of catch and effort in proximity to seal populations.
3. Review the management responses related to the extent of protected species interactions with similar species and fisheries on a global scale.
4. Develop a proposal for a comprehensive study to assess the level and nature of interactions between seals and the SA Rock Lobster and Commonwealth shark fisheries, including the development of guidelines for measuring the performance of systems for monitoring, assessing and mitigating interactions between the fisheries and seals

OUTCOMES ACHIEVED TO DATE

This report provides the most comprehensive appraisal of the risk posed by bycatch to subpopulations of Australian sea lions and New Zealand fur seals, by the SA rock lobster and gillnet sector SESSF fisheries. Further it has identified the research required to ensure that SA rock lobster and the gillnet sector SESSF fisheries are managed according to ESD principles, and that interactions with seals are measured, assessed and mitigated. Adoption of these recommendations will lead to the development, and adoption by industry and management of mitigation options to reduce seal bycatch. This will ensure that outstanding ESD recommendations detailed in fishery ESD assessments and the mitigation of the key threatening process identified in the Australian sea lion Draft Recovery Plan are addressed, leading to the recovery and potential future delisting of the species.

Recent Commonwealth Department of the Environment and the Heritage (DEH) Ecological Sustainable Development (ESD) assessments of the South Australian (SA) rock lobster (SARLF) and southern and eastern scalefish and shark fishery (SESSF) identified interactions with protected species (particularly seals), as one of the key bycatch issues. The issues are most relevant to SA waters where the majority of Australia's New Zealand fur seal (NZFS) and endemic and *threatened* Australian sea lion (ASL) populations are located, and where un-quantified interactions between seals and the SARLF and gillnet sector of the SESSF fisheries are known to occur. Recommendations from fishery ESD assessments, fishery Bycatch Action Plans, and a recently drafted Recovery Plan for the ASL, have all identified the importance of assessing and mitigating interactions between seals and commercial fisheries. This study provides a desk-top risk-assessment of seal fisheries interactions in the SARLF and gillnet sector SESSF in SA and adjacent waters, and makes recommendations on future research and management responses.

A review of the PIRSA and AFMA fishery logbooks identified the major constraint to the assessment of bycatch risk to seal subpopulations was the absence of quantitative data on bycatch rates in both the gillnet sector SESSF and SARLF. Anecdotal evidence and entanglement data suggest there has been significant underreporting of seal interactions in these fisheries.

In SA there are 38 ASL subpopulations that produce around 2,674 pups, with the total population size estimated at about 10,900. However, most pup production (67%) occurs at 6 sites, hence the median pup production is very low (25.5 pups), with the majority of sites producing small numbers of pups (60% produce <30 pups per season). Not surprisingly, population viability analysis (PVA) on ASL subpopulations reinforced the recent listing of the ASL as a *threatened* species, by confirming that large numbers of subpopulations with low pup production are vulnerable to extinction. PVA simulations suggested that in absence of anthropogenic mortality, a number of ASL subpopulations will go *quasi-extinct* (<10 females), but in the face of small (1-2 additional females/year) but sustained anthropogenic mortality (eg. from fishery bycatch), most other small subpopulations will become *quasi-extinct* and negative growth will become a feature of even the largest subpopulations. There is apparent depletion (ie. very low pup production) of a large number of subpopulations that may be indicative of widespread subpopulation declines in the species. That such declines may be ongoing and attributable to anthropogenic mortality (ie. fishery bycatch) is a hypothesis that requires urgent attention.

In contrast to ASL, there are relatively few NZFS subpopulations (13) in SA, but the total pup production is considerably greater (17,622), with an estimated total population size of around 83,800. Populations are increasing, and PVA identified that most subpopulations were not-threatened. The risk of bycatch to both seal species in the gillnet SESSF and SARLF were assessed based on estimates of interaction probabilities. These were a function of the extent to which historic fishing effort and seal foraging effort (based on foraging distribution and population models) overlap in space and time. ASL demonstrated the highest risk of significant depletion and quasi-extinction as a result of fishery bycatch. In contrast, the risk to NZFS subpopulations is very low. By combining PVA outcomes with bycatch scenarios based on interaction probabilities, this study identified the subpopulations, regions and marine fishing areas (MFAs) most at-risk from seal bycatch.

Bycatch from the gillnet SESSF is most likely to provide the greatest risk to ASL, because of almost complete spatial overlap in fishing effort with ASL foraging effort, it is a year-round fishery with relatively high fishing effort that can potentially target all ASL age-classes. The impact from SA RLF is likely to be less because there is less overlap in fishing effort with ASL foraging effort, fishing is restricted to seven months of the year (November-May), and bycatch is likely to be restricted to pups and juvenile seals. However, the potential additive and interactive impacts posed by combined bycatch in these fisheries could be significant, especially for ASL.

Results from this study suggest the two fisheries investigated lend themselves to different mitigation approaches to addressing seal bycatch issues. In the gillnet SESSF, gear modification options are limited, but spatial management of fishing effort may provide a range of risk-reduction options to management, but would need to be coupled with independent observer bycatch data to demonstrate and justify the benefits from different closure options. In contrast, there are significant options for gear modification in the SARLF, with pot-protection devices already used in some parts of the fishery. Quantitative testing of these and alternate protection measures (as is taking place in the WA WRLF), and industry wide adoption of best-mitigation practices may eliminate seal bycatch in this fishery, without the need for an expansive and costly independent observer program. Recommendations for future research are made, that should result in the successful mitigation of seal bycatch issues, and as a consequence address the recommendations of the fishery ESD, Bycatch Action Plan, ASL Recovery Plan and assist in the recovery of the *threatened* ASL.

KEYWORDS: SA rock lobster fishery (SARLF), gillnet sector of the South Eastern Scalefish and Shark fishery (SESSF), Australian sea lion (ASL), New Zealand fur seal (NZFS), bycatch

2 BACKGROUND

In Australia, the ecologically sustainable use and conservation of the marine environment by commercial fisheries and the aquaculture industry is a major focus of the *Environment Protection and Biodiversity Conservation Act 1999* (the *EPBC Act*). This legislation provides a framework that will enable the Australian Government to ensure that any harvesting of marine species is managed for ecological sustainability. At present, the environmental performance of fisheries for strategic assessments under Part 10 of the *EPBC Act* assessments relating to impacts on protected marine species (Part 13) and those required for approval of export of fisheries product (Part 13A) are being evaluated for all wild fisheries.

In southern Australia waters one of the key marine protected species groups, which are impacted by fisheries, are the pinnipeds (seals), with three species present in domestic waters: the Australian sea lion (*Neophoca cinerea*), Australian fur seal (*Arctocephalus pusillus doriferus*) and the New Zealand fur seal (*A. forsteri*). All of these species have been recorded to interact with, and form bycatch in a range of Australian wild fisheries, including trawl (Knuckey et al. 2002, Shaughnessy et al. 2003, Tilzey et al. 2006); line (Constable and Shaughnessy 1999, Hume 2000), trap (Gales et al. 1994, Kirkwood et al. 1992, Shaughnessy et al. 2003, Temby 1998), and gillnet (Ling and Walker 1979, Robinson and Dennis 1988, Gales et al. 1994, Page et al. 2004, Shaughnessy et al. 2003, Walker et al. 2005).

Although populations of fur seals (Australian and New Zealand) have significantly increased in number over the last 15-20 years (Goldsworthy et al. 2003, Kirkwood et al. 2005, Shaughnessy et al.1995, Shaughnessy et al. 2000, Shaughnessy and McKeown 2002, Shaughnessy et al. 2002), populations of the ASL remain low (Shaughnessy 1999), and there is evidence for a decline over parts of their range (McKenzie et al. 2005, Shaughnessy et al. 2006). A recent report to the Commonwealth Department of the Environment and Heritage (DEH) identified that anthropogenic and top-down (mortality driven) factors were the most likely causes of declines in ASL populations, and of these, fishery bycatch and entanglement were the only factors for which there was supporting evidence, at least in parts of the species range (McKenzie et al. 2005). The fisheries of major concern were the southern rock lobster (*Jasus edwardsii*) and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) (McKenzie et al. 2005). As a consequence of concerns regarding the status of ASL populations, their conservation status was recently upgraded to *"Threatened"*, *"Vulnerable"* category (gazetted February 2005) by the Commonwealth base on the recommendations of its Threatened Species Scientific Committee (Department of the Environment and Heritage), and a Recovery Plan has been drafted.

Southern rock lobster fishery

The total gross-value of product (GVP) of the Australian fishery for southern rock lobster is approximately $200M. The fishery extends from south-western WA, through to South Australia, Victoria and Tasmania and northern NSW, and overlaps significantly with the breeding ranges and distributions of the three species of seals that breed in Australia (Goldsworthy et al. 2003).

Seals are known to interact with lobster fisheries (Shaughnessy et al. 2003) and may be attracted to bait and lobsters in pots. As a consequence, small individuals (pups and juveniles) may enter pots and drown. In addition, seals scavenge old baits as they are discarded, which may attract them to lobster vessels. Further, discarded lobster bait-box straps form the largest component (30%) of entanglement material recorded/recovered from New Zealand fur seals on the south coast of Kangaroo Island (Page et al. 2004).

Warneke (1975) suggested that 43 of 182 tagged juvenile Australian fur seals were drowned in lobster pots (Victoria). Gales et al. (1994) suggested that a significant proportion of sea lion pups drown in lobster pots in Western Australia, and recently the extraordinary capabilities of Australian sea lions to remove western rock lobster from pots has been documented with underwater video footage (Campbell et al. 2004). Based on volunteer logbook entries by fishers and annual independent surveys, bycatch rates have been estimated to range from 3.3 - 5.4 seals per year (Campbell 2004).

Devices for protecting bait and excluding pinnipeds from pots are used extensively in some areas. Shaughnessy et al. (2003) noted that in Tasmania, fishers use "seal-proof" bait holders to make it more difficult for seals to remove bait. In Victoria, fishers place baits in PVC pipes in order to prevent seals taking bait (Kirkwood et al. 1992; Temby 1998). In South Australia, fishers use vertical "spikes" to impede seals from entering pots, but the effectiveness of these devices has not been quantified. Other devices, including bars across the mouth of the pot are used, or are being developed in other States (Dr David Hobday and Dr Chris Chubb, pers. Comm., Campbell et al. 2004). The effectiveness of such devices in deterring seals and preventing them removing rock lobsters from pots is being investigated in the western rock lobster fishery (Campbell et al. 2004), but has not been quantified in the southern rock lobster fishery.

The largest and most valuable fishery for southern rock lobster (*Jasus edwardsii*) is located in South Australia ($80-100M), where most of Australia's ASL and NZFS populations occur (Goldsworthy et al. 2003). Anecdotal information from South Australian fishers suggests that juveniles seals occasionally enter rock lobster pots and drown; however, there has not been any quantitative assessments of the nature and extent of seal-southern rock lobster interactions, the extent of predation on pots by seals or risk assessment posed by bycatch in the fishery to seal populations.

ESD Assessment - SA Rock lobster fishery

In December 2002, a report was submitted to the Department of the Environment and Heritage (DEH) by South Australia's Department of Primary Industries SA (PIRSA) under Parts 13 and 13A of the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) titled 'Ecological Assessment of the South Australian Rock Lobster Fishery' (Sloan 2003). The submission reported on the South Australian Rock Lobster Fishery (SARLF) against the Commonwealth 'Guidelines for the Ecologically Sustainable Management of Fisheries'. In October 2003, the DEH responded to the submission by providing a series of recommendations aimed to 'further strengthen the effectiveness of the management arrangements for the SARLF, and to contain the environmental risks in the medium to long term'. The DEH stated that the implementation of these recommendations by PIRSA will 'be monitored and reviewed as part of the next Commonwealth review of the fishery in five years time' (2008).

Overall, 3 of the 13 DEH recommendations specifically focus on the interactions of the rock lobster fishery and *endangered*, threatened or protected species.

Recommendation 10 states that as there has not been any formal assessment of the impact of the fishery on *endangered*, threatened or protected species. PIRSA will 'within 18 months (ie. by December 2004) introduce mandatory structured reporting of all interactions between the rock lobster fishery and *endangered*, threatened or protected species'. This recommendation is based on the acceptance that although infrequent, 'interactions between rock lobster fishing and… seals (including sea lions and fur seals) are the most common'. DEH indicated that the first step in minimising seal interactions and providing guidance on the need for further mitigation strategies is the establishment of preliminary reference points, which describe the level of interaction between the rock lobster fishery and seals. DEH states that this can be achieved on the basis of Recommendation 11 i.e. 'PIRSA and industry to continue to monitor the extent of the interactions between rock lobster fishery and fur seals and sea lions, and to develop appropriate mitigation measures, including establishment within two years (ie. by October 2005) of preliminary trigger and reference points, to minimise these interactions'.

DEH also considers it appropriate that PIRSA leads an intermediate risk assessment addressing the interactions between the SARLF and marine wildlife, which should be aimed at supporting management controls. This is addressed in Recommendation 12 i.e. 'PIRSA within 12 months (ie. by April 2004) to conduct a qualitative risk assessment of the interactions of the rock lobster fishery and protected species off SA and use the outcomes of this assessment to implement further protected species mitigation measures as required'.

It is important that these recommendations are acted upon, because PIRSA's ecological assessment report was aimed at providing DEH with a detailed assessment of the management arrangements in place for the SARLF, against the 'guidelines for the ecologically sustainable management of fisheries' (set out in the *EPBC Act*), in order to have southern rock lobster taken from South Australian waters, placed on the list of exempt native specimens for export under Part 13 and 13(A) of the *EPBC Act*. Therefore there is an imperative to address the ESD recommendations, because failure to do so may jeopardise current and future export exemptions.

Gillnet sector Southern and Eastern Scalefish and Shark Fishery (SESSF)

The total annual GVP of the gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF), which primarily targets gummy (*Mustelus antarcticus*) and school shark (*Galeorhinus galeus*), is approximately $15.3 million. Bycatch of seals (particularly Australian sea lions) in this fishery has been recognised as an important issue in Bycatch Action Plans (AFMA 2001) and recent ESD assessments (Assessment of the Southern and Eastern Scalefish and Shark Fishery, DEH 2003a). Further, monofilament gillnet (from the gillnet sector of the SESSF) is the most prevalent entanglement material found on Australian sea lions at Kangaroo Island (55% of all entanglements over a 15 year period, Page et al. 2004).

Gillnet Sector SESSF fishers have recorded interactions with protected species in logbooks since 1998. The Bycatch Action Plan (Australian Fisheries Management Authority 2001) indicated that reported interaction rates were relatively low. Based on logbook entries, Walker et al. (2005) also reported low interaction rates, with just two Australian fur seals deaths as a result of entanglement in shark gill-nets in the SESSF between 1998-2001. However, these are considered to be underestimates, because logbook recording has been voluntary (Shaughnessy et al. 2003). In addition, other data suggest that interaction rates are much higher than that reported: 1) the rates of entanglement of sea lions in monofilament net at Kangaroo Island (Page et al. 2004), 2) anecdotal reports of high rates of interactions when nets are set inshore, and 3) the admission by a fisherman claiming that he caught 20 sea lions per annum in gillnets, mostly near Kangaroo Island and the Neptune Islands (reported to PD Shaughnessy cited in Shaughnessy et al. 2003).

ESD assessment – gillnet sector of the SESSF

Bycatch Action Plans for the SESSF and South East Non-trawl Fisheries (AFMA 2001) identified several research priorities, under Action 6, Performance Indicator 6.1 – Analysis of pilot Integrated Scientific Monitoring Program and logbook data identifying incidences of gear and sea lion interaction by December 2001; and Performance Indicator 6.2 – Research proposal initiated through AFMA to map sea lion colonies by March 2002.

The recent ESD Assessment of the SESSF (DEH 2003a), made the following recommendations:

1. That within two years (by September 2005) the AFMA would develop a document that describes the structure of a monitoring program required under Section 6(a) of the Management Plan, to prioritise monitoring issues such as discarding rates, threatened and listed species' interactions and appropriate levels of observer coverage and fishery-independent studies in all sectors of the fishery (Point 3, Summary Recommendations).

2. Within 3 years (by September 2006) AFMA will identify and implement management responses to fishing impacts, taking into account (amongst other

things) listed threatened species under the *EPBC Act* (Point 6, Summary Recommendations) (ie. Australian sea lions),

3. Within 3 years (by September 2006) AFMA will develop and implement a system of spatial and temporal management to assist in the fishery being managed in an ecologically sustainable manner, with a system of strategic closures to take into account impact of fishing on (amongst other things), species and populations identified by the ecological risk assessment process as high risk (Point 10, Summary Recommendations, ie. Australian sea lions).

4. AFMA will, in consultation with industry, DEH, researchers and other stakeholders, further assess and reduce the extent of interactions with seals, cetaceans and seabirds across all sectors of the SESSF, and interactions with sygnathids in the trawl sectors, and white sharks in the gillnet and hook sector (Point 18, Summary Recommendations). AFMA will for all of the above species:
- Within 12 months (ie. by September 2004) establish robust data collection and reporting systems to quantify the extent of interactions; and
- Within 3 years (by September 2006), assess, trial and implement as appropriate mitigation or avoidance measures including further trials of bycatch exclusion devices and spatial or temporal closures.

With respect to seal interactions, little, if any progress has been made on any of the above recommendations for either fishery.

Background to seal species

Australian sea lion (ASL)

The ASL is Australia's only endemic seal species. The species has a unique life-history, which sets it apart from other seals that share the typical pattern of annual and synchronous breeding. It is the only pinniped species with a non-annual, aseasonal breeding cycle of 17.5 months, that is also temporally asynchronous across its breeding range (Gales et al. 1994, Gales and Costa 1997, Higgins 1993). A breeding cycle of slightly less than 18 months causes a seasonal drift in the timing of breeding, so that for any site, breeding will take place at all times of the year over about a 20 year period (Gales et al. 1992, Higgins 1990).

Like other otariid seals (fur seals and sea lions), ASL come into oestrus about a week following parturition, followed by a 4 month embryonic diapause (Gales and Costa 1997). The duration of the breeding season (5-7 months) and the placental phase of gestation (up to 14 months) are the longest of any seal (Gales and Costa 1997, Shaughnessy et al. 2006). Pups are typically nursed for between 15-18 months, although females that fail to pup in consecutive seasons (about 30%) typically nurse their pups until the next breeding season (a further 15-18 months) (Higgins and Gass 1993). During lactation, females take their young to the water and often disperse to other haul-outs, and it has been suggested that in so doing, mothers may play an active role in teaching their offspring where to forage and how to catch prey (Gales et al. 1994), although a recent study found no evidence of this (Fowler et al. 2006). Females typically forage for about two-days between shore attendance bouts of about 1.5 days, when pups are nursed (Higgins and Gass 1993). The diet of ASL is poorly understood, because unlike other otariid seals, few diagnostic prey remains can be recovered from their scats (Gales and Cheal 1992). This is most likely due to the presence of stomach stones (gastroliths) (Needham 1997). It is thought that ASL feed on a wide variety of prey including cephalopods, rock lobsters, fish and shark (Gales and Cheal 1992, Ling 1992, McIntosh et al. 2006 b). A recent study on the diving behaviour and energetics of ASL, suggests that they are specialist benthic feeders that dive almost continuously when at sea, with more than 60% of each dive spent at the deepest 20% of dives (Costa and Gales 2003). Average dive depths range from 42-83m, with maximum dives ranging from 60-105 m (Costa and Gales 2003).

There are approximately 70 known breeding locations for ASL, 40 of which occur in South Australia, where the species is most numerous (75% of pup production), with the remainder occurring in Western Australia (Goldsworthy et al. 2003, McKenzie et al. 2005). The species was subject to sealing in the late 18th and early 19th century, resulting in a reduction in population size and range (Ling 1999). Despite the large number of breeding sites, the average number of pups born at each colony is low (44), with total pup production for the species during each breeding cycle estimated at 2,861, and an estimated population size of 11,000 seals (Goldsworthy et al. 2003).

The ASL has not recovered since harvesting ceased, unlike fur seals throughout southern Australia. There are limited data on the status of sea lion populations, the best data being available for Seal Bay, Kangaroo Island. Based on assessment of the numbers of pups counted in each breeding season since 1985 (when systematic surveying commenced), the population at Seal Bay has been declining by about 0.77% per year, or approximately 1.1% per breeding season, equating to a 13% decline since 1985 (18 year period, Shaughnessy et al. 2006). At Dangerous Reef, data on the numbers of pups born are available for eleven seasons since 1975 to 2005 although three of these counts are likely to be underestimates, having been undertaken before the end of the breeding season (Shaughnessy 2005). An analysis of the remaining seven seasons suggests the population is stable or increasing slightly (by 1.25% per annum, 1.8% per breeding season).

The Australian sea lion is Australia's only endemic pinniped, and was recently listed under the Environment Protection and Biodiversity Conservation Act as *Threatened*, *'Vulnerable'* category (gazetted 14 Feb 2005), and a recovery plan is has been drafted by Commonwealth DEH.

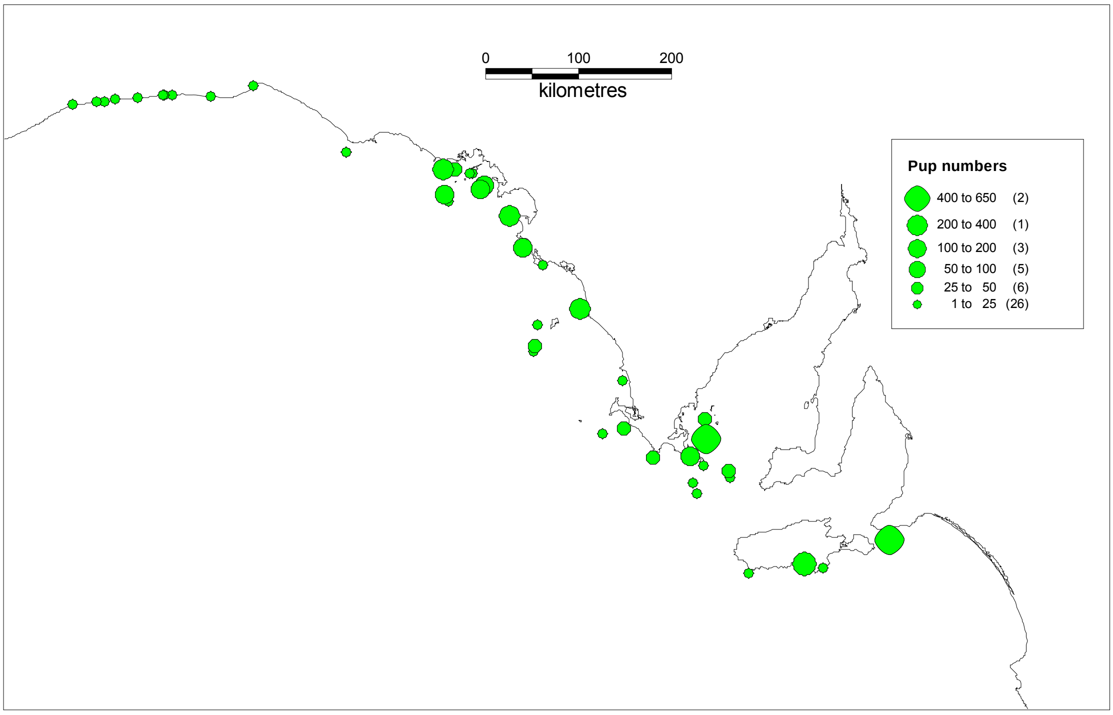


Figure 2.1. Location and relative size of Australian sea lion breeding colonies (green circles, based on pup production) in South Australia.

New Zealand fur seals (NZFS)

The NZFS (*Arctocephalus forsteri*) is a temperate latitude species, which breeds on offshore islands along the southern coastline of Australia and in New Zealand and its subantarctic islands (Goldsworthy & Shaughnessy 1994; Shaughnessy et al. 1995). Like most other otariid seals (fur seals and sea lions), they are annual breeders.

Breeding is highly synchronised and commences in late November, with the bulk of births occurring over a five-week period (Goldsworthy & Shaughnessy 1994). In SA, the median date of pupping is 21 December (Goldsworthy & Shaughnessy 1994). Females give birth to a single pup and nurse it until it is approximately 10 months old, at which point pups wean themselves (Goldsworthy 2006). Females alternate between foraging trips to sea lasting anywhere between 3-20 days, and shore attendance bouts typically last 1-2 days when pups are nursed (Goldsworthy 2006). On Kangaroo Island, NZFS prey primarily on pelagic fish (eg. redbait and jack mackerel) and squid, benthic fish such as ocean jackets and swallowtails, and seabirds (primarily little penguins) (Page et al. 2005). Satellite tracking studies undertaken at Cape Gantheaume, Kangaroo Island, have shown marked spatial differences in the distribution of foraging effort of juveniles, adult females and male NZFS. Juveniles primarily feed in oceanic waters (ie. beyond the continental shelf), lactating females feed in mid-outer shelf waters, approximately 50-100 km from the colony, and adult males focus their foraging effort over the continental slope (Page et al. 2006).

Fur sealing was an important industry to early colonial Australia, and recent estimates based on analysis of historical shipments of skins indicates that at least 350,000 fur seals (Australian fur seals and NZFS combined) were harvested, most of which were taken between 1800-1830 (Ling 1999). Ling (1999) suggests that these figures are likely to be underestimates due to unreported cargos and wastage. NZFS populations were drastically reduced as a consequence of sealing, and they were eliminated from Bass Strait, although the species has recently begun recolonising the area (Littnan and Mitchell 2002, Shaughnessy et al. 2002). Recovery of NZFS populations has taken considerable time, with most of the recovery occurring since the early 1980s. At present there are 39 known breeding colonies in Australia (18 in South Australia, 17 in Western Australia, 3 in Victoria and 1 in Tasmania), with most of the population (84%) in South Australia (Goldsworthy et al. unpublished data, Shaughnessy 2006) (Figure 2.2).

New Zealand fur seals are abundant in South Australia, with recent censuses estimating over 17,600 pups born over the 2005/06 breeding season (Goldsworthy et al. unpublished data, Shaughnessy 2006), representing about 84% of Australia's total NZ fur seal population. Most pups are born at the Neptune (48% of SA's total), Kangaroo (40% of SAs total) and Liguanea Islands (12% of SA's total) (Figure 2.3). Ongoing surveys of populations of NZFS on Kangaroo Island have shown that between 1988 (when surveys began) and 2006, populations increased exponentially by about 12.6% per year (from data presented in Shaughnessy 2006). There have been fewer surveys undertaken at the Neptune Islands, with current data suggesting population growth rates are about 4.3% per year, which is relatively lower than on Kangaroo Island. Overall, the rate of increase for populations in SA averages about 6.8% per year (Figure 2.3).

The NZFSs is listed as a protected species under the South Australian National Parks and Wildlife Act 1972, and the Commonwealth Environment Protection and Biodiversity Conservation Act, 1999 (*EPBC Act*).

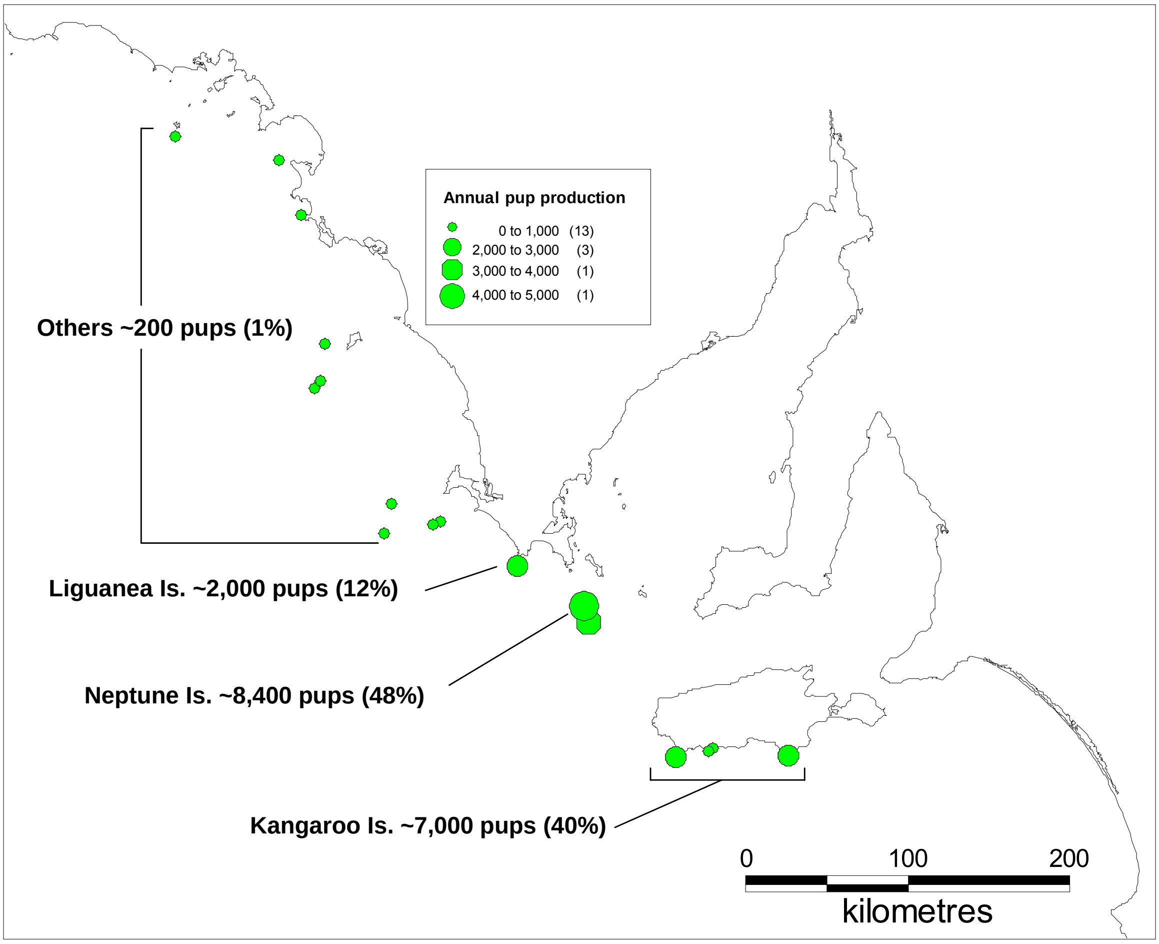


Figure 2.2. Location and relative size of New Zealand fur seal breeding colonies (green circles, based on annual pup production) in South Australia.

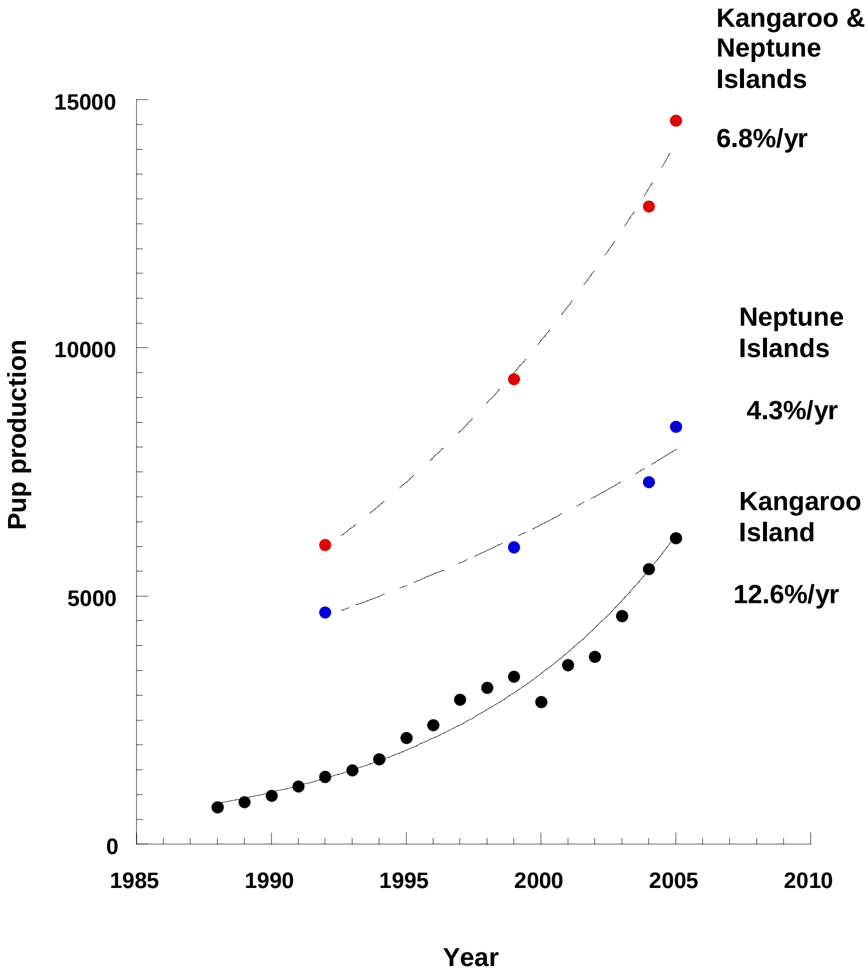


Figure 2.3. Trends in New Zealand fur seal pup production on Kangaroo Is and the Neptune Islands between 1988-2005 (trend estimates based on data present ed in Shaughnessy 2006 and Goldsworthy et al. unpublished data).

3 NEED

Provisions of the Commonwealth Environment Protection and Biodiversity Conservation Act (*EPBC Act*), require strategic assessment of fisheries against the principles of ESD including the need to monitor, assess and, if necessary, mitigate the interactions of fisheries with protected species (Fletcher et al. 2002).

In both the SARLF and gillnet sector of the SESSF there are considerable policy and research requirements relating to fishery interactions with fur seals and sea lions that need to be undertaken in order to fulfil recommendations detailed in recent Bycatch Action Plans and ESD Assessments (detailed in Section 2).

The Australian Governments' National Seal Action Plan requires the estimation of sea lion and fur seal bycatch in gillnet, trawl, trap, dropline and longline fisheries and quantification of interactions with fishing equipment.

Pinnipeds are listed as protected species under the Commonwealth *EPBC Act*, and are known to interact with lobster and gillnet fisheries.

Methods for assessing, monitoring and mitigating the interactions of pinnipeds with lobster and gillnet fisheries are needed urgently.

This need is greatest in South Australia, where:

1. the majority of subpopulations of the Australian sea lion occur, and where declining populations have been identified,
2. Australia's largest subpopulations of New Zealand fur seal occur,
3. a valuable ($70 M) fishery for southern rock lobster (*Jasus edwardsii*) is located, and where
4. un-quantified interactions between pinnipeds and the SARLF and gillnet sector of the SESSF fisheries are known to occur.

The need to assess the interaction of the Australian sea lion with these fisheries is particularly pressing, because the Australian sea lion:

1. is Australia's only endemic pinniped,
2. may be more vulnerable to fishery-induced mortality than other species,
3. is mainly confined to South Australia, with ~80% of pup production occurring in the State, and
4. has recently been listed as *Threatened* (*Vulnerable* Category) under Commonwealth *EPBC Act* legislation.

4 OBJECTIVES

1. Synthesise and review the PIRSA and AFMA fishery logbooks for the SA Rock Lobster and gillnet sector of the SESSF fisheries for reports of interactions with seals.

2. Undertake a desktop risk assessment of seal-fishery interactions in the SA Rock lobster and gillnet sector SESSF, based on distribution of catch and effort in proximity to seal populations.

3. Review the management responses related to protected species interactions with similar species and fisheries on a global scale.

4. Develop a proposal for a comprehensive study to assess the level and nature of interactions between seals and the SA Rock Lobster and gillnet sector SESSF, including the development of guidelines for measuring the performance of systems for monitoring, assessing and mitigating interactions between the fisheries and seals.

5 REPORT FORMAT

The format of this report addresses each of the above objectives as separate sections. Objective 4 above is addressed in Chapter 9 as part of Recommendations for further research.

6 SYNTHESISE AND REVIEW THE FISHERY LOGBOOKS FOR THE SA ROCK LOBSTER AND GILLNET SECTOR SESSF FISHERIES FOR REPORTS OF INTERACTIONS WITH SEALS

Derek Hamer

Introduction

The South Australian Rock Lobster Fishery (SARLF) is currently managed by Primary Industries and Resources South Australia (PIRSA), who receive advice about management of southern rock lobster (*Jasus edwardsii*) from the South Australian Research and Development Institute (SARDI). In contrast, the Australian Fisheries Management Authority (AFMA) manages gummy shark (*Mustelus antarcticus*) and school shark (*Galeorhinus gelaus*) catches by the gill-net sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) at an Australian Commonwealth level. In spite of these differing management arrangements, both fisheries operate in State and Commonwealth waters adjacent to the South Australian coast.

All commercial fisheries operating in South Australian State waters are managed pursuant to the *Fisheries Act 1982*, which does not currently require the use of logbooks for maintaining records of fishing activity. Conversely, the Commonwealth *Fisheries Management Act 1991* gives AFMA the powers to request any fishery operating in Commonwealth waters to maintain logbook records. Notwithstanding, the regulations under both Acts require that logbooks be maintained.

In general, logbook systems are typically established and maintained by fisheries management organisations and are used as the underlying conduit for collecting information about parameters considered important for the sustainable management of the target fish stock. Information of interest to AFMA and SARDI includes catch and effort, length and weight, recruitment and fecundity for estimating stock health and size and for setting quotas (Linnane et al. 2006). Commercial fishers operating in state and Commonwealth waters adjacent to the South Australian coast are required to submit logbook records at a predetermined frequency and within a specified time period to ensure that up to date records are maintained. Both AFMA and PIRSA Fisheries provide the SESSF gill-net sector and SARLF licence holders, with a hard copy logbook for completion. Maintenance of logbooks and regular submission of log sheets is mandatory, with failure to provide accurately completed log sheets being an offence under the regulations pertaining to each fishery.

In spite of the volumes of information collected in logbooks used to manage fisheries both in Australia and elsewhere, there are conflicting conclusions about their accuracy and thus reliability as a tool for managing fisheries effectively. A lack of motivation and incorrect recording by fishers are likely to be the principal causes, and may significantly affect the reliability and quality of the data provided to fishery managers (Robins et al. 2002). However, comparisons between industry logbook data and observer data collected over several seasons in a New Zealand rock lobster fishery suggest that logbooks provide a reliable source of information (Starr and Vignaux 1997).

The impacts of commercial fisheries on bycatch or non-target species have received increasing attention in recent years. The impetus to take a more ecosystem-based approach to the management of commercial fishing activities is derived from an increasing understanding of their impacts on the broader environment at a community level (Bache 2003). Logbook recording of bycatch incidence and rates is motivated by a need to understand the magnitude and impact of commercial fishing activity (Barratt et al. 2001, Robins et al. 2002, Bache 2003). The logbooks for both fisheries now reflect this requirement, with provisions for recording information about non-target and bycatch fish species typically encountered and landed.

In spite of the growing need and progress toward managing fisheries with a more ecosystem-based approach, few fisheries include interactions with marine mammals as a part of the logbook recording requirements. The current logbook provided to the SESSF gill-net sector (GNO1A form) gives fishers the opportunity to record interactions with ‘native wildlife’ should they occur, although no advice is given to ensure that fishers can accurately identify marine mammals to a species level, as is the current requirement under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). In addition, the SARLF logbook only requires the recording of giant crab (*Pseudocarcinus gigas*) and octopus (*Octopus* spp.) bycatch, with no provision for entry of interactions with marine mammals.

The recent advent of the EPBC Act has been critical for the evolution of protection of marine mammals in Australian waters and serves to strengthen the argument that commercial fisheries must demonstrate their commitment to the current legislation and related regulations. Under the EPBC Act, pinnipeds were listed as *Conservation Dependent* on the Threatened Species List, although the Australian sea lion (*Neophoca cinerea*) has recently been upgraded to *Vulnerable*, with the subsequent requirement to establish a recovery plan. In addition, the EPBC Act now requires that significant commercial fisheries undergo an *Environmental Assessment*, as a review of management strengths and weaknesses in mitigating impacts on the broader environment. Both fisheries have undergone an assessment and both have identified the need to improve the standard of logbook records with regard to interactions with marine mammals. This section briefly reviews the available information regarding interactions with pinnipeds in each fishery.

AFMA logbook records for the Southern and Eastern Scalefish and Shark Fishery (SESSF) shark gill-net sector

There are few logbook records of interactions with pinnipeds for the SESSF gill-net sector for State and Commonwealth waters adjacent to the South Australian coast. No records are available for the years between 1973 and 1999, prior to the enactment of the EPBC Act. From the 68,070 recorded net-sets between October 1999 and October 2004, nine entanglement events (10 animals) were reported by five vessels (Table 6.1). Seven of those entanglements resulted in single fatalities, while one animal was released alive. Animals were observed and recorded swimming near the vessels on two other occasions.

All interactions involving pinnipeds were recorded as ‘seal’ by vessel operators. The species most likely to encounter commercial gill-net vessels are either the Australian sea lion (*Neophoca cinerea*) or the New Zealand fur seal (*Arctocephalus forsteri*), based on the distribution of seal species in southern Australia (Shaughnessy and Dennis 2002, Shaughnessy and Dennis 2003, McKenzie et al. 2005, Shaughnessy 2005, Shaughnessy et al. 2005, Shaughnessy et al. 2006).

Prior to the enactment of the EPBC Act, commercial fishers were required to record deaths of marine mammals under the National Parks and Wildlife Regulations made under the National Parks and Wildlife Conservation Act 1975. Since the enactment of the *EPBC Act* in 2000 the number of reported interactions remains low and location information is not available.

Table 6.1. The number and rate (interactions/net-sets) of seals entangled, killed and released in the South Australian component of the Southern and South and Eastern Scalefish and Shark Fishery (SESSF) gill-net sector, between October 1999 and October 2004 (AFMA, unpublished data).

	Entangled	Killed	Alive
Number	10	7	3
Rate (seals/1,000 net sets)	1.47	0.10	0.04

SESSF gill-net sector logbook data indicates widespread, but patchy geographic distribution of fishing effort over the last 33 years (Australian Fisheries Management Authority, unpublished data, also see Section 7). Anecdotal evidence suggests that most interactions with seals occur close to shore and adjacent to seal colonies (Matthew Larsson pers comm.; Kyriakos Toumazos pers. comm.). Further, the extent of potential geographic overlap between foraging Australian sea lions and the SESSF gill-net sector (see Section 7) and the reported occurrence of entanglement in monofilament gill-net (Shaughnessy et al. 2003, Page et al. 2004, Campbell 2004; Walker et al. 2005) provides further evidence that interactions with pinnipeds may not always be recorded in logbooks. Under-reporting of operational interactions between marine mammals and commercial fisheries has also been documented in the eastern tropical Pacific (Gerrodette and Forcada 2005), suggesting that such behaviour may be engrained in commercial fisheries, due to a fear of community reprisals and revocation of fishing licences (Shaughnessy et al. 2003).

It is difficult to establish the real extent of interaction rates when considering the potential for industry logbooks to be incomplete. Possible solutions to this problem include:

1. A modified logbook that contains a section specifically for recording interactions with seals (as has been achieved for the SESSF trawl fishery).
2. Either an educational workshop or program to improve the accuracy of recording to species' level. The logbook does not ask for species information .
3. Either an educational workshop or program to improve the awareness of the fishery of their obligations under the relevant fisheries acts and the EPBC Act. There is currently considerable confusion about licence holder and vessel operator requirements and obligations under the legislation and regulations under which the conditions associated with their licence is associated.

4. A short-term observer program to verify the current level of interactions and to provide guidance to fishers for future industry-based logbook record keeping.

The Commonwealth DEH recommendations handed down in response to the original SESSF *Ecological Assessment* flagged the need to establish an accurate data collection and reporting system to quantify the extent of interactions with seals (Department of the Environment and Heritage, 2003a). The timeframes specified by Commonwealth DEH in their ESD assessments for undertaking this work have now expired, highlighting the need for the fishery to respond immediately. Therefore, AFMA should take action by immediately implementing an independent monitoring program to determine the nature and extent of these interactions.

Logbook records for the South Australian rock lobster fishery (SARLF)

There are no reports of marine mammal interactions available for the South Australian rock lobster fishery (SARLF). However, a recent study demonstrated that juvenile Australian sea lions in Western Australia interact with rock lobster (*Panulirus cygnus*) pots and are proficient at removing them (Campbell 2004). In addition, 43 of 182 Australia fur seal (*Arctocephalus pusillus doriferus*) pups were suggested to have drowned in rock lobster pots in Victorian waters (Warneke 1975), and it has been suggested that similar mortalities occur in Australian sea lion pups (Gales et al. 1994). Furthermore, dead New Zealand fur seal pups were found recently in a rock lobster pot, washed ashore on the south coast of Kangaroo Island (Brad Page, pers, comm.). Therefore, even though there are no recorded accounts of interactions with pinnipeds by the SARLF, there is sufficient evidence to suggest that both Australian sea lions and New Zealand fur seals interact with the fishery in South Australian waters and may occasionally enter pots, become entrapped and die.

Reporting of interactions between pinnipeds and the SARLF requires significant improvement before its extent and nature can be determined. The same recommendations suggested for improvement of logbook recording mechanisms in the SESSF gill-net sector also apply to the SARLF, namely recommendations for amendments to the current logbook, education programs and observer programs. Again, these changes have been recommended by the Commonwealth DEH in response to the *Ecological Assessment* submitted by the fishery in 2003, but to date little action has been taken.

7 RISK-ASSESSMENT OF SEAL INTERACTIONS IN THE SOUTH AUSTRALIAN ROCK LOBSTER AND GILL-NET SECTOR OF THE SOUTHERN AND EASTERN SCALEFISH AND SHARK FISHERY

Simon Goldsworthy and Brad Page

Introduction

As detailed in the Background, the aim of this section is to undertake a desktop risk assessment of seal bycatch in the SA rock lobster fishery (SARLF) and gillnet sector of the Commonwealth Southern and Eastern Scalefish and Shark Fishery (SESSF). The two seal species investigated are the Australian sea lion (ASL, *Neophoca cinerea*) and the New Zealand fur seal (NZFS, *Arctocephalus forsteri*), both of which breed in South Australia. The approach taken is to:

- o Develop population and foraging distribution models for seal populations so that the spatial distribution of foraging effort for different sex and age classes within each species can be estimated.
- o Undertake a population viability analysis (PVA) of seal subpopulations to identify those most vulnerable to bycatch.
- o Collate historic data on the spatial and temporal variation in fishing effort in both the gillnet SESSF and SARLF, and estimate probabilities of seal-fishery interactions by overlaying spatial distribution of seal foraging effort with historical fishing effort.
- o Combine interaction probabilities with bycatch scenarios and PVA to identify subpopulations/regions/marine fishing areas (MFAs) with the greatest risk from fishery bycatch.

Methods

Seal distribution, population size and population viability analysis

Location of breeding sites

The location of ASL and NZFS breeding colonies, and the pup production at each site (subpopulation) within South Australian waters was derived from published and unpublished sources (Tables 7.1 and 7.2). Pup production estimates (numbers of pups born per breeding cycle) for each subpopulation for each species, were used as the basis for estimating subpopulation sizes, with the aid of life tables developed for each species. Breeding colonies for both species were defined as those sites where a minimum of five pups has been recorded at least once during the past 20 years (McKenzie et al. 2005).

Population estimates

The population size of each subpopulation was estimated utilising species-specific life tables and pup production estimates. For NZFS, life-tables were based on those developed by Goldsworthy et al. (2003), utilising data available for closely related species (mean age-specific survival data for female Antarctic fur seals (*A. gazella*) (2-15 years), South American fur seals (*A. australis*) (0-20 years) and northern fur seals (*C. ursinus)* (0-20 years); Boyd et al. 1995; Lima and Paez 1997; Barlow and Boveng 1991). Using these data, an average age-specific survival relationship was generated, with the best fit resulting from a third-order polynomial equation (1-20 years; $S = 0.627 - 0.073a + 0.003a^2 - (5.91 \times 10^{-5})a^3$, $r^2=0.999$), where S is survival and a is age in years) (Table 7.3). Based on age-specific survival data for female South American and northern fur seals (Lima and Paez 1997; Barlow and Boveng 1991), mean maximum age was set at 20 for females, and 15 for males (actual maximum ages identified for this species are 23.4 and 16.7 for females and males, respectively; J McKenzie pers. comm.). As few data are available on age-specific survival rates of male otariids, these were estimated by scaling the female survival equation to a 15-year life-span by multiplying the year value by 0.75 (15/20), and re-fitting the third-order polynomial equation (males: $S = 0.627 - 0.097a + 0.006a^2 - (0.140 \times 10^{-3})a^3$) (see life-table, Table 7.3).

For the ASL, which breeds about every 17.6 months (Higgins 1993), survival was calculated for every 1.5 year interval following the approach used by Goldsworthy et al. (2003). This study set longevity for females to 30.5 years (to provide the same number of reproductive opportunities as available to annually breeding seals). However, recent age-estimates for the species (R. McIntosh, La Trobe University), using annual growth-layer groups identified from sectioned teeth, have identified the oldest female at 25 years (R. McIntosh, unpublished data). Based on these data, the age-specific survival model developed by Goldsworthy et al. (2003) was adjusted and balanced by increasing annual survival levels and scaling to a maximum of 25.5 years (17 x 1.5 year stages) for females; ($S = 0.627 - 0.048a + 0.001a^2 - (0.159 \times 10^{-4})a^3$; and 15 years for males: $S = 0.627 - 0.082a + 0.005a^2 - (0.962 \times 10^{-4})a^3$).

The sex ratio at birth for each species was assumed to be 1:1. The number of live individuals *N,* in each age-class *a* and sex *s*, was calculated as:

$$N_{a,s} = N_{a-1,s} S_{a-1,s} \quad (1)$$

where *S* is the age-specific survival rate. The size of a population *N* was estimated as:

$$N = \sum_{s=1}^{s=2} \sum_{a=1}^{a=A} N_{a,s} \quad (2)$$

where *A* is the number of age classes (stages) in the population.

All subpopulations within each species were assumed to have the same population parameters as detailed above.

Leslie matrix and population model development

Simple deterministic and density-independent (exponential) Leslie matrices were developed to project the subpopulations of both seal species through time. We used the RAMAS® Metapop software (Version 3.0, Applied Biomathematics, Setauket, New York, Akçakaya and Root 1998) to model female populations of both species. Age-specific survival estimates from life-tables along with estimates of age-specific fecundity were adjusted until a balanced population model was developed (population size remained stable over time, with finite rate of increase (λ) equal to 1, Table 7.4). Fecundity estimates were based on those determined for closely related species (eg. Boyd et al. 1995; Lima and Paez 1997; Barlow and Boveng 1991) and a minimum age of reproduction of 4 and 4.5 years for NZF and ASL, respectively (J. McKenzie pers. comm, R McIntosh pers. comm).

Because only the female part of subpopulations was modelled, pup production was halved (assuming 1:1 sex-ratio at birth) and fecundity defined as the proportion of female offspring born to each female per stage. For each subpopulation being modelled, initial population abundances were set so that the estimated numbers in the first stage (pups) equalled half of the estimated pup production for that subpopulation. Final stage survival rates were set to zero, and a standard deviation of 0.1 set for all stage survival and fecundity estimates.

Density-independent models were used for both species for a numbers of reasons. Firstly, populations of both species are believed to be below their carrying capacity, following significant range and population reductions and incomplete recovery from historic sealing (Gales et al. 1994, Goldsworthy et al. 2003, Ling 1999, Shaughnessy et al. 1994). Secondly, pre-sealing or carrying capacity population estimates are unavailable, hence it is unclear at what population threshold in each species density-dependent factors would become significant. For the NZFS, subpopulations in SA are currently increasing at an exponential rate, hence density-dependent factors do not appear to be limiting growth. For ASL, most subpopulations are so small that we believe present density levels would not elicit a significant feedback on a subpopulation's vital rates (although there is some evidence for density dependence in pup mortality at some subpopulations, Ling and Walker 1977, Campbell 2005). Similarly, the importance of Allee effects (where there is a positive relationship between aspects of fitness and population size) in regulating pinniped populations is poorly understood. Although there is growing appreciation for the importance of Allee Effects and the need to incorporate them into population models (Stephens and Sutherland 1999), given the uncertainty in the significance of their role in ASL and NZFS populations, we have chosen to exclude them from our subpopulation modelling.

Individual subpopulations were modelled separately, and assumed to be closed (ie. no immigration or emigration). For ASL, there is good evidence to support this assumption, with population genetic data indicating that the species demonstrates one of the highest levels of population subdivision among pinnpeds, with very high levels of mtDNA haplotype fixation among subpopulations (Campbell 2003). These findings suggest that ASL females display extreme levels of philopatry, with little or no interchange of females among breeding colonies.

Table 7.1. Summary of estimates of pup production per breeding cycle for Australian sea lion breeding sites (subpopulations) in South Australia, including the census date, source of information and location (decimal degrees). Only colonies where 5 or more pups have been reported are listed. Data were current in April 2006.

Breeding site	Pups	Census	Sources	Lat	Long
The Pages[1]	577	Oct-05	Shaughnessy (2005a)	-35.767	138.300
Seal Slide (Kangaroo Is.)	11	Sep-04	Shaughnessy et al. (2006)	-36.028	137.539
Seal Bay (Kangaroo Is.)	214	Jun-03	McIntosh et al (2006a)	-36.000	137.333
Peaked Rock	24	Mar-90	Gales et al. 1994	-35.183	136.483
North Is.	28	Jul-05	Goldsworthy 2005	-35.117	136.467
English Is.	27	Jun-05	Goldsworthy 2005	-34.633	136.200
North Neptune, East	14	May-05	Goldsworthy 2005	-35.226	136.077
South Neptune, Main	6	1993	Shaughnessy, Dennis & Seager 2005	-35.333	136.117
Dangerous Reef	585	Jun-05	Shaughnessy (2005b)	-34.817	136.217
Lewis Is.	73	Nov-05	D. Hamer, & Goldsworthy et al. 2005	-34.983	136.033
Albatross Is.	15	Jul-05	Goldsworthy 2005	-35.067	136.183
Liguanea Is.	43	Jan-05	Shaughnessy (2005a)	-35.000	135.617
Four Hummocks Is. (North)	12	Jan-96	Shaughnessy, Dennis & Seager 2005	-34.767	135.033
Price Is.	25	Jan-96	Shaughnessy, Dennis & Seager 2005	-34.717	135.283
Rocky (North) Is.	16	Jan-96	Shaughnessy, Dennis & Seager 2005	-34.267	135.267
Pearson Is.	27	Sep-03	B Page pers. comm	-33.950	134.267
Ward Is.	8	Nov-95	Shaughnessy, Dennis & Seager 2005	-33.750	134.300
West Waldegrave Is.	157	Jul-03	Shaughnessy, Dennis & Seager 2005	-33.600	134.783
Jones Is.	15	Jan-05	Shaughnessy et al. 2005	-33.183	134.367
Nicolas Baudin Is.	72	Feb-02	Shaughnessy, Dennis & Seager 2005	-33.010	134.126
Olive Is.	131	Jan-05	Shaughnessy (2005b)	-32.717	133.983
Lilliput Is. (E Franklin Reef)	67	Mar-05	Goldsworthy et al. 2005	-32.433	133.700
Blefuscu Is. (W Franklin Reef)	84	Mar-05	Goldsworthy et al. 2005	-32.467	133.650
Gliddon Reef	7	Jun-05	Goldsworthy et al. 2005	-32.323	133.564
Breakwater Is.	17	Jun-05	Goldsworthy et al. 2005	-32.322	133.529
Fenelon Is.	21	Sep-90	Gales et al. 1994	-32.583	133.283
Masillon Is.	9	Sep-02	Robinson et al. 2003	-32.562	133.286
West Is.	56	May-05	Goldsworthy et al. 2005	-32.517	133.250
Lounds Is.	26	Nov-90	Gales et al. 1994	-32.283	133.367
Purdie Is.	132	May-05	Goldsworthy et al. 2005	-32.283	133.233
Western Nuyts Reef	14	Apr-04	Shaughnessy, Dennis & Seager 2005	-32.117	132.133
GAB B1[2]	15	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.492	131.067
GAB B2[2]	5	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.594	130.583
GAB B3[2]	31	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.580	130.150
GAB B5[2]	43	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.589	130.050
GAB B6[2]	12	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.609	129.767
GAB B8[2]	38	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.643	129.383
GAB B9[2]	17	1995	Dennis & Shaughnessy 1996, Goldsworthy et al. 2003	-31.648	129.300
Total	2,674				

[1]The Pages comprise two islands (North and South Page) and ASL breed on both. For the purposes of this study, they have been considered a single subpopulation.
[2]Apportioning pups among the Bunda Cliffs subpopulations in the Great Australian Bight (GAB) follows the approach used by Goldsworthy et al. 2003.

Table 7.2. Summary of estimates of annual pup production of New Zealand fur seals at breeding sites (subpopulations) in South Australia, including the census date, source of information and location (decimal degrees). Only colonies where 5 or more pups have been reported are listed.

Breeding site	Pups	Census	Source	Lat	Long
Berris Pt	697	Feb 06	Shaughnessy 2006	-36.078	137.460
Cape Gantheaume	3,135	Feb 06	Shaughnessy 2006	-36.150	137.460
Cape Bouguer	20	Feb 06	Shaughnessy 2006	-36.050	136.917
Cave Point	25	Feb 06	Shaughnessy 2006	-36.029	137.044
Cape du Couedic[1]	3,085	Feb 06	Shaughnessy 2006, 1997, 1998	-36.067	136.700
South Neptune Is[2]	3,818	Jan 06	Goldsworthy unpublished	-35.333	136.117
North Neptune Is[3]	4,585	Jan 06	Goldsworthy unpublished	-35.233	136.067
Liguanea Island	2,072	Jan 06	Goldsworthy unpublished	-35.000	135.617
Little Hummock Is	7	Jan 90	Shaughnessy et al. 1994	-34.750	135.083
Four Hummocks Is	57	Jan 96	Shaughnessy et al. 2005	-34.767	135.033
Greenly Is	7	Jan 04	B. Page, in Shaughnessy et al. 2005	-34.650	134.750
Rocky (South) Is	50	Jan 96	Shaughnessy et al. 2005	-34.817	134.700
Ward Island	64	Jan 90	Shaughnessy et al. 1994	-33.750	134.300
Total	17,622				

[1]Represents a cluster of colonies around Cape du Couedic, including Knife and Steel Point (98 pups), Weirs Cove North (255 pups), Weirs Cove South (103 pups), Nautilus Rock (140 pups), Nautilus North (463 pups), Spooks Bay (260 pups), Libke (975 pups), Admirals Arch (14 pups) (all surveyed February 2006, Shaughnessy 2006); Ladders North (257 pups), Ladders South (21 pups) (surveyed January/February 1998, Shaughnessy 1998) and North Casuarina Island (499 pups, surveyed January/February 1996, Shaughnessy 1997).
[2]Includes Main Island (3667 pups), Middle Island (93 pups) and Lighthouse Island (58 pups).
[3]Includes West Island (4391 pups) and East Island (194 pups).

Table 7.3. Simplified hypothetical life-tables for NZFS and ASL, including age-specific survival (*S*), and numbers (N) per stage. Numbers are based on pup production estimates from Tables 7.1 and 7.2, assuming a 1:1 sex-ratio at birth.

	NZFS			ASL		
	Age (y)	S	N	Age (y)	S	N
Females	0	1.000	8,811	0	1.000	1,337
	1	0.557	4,908	1.5	0.558	746
	2	0.493	4,346	3	0.495	662
	3	0.435	3,837	4.5	0.438	585
	4	0.383	3,377	6	0.386	516
	5	0.336	2,963	7.5	0.339	453
	6	0.294	2,593	9	0.296	396
	7	0.257	2,262	10.5	0.258	344
	8	0.223	1,967	12	0.223	298
	9	0.194	1,707	13.5	0.193	257
	10	0.168	1,477	15	0.165	221
	11	0.145	1,274	16.5	0.141	188
	12	0.124	1,095	18	0.119	159
	13	0.106	938	19.5	0.100	133
	14	0.091	798	21	0.082	110
	15	0.076	673	22.5	0.067	89
	16	0.064	560	24	0.052	70
	17	0.052	456	25.5	0.039	52
	18	0.041	357			
	19	0.030	261			
	20	0.019	163			
Female total			44,823			6,617
Males	0	1.000	8,811	0	1.000	1,337
	1	0.545	4,805	1.5	0.514	687
	2	0.472	4,161	3	0.416	557
	3	0.407	3,588	4.5	0.334	447
	4	0.350	3,081	6	0.265	354
	5	0.299	2,634	7.5	0.207	277
	6	0.255	2,243	9	0.160	214
	7	0.216	1,903	10.5	0.121	162
	8	0.183	1,608	12	0.089	119
	9	0.154	1,354	13.5	0.062	83
	10	0.129	1,135	15	0.039	52
	11	0.107	946			
	12	0.089	783			
	13	0.073	639			
	14	0.058	510			
	15	0.044	392			
	16	0.032	278			
	17	0.019	163			
Male total			39,034			4,288
Total Population Estimate			83,857			10,905

Population viability analysis (PVA)

PVA provides a means to predict future population abundances, the time to extinction (or a prescribed level of reduced abundance) and the probability of extinction or reaching an abundance threshold within a specified period. These are usually undertaken using stochastic simulation models (Shaffer 1981, Gilpin and Soulé 1986, Reed et al. 2002). We used the Leslie matrices developed for each species to undertake PVAs on their subpopulations. Two measures of risk were calculated, *terminal extinction risk* (the probability that a population will go extinct during a specified time period) and *quasi-extinction time* (Q_t, the time for the median of the simulated population trajectory replicates to go *quasi-extinct*) (Akçakaya 1998). We defined quasi-extinction (*Q*) as occurring when the numbers of females in a subpopulation fell to, or below a threshold of 10 individuals. Demographic stochasticity was simulated within RAMAS® Metapop, by sampling the number of survivors from a binomial distribution and young from a Poisson distribution (Akçakaya 1998).

PVA was undertaken to investigate the potential implication of additional (anthropogenic) mortality on the conservation status of each subpopulation. This was achieved by applying virtual harvests of female seals to each subpopulation, and determining the level of additional mortality required to increase the risk of extinction. RAMAS® Metapop allows the user to define the number animals from each stage to be harvested from each year. For consistency, we removed pre-recruit seals from the first stage (<1.5 years old in ASL) when undertaking simulations. In ASL, the potential implications of additional mortality were investigated under three scenarios of population trajectory: increasing, stable and decreasing. The increasing trajectory was set at 5%/year based on current growth in the Dangerous Reef subpopulation (Shaughnessy unpublished data). Although the Dangerous Reef subpopulation appears to be increasing at a higher rate, part of this is likely to be an artefact of improved census methodology in recent years (Shaughnessy unpublished data). The base model (above) was used as the stable trajectory. The decreasing trajectory was based in part on the current rate of decline observed in the Seal Bay subpopulation (-0.77%/year, Shaughnessy et al. 2006). We adjusted this to the nearest integer (-1%). Different population growth models were simulated by adjusting relative survival levels and then calculating the resultant population trajectory (500 replicates of 100 stages). The exponential rate of increase (*r*), calculated from the slope of exponential regressions of population size over time was expressed as a percentage increase as follows, (e^r – 1) x 100. Relative survival multipliers of 1.0985 and 0.9801 were used to simulate increasing (5%/year) and decreasing (-1%/year) population trajectories, respectively.

Because NZFS populations in South Australia are currently increasing (Shaughnessy et al. 1994, Shaughnessy 2006), the potential implications of additional mortality were investigated assuming that subpopulations are increasing in size. The average rate of growth of 6.4%/year (average of Kangaroo and Neptune Islands) was used, and simulated using a relative survival multiplier of 1.08.

PVA outputs for each subpopulation scenario were based on 1,000 replicates for 100 stages (ie. 100 years for NZFS and 150 years for ASL), and categorised against four risk criteria, adapted from Mace and Lande (1991):

1) Quasi-extinct – defined here as <10 females

2) Critical – 50% probability of extinction within 5 years or 2 generations, whichever is longer.

3) Endangered – 20% probability of extinction within 20 years or 10 generations, whichever is longer;

4) Vulnerable – 10% probability of extinction within 100 years.

For species with overlapping generations, generation time is defined as the mean age of mothers of all newborn females, assuming a stable distribution (the mean interval between the birth of a mother and the birth of her offspring, weighted by the proportion of individuals in each age class, Caughley, 1977). Generation time was calculated for each species using their Leslie Matrices in Poptools (Version 2.7) (Hood, 2006). The generation time for Australian sea lions and New Zealand fur seals was calculated as 12.4 and 9.9 years, respectively.

Seal foraging models and spatial distribution of foraging effort

Simple, distance (and in some cases) direction-based foraging models were developed for different age/gender classes within each species, to enable the spatial distribution of foraging effort (seal days·year^{-1}) to be estimated for each age/gender group, within each subpopulation and for each species within the study area. These models assumed that seals within a subpopulation foraged within a set range and in some cases a specific direction from their colony of origin, according to the normal probability density function. Foraging distance and heading parameters used for each age/gender group are detailed in Table 7.6.

Table 7.4. Leslie Matrix for NZFS populations. The first row indicates the stage (age) of females in years. The second row indicates stage-specific fecundity (proportion of female pups born to each female per stage) and the diagonal cells denote stage-specific survival (proportion of the previous stage surviving to the next stage) (note final stage 20 has a survival of 0).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.000	0.000	0.000	0.050	0.125	0.360	0.400	0.415	0.425	0.430	0.430	0.425	0.420	0.415	0.400	0.380	0.340	0.300	0.250	0.200
0.560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0.891	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0.888	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0.886	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0.883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.881	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0.879	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0.877	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0.874	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0.872	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0.870	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0.868	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0.865	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0.861	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.856	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.848	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.836	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.818	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.788	0

Table 7.5. Leslie Matrix for ASL populations. The first row indicates the stage (age) of females in years. The second row indicates stage-specific fecundity (proportion of female pups born to each female per stage) and the diagonal cells denote stage-specific survival (proportion of the previous stage surviving to the next stage) (note final stage 25.5 has a survival of 0).

1.5	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18	19.5	21	22.5	24	25.5
0.000	0.000	0.100	0.200	0.315	0.370	0.395	0.410	0.415	0.420	0.420	0.400	0.375	0.350	0.300	0.200	0.100
0.558	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0.887	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0.884	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0.881	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0.878	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.874	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0.871	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0.867	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0.862	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0.858	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0.852	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0.845	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0.837	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0.826	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.809	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.785	0.000

Using the geographic information systems (GIS) software package MapInfo™ (Version 6.0, MapInfo Corporation, Troy New York, USA), continental shelf (0-200m) and slope (200-1000m) waters in South Australia were overlaid with a 10 x 10 km grid, and the coordinates (latitude and longitude) of each node were extracted. Beyond the continental slope, a 20 x 20 km grid was established to account for oceanic foraging (NZFS only). The distance and heading (bearing) from each seal colony to each node in the array was then calculated. The probability (*f*) of an animal from a given colony foraging at a particular node (*d*) was then calculated based on the distance (*D*) of the node from the subpopulation, and the designated mean (μ) and standard deviation (σ) of foraging distance (km), using the normal probability density function, where

$$f(D_d) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{D_d - \mu}{2\sigma}\right)^2} \quad (3)$$

Similarly, the probability (*f*) of an animal from a given colony foraging at a particular node (*d*) was also calculated based on the heading (*H*) of the node from the subpopulation, and the designated mean (μ) and standard deviation (σ) of heading (degrees), where

$$f(H_d) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{H_d - \mu}{2\sigma}\right)^2} \quad (4)$$

The estimated distribution of seal foraging effort (*FE*) was then calculated based on the average number of days spent at sea per year by each age/gender category (seal days·year^{-1}) (Table 7.6).

$$FE_{a,s} = 365 N_{a,s} P_{a,s} \quad (5)$$

Where *P* is the proportion of time spent at sea (Table 7.6). The overall probability of foraging effort *f(FE)* by each age/gender group from a given subpopulation (*c*) at each node (*d*) was then calculated as

$$f(FE_{c,d}) = \sum_{c=1}^{c=N_c} \left\{ FE_{c,d} \frac{f(D_d)\, f(H_d)}{\sum_{d=1}^{d=N_d} f(D_d)\, f(H_d)} \right\} \quad (6)$$

where N_c is total number of subpopulations and N_d is total number nodes. The actual *FE* (seal days·year^{-1}) of age/gender group from a given subpopulation (*c*) at each node (*d*) was then calculated as

$$FE_{c,d} = f(FE_{c,d}).FE \quad (7)$$

NZFS populations were divided into four age/gender groups: pups (0-1 years), juveniles (1-3 year females, 1-4 year males), adult females (≥4yrs), and adult males (≥5 years). For ASL, populations were divided into five age/gender groups; pups (0-1.5 years); juveniles (1.5-3 years); sub-adult males (SAM, 3-7.5 years); adult females (≥4.5 years) and adult males (≥7.5 years). Numbers of individuals present in each age/gender group were calculated using the life-table developed for each species (Table 7.3). The proportion of time spent at sea, mean foraging distance and direction for juvenile, adult female and male NZFS were estimated based on satellite tracking data from Cape Gantheaume and Cape du Couedic colonies (Kangaroo Island, Page et al. 2006, B. Page and A. Baylis pers comm.). Estimates of the proportion of time spent at sea and mean foraging distance for and juvenile, SAM, adult female and male ASL were also based on satellite tracking data from the Nuyts Archipelago and Dangerous Reef (Goldsworthy et al. unpublished data) (Table 7.6-7.8). For NZFS, the mean direction (heading) of foraging from colonies was to mid-outer shelf and off-shelf waters (ie. not inshore, Page et al. 2006). For ASL, no directionality was imposed on foraging models, with the exception of adult males. Tracking studies of adult males off the west coast of the Eyre Peninsula indicate that animals forage predominantly in outer shelf waters (Goldsworthy et al. unpublished data). Because of the geography of the region, a directionless model for age/gender groups that feed at distance from colonies may project some foraging effort in the reverse direction (eg. into northern Gulf waters) to the regions that these age/sex groups are known to use. Distance and directional parameters used in developing the forging models are detailed in Tables 7.6-7.8.

These data were imported into MapInfo™, and then interpolated (triangular irregular network interpolation with 5th order polynomial) and plotted using VerticalMapper™ (Version 2.0, Northwood Geosciences Ltd, Nepean, Ontario, Canada).

Spatial and temporal distribution of fishing effort

Commercial fishing effort data for the gill-net sector of the SESSF within and adjacent to South Australian waters, were derived from AFMA for each year between 1973 and 2004 (32 years) (see Table 7.9). Fishing effort data for the South Australian southern rock lobster fishery (SARLF) were obtained from SARDI Aquatic Sciences for 35 consecutive years between 1970 and 2004 (see Table 7.10). Fishing effort data for each fishery has been recorded for individual marine fishery areas (MFAs) that are roughly based around a 1º x1º grid (Figures 7.1 and 7.2). In order to present the spatial and temporal changes in fishing effort, each zone was represented by multiple nodes spaced equidistant where possible, to spread fishing effort equally throughout the node. Data were interpolated and plotted using MapInfo™ and VerticalMapper™ (triangular irregular network interpolation with 5th order polynomial).

Spatial and temporal overlap in fishery effort and seal foraging effort

Using the distribution of foraging effort models, which were developed for the different age/gender groups of each seal species, the total amount of foraging effort by each species within each fishery MFA was calculated by summing the values for each 10 x 10km node within each fishery MFA. The proportion of the total foraging effort (*FE*) calculated for each species, which occurred within each fishery MFA, was then derived. For each year of fishing effort records, the product of the proportion of seal *FE* and fishing effort (*F*) were calculated within each MFA. The extent of overlap between fishing effort and seal foraging (overlap index, *OI*, adapted from Schoener (1968)) within each MFA was then calculated as a probability (*f*) by dividing the product of the proportion of fishing effort (F_{FMA}) and the proportion of seal foraging effort (FE_{FMA}) within each MFA, by the sum of all the products from all MFAs, as follows:

$$f(OI)_{FMA} = \frac{f(FE_{FMA}).f(F_{FMA})}{\sum_{FMA=1}^{FMA=N_{FMA}} f(FE_{FMA}).f(F_{FMA})} \qquad (8)$$

where N_{FMA} is the total number of MFAs.

Table 7.6. Mean estimated foraging range, proportion of time at sea and estimated foraging effort (seal days.year^{-1}) for different age/gender groups for ASL and NZFS populations in South Australia.

Age/gender	ASL				NZFS			
	Foraging distance (km)		Proportion time at sea	*FE*	Foraging distance (km)		Proportion time at sea	*FE*
	Mean	sd		Seal days/year	Mean	sd		Seal days/year
Adult male	80[1]	55	0.58	132,231	135[3]	88	0.73	3,802,898
Adult female	20[1]	15	0.53	746,563	68[3]	51	0.82	6,860,245
Sub-adult male	24[1]	15	0.51	200,227				
Juvenile	18[1]	9	0.46	244,003	599[3]	207	0.78	7,169,927
Pup	10[2]	10	0.25	244,003	5[2]	5	0.25	1,286,406
Total				1,772,395				19,119,477

[1]Mean and standard deviation of foraging distance and the proportion of time spent at sea are based on satellite tracking data (Goldsworthy et al., unpublished data).
[2]Estimated.
[3]Mean and standard deviation of foraging distance and the proportion of time spent at sea based on satellite tracking data from Page et al. (2006).

Table 7.7. Estimated mean foraging heading (and sd) for pup, juveniles, adult females and male NZFS from South Australian subpopulations based on satellite tracking studies (Page et al. 2006, Page pers. Comm. and Baylis pers. Comm.).

Colony	Pups		Juveniles		Females		Males	
	Heading	sd	Heading	sd	Heading	sd	Heading	sd
Berris Pt	135	90	163	45	128	45	146	45
Cape Gantheaume	135	90	163	45	128	45	146	45
Cape Bouger	180	90	180	45	180	45	180	45
Cave Point	180	90	180	45	180	45	180	45
Cape du Couedic	190	90	190	45	190	45	190	45
South Neptune Is	190	90	225	45	225	45	225	45
North Neptune Is	200	90	225	45	225	45	225	45
Liguanea Island	240	90	225	45	225	45	225	45
Little Hummock Is	250	90	225	45	225	45	225	45
Four Hummocks Is	250	90	225	45	225	45	225	45
Greenly Is	250	90	225	45	225	45	225	45
Rocky (South) Is	250	90	225	45	225	45	225	45
Ward Island	250	90	225	45	225	45	225	45

Table 7.8. Estimated mean foraging heading (and sd) for adult male ASL based on satellite tracking studies at several locations in SA (Goldsworthy et al. unpublished data)

Colony	Heading	sd
North Pages Is.	135	90
Seal Slide (Kangaroo Is.)	160	90
Seal Bay (Kangaroo Is.)	180	90
Peaked Rock	180	90
North Is.	180	90
English Is.	190	90
North Neptune, East	190	90
South Neptune, Main	190	90
Dangerous Reef	190	90
Lewis Is.	190	90
Albatross Is.	190	90
Liguanea Is.	200	90
Four Hummocks Is. (north)	200	90
Price Is.	225	90
Rocky (North) Is.	225	90
Pearson Is.	225	90
Ward Is.	225	90
West Waldegrave Is.	225	90
Jones Is.	225	90
Nicolas Baudin Is.	225	90
Olive Is.	225	90
Lilliput Is.	225	90
Blefuscu Is.	225	90
Gliddon Reef	225	90
Breakwater Is.	225	90
Fenelon Is.	225	90
Masillon Is.	225	90
West Is.	225	90
Lounds Is.	225	90
Purdie Is.	225	90
Western Nuyts Reef	200	90
GAB B1	180	90
GAB B2	180	90
GAB B3	180	90
GAB B5	180	90
GAB B6	180	90
GAB B8	180	90
GAB B9	180	90

Results

Population distribution and size

The location and estimated pup production for colonies of ASL and NZFS in SA are detailed in Tables 7.1 and 7.2, and Figure 7.3. Life tables detailing the estimated age-specific survival, total numbers of individual within each age-class (stage), and total population size based on the estimated pup production for each species within SA are detailed in Table 7.3. Based on this life-table, and a pup production of 2,674 per breeding cycle, the size of the SA ASL populations is estimated at 10,905 individuals, of which 6,617 (61%) are females and 4,288 (39%) are male (Table 7.3). For NZFS, based on an annual pup production of 17,622, the SA NZFS population is estimated to number 83,857, of which 44,823 (53%) are female and 39,034 (47%) are male. The life-tables produced population estimates that were 4.76 and 4.08 times that of pup-production in NZFS and ASL populations, respectively.

There are 38 breeding sites of the ASL in SA, where pup production has been recorded to number ≥ 5 (Table 7.1). Of the 38 breeding sites, only 6 (16%) produce more than 100 pups, accounting for 67% of the State's pup production. The largest population is Dangerous Reef in southern Spencer Gulf (585 pups), followed by The Pages (577 pups) in Backstairs Passage between Kangaroo Island and mainland Australia. The next largest populations are Seal Bay (214 pups) on Kangaroo Island, West Waldegrave (157 pups) and Olive Islands (131 pups) off the west coast of the Eyre Peninsula, and Purdie Island (132 pups) in the Nuyts Archipelago. The median pup production for SA colonies is 25.5, with 60% of breeding sites producing fewer than 30 pups per season, 42% producing fewer than 20 pups, and 13% fewer than 10 pups. These analyses do not take into account at least another 11 breeding sites (termed haul-outs with occasional pupping), where fewer than 5 pups have been recorded at some time (McKenzie et al. 2005).

There are 13 known breeding sites of the NZFS in SA, where pup production exceeds 5 pups (Table 7.2). The largest breeding sites are at the Neptune Islands that collectively produce more than 8,000 pups per annum (Table 7.2). Two southern headlands on Kangaroo Island, Cape Gantheaume (including Berris Point) and Cape du Couedic are also significant sites for the species, because each produces over 3,000 pups per annum. Liguanea Island off the southern coast of the Eyre Peninsula is the next largest colony that produces just over 2,000 pups. The remaining breeding colonies are relatively small, and situated on offshore islands, off the west coast of the Eyre Peninsula (Table 7.2).

Distribution of seal foraging effort

The estimated distribution of foraging effort by ASL and NZFS in SA is presented in Figures 7.4a-f and 7.5a-e. Not surprisingly, the greatest density of foraging effort in ASL occurs in waters adjacent to breeding colonies, with relative foraging distances increasing from pups, to juveniles, adult females and sub-adult males. Because adult males typically forage in outer shelf waters and range widely (Goldsworthy et al. unpublished), their estimated spatial distribution of foraging effort differs markedly from the other age/gender groups, because they do not focus their foraging near colonies (Figure 7.4e). The estimated total distribution of foraging effort (age/gender groups combined) is presented in Figure 7.4f, and demonstrates the greatest concentration of foraging effort associated with the larger subpopulation centres, especially The Pages (just east of Kangaroo Island), Seal Bay (south coast of Kangaroo Island), Dangerous Reef (southern Spencer Gulf) and the Nuyts Archipelago (west Eyre Peninsula). With the exception of the south-east and northern Gulf waters, some level of ASL foraging effort occurs in almost all near-coastal waters from Encounter Bay to the West Australian border (Figure 7.4f).

NZFS undergo a marked transition in foraging behaviour as they mature. As pups, foraging activity is localised to near colony waters (Baylis et al. 2005), then shifts to oceanic (off-shelf) waters as juveniles, and then contracts to mid-outer shelf waters in adult females and to slope waters in adult males (Page et al. 2006, Figures 7.5 a-d). Given that most of the SA NZFS population occurs in four main regions; Cape Gantheaume and Cape du Couedic (Kangaroo Island), the Neptune and Liguanea Islands, there is a marked concentration of foraging effort in near-colony waters and adjacent shelf and slope waters, between south-east Kangaroo Island and south-west of the Eyre Peninsula (Figure 7.5e). However, given the size of the SA NZFS population and based on the foraging effort models developed here, some degree of foraging effort occurs in all shelf, slope and oceanic waters off SA (Figure 7.5e).

Distribution of fishing effort

Gill-net sector of the SESSF

Data detailing the annual fishing effort (km net-lifts.year^{-1}) for the 29 SA MFAs of the gill-net sector of the SESSF, spanning 32 years between 1973 and 2004, are presented in Table 7.9 and Figure 7.6a. Over this period, there was a total of 634,496 km of net-lifts, averaging about 20,000 km of net-lifts per year (Table 7.9, Figure 7.6a). Annual effort changed markedly in this region of the fishery, with a steady increase from around 3,000 km to 12,000 km net-lifts per year between 1973-1983, with a very significant increase in fishing effort between 1984-1987 peaking at nearly 43,000 km net-lifts in 1987 (Table 7.9, Figure 7.6a). Fishing effort then decreased annually to about 23,000 km net-lifts in 1993 and then increased to just over 32,000 km net-lifts in 1998. Fishing effort reduced to around 17,000 km net-lifts in 2000, and has remained at about this level up until 2004 (Table 7.9, Figure 7.6a).

The spatial distribution of fishing effort between 1973 and 2004 is summarised for four-year averages in Figures 7.7a-h, and total and average annual fishing effort are present in Figure 7.7i and 7.7j, respectively. Essentially these track the increase in fishing effort from the 1970s and the 1980s, with the major regions of fishing effort occurring south and south-east of Kangaroo Island, and off the west coast of the Eyre Peninsula (Figures 7.7a-j). Between 2000-2004, about 42% of total fishing effort occurred south and south east of Kangaroo Island (MFA 149-151, Table 7.9).

SA Rock lobster fishery (SARLF)

Data detailing annual changes in fishing effort over a 35 year period (1970-2004) in 19 MFAs of the SARLF are presented in Table 7.10 and Figure 7.6b. Over this period there was a total of 78.9 million pot-lifts, averaging about 2.3 million pot-lifts/year (Table 7.10, Figure 7.6b). Annual effort in the fishery increased from around 2.2 to 2.5 million pot-lifts per year between the 1970s and 1980s, to a maximum of 2.7 million pot-lifts in 1991. Since then, fishing effort has decreased and in 2003 and 2004, averaged just over 1.5 million pot-lifts (Table 7.10, Figure 7.6b).

Changes in the spatial distribution of fishing effort in the SARLF between 1970 and 2004 are presented in Figures 7.8a-i. Over this period, about 70% of the total fishing effort has been concentrated in the south-east of the state in MFAs 55, 56 and 58 (Figures 7.8a-i). Elsewhere, effort is focused close to the shore along the south coast of Kangaroo Island, and the southern and west coasts of the Eyre Peninsula (Figures 7.8a-i).

Table 7.9. Annual fishing effort (km net-lifts.year^{-1}) for the 29 SA MFAs of the gill-net sector of the Commonwealth SESSF, spanning 32 years between 1973 and 2004.

MFA	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
101	0	0	0	0	0	0	0	0	0	0	108	0	174	0	560	107	741
102	0	0	41	0	0	22	16	0	0	80	0	0	0	0	0	14	66
103	0	14	2	0	0	0	41	127	79	275	541	48	182	135	504	344	524
104	0	0	0	0	0	0	0	0	0	0	0	0	0	120	315	763	482
105	0	0	0	0	0	0	0	0	0	0	267	0	0	0	386	279	581
106	0	6	0	0	0	0	0	0	72	10	53	15	0	0	256	923	274
107	165	279	139	32	108	0	13	287	336	334	810	404	660	1591	2027	1469	821
108	674	746	438	273	626	1029	725	1467	1117	1315	1258	2991	2467	3059	4049	3201	3421
112	0	0	4	0	0	0	0	0	0	0	20	0	0	189	27	444	570
113	0	0	6	0	0	0	0	0	0	202	65	74	150	856	524	1200	753
114	13	11	2	0	0	0	0	0	96	389	75	461	606	688	1277	2085	1155
115	216	70	156	60	103	35	319	333	524	667	1155	1072	898	1799	1388	1073	2063
122	58	75	117	29	106	115	100	276	512	676	413	381	230	229	288	135	42
125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	43	3	1	15	0	20	80	103	830	1045	352	911	1697	1190	1663	2494	2475
128	58	107	0	21	145	284	299	634	888	965	705	1101	870	1035	1108	1095	1579
129	0	0	0	0	206	764	1072	1146	1206	1199	440	419	556	1677	1810	1124	1234
132	52	55	38	14	388	108	181	0	409	478	1209	2782	1260	504	1080	687	853
136	78	161	9	0	236	580	165	345	162	122	90	130	38	52	323	372	131
138	7	5	43	13	0	0	57	401	345	699	334	1061	923	787	1997	1626	1980
139	57	103	91	92	183	226	233	301	461	1092	558	686	751	1531	3112	1637	2549
140	67	60	74	79	64	445	322	440	519	164	246	462	387	549	1275	1854	2092
144	233	212	415	60	471	471	466	452	417	393	313	303	459	1088	1312	1326	948
148	6	140	0	74	65	84	24	28	51	104	57	345	417	1509	1843	1200	1393
149	124	211	245	93	276	33	0	120	110	183	312	831	965	3417	4620	3975	2425
150	184	236	202	122	40	16	108	274	424	368	694	2093	1388	2991	4329	2327	3120
151	615	233	831	429	805	990	989	1471	996	443	1100	3507	2342	3404	4692	6512	3392
155	313	352	144	183	315	552	1198	328	92	181	123	274	1379	1437	1490	1598	3913
158	165	362	193	344	353	313	288	456	457	220	593	198	187	349	734	488	759
Total	3127	3441	3189	1933	4489	6086	6695	8986	10102	11603	11892	20548	18986	30185	42989	40349	40338

Table. 7.9 Cont.

MFA	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total	%	Average
101	443	339	13	168	160	181	25	208	280	505	189	244	222	0	0	4666	0.7%	146
102	242	828	299	37	0	267	551	191	248	252	47	65	53	0	0	3320	0.5%	104
103	524	960	764	380	245	424	647	200	452	398	101	200	276	0	0	8390	1.3%	262
104	791	750	190	70	120	42	13	111	516	284	105	27	4	545	612	5859	0.9%	183
105	420	364	600	280	175	580	68	322	628	412	335	247	146	309	115	6515	1.0%	204
106	989	490	333	292	284	212	441	232	700	222	205	84	33	393	338	6857	1.1%	214
107	1593	730	786	982	560	947	729	573	985	1043	273	492	371	579	343	20461	3.2%	639
108	2070	2059	2755	1429	1798	1415	1103	2422	1431	1331	765	771	1055	871	890	51024	8.0%	1594
112	292	391	592	253	25	185	63	145	176	97	61	23	53	21	17	3647	0.6%	114
113	312	683	823	603	1091	604	764	545	601	291	81	155	8	105	103	10599	1.7%	331
114	1200	1240	1897	1002	1899	1235	827	1497	1587	1239	632	495	194	847	472	23121	3.6%	723
115	582	677	1223	632	1133	1795	2342	1745	1712	1866	1017	913	950	1322	1131	30968	4.9%	968
122	16	15	67	81	18	179	152	81	50	59	57	25	0	0	0	4583	0.7%	143
125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	585	585	0.1%	18
126	2163	1220	839	1616	1458	2040	1161	1372	2124	1225	835	645	699	1288	1411	33014	5.2%	1032
128	1094	585	965	512	385	304	925	903	760	752	326	320	354	334	816	20226	3.2%	632
129	1160	629	772	373	1094	991	1275	1278	955	1613	205	184	7	32	9	23430	3.7%	732
132	722	486	110	338	142	277	378	569	346	593	307	28	31	2	0	14425	2.3%	451
136	128	8	34	137	79	122	101	122	57	26	22	66	2	2	5	3901	0.6%	122
138	3625	2494	1284	1334	1282	1570	1099	1127	1530	728	388	448	639	829	771	29424	4.6%	919
139	1103	1030	605	703	942	735	553	809	820	535	420	260	445	733	490	23845	3.8%	745
140	1165	914	590	444	1282	877	707	1218	830	732	478	404	516	521	282	20058	3.2%	627
144	1273	1553	910	502	746	564	871	1217	1672	1575	1102	1239	437	485	541	24023	3.8%	751
148	2487	2183	1377	865	366	1178	389	1712	1101	700	435	478	406	600	1044	22660	3.6%	708
149	2871	2613	1418	2117	2368	2756	1554	2243	2947	1598	1410	1132	1178	1966	1835	47947	7.6%	1498
150	2568	3665	1847	2461	2028	2764	3511	3593	5250	3539	3312	3559	3114	3026	2833	65986	10.4%	2062
151	4530	4231	3170	3358	2992	2781	2443	3203	3470	2994	3220	2940	2928	1872	1771	78650	12.4%	2458
155	2107	2697	1114	1338	1351	453	1053	1114	846	1066	729	746	1114	979	1042	31621	5.0%	988
158	1446	367	200	556	769	1190	531	765	404	442	320	311	387	339	207	14692	2.3%	459
Total	37917	34202	25575	22862	24793	26665	24274	29516	32481	26114	17376	16501	15620	17999	17663	634496		19828

Spatial overlap in fishing and seal foraging effort

Australian sea lions

The estimated spatial overlap between ASL foraging effort and the mean fishing effort in the gill-net sector of the SESSF (1973-2004) and the SA RLF (1970-2004) are presented in Figures 7.9a-l. These figures represent the expected spatial distribution of ASL-fishery interactions, assuming that the probability, or risk of interaction, is directly proportional to the extent of seal foraging and commercial fishing effort in each region. Hence areas where seals forage, but no fishing occurs, or vice versa, have a zero probability of interactions. As such, the expected level of interaction will be highest in regions with high seal foraging and high commercial fishing effort.

Figures 7.9a and 7.9b, indicate the overlap index (*OI*) for combined age/gender groups in the ASL for the SESSF gill-net and SA RLF, respectively. Because fishing effort in the SESSF gill-net sector occurs in most continental shelf and gulf waters, the *OI* highlights that regions where interaction are most likely to occur are closely associated with the main population centres of ASL, namely, The Pages and Seal Bay (east and south of Kangaroo Island), Dangerous Reef (southern Spencer Gulf) and the west coast of the Eyre Peninsula (especially the Nuyts Archipelago) and the GAB (Figure 7.9a).

This contrasts with the expected spatial interaction with the SARLF. Because most of the fishing effort in SA RLF is concentrated in the south-east of the State, and in near coastal waters south and east of Kangaroo Island, and along the southern and west coasts of the Eyre Peninsula, the *OI* suggests relatively low interaction rates with The Pages, and Dangerous Reef ASL subpopulations (Figure 7.9b). However, interactions with the latter subpopulation occur where their foraging effort intersects fishing effort in southern Spencer Gulf (Figure 7.9b). As with the SESSF gill-net sector, interactions rates are expected to be high on the west coast of the Eyre Peninsula, especially in the Nuyts Archipelago (Figure 7.9b).

Table 7.10. Annual fishing effort (x1,000's pot-lifts.year^{-1}) for the 19 Marine Fishing Areas (MFAs) of the SARLF, spanning 35 years between 1970 and 2004

MFA	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
7	5.8	6.2	10.4	11.7	13.0	12.3	12.0	12.5	12.2	9.6	5.9	4.0	6.1	12.6	13.5	5.9	3.7	10.4	7.8
8	23.5	27.7	24.3	25.7	28.7	51.0	40.9	20.8	21.5	16.4	6.8	1.6	5.2	7.9	15.9	22.9	18.4	5.4	16.1
10	16.4	18.0	18.4	10.6	12.3	19.7	12.7	13.7	9.8	4.9	0.9	3.6	0.4	3.1	1.8	1.1	0.5	3.2	3.6
15	32.9	44.6	37.0	51.9	52.2	46.4	52.5	38.7	38.8	49.3	28.8	23.1	25.5	38.4	60.5	43.1	69.2	79.3	74.2
18	0.0	0.0	0.0	0.8	2.7	0.0	0.0	0.9	3.1	0.0	0.0	2.0	0.0	0.0	0.2	3.2	3.0	3.4	3.1
27	0.5	3.4	2.1	0.3	3.8	1.5	7.1	5.5	11.9	28.3	32.2	38.2	32.8	43.2	42.7	47.7	45.5	36.6	41.2
28	76.5	73.2	84.4	70.7	75.8	65.6	66.8	61.3	69.6	57.4	70.9	106.4	97.5	123.0	138.6	135.5	138.8	126.8	119.1
39	91.6	89.3	97.8	81.4	77.1	70.4	82.2	92.1	107.9	110.7	99.2	94.1	114.3	134.3	121.6	117.4	114.4	159.6	135.2
40	6.2	8.1	2.8	7.1	14.8	14.7	10.1	31.8	32.3	25.7	43.7	41.8	42.8	47.6	57.8	54.8	53.5	50.0	73.1
44	0.0	0.0	0.0	0.1	0.3	0.8	0.0	0.3	0.3	0.0	0.5	1.0	0.7	7.5	2.4	2.2	2.8	5.2	3.9
45	13.6	16.6	19.8	12.7	14.9	14.3	11.4	14.2	13.8	9.5	11.8	14.4	11.0	4.1	2.8	2.5	2.7	4.4	0.5
46	0.0	0.0	6.7	4.7	0.5	3.2	2.1	1.3	0.4	0.3	0.0	0.0	1.4	0.3	0.0	7.9	3.9	0.0	2.0
48	12.0	18.8	22.2	15.9	17.2	21.1	14.3	11.9	16.0	27.2	42.9	38.7	50.4	45.8	57.7	45.3	37.6	38.8	70.1
49	23.2	21.9	44.3	22.7	18.1	16.2	12.4	22.1	20.6	26.4	35.0	44.1	61.7	63.3	51.6	51.8	51.6	47.0	47.1
50	1.6	4.5	2.0	0.6	0.9	0.1	7.7	3.5	5.9	8.0	2.4	7.3	13.7	42.3	40.9	39.3	38.0	22.4	33.2
51	219.5	285.3	305.1	279.7	221.1	244.3	225.6	234.2	210.9	203.3	214.6	218.0	238.0	151.5	155.9	141.4	109.2	143.4	121.9
55	489.2	509.6	600.2	570.3	456.2	517.2	472.6	492.5	487.8	505.6	508.0	612.7	692.3	905.9	793.4	789.0	788.4	809.7	712.3
56	615.6	663.4	671.6	675.6	567.3	690.7	675.8	683.0	656.7	598.9	744.7	751.3	710.3	609.1	537.6	558.1	509.2	625.9	515.5
58	499.0	528.6	542.8	591.0	481.2	543.0	484.4	455.5	437.2	481.5	553.4	520.1	509.1	537.8	462.7	481.5	467.7	517.9	503.9
Total	2127	2319	2492	2433	2058	2333	2191	2196	2156	2163	2402	2522	2613	2778	2558	2551	2458	2689	2484

Table 7.10. Cont.

MFA	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total	%	Average
7	3.7	9.0	7.8	8.6	24.9	17.6	29.1	19.2	14.3	13.7	15.1	17.5	15.6	13.8	12.6	5.2	410	1%	11.4
8	20.6	18.4	17.8	31.2	38.7	33.9	35.6	32.4	24.7	21.8	24.3	30.2	23.1	19.9	20.9	26.6	809	1%	22.5
10	1.5	7.1	7.6	5.5	10.9	9.3	9.9	10.9	4.1	6.0	5.1	9.6	9.7	6.3	2.4	2.5	273	0%	29.1
15	65.1	93.3	103.8	80.6	78.9	69.2	107.3	106.7	86.9	93.8	73.8	72.4	68.3	54.2	43.8	35.4	2135	3%	59.3
18	2.7	4.1	9.2	7.3	5.9	5.2	9.9	8.3	6.8	9.8	6.1	5.9	5.5	5.7	1.1	1.6	136	0%	16.8
27	48.4	37.4	38.2	41.7	35.5	38.9	36.2	22.4	29.9	32.4	36.2	22.4	30.9	19.7	24.1	16.5	962	1%	26.7
28	130.2	108.8	150.6	136.6	118.1	131.9	119.5	139.2	170.0	143.5	110.6	126.9	119.2	110.2	101.9	85.2	3788	5%	105.2
39	138.1	133.7	143.7	125.5	107.1	117.8	90.4	110.7	115.6	122.0	146.6	116.0	97.8	105.3	107.6	126.6	3934	5%	109.3
40	72.4	73.0	88.8	78.5	68.8	64.7	76.3	69.5	65.6	66.8	67.4	55.8	41.5	43.8	62.4	67.5	1722	2%	47.8
44	4.3	3.2	3.6	3.9	3.6	4.4	6.3	5.2	2.7	4.1	6.8	5.7	5.1	8.9	4.5	4.7	1.6	0%	4.1
45	0.9	1.9	3.1	1.9	0.8	2.9	1.9	1.7	2.0	0.7	0.0	0.2	2.7	1.9	3.4	1.6	267	0%	23.9
46	4.9	3.2	2.3	6.3	4.1	0.7	0.9	2.5	2.0	2.2	1.6	0.0	0.3	0.0	0.0	1.0	113	0%	10.3
48	62.9	67.0	78.4	80.3	62.8	48.3	43.3	42.4	46.8	48.9	58.9	50.6	47.5	48.5	53.1	58.7	1551	2%	43.1
49	60.9	65.5	81.5	70.0	76.9	85.2	80.0	69.4	68.5	67.3	83.9	86.1	90.0	75.2	101.8	67.1	1959	2%	54.4
50	49.4	17.1	24.2	21.2	30.2	26.7	29.7	26.6	24.6	21.7	20.8	29.5	28.5	18.9	20.9	24.8	689	1%	19.7
51	124.2	139.1	176.0	119.6	111.5	72.2	73.9	78.0	58.8	45.0	27.2	42.0	21.2	14.8	16.0	18.3	5112	6%	142.0
55	729.0	803.3	811.2	730.4	683.3	584.2	610.3	656.5	682.8	573.9	437.3	342.4	299.8	276.1	349.0	326.1	20664	26%	574.0
56	487.4	515.2	561.6	462.8	422.7	442.7	482.8	539.0	552.6	473.4	359.2	333.0	287.6	256.0	322.0	321.6	18936	24%	526.0
58	407.8	440.4	474.6	431.5	403.9	394.7	410.2	471.4	449.0	429.9	330.5	312.2	284.3	287.2	346.0	370.7	15901	20%	441.7
Total	2414	2541	2784	2443	2289	2150	2254	2412	2408	2177	1811	1658	1479	1366	1593	1562	78865		2253

For ASL, over 60% of the estimated foraging effort occurs in four SESSF gill-net sector MFAs: MFA 129 (19%, southern Spencer Gulf), MFA 108 (18%, Nuyts Archipelago), MFA 144 (16%, southern Fleurieu Peninsula) and MFA 149 (8%, south of Kangaroo Island) (Table 7.11). Importantly, <1% of the estimated ASL foraging effort, occurs outside SA MFAs, although at least part of this is in waters to the west of the SA/WA border, where the SESSF gillnet sector fishery also occurs. Similarly, over 40% of the estimated ASL foraging effort occurs in four SARL MFAs: MFA 8 (15%, Nuyts Archipelago), MFA 44 (13%, southern Fleurieu Peninsula), MFA 15 (8%, mid-west coast Eyre Peninsula) and MFA 49 (8%, southern Kangaroo Island). However, in contrast to the SESSF gill-net sector, 36% of ASL foraging effort occurs outside of SA RLF MFAs where historical catches have been reported in the SARLF (Table 7.11).

Estimated *OI* between foraging effort in ASL adult females, adult males, sub-adult males, juveniles and pups with fishing effort in the SESSF gill-net sector and SA RLF are presented in Figures 7.9c-l. These estimates of spatial overlap indicate that the probability of interactions is highest close to breeding colonies, where foraging effort is most focused, especially for pups, juveniles and adult females. Because adult males do not utilise waters in close proximity to their colonies, the spatial distribution of *OI* is relatively dispersed. Because fishing effort in the SARLF has been concentrated in near coastal waters, the *OI* is most highly concentrated in ASL pups and juveniles, especially near breeding colonies (Figures 7.9j and l).

New Zealand fur seals

The estimated spatial overlap between NZFS foraging effort and the mean fishing effort in the gill-net sector of the SESSF (1972-2004) and the SARLF fishery (1970-2004) are presented in Figures 7.10a-j. As with the ASL-fishery *OI*, these figures represent the expected spatial distribution of NZFS-fishery interactions, assuming that the probability (or risk) of interaction is proportional to the extent of seal foraging and fishing effort in each region. Figures 7.10a and b summarise the expected *OI* between combined age/gender foraging in NZFS, with mean fishing effort in the gill-net sector of the SESSF and SARLF. Data are summarised for each fishery MFA in Table 7.11.

An important distinction between fishery overlaps with ASL and NZFS, is that the extent of spatial overlap in foraging with the SESSF gill-net-sector is comparatively low for the NZFS, with 62.3% of all estimated foraging effort occurring outside MFAs (Table 7.11). This is most apparent for juveniles (93.5% outside gillnet sector MFAs, Table 7.11, Figure 7.10g) and adult males (61.8% outside gillnet sector MFAs, Table 7.11, Figure 7.10e). The greatest spatial overlap occurs with adult females (60% foraging effort occurring within SESSF gillnet-sector MFAs, Table 7.11, Figure 7.10c), and pups (94% of foraging effort occurring within gillnet-sector MFAs, Table 7.11, Figure 7.10i). Given that the New Zealand fur seal subpopulation in South Australia is concentrated south and south-east of Eyre Peninsula and along the southern coast of Kangaroo Island, the demersal gillnet marine fishing areas (MFAs) with the greatest overlap between fishing and New Zealand fur seal foraging effort are MFAs 148,149 and 150 (7.5%, 8.6% and 8.7%, respectively), all of which are off the south coast of Kangaroo Island and MFAs 138 and 139 (17.7% and 4.5 %, respectively), to the south of the Eyre Peninsula and southern Spencer Gulf (Table 7.11, Figures 7.10a, c, e, g and i).

The level of overlap in fishing and foraging effort between the SARLF and NZFS is relatively low, with over 77% of the estimated NZFS foraging effort occurring outside MFAs where catch has been reported (Table 7.11, Figure 7.10b). This is especially the case for juveniles (>98% outside SARLF MFAs, Table 7.11, Figure 7.10h), adult males (>77% outside SARLF MFAs, Table 7.11, Figure 7.10f) and adult females 66% outside gillnet sector MFAs, Table 7.11, Figure 7.10c). The greatest level of spatial overlap occurred with pups (>73% of foraging effort occurring within gillnet-sector MFAs, Table 7.11, Figure 7.10j), with their foraging being concentrated in near coastal areas, especially in SARLF MFAs 39 (23.2%), 49 (22.9%), 48 (18.8%) and 28 (5.9%, Table 7.11, Figure 7.10j).

Table 7.11. Average percentage fishing effort among all MFAs in the SESSF gill-net sector and SARLF, relative to the estimated percentage of foraging effort by different age/sex classes of ASL and NZFS within each MFA of each fishery. ‘Outside’ refers to the percentage of seal foraging effort that occurs outside the listed MFAs.

Gill-net	%Fishery	ASL % Foraging Effort						% Foraging Effort NZFS				
MFA	Effort	Females	Males	SAM	Juveniles	Pups	All ASL	Females	Males	Juveniles	Pups	All NZFS
101	0.7	3.2	0.5	3.1	3.6	3.6	2.8	0.0	0.0	0.2	0.0	0.0
102	0.5	1.9	0.5	1.9	2.0	2.1	1.7	0.0	0.0	0.2	0.0	0.0
103	1.3	0.4	0.5	0.4	0.4	0.4	0.4	0.0	0.0	0.2	0.0	0.0
104	0.9	0.3	1.7	0.4	0.0	0.0	0.5	0.0	0.0	1.2	0.0	0.0
105	1.0	0.1	1.6	0.1	0.0	0.0	0.4	0.0	0.0	1.1	0.0	0.0
106	1.1	0.2	1.9	0.2	0.2	0.2	0.5	0.0	0.0	0.6	0.0	0.0
107	3.2	2.4	5.2	2.7	1.5	1.0	2.5	0.0	0.0	0.3	0.0	0.0
108	8.0	18.5	4.0	17.9	19.9	20.4	16.1	0.0	0.0	0.1	0.0	0.0
112	0.6	0.0	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.0
113	1.7	0.0	4.2	0.0	0.0	0.0	0.8	0.0	0.1	0.5	0.0	0.0
114	3.6	1.7	7.4	1.9	1.2	0.9	2.6	0.1	0.3	0.2	0.0	0.1
115	4.9	8.1	4.0	7.9	8.4	8.8	7.4	0.1	0.5	0.1	0.4	0.1
122	0.7	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
125	0.1	0.1	2.0	0.1	0.0	0.0	0.4	0.4	1.6	0.2	0.1	0.4
126	5.2	1.0	6.5	1.2	0.7	0.5	2.0	6.3	7.2	0.1	1.8	6.3
128	3.2	4.6	3.4	4.7	4.2	3.6	4.1	2.0	1.1	0.0	6.1	2.0
129	3.7	18.4	2.8	17.4	21.4	23.1	16.6	0.0	0.0	0.0	0.8	0.0
132	2.3	0.1	2.1	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.4	0.0
136	0.6	0.0	0.9	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.1	0.1
138	4.6	2.8	7.5	3.1	2.0	1.7	3.4	17.7	5.2	0.1	17.5	17.7
139	3.8	6.1	7.9	6.6	4.5	3.8	5.8	4.5	1.2	0.0	23.4	4.5
140	3.2	2.3	4.1	2.9	0.6	0.2	2.0	0.5	0.3	0.0	1.2	0.5
144	3.8	15.5	3.2	14.2	19.7	20.9	14.7	1.8	0.8	0.0	0.2	1.8
148	3.6	0.7	3.7	0.8	0.2	0.1	1.1	7.5	4.6	0.1	18.8	7.5
149	7.6	8.4	7.2	8.4	8.5	8.4	8.2	8.6	4.8	0.1	22.9	8.6
150	10.4	3.1	9.4	3.7	1.0	0.4	3.5	8.7	6.3	0.2	0.2	8.7
151	12.4	0.0	5.2	0.0	0.0	0.0	1.1	1.1	2.8	0.2	0.0	1.1
155	5.0	0.0	0.5	0.0	0.0	0.0	0.1	0.1	1.2	0.2	0.0	0.1
158	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Outside		0.2	1.0	0.2	0.0	0.0	0.3	40.6	61.8	93.5	5.9	40.6
SARLF MFA												
7	0.5	2.4	3.2	2.7	1.5	1.0	1.3	0.0	0.0	0.3	0.0	0.1
8	1.0	15.3	1.9	14.9	16.3	17.1	16.6	0.0	0.0	0.1	0.0	0.0
10	0.3	1.3	0.4	1.2	1.7	1.6	1.6	0.0	0.0	0.0	0.0	0.0
15	2.7	8.1	0.3	7.9	8.4	8.8	8.5	0.1	0.5	0.1	0.4	0.2
18	0.1	0.3	0.1	0.3	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0
27	1.2	0.4	0.2	0.4	0.5	0.6	0.5	0.2	0.2	0.0	0.1	0.1
28	4.8	2.6	2.4	2.7	2.4	2.4	2.4	1.8	0.8	0.0	5.9	1.2
39	4.9	5.8	18.5	6.3	4.3	3.7	4.1	4.4	1.2	0.0	23.2	3.4
40	2.1	0.6	0.0	0.7	0.2	0.1	0.2	0.3	0.2	0.0	1.0	0.2
44	0.1	11.4	0.0	9.6	17.2	19.8	18.1	1.0	0.4	0.0	0.1	0.4
45	0.3	4.0	0.0	4.4	2.5	1.1	2.0	0.7	0.4	0.0	0.0	0.3
46	0.1	0.0	1.7	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.1
48	1.9	0.7	8.1	0.8	0.2	0.1	0.1	7.5	4.6	0.1	18.8	4.9
49	2.4	8.4	0.1	8.4	8.5	8.4	8.5	8.6	4.8	0.1	22.9	5.6
50	0.9	3.1	1.0	3.7	1.0	0.4	0.8	8.2	5.4	0.1	0.2	4.1
51	6.4	0.0	4.6	0.0	0.0	0.0	0.0	0.9	2.5	0.1	0.0	0.9
55	26.1	0.0	2.8	0.0	0.0	0.0	0.0	0.1	1.2	0.2	0.0	0.4
56	23.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
58	20.1	0.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1
Outside		35.6	43.8	35.8	35.2	35.0	35.1	66.0	77.5	98.4	27.2	77.8

Population viability analysis

Because of the relative long generation time for both species, neither species subpopulations were classified as vulnerable (10% probability of quasi-extinction within 100 years) before they were classified as *endangered* (20% probability of quasi-extinction in 10 generations; 124 years in Australian sea lions, 99 years in New Zealand fur seals). As such, the vulnerable category was superfluous. Further, the critical and *endangered* risk categories were grouped because in most simulations, subpopulations went directly from *endangered* to *quasi-extinct*, with no transition through a critical risk category. As such, population viability analyses delineated subpopulations as not-threatened, *endangered* or *quasi-extinct*, with the *endangered* category being inclusive of vulnerable, *endangered* and critical risk categories.

Results from the population viability analysis for Australian sea lion subpopulations based on results from simulations which assessed the level of additional (ie. anthropogenic) female pre-recruit mortality (modelled as removals of 0-1.5 year olds per year) required to place individual subpopulations into different risk categories, with three population trajectory scenarios (stable r= 0.00, decreasing r =-0.01, and increasing r =0.05), are presented in Table 7.12. Results indicate that assuming no additional female mortalities with the stable and decreasing models developed, 13-27 subpopulations (34-71% of total) respectively, are classed as *endangered* (20% probability of extinction within 10 generations, Table 7.12). Small increases in pre-recruit female mortality markedly increased the numbers of *endangered* subpopulations. An additional mortality of one female per subpopulation/year resulted in 71% of stable, 84% of decreasing and 5% of increasing subpopulation being categorised as *endangered*. Two additional female mortalities per/subpopulation/year resulted in 84% of stable, 92% of decreasing and 13% of increasing subpopulation being classed as *endangered*. The lowest additional mortality level to result in a subpopulation becoming *quasi-extinct* was at 0.7 pre-recruit female seals/year (or 1 female per breeding cycle, 1.5 years). At this level of theoretical harvest, 2-5 (5-13%) subpopulations became *quasi-extinct* with the stable and decreasing population models, respectively. Q_t times were very short (<2 years, Table 7.12).

Because of the large number of very small Australian sea lion populations, small increases in additional mortality resulted in increasing numbers of subpopulations reaching the *quasi-extinct* threshold. For example, an additional pre-recruit mortality of only two females/subpopulation/year resulted in 16 subpopulations (42%) becoming *quasi-extinct* in the stable model, or 27 (71%) becoming *quasi-extinct* in the decreasing model (Table 7.12, Figure 7.11). With an additional mortality level of only 3.3 pre-recruit females/subpopulation/year (5 females/1.5 year stage), 74% of decreasing, 63% of stable and 11% of increasing subpopulations became *quasi-extinct* (Table 7.12, Figure 7.11). Q_t times ranged from as little as 1.5 to 43.1 years in these scenarios. These population viability simulations suggest that even in the best scenario (populations increasing at around 5% per/year) many subpopulations are highly vulnerable to becoming *quasi-extinct* from low-level additional mortality (Figure 7.11).

Effects of mortality directed at different stages

The above scenarios for Australian sea lions demonstrate the susceptibility of subpopulations to *quasi-extinct*ion relative to different rates of female mortality directed at the youngest age group (0-1.5 years). To investigate how these results may vary in response to mortalities being directed at other ages/stages, a range of simulated removals of 20 female seals per year was undertaken on a hypothetical population of 1000 female Australian sea lions (slightly larger than the Australian sea lion population at Seal Bay, Kangaroo Island) using the stable population model over 50 reproductive cycles (75 years) (Figure 7.12). Results indicate that the highest rate of population reduction is achieved following removal of females between 3 and 12 years of age, with the greatest impacts achieved from removal of 4.5-6, 6-7.5 and 7.5-9 age-groups (Figure 7.12). These are females that are breeding for their first, second or third times (R. McIntosh pers comm.). In fact the rate of population decline resulting from mortalities directed at 6-7.5 year olds (-3.4%/year) was more than three times that of mortalities directed at pups (-1.1%/year) (Figure 7.12). Rates of decline were lowest when mortality was directed towards females older than 18 years of age (Figure 7.12).

Using the stable (r=0) population model, a comparison was made of the proportion of subpopulations that reached quasi-extinction under five different scenarios of female age-groups being subjected to mortality, from ages 0-1.5, 1.5-3, 3-4.5, 4.5-6, and 6-7.5 (Table 7.13). Results indicate the increasing vulnerability of subpopulations if mortality is directed at recruiting-age females. For example, if mortality is directed at pups, annual mortalities of one female per subpopulation per year result in 5% of subpopulations becoming *quasi-extinct* (Table 7.13). However, when mortalities are directed at the 6-7.5 year age group, annual mortalities of one female per subpopulation per year result in 26% of subpopulations becoming *quasi-extinct* (a five-fold increase compared to mortality directed at pups) (Table 7.13). Based on these estimates, additional mortalities of 1-2 female seals per subpopulation per year could result in between 5-26% and 42-71% of subpopulations in South Australia becoming *quasi-extinct*, respectively, depending on the age of females removed from subpopulations (Table 7.13).

Risk classification of subpopulations

To examine whether subpopulations could be grouped according to extinction risk, a Bray-Curtis similarity matrix and hierarchical clustering analysis procedure (Primer V5.2.2) was undertaken based on PVA outputs using the stable population model (number of additional female deaths to change status from *not threatened* to *endangered*, *endangered* to *extinct* and Q_t). This analysis produced four major groupings, and seven minor groups (Figure 7.13 and 7.15). The first major grouping, termed *Very High Risk* included 4 subpopulations (11%) (in two subgroups) that were characterised by fewer than 9 pups, and categorised as *endangered* in the PVA analysis with no additional mortality, and had low thresholds of quasi-extinction (0.7-1.3 additional females/year) and Q_t (<10 years). The difference between these two subpopulations is attributed to slight differences in minimum number of pre-recruit (aged 0-1.5 years) female deaths/year to bring about extinction (0.7 and 1.3) and Q_t value (Figure 7.13 and 7.15).

The next group was termed *High Risk*, and was the largest group in the analysis with 23 subpopulations (61%). This group contained two subgroups that differed slightly in risk and Q_t. The first subgroup was characterised as having between 9 and 17 pups, low thresholds of quasi-extinction (≤ 2.0 additional females/year) and moderate Q_t 14-26 years). The second subgroup was characterised by larger pup production (21-43) and slightly greater quasi-extinction threshold (≤ 4.0 additional females/year) and Q_t (<38 years) (Figure 7.13, Table 7.12 and 7.14).

The *Moderate Risk* group included nine subpopulations (24%), and also contained two subgroups. The first subgroup was characterised by moderate pup production (56-84) and extinction thresholds achieved with between 4.7 – 8.7 additional female deaths/year and Q_t times ranging between 39-43 years. The second subgroup was characterised by producing more than 100 pups (131-214), with quasi-extinction thresholds between 11.3 – 23.3 additional female deaths/year and Q_t times ranging between 42-47 years (Figure 7.13, Table 7.12 and 7.14).

The *Low Risk* groups included the two largest subpopulations (Dangerous Reef and The Pages), which are at least twice the size as any other subpopulation for the species. Quasi-extinction thresholds and Q_t times were relatively high, requiring 50 additional female deaths/year over a 53-58 year period (Figure 7.13, Table 7.12 and 7.14).

Spatial distribution of subpopulation risk category

There is no clear pattern to the geographical distribution of different risk category subpopulations, with the four *very high risk* sites equally spaced along the lower and western Eyre Peninsula, the Nuyts Archipelago and the Bunda Cliffs (west of the Head of the Bight). Similarly, *high-risk* subpopulations are distributed along the same stretch of coastline, although there is greater density of these subpopulations in the Bunda Cliffs and lower Eyre Peninsula regions, with one site at Kangaroo Island. *Moderate risk* subpopulations are focused in the Nuyts Archipelago and Western Eyre Peninsula regions (seven sites), with two additional subpopulations in southern Spencer Gulf and one on Kangaroo Island. The two *low risk* subpopulations, Dangerous Reef and The Pages are located in southern Spencer Gulf and east of Kangaroo Island, respectively. In terms of proximity to particular MFAs within each fishery, those MFAs in the region of the Bunda Cliffs, the Nuyts Archipelago and western and lower Eyre Peninsula all contain *high* and *very high* risk subpopulations.

New Zealand fur seals

Results from the population viability analysis for New Zealand fur seals, based on results from simulations assessing the level of additional female pre-recruit mortality (modelled as removal of one and two year olds) required to place individual subpopulations into different risk categories, with an increasing population trajectory scenario ($r = 0.064$, $\lambda = 1.08$), are presented in Table 7.15. Given the subpopulation *quasi-extinct* criteria of $Q \leq 10$ females, population viability analysis results suggest that the six large populations with more than 600 pups (range 697- 4585), which collectively account for about 99% of the South Australia's New Zealand fur seal population, are at very low risk of becoming *quasi-extinct*. With an increasing population, these subpopulations have high thresholds for *endangered* (237-1560 additional female mortalities/year) and *quasi-extinct* categories (337-2180 additional female mortalities/year, Q_t ~32-34 years) (Table 7.15).

The remaining seven subpopulations have annual pup productions of between 7 and 64, with the most vulnerable being Little Hummock and Greenly Islands, which only produce seven pups (Table 7.15). These sites are the highest risk New Zealand fur seal subpopulations, with only 3 additional female mortalities per year to class them as *endangered*, and 5 annual mortalities to become *quasi-extinct* with low Q_t values (8.5 years) (Table 7.15). Cape Bouguer and Cave Point (both on Kangaroo Island) had modest risk levels requiring 8-9 additional female mortalities/year to be classed *endangered* and 12-14 per year to be *quasi-extinct* (Q_t ~18-20 years) (Table 7.15). Rocky, Four Hummock and Ward Islands all have between 50-64 pups, and are at low risk of being classed *endangered* (17-22 additional female mortalities/year, Q_t ~25 years) (Table 7.15).

Risk classification and distribution of subpopulations

Following the approach used for ASL, we examined whether NZFS subpopulations could be grouped according to extinction risk. This analysis produced two major groups, and following the risk criteria used for ASL, we divided the NZFS subpopulation among three main risk categories (Figure 7.14, Table 7.15). The Little Hummock and Greenly Island subpopulations (15% of total) were categorised as *moderate risk*, given their low pup production (7 pups), and with moderate thresholds of extinction (4-8 additional females mortalities/year) and Q_t (12 years) (Table 7.15). Five subpopulations (Cape Bouger, Cave Point and Rocky, Four Hummocks and Ward Islands, 38% of total sites) were categorised as being of *low-risk*, with annual pup production ranging between 8-22 and with high thresholds of extinction (16-52 additional females mortalities/year) and Q_t (18-22 years) (Table 7.15). The remaining six subpopulations (Berris Point, Cape du Couedic and Cape Gantheaume, and Liguanea, North and South Neptune Islands, 46% of sites) were categorised as being of *very-low risk* on the basis of the large annual pup productions (2,072 – 4,585) and high thresholds of quasi-extinction (>530 additional females mortalities/year) and Q_t (27-28 years) (Table 7.15). These six *very-low risk* subpopulations account for approximately 99% of annual NZFS pup production in SA.

The moderate and low-risk subpopulations are located west and south-west of Eyre Peninsula, and on the south coast of Kangaroo Island. The very-low risk subpopulations are located off lower Eyre Peninsula and on the two most southern headlands on the south coast of Kangaroo Island.

Fishery bycatch scenarios

The approach here is to firstly present the expected distribution of bycatch for ASL and NZFS at the subpopulation, region and MFA level for both fisheries based on historic distribution of fishing effort and the expected distribution of seal foraging effort. Secondly, temporal variation in expected bycatch levels (by region and MFA) are examined based on historic changes in the distribution of fishing effort in each fishery. Thirdly, scenarios of different bycatch levels within each fishery are examined with respect to the historic average distribution of fishing effort to examine the potential outcomes of different catch rates and how bycatch rates may have varied among different MFAs. Finally, different scenarios of bycatch level in each fishery are examined relative to their expected impact on individual subpopulations, in terms of placing them in different risk categories based on the PVA outputs. These outputs provide the most coherent presentation of risk-assessment to all subpopulations from each fishery, and essentially pull together the subpopulation PVAs, the spatial and temporal overlap in fishing and seal foraging effort in conjunction with different scenarios of bycatch in each fishery.

Australian sea lion - gill-net sector SESSF

Spatial distribution of historic bycatch

Based on 32 years (1973-2004) of spatial and temporal variability in fishing effort in the SESSF gillnet sector, the expected apportioning of bycatch (with a breakdown by sex) among the different ASL subpopulations is presented in Figure 7.15a. These analyses indicate that most seals would have been taken from the large populations of The Pages, Dangerous Reef and Seal Bay, with many of the colonies in the Nuyts Archipelago and western Eyre Peninsula making up the remainder. From a regional perspective, The Pages, southern Spencer Gulf (including Dangerous Reef, Peaked Rocks, North, English, North Neptune (East), South Neptune, Lewis and Albatross Islands) and the greater Nuyts Archipelago (including Lilliput, Blefuscu, Breakwater, Fenelon, Masillon, Purdie, and Lounds Islands, Gliddon and Western Nuyts Reef) make up about 67% of the expected bycatch, followed by Kangaroo Island (Seal Bay and the Seal Slide)and the Chain of Bays (including Olive, Nicolas Baudin and Jones islands) (Figure 7.16a). With respect to the expected breakdown of historical bycatch in different MFAs, the most prominent is MFA 108 (Nuyts Archipelago), which is expected to have accounted for more than a quarter of the total historic ASL bycatch in the fishery (Figure 7.18a). MFAs 149 and 144 (Kangaroo Island and The Pages) and MFA 129 (southern Spencer Gulf) are expected to have each accounted for about 10% of the overall historic ASL bycatch (Figure 7.18a).

Spatial and temporal distribution of historic bycatch

Figures 7.20a, 7.21a, 7.22a and 7.23a present the expected breakdown of bycatch per colony and region, by proportion and number based on historic variability in the amount and distribution of fishing effort in the SESSF gillnet sector (1973-2004). Due to variability and the amount and location of fishing effort, the potential impact on ASL in different regions has changed markedly. The marked increase in fishing effort between the mid-1980s and 1990s is likely to have resulted in greater levels of bycatch for many regions (Figure 7.21a, 7.23a). For the most part, the Greater Nuyts and Southern Spencer Gulf Regions have been the most impacted (in terms of numbers) based on historic fishing effort data. However, with increased fishing effort in the southeast of SA since the late 1990s, the relative contribution of The Pages subpopulation to overall bycatch numbers has likely increased during this period (Figures 7.20a, 7.22a). Predicted temporal variation in historic bycatch contributions for the six most significant MFAs (in terms of estimated contribution of ASL bycatch, MFAs 108,115,129, 144, 149 and 150) are presented in Figures 7.243a and 7.25a. MFA 108 is predicted to have contributed the highest proportion of ASL bycatch between 1973-2004, even though fishing effort, and the relative contribution of bycatch in most of the other MFAs increased throughout the period.

At the end of the historic time series (2004), the proportion and number of seals expected to have been derived from The Pages, greater Nuyts and southern Spencer Gulf regions was similar (Figures 7.20-7.23a). Furthermore, in 2004 MFA 108 is predicted to have accounted for about 26% of bycatch, with MFA 149, 144 and 129 accounting for between 11-13%, and MFA 150 and 115 about 7% (Figure 7.24a).

MFA bycatch scenarios

Table 7.16 presents for each gillnet SESSF MFA the average (1973-2004) annual fishing effort and the proportion of fishing effort and expected ASL bycatch. A range of possible bycatch scenarios is presented, ranging from and average of 0.0005 to 0.0400 seals per km net-lift/year. Average bycatch rates are calculated by dividing the number of seals caught by the total fishing effort in those MFAs where seals where caught. Based on the ASL foraging effort models, the only MFA in SA where ASL are not expected to become bycatch is in MFA 158. At a bycatch rate of 0.0005 seals/km lift/year (approximately 10 seals, ie.1 seal/2,000km net-lift), the bycatch rates among MFAs ranges from 0 to 0.08 (Table 7.16). At an average bycatch rate of 0.04 seals/km-lift/year (775 seals, ie. 1 seal/25km net-lift), the MFA bycatch rates vary from 0 to 0.128 (Table 7.16). In all bycatch scenarios, the proportion of bycatch apportioned to each MFA is the same.

Subpopulation PVA with bycatch scenarios

Figure 7.26a and b indicates the overall bycatch number and average rate required to place different ASL subpopulations into different risk categories. These are based on the number of female mortalities attributed to individual subpopulations, as determined by the overlap in estimated foraging effort and the average (1973-2004) distribution of fishing effort (see Table 7.16). The bycatch number refers to the total number seals caught per year, of which about 52% are female that are apportioned out among the 38 subpopulations. The estimated number of additional female mortalities per year required to place subpopulations into the various risk categories (based on PVA using the stable population model, see Table 7.12) was combined with the bycatch scenario analysis to provide an integrated risk assessment analyses. The PVA indicates which subpopulations can least afford to lose individuals, but it does not indicate whether those subpopulations are likely to lose individual seals based on the distribution of seal foraging and fishing effort. Figure 7.26a integrates the spatial bycatch analysis with the PVA approach, and therefore identifies which subpopulation should be classified as most at risk under different bycatch scenarios.

With no additional bycatch mortalities, 24% of Australian sea lion subpopulations in South Australian are categorised as *endangered*. However, if bycatch mortality in the demersal shark fishery was 50, 100, 150 and 200 seals per year, the percentage of *endangered* subpopulations would increase to 45%, 68%, 84% and 92%, respectively (Figure 7.26a). These results highlight just how vulnerable subpopulations are to small increases in additional mortality. The ten most at risk subpopulations (risk of quasi-extinction from bycatch mortality) in the demersal shark fishery, occur in the Nuyts Archipelago and Kangaroo Island regions. Seven subpopulations occur within the Nuyts Archipelago, all within demersal gillnet marine fishing area (MFA) 108 (Olive, Lilliput, West, Purdie, Blefuscu, and Lounds Island and Breakwater Reef). Based on population viability analyses, subpopulation foraging models and fishery interaction probabilities, these seven subpopulations would become *quasi-extinct* if total annual bycatch levels in the whole gillnet fishery were between 262 and 346 seals (Figure 7.26a). For individual subpopulations this equated to as little as between two (Breakwater Reef) and 12 (Purdie Island) female bycatch mortalities per year (Table 7.12). The next three most vulnerable subpopulations were in the Kangaroo Island region (Seal Bay, Seal Slide and The Pages), which were estimated to become *quasi-extinct* when total annual bycatch in the fishery reached between 349 and 392 seals (Figure 7.26a). For these three subpopulations, this equated to between 1.3 (Seal Slide) and 50 (The Pages) female bycatch mortalities per year (Table 7.12).

Table 7.12. Summary of population viability analysis (PVA) for Australian sea lion subpopulations in South Australia. The table presents results from simulations assessing the level of additional female pre-recruit mortality (modelled as annual removal of 1.5 year olds) required to place individual subpopulations into different risk categories (E+C= *endangered* and *critical*, Extinct = *quasi-extinct*), based on the three population trajectory scenarios (stable *r*= 0.00, decreasing *r* =-0.01, and increasing *r* =0.05). Q_t represents quasi-extinction time (years). The estimated pup production of each subpopulation is given (see Table 7.1) and subpopulations are ranked according to risk.

		Amount of annual additional pre-recruit female mortality to change subpopulation risk								
Subpopulation	Pup	Decreasing λ= 0.9801, r=-0.01			Stable λ =1, r=0			Increasing λ = 1.0985, r=0.05		
	No.	E+C	Extinct	Q_t	E+C	Extinct	Q_t	E+C	Extinct	Q_t
GAB B2	5	0.0	0.7	1.5	0.0	0.7	1.7	0.7	2.7	1.8
South Neptune Is.	6	0.0	0.7	1.5	0.0	0.7	1.8	0.7	2.7	1.8
Gliddon Reef	7	0.0	0.7	9.9	0.0	1.3	7.5	1.3	3.3	10.5
Ward Is.	8	0.0	0.7	9.9	0.0	1.3	9.5	1.3	3.3	10.5
Masillon Is.	9	0.0	0.7	16.8	0.0	1.3	14.6	2.0	4.0	17.0
Seal Slide	11	0.0	1.3	15.2	0.0	1.3	19.2	2.7	4.7	17.0
Four Hummocks Is.	12	0.0	1.3	15.2	0.0	2.0	15.8	2.7	4.7	17.0
GAB B6	12	0.0	1.3	15.2	0.0	1.3	19.2	2.7	4.7	17.0
North Neptune (East) Is.	14	0.0	1.3	20.3	0.0	2.0	19.2	3.3	5.3	19.4
Western Nuyts Reef	14	0.0	1.3	20.3	0.0	2.0	19.2	3.3	6.0	19.5
Albatross Is.	15	0.0	1.3	22.8	0.0	2.0	21.8	3.3	6.7	12.5
Jones Is.	15	0.0	1.3	22.8	0.0	2.0	21.8	3.3	6.7	18.8
GAB B1	15	0.0	1.3	22.8	0.0	2.0	21.8	3.3	6.7	18.8
Rocky (North) Is.	16	0.0	1.3	22.8	0.1	2.0	23.7	3.3	6.7	18.8
GAB B9	17	0.0	2.0	21.3	0.1	2.0	25.1	4.0	7.3	21.0
Breakwater Reef	17	0.0	2.0	21.3	0.1	2.0	25.7	3.3	6.0	20.6
Fenelon Is.	21	0.0	1.3	33.9	0.2	2.7	25.1	4.7	8.7	22.8
Peaked Rock	24	0.0	1.3	36.2	0.4	2.7	30.3	5.3	8.7	23.3
Price Is.	25	0.0	2.0	28.5	0.3	2.7	30.3	5.3	10.0	23.3
Lounds Is.	26	0.0	2.0	28.5	0.3	2.7	31.2	5.3	10.0	23.4
Pearson Is.	27	0.0	2.0	33.9	0.4	3.3	30.0	6.0	10.0	26.6
English Is.	27	0.0	2.0	34.2	0.4	3.3	29.7	5.3	10.0	24.0
North Is.	28	0.0	2.0	34.2	0.4	3.3	29.7	5.3	10.0	24.0
GAB B3	31	0.0	2.0	36.6	0.5	3.3	32.3	6.7	11.3	25.4
GAB B8	38	0.0	2.0	39.6	1.0	4.0	34.8	8.0	13.3	28.1
Liguanea Is.	43	0.0	2.0	45.9	1.0	4.0	37.2	9.3	16.0	26.1
GAB B5	43	0.0	2.0	45.9	1.0	4.0	37.2	8.7	15.3	27.0
West Is.	56	0.3	3.3	43.1	1.3	4.7	42.8	11.3	23.3	25.1
Lilliput Is.	67	0.3	4.0	45.3	1.3	6.0	41.9	14.0	23.3	31.7
Nicolas Baudin Is.	72	0.0	4.0	47.3	2.0	7.3	39.3	14.7	26.7	0.0
Lewis Is.	73	0.3	4.0	46.7	2.0	7.3	40.5	14.0	24.7	32.4
Blefuscu Is.	84	0.4	5.3	44.1	2.0	8.7	39.3	20.0	30.0	30.6
Olive Is.	131	1.3	6.0	55.7	3.3	11.3	46.5	26.7	43.3	34.8
Purdie Is.	132	1.3	6.7	52.5	3.3	12.0	45.0	26.0	45.3	33.0
West Waldegrave Is.	157	2.0	8.0	52.8	4.0	14.0	45.6	33.3	53.3	33.8
Seal Bay	214	2.7	10.0	59.6	5.3	21.3	44.9	42.0	72.7	34.1
The Pages	577	6.7	27.3	62.7	16.7	50.7	53.9	120.0	183.3	39.2
Dangerous Reef	585	6.7	28.0	60.3	16.7	48.7	55.1	117.3	190.0	38.1

Table 7.13. Comparison of the proportion of subpopulations of ASL reaching quasi-extinction subject to increasing additional female mortality, under five scenarios of different age-groups subjected to mortality. The age-groups are 0-1.5, 1.5-3, 3-4.5, 4.5-6, and 6-7.5 years. Calculations are based on the stable population model (*r*=0).

Number of additional female deaths/ subpopulation/year	Percentage of subpopulations that become *quasi-extinct* relative to age-group from which additional females are removed Stages/Age-group				
	0.-1.5	1.5-3	3-4.5	4.5-6	6-7.5
0.10	0	0	0	0	0
0.22	0	0	0	0	0
0.33	0	0	0	0	0
0.44	0	0	0	0	0
0.50	0	0	0	0	0
0.67	5	13	13	21	26
1.00	5	13	16	26	26
1.33	5	13	16	26	26
2.00	42	63	71	71	71
2.7	53	71	74	74	79
3.3	53	71	74	74	79
4.0	71	82	84	84	84
4.7	74	84	84	84	89
5.3	74	84	84	84	89
6.0	76	84	89	89	89
6.7	76	84	89	92	92
7.3	76	84	89	92	92
8.0	82	89	92	92	92
8.7	84	92	92	92	95
9.3	84	92	92	92	95
10.0	84	92	92	95	95
10.7	84	92	95	95	95
11.3	84	92	95	95	95
12.0	89	95	95	95	95
12.7	89	95	95	95	95
13.3	89	95	95	95	95
14.0	92	95	95	95	95
16.7	92	95	95	95	95
20.0	92	95	95	95	95
23.3	92	95	95	95	100
26.7	95	95	100	100	100
30.0	95	97	100	100	100
33.3	95	97	100	100	100
36.7	95	100	100	100	100
40.0	95	100	100	100	100
43.3	95	100	100	100	100
46.7	97	100	100	100	100
50.0	100	100	100	100	100

Table 7.14. Summary of PVA outcomes for SA ASL subpopulations, grouped in risk categories based on the hierarchical clustering procedure illustrated in Figure 7.12 and PVA details in Table 7.12.

				Additional female mortalities to change subpopulation status		
Risk Category	Group	No. pups	No. subpops	*Endangered* /critical	Extinct	Q_t (years)
Very High Risk (11%)	1	5-6	2	0.0	0.7	1.7-1.8
	2	7-8	2	0.0	1.3	7.5-9.5
High Risk (61%)	3	9-17	12	0.0-0.1	1.3-2	14.6-25.7
	4	21-43	11	0.2-1.0	2.7-4	25.1-37.2
Moderate Risk (24%)	5	56-84	5	1.3-2.0	4.7-8.7	39.3-42-8
	6	131-214	4	3.3-5.3	11.3-21.3	42-46.5
Low Risk (5%)	7	577-585	2	16.7	18.7-50.9	53.6-57.5

Table 7.15. Summary of population viability analysis (PVA) for New Zealand fur seal subpopulations in South Australia. The table presents results from simulations assessing the level of additional female pre-recruit mortality (modelled as annual removal of 1and 2 year olds) required to place individual subpopulations into different risk categories (E+C= *endangered* and *critical*, Extinct = *quasi-extinct*), based on an increasing population trajectory scenario (r= 0.064, λ= 1.072). Q_t represents quasi-extinction time in years. The estimated pup production of each subpopulation from Table 7.2 and subpopulations are ranked according to Risk Category.

		Amount of annual additional pre-recruit female mortality to change subpopulation risk			Risk Category
		Increasing λ = 1.08, r=0.064			
Subpopulation	Pup No.	E+C	Extinct	Q_t	
Little Hummock Is.	7	3	5	8.5	Moderate Risk
Greenly Is.	7	3	5	8.5	Moderate Risk
Cape Bouguer	20	8	12	18.0	Low Risk
Cave Point	25	9	14	19.6	Low Risk
Rocky (South) Is.	50	17	25	24.9	Low Risk
Four Hummocks Is.	57	19	28	25.3	Low Risk
Ward Is.	64	22	34	24.2	Low Risk
Berris Pt	697	237	337	32.0	Very Low Risk
Liguanea Is.	2072	715	1020	31.8	Very Low Risk
Cape du Couedic	3085	1070	1490	32.8	Very Low Risk
Cape Gantheaume	3135	1075	1495	32.7	Very Low Risk
South Neptune Is.	3818	1310	1800	33.2	Very Low Risk
North Neptune Is.	4585	1560	2180	33.6	Very Low Risk

Australian sea lion and the SA Rock lobster fishery

Spatial distribution of historic bycatch

Based on 35 years (1970-2004) of spatial and temporal variability in fishing effort in the SA RLF, the estimated apportioning of bycatch among the different ASL subpopulations is presented in Figure 7.15b. This analysis suggest that in terms of numbers, most bycatch seals would have been taken from Seal Bay (20%) and West Waldegrave Island (16%) (Figure 7.15b). Many of the subpopulations in the southern Spencer Gulf region, including Dangerous Reef, Lewis, Liguanea and Price Islands were also likely to have contributed significantly to bycatch in the SA RLF (Figure 7.15b). These southern Spencer Gulf subpopulations likely contributed to most of the bycatch (24%), followed by Kangaroo Island (21%), Western Eyre Peninsula (195) and the Greater Nuyts Archipelago (13%, Figure 7.16b).

With respect to the estimated spread of historical bycatch across different MFAs, five MFAs would have accounted for most (94%) of it (Figure 7.19a. The main ones being MFA 15 (24%), MFA 39 (20%) and MFA 49 (21%), followed by MFA 8 (17%) and MFA 28 (12%) (Figure 7.19a).

Spatial and temporal distribution of historic bycatch

Figures 7.22a and 7.23a present the expected breakdown of bycatch per region by proportion and number based on historic variability in the amount and distribution of fishing effort in the SA RLF (1970-2004). The proportion and number of seals taken from the different regions are likely to have varied considerably over this period, with a general increase in the importance of Kangaroo Island, especially since the late 1990s (Figures 7.22a and 7.23a). Southern Spencer Gulf and the western Eyre regions are also likely to have been significant in their contribution to bycatch, and to a lesser extent, the Greater Nuyts Archipelago (Figures 7.22a and 7.23a).

Predicted temporal variation in historical bycatch contributions from the five most significant MFAs (MFAs 49, 39, 28, 15, and 8), is presented in Figures 7.27a and 7.28a. There is a clear trend for increasing bycatch contribution (both percentage and number) from MFA 49, especially since the late 1990s, when the contribution from MFA 15 began to decline markedly.

MFA bycatch scenarios

Table 7.17 presents the average (1970-2004) annual fishing effort per SA RLF MFA, and the proportion of fishing effort and expected ASL bycatch for each MFA. A range of possible bycatch scenarios is presented, ranging from an average of 0.005 to 0.500 seals/1,000 pot-lifts/year. Average bycatch rates were calculated by dividing the number of seals caught by the total fishing effort in those MFAs where seals where caught. Based on the ASL foraging effort models and these bycatch scenarios, there are five MFAs in SA where ASL are not expected to become bycatch. These are MFA 46, 51, 55, 56 and 58 (Table 7.17). At a bycatch rate of 0.005 seals/1,000 pot-lifts/year (ie.1 seal/200,000 pot-lifts), the bycatch rates among MFAs ranges from 0 to 0.02 seals/1,000 pot-lifts (Table 7.17). At an average bycatch rate of 0.500 seals/1,000 pot-lifts/year (ie. 1 seal/2,000 pot-lifts), the MFA bycatch rates vary from 0 to 2.2 seals/1,000 pot-lifts (Table 7.17).

Subpopulation PVA with bycatch scenarios

If bycatch mortality in the southern rock lobster fishery was 50, 100, 150 and 200 Australian sea lions per year (Figure 7.26b), then the percentage of subpopulations in South Australian categorised as *endangered* would increase from 24% (zero bycatch) to 53%, 66%, 79% and 82%, respectively. The ten Australian sea lion subpopulations at greatest risk of extinction to bycatch in the South Australian southern rock lobster fishery included Price Island, Peaked Rocks, South and North Neptune Islands, North and Liguanea Islands in the southern Spencer Gulf/lower Eyre Peninsula region, West Waldegrave and Jones Island (west Eyre Peninsula) and Seal Bay and the Seal Slide (Kangaroo Island) (Figure 7.26b). Based on population viability analyses, subpopulation foraging models and fishery interaction probabilities, the most at-risk subpopulations would become extinct if total annual bycatch levels in the fishery reached between 127 and 254 seals (Figure 7.26b). For individual subpopulations, this equated to as little as between 0.7 (South Neptune Island) and 23 (Seal Bay) female bycatch mortalities per year.

New Zealand fur seal and the gillnet SESSF

Spatial distribution of historic bycatch

Based on 32 years (1973-2004) of spatial and temporal variability in fishing effort in the gillnet SESSF, the expected apportioning of bycatch (with a breakdown by sex) among the different NZFS subpopulations is presented in Figure 7.17a. This analysis suggest that in terms of bycatch numbers, most seals would have been taken from the large populations in SA, namely Cape Gantheaume (32%), North Neptune (22%)

and South Neptune Islands (16%), Cape du Couedic (13%) and Liguanea Island (9%) (Figure 7.17a). With respect to the expected breakdown of historical bycatch in different MFAs, the MFAs with the highest bycatch were 148,149 and 150 (10%, 25% and 15%, respectively) all off the south coast of Kangaroo Island and MFAs 138 and 139 (18% and 11 %, respectively), south of the Eyre Peninsula and southern Spencer Gulf (Figure 7.18b).

Spatial and temporal distribution of historic bycatch

Figures 7.20b and 7.21b present the expected breakdown of bycatch per subpopulation by proportion and number based on historic variability in the amount and distribution of fishing effort in the gillnet SESSF (1973-2004). The increase in fishing effort between the mid-1980s and 1990s would have resulted in greater levels of risk to bycatch for many subpopulations during this period (Figure 7.21b). Both Cape Gantheaume and North Neptune Island populations are likely to have accounted for the greatest proportion of risk and bycatch, followed by South Neptune Island, Cape du Couedic and Liguanea Islands. Temporal variation in the expected risk to bycatch across the six most significant MFAs are present in Figures 7.24b and 7.25b. These figures demonstrate that the expected proportion of risk and bycatch numbers would be greatest among the MFAs to the south of Kangaroo Island (148, 149, 150) and to the south of the Eyre Peninsula and southern Spencer Gulf (Figures 7.26b).

MFA bycatch scenarios

Table 7.18 presents the average (1973-2004) annual fishing effort per gillnet SESSF MFA, and the proportion of fishing effort and expected proportion of NZFS bycatch per MFA. A range of hypothetical bycatch scenarios are presented, ranging from and average of 0.0005 to 0.0400 seals per km net-lift/year (Table 7.18). Average bycatch rates are calculated by dividing the number of seals caught by the total fishing effort in those MFAs where seals were caught. Based on the NZFS foraging effort models, all MFAs could potentially contribute to bycatch. At a bycatch rate of 0.0005 seals/km lift/year (approximately 10 seals, ie.1 seal/2,000km net-lift), the bycatch rates among MFAs range from 0 to 0.0019 (Table 7.18). At an average bycatch rate of 0.04 seals/km-lift/year (793 seals, ie. 1 seal/25km net-lift), the bycatch rates vary across MFAs from 0.001 to 0.155 (Table 7.18). In all bycatch scenarios, the proportion of bycatch apportioned to each MFA is the same.

Subpopulation PVA with bycatch scenarios

Figure 7.29a indicates the overall bycatch number and average bycatch rate required to place different NZFS subpopulations into different risk categories. These are based the number of female mortalities attributed to individual subpopulations, as determined by the overlap in estimated foraging effort and the average (1973-2004) distribution of fishing effort (see Table 7.18). The bycatch number refers to the total number seals caught per year, of which 56% are estimated to be female, which are apportioned among the 13 subpopulations. The estimated number of additional female mortalities per year required to place subpopulations into the various risk categories (based on PVA using the stable population model, see Table 7.15), was combined with the bycatch scenario analysis to provide an integrated risk assessment analysis.

The level of New Zealand fur seal bycatch in the demersal gillnet fishery in South Australia, required to change subpopulation status from *not-threatened* to *endangered* was very high. The lowest thresholds were reached when total annual bycatch exceeded 4,713 and 4,837, with the most at-risk subpopulations being the Cape Gantheaume (1,075 female mortalities/year), Berris Point (237 female mortalities/year) and Cave Point subpopulations (Figure 7.29a). The remaining subpopulations were estimated to remain *not threatened* until total annual bycatch exceeded 7,355 for Cave Point and >10 500 seals for all other subpopulations (Figure 7.29a).

New Zealand fur seal and the SARLF Fishery

Spatial distribution of historic bycatch

Based on 35 years (1975-2004) of spatial and temporal variability in fishing effort in the SA RLF Fishery, the expected apportioning of bycatch risk (with a breakdown by sex) among the different NZFS subpopulations is presented in Figure 7.17b. This analysis suggest that in terms of bycatch numbers, most seals would have been taken from the largest subpopulation of the species in SA, at North Neptune Island (38%) (Figure 7.17b). Cape Gantheaume (19%), Cape du Couedic (15%), South Neptune (12%), and Liguanea Islands (10%) make of the bulk of the remainder (Figure 7.17b). With respect to the expected breakdown of historical bycatch in different MFAs, the stand-out MFA in terms of risk of bycatch was MFA 39 (45%), between southern Spencer Gulf and the west coast of Kangaroo Island (Figure 7.19b). Other important MFAs are MFA 48 and 49 (14% and 22%, respectively) off the south coast of Kangaroo Island and MFA 28 (11%) south of the Eyre Peninsula (Figure 7.19b).

Spatial and temporal distribution of historic bycatch

Figures 7.22b and 7.23b present the expected breakdown of bycatch risk per subpopulation by proportion and number based on historic variability in the amount and distribution of fishing effort in the SARLF fishery (1970-2004). Temporal variability in bycatch risk indicates that the majority of bycatch risk over the last 30 years came from the North Neptune Island subpopulation and the Cape Gantheaume subpopulation contribution to bycatch risk has increased since the early 1990s (Figures 7.22b and 7.23b).

MFA bycatch scenarios

Table 7.19 presents the average (1970-2004) annual fishing effort per SA RLF MFA, and the proportion of fishing effort and expected NZFS bycatch per MFA. A range of possible bycatch scenarios are presented, ranging from an average of 0.005 to 0.500 seals/1,000 pot-lifts/year (Table 7.19). Based on the NZFS foraging effort models, there are eight MFAs in SA where NZFS are expected to be at or close to zero. These include MFA 7, 8, 10, 18, 27, 44, 45, 46 (Table 7.19). At a bycatch rate of 0.005 seals/1,000 pot-lifts/year (ie.1 seal/200,000 pot-lifts), the bycatch rates among MFAs range from 0 to 0.046 seals/1,000 pot-lifts (Table 7.19). At an average bycatch rate of 0.500 seals/1,000 pot-lifts/year (ie. 1 seal/2,000 pot-lifts), the MFA bycatch rate varies from 0.001 to 4.560 seals/1,000 pot-lifts (Table 7.19).

Subpopulation PVA with bycatch scenarios

Figure 7.28b indicates the overall bycatch number and average bycatch rate required to place NZFS subpopulations into different risk categories. These are based the number of female mortalities attributed to individual subpopulations, as determined by the overlap in estimated foraging effort and the average (1970-2004) distribution of fishing effort in the SARLF fishery (see Table 7.19). The bycatch number refers to the total number seals caught per year, of which 50% are estimated to be female that are then apportioned out among the 13 subpopulations. The estimated number of additional female mortalities per year required to place subpopulations into the various risk categories (based on PVA using the stable population model, see Table 7.19), was combined with the bycatch scenario analysis to provide an integrated risk assessment analysis.

Table 7.16. Hypothetical ASL bycatch scenarios in the gillnet sector of the SESSF off SA. Average (1973-2004) annual fishing effort per MFA, the proportion of fishing effort and expected proportion of ASL bycatch per MFA are presented with a range of possible bycatch scenarios, ranging from an average of 0.0005 to 0.0400 seals per km net-lift/year. Individual MFA bycatch rates are given for each scenario.

Gillnet SESSF			Prop. seal bycatch	Average bycatch rate gillnet SESSF (seals/km net-lift)													
				0.0005		0.0010		0.0020		0.0030		0.0040		0.0050		0.006	
MFA	Fishing effort (km lifts)	Prop. fishing effort		No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
101	146	0.007	0.004	0.0	0.0003	0.1	0.0006	0.2	0.0011	0.2	0.0017	0.3	0.0022	0.4	0.0028	0.5	0.0033
102	104	0.005	0.002	0.0	0.0002	0.0	0.0003	0.1	0.0007	0.1	0.0010	0.1	0.0013	0.2	0.0017	0.2	0.0020
103	262	0.013	0.001	0.0	0.0000	0.0	0.0001	0.0	0.0002	0.1	0.0002	0.1	0.0003	0.1	0.0004	0.1	0.0005
104	183	0.009	0.001	0.0	0.0000	0.0	0.0001	0.0	0.0002	0.1	0.0003	0.1	0.0004	0.1	0.0005	0.1	0.0006
105	204	0.010	0.001	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.1	0.0003	0.1	0.0004	0.1	0.0004
106	214	0.011	0.001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.1	0.0003	0.1	0.0004	0.1	0.0005	0.1	0.0006
107	639	0.032	0.017	0.2	0.0003	0.3	0.0005	0.6	0.0010	1.0	0.0015	1.3	0.0020	1.6	0.0025	1.9	0.0030
108	1594	0.080	0.264	2.6	0.0016	5.1	0.0032	10.2	0.0064	15.3	0.0096	20.5	0.0128	25.6	0.0160	30.7	0.0192
112	114	0.006	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001
113	331	0.017	0.003	0.0	0.0001	0.1	0.0002	0.1	0.0003	0.2	0.0005	0.2	0.0007	0.3	0.0008	0.3	0.0010
114	723	0.036	0.019	0.2	0.0003	0.4	0.0005	0.7	0.0010	1.1	0.0016	1.5	0.0021	1.9	0.0026	2.2	0.0031
115	968	0.049	0.074	0.7	0.0007	1.4	0.0015	2.9	0.0030	4.3	0.0044	5.7	0.0059	7.2	0.0074	8.6	0.0089
122	143	0.007	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001
125	18	0.001	0.000	0.0	0.0000	0.0	0.0001	0.0	0.0002	0.0	0.0003	0.0	0.0003	0.0	0.0004	0.0	0.0005
126	1032	0.052	0.021	0.2	0.0002	0.4	0.0004	0.8	0.0008	1.2	0.0012	1.6	0.0016	2.0	0.0020	2.4	0.0024
128	632	0.032	0.026	0.3	0.0004	0.5	0.0008	1.0	0.0016	1.5	0.0024	2.0	0.0032	2.6	0.0040	3.1	0.0049
129	732	0.037	0.125	1.2	0.0017	2.4	0.0033	4.8	0.0066	7.3	0.0099	9.7	0.0132	12.1	0.0165	14.5	0.0198
132	451	0.023	0.002	0.0	0.0000	0.0	0.0001	0.1	0.0002	0.1	0.0003	0.2	0.0004	0.2	0.0005	0.3	0.0006
136	122	0.006	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0002
138	919	0.046	0.032	0.3	0.0003	0.6	0.0007	1.2	0.0014	1.9	0.0020	2.5	0.0027	3.1	0.0034	3.7	0.0041
139	745	0.038	0.044	0.4	0.0006	0.9	0.0011	1.7	0.0023	2.6	0.0034	3.4	0.0046	4.3	0.0057	5.1	0.0069
140	627	0.032	0.013	0.1	0.0002	0.3	0.0004	0.5	0.0008	0.8	0.0012	1.0	0.0016	1.3	0.0020	1.5	0.0024
144	751	0.038	0.113	1.1	0.0015	2.2	0.0029	4.4	0.0058	6.6	0.0088	8.8	0.0117	11.0	0.0146	13.1	0.0175
148	708	0.036	0.008	0.1	0.0001	0.2	0.0002	0.3	0.0004	0.5	0.0007	0.6	0.0009	0.8	0.0011	0.9	0.0013
149	1498	0.076	0.126	1.2	0.0008	2.4	0.0016	4.9	0.0033	7.3	0.0049	9.8	0.0065	12.2	0.0081	14.6	0.0098
150	2062	0.104	0.074	0.7	0.0003	1.4	0.0007	2.9	0.0014	4.3	0.0021	5.8	0.0028	7.2	0.0035	8.7	0.0042
151	2458	0.124	0.027	0.3	0.0001	0.5	0.0002	1.0	0.0004	1.5	0.0006	2.1	0.0008	2.6	0.0010	3.1	0.0013
155	988	0.050	0.001	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.1	0.0001	0.1	0.0001	0.1	0.0001	0.1	0.0001
158	459	0.020	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
Sum	19,828		Total seals	10		19		39		58		77		97		116	

Continued on next page.

Table 7.16. Cont.

MFA	Average bycatch rate gillnet SESSF (seals/km net-lift)															
	0.007		0.008		0.009		0.010		0.015		0.020		0.030		0.040	
	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
101	0.6	0.0039	0.6	0.0044	0.7	0.0050	0.8	0.0055	1.2	0.0083	1.6	0.0110	2.4	0.0165	3.2	0.0220
102	0.2	0.0024	0.3	0.0027	0.3	0.0030	0.3	0.0034	0.5	0.0050	0.7	0.0067	1.0	0.0101	1.4	0.0134
103	0.1	0.0005	0.2	0.0006	0.2	0.0007	0.2	0.0008	0.3	0.0012	0.4	0.0016	0.6	0.0023	0.8	0.0031
104	0.1	0.0007	0.1	0.0008	0.2	0.0009	0.2	0.0010	0.3	0.0014	0.3	0.0019	0.5	0.0029	0.7	0.0038
105	0.1	0.0005	0.1	0.0006	0.1	0.0007	0.1	0.0007	0.2	0.0011	0.3	0.0015	0.4	0.0022	0.6	0.0029
106	0.2	0.0007	0.2	0.0009	0.2	0.0010	0.2	0.0011	0.3	0.0016	0.5	0.0021	0.7	0.0032	0.9	0.0043
107	2.3	0.0035	2.6	0.0040	2.9	0.0045	3.2	0.0051	4.8	0.0076	6.5	0.0101	9.7	0.0152	12.9	0.0202
108	35.8	0.0224	40.9	0.0257	46.0	0.0289	51.1	0.0321	76.7	0.0481	102.3	0.0641	153.4	0.0962	204	0.1283
112	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.1	0.0004	0.1	0.0007	0.1	0.0009
113	0.4	0.0012	0.4	0.0013	0.5	0.0015	0.6	0.0017	0.8	0.0025	1.1	0.0034	1.7	0.0050	2.2	0.0067
114	2.6	0.0036	3.0	0.0042	3.4	0.0047	3.7	0.0052	5.6	0.0078	7.5	0.0104	11.2	0.0156	15.0	0.0208
115	10.0	0.0104	11.5	0.0118	12.9	0.0133	14.3	0.0148	21.5	0.0222	28.6	0.0296	42.9	0.0444	57.3	0.0592
122	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.1	0.0004	0.1	0.0007	0.1	0.0009
125	0.0	0.0006	0.0	0.0007	0.0	0.0008	0.0	0.0009	0.0	0.0013	0.0	0.0017	0.0	0.0026	0.1	0.0034
126	2.8	0.0028	3.3	0.0032	3.7	0.0035	4.1	0.0039	6.1	0.0059	8.1	0.0079	12.2	0.0118	16.3	0.0158
128	3.6	0.0057	4.1	0.0065	4.6	0.0073	5.1	0.0081	7.7	0.0121	10.2	0.0162	15.3	0.0243	20.5	0.0324
129	16.9	0.0231	19.4	0.0264	21.8	0.0297	24.2	0.0330	36.3	0.0496	48.4	0.0661	72.6	0.0991	96.8	0.1321
132	0.3	0.0007	0.3	0.0008	0.4	0.0008	0.4	0.0009	0.6	0.0014	0.8	0.0019	1.3	0.0028	1.7	0.0038
136	0.0	0.0002	0.0	0.0003	0.0	0.0003	0.0	0.0003	0.1	0.0005	0.1	0.0007	0.1	0.0010	0.2	0.0014
138	4.4	0.0047	5.0	0.0054	5.6	0.0061	6.2	0.0068	9.3	0.0102	12.5	0.0136	18.7	0.0203	24.9	0.0271
139	6.0	0.0080	6.8	0.0092	7.7	0.0103	8.5	0.0115	12.8	0.0172	17.1	0.0229	25.6	0.0344	34.2	0.0459
140	1.8	0.0028	2.0	0.0032	2.3	0.0036	2.5	0.0040	3.8	0.0061	5.1	0.0081	7.6	0.0121	10.1	0.0161
144	15.3	0.0204	17.5	0.0234	19.7	0.0263	21.9	0.0292	32.9	0.0438	43.8	0.0584	65.7	0.0876	87.6	0.1168
148	1.1	0.0015	1.2	0.0017	1.4	0.0020	1.5	0.0022	2.3	0.0033	3.1	0.0043	4.6	0.0065	6.2	0.0087
149	17.1	0.0114	19.5	0.0130	21.9	0.0146	24.4	0.0163	36.6	0.0244	48.8	0.0325	73.1	0.0488	97.5	0.0651
150	10.1	0.0049	11.5	0.0056	13.0	0.0063	14.4	0.0070	21.6	0.0105	28.9	0.0140	43.3	0.0210	57.7	0.0280
151	3.6	0.0015	4.1	0.0017	4.6	0.0019	5.1	0.0021	7.7	0.0031	10.3	0.0042	15.4	0.0063	20.6	0.0084
155	0.1	0.0001	0.1	0.0001	0.2	0.0002	0.2	0.0002	0.3	0.0003	0.4	0.0004	0.6	0.0006	0.7	0.0007
158	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
	136		155		174		194		291		387		581		775	

Table. 7.17. Hypothetical ASL bycatch scenarios in the SA RLF. Average (1970-2004) annual fishing effort per MFA, the proportion of fishing effort and expected proportion of ASL bycatch per MFA are presented. A range of possible bycatch scenarios is presented, ranging from an average of 0.005 to 0.500 seals per 1,000 pot-lifts/year and bycatch rates are given for each scenario.

SA Rock Lobster			Prop. seal bycatch	Average bycatch rate SA Rock Lobster Fishery (seals/1,000 pot-lift)																													
				0.005		0.010		0.020		0.030		0.040		0.050		0.06		0.070		0.080		0.090		0.100		0.200		0.300		0.400		0.500	
MFA	Fishing effort (1,000 lifts)	Prop. fishing effort		No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatc h rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
7	11.5	0.005	0.006	0.0	0.0015	0.0	0.0029	0.1	0.0058	0.1	0.0087	0.1	0.0117	0.2	0.0146	0.2	0.0175	0.2	0.0204	0.3	0.0233	0.3	0.0262	0.3	0.0291	0.7	0.0583	1.0	0.0874	1.3	0.1165	1.7	0.1457
8	22.9	0.010	0.1732	0.5	0.0199	0.9	0.0398	1.8	0.0796	2.7	0.1194	3.6	0.1592	4.6	0.1990	5.5	0.2388	6.4	0.2786	7.3	0.3184	8.2	0.3581	9.1	0.3979	18.2	0.7959	27.3	1.1938	36.4	1.5918	45.5	1.9897
10	7.5	0.003	0.0055	0.0	0.0019	0.0	0.0039	0.1	0.0078	0.1	0.0116	0.1	0.0155	0.1	0.0194	0.2	0.0233	0.2	0.0272	0.2	0.0310	0.3	0.0349	0.3	0.0388	0.6	0.0776	0.9	0.1164	1.2	0.1552	1.5	0.1940
15	60.6	0.027	0.2362	0.6	0.0103	1.2	0.0205	2.5	0.0410	3.7	0.0615	5.0	0.0820	6.2	0.1026	7.5	0.1231	8.7	0.1436	9.9	0.1641	11.2	0.1846	12.4	0.2051	24.8	0.4102	37.3	0.6154	49.7	0.8205	62.1	1.0256
18	3.4	0.001	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0003	0.0	0.0004	0.0	0.0005	0.0	0.0007	0.0	0.0008	0.0	0.0009	0.0	0.0010	0.0	0.0012	0.0	0.0013	0.0	0.0026	0.0	0.0039	0.0	0.0052	0.0	0.0065
27	26.7	0.012	0.0065	0.0	0.0006	0.0	0.0013	0.1	0.0026	0.1	0.0038	0.1	0.0051	0.2	0.0064	0.2	0.0077	0.2	0.0089	0.3	0.0102	0.3	0.0115	0.3	0.0128	0.7	0.0256	1.0	0.0383	1.4	0.0511	1.7	0.0639
28	107.4	0.048	0.1172	0.3	0.0029	0.6	0.0057	1.2	0.0115	1.8	0.0172	2.5	0.0229	3.1	0.0287	3.7	0.0344	4.3	0.0401	4.9	0.0459	5.5	0.0516	6.2	0.0574	12.3	0.1147	18.5	0.1721	24.6	0.2294	30.8	0.2868
39	111.3	0.049	0.2016	0.5	0.0048	1.1	0.0095	2.1	0.0191	3.2	0.0286	4.2	0.0381	5.3	0.0476	6.4	0.0572	7.4	0.0667	8.5	0.0762	9.5	0.0857	10.6	0.0953	21.2	0.1905	31.8	0.2858	42.4	0.3810	53.0	0.4763
40	48.0	0.021	0.0042	0.0	0.0002	0.0	0.0005	0.0	0.0009	0.1	0.0014	0.1	0.0018	0.1	0.0023	0.1	0.0028	0.2	0.0032	0.2	0.0037	0.2	0.0042	0.2	0.0046	0.4	0.0092	0.7	0.0138	0.9	0.0185	1.1	0.0231
44	3.0	0.001	0.0251	0.1	0.0220	0.1	0.0441	0.3	0.0882	0.4	0.1323	0.5	0.1763	0.7	0.2204	0.8	0.2645	0.9	0.3086	1.1	0.3527	1.2	0.3968	1.3	0.4408	2.6	0.8817	4.0	1.3225	5.3	1.7633	6.6	2.2042
45	6.4	0.003	0.0052	0.0	0.0021	0.0	0.0043	0.1	0.0086	0.1	0.0128	0.1	0.0171	0.1	0.0214	0.2	0.0257	0.2	0.0300	0.2	0.0342	0.2	0.0385	0.3	0.0428	0.5	0.0856	0.8	0.1284	1.1	0.1711	1.4	0.2139
46	1.9	0.001	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
48	42.9	0.019	0.0024	0.0	0.0001	0.0	0.0003	0.0	0.0006	0.0	0.0009	0.0	0.0012	0.1	0.0014	0.1	0.0017	0.1	0.0020	0.1	0.0023	0.1	0.0026	0.1	0.0029	0.2	0.0058	0.4	0.0087	0.5	0.0116	0.6	0.0145
49	54.6	0.024	0.2102	0.6	0.0101	1.1	0.0203	2.2	0.0405	3.3	0.0608	4.4	0.0810	5.5	0.1013	6.6	0.1215	7.7	0.1418	8.8	0.1620	9.9	0.1823	11.1	0.2025	22.1	0.4051	33.2	0.6076	44.2	0.8101	55.3	1.0127
50	19.7	0.009	0.0063	0.0	0.0008	0.0	0.0017	0.1	0.0033	0.1	0.0050	0.1	0.0067	0.2	0.0083	0.2	0.0100	0.2	0.0117	0.3	0.0134	0.3	0.0150	0.3	0.0167	0.7	0.0334	1.0	0.0501	1.3	0.0668	1.6	0.0835
51	144.6	0.064	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
55	588.8	0.261	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
56	539.4	0.239	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
58	452.6	0.201	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000
Sum	2253			3		5		11		16		21		26		32		37		42		47		53		105		158		210		263	

Table 7.18. Hypothetical NZFS bycatch scenarios in the gillnet sector of the SESSF off SA. Average (1973-2004) annual fishing effort per MFA, the proportion of fishing effort and expected proportion of NZFS bycatch per MFA is presented. A range of possible bycatch scenarios is presented, ranging from an average of 0.0005 to 0.0400 seals per km net-lift/year, and individual MFA catch bycatch rates are also given for each scenario.

Gillnet SESSF			Prop. seal bycatch	Average bycatch rate gillnet SESSF (seals/km net-lift)													
				0.0005		0.0010		0.0020		0.0030		0.0040		0.0050		0.006	
MFA	Fishing effort (km lifts)	Prop. fishing effort		No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
101	146	0.007	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001
102	104	0.005	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001
103	262	0.013	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001
104	183	0.009	0.001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.1	0.0003	0.1	0.0005	0.1	0.0006	0.1	0.0007
105	204	0.010	0.001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.1	0.0003	0.1	0.0004	0.1	0.0005	0.1	0.0006
106	214	0.011	0.001	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.1	0.0003	0.1	0.0003
107	639	0.032	0.001	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.1	0.0001	0.1	0.0001	0.1	0.0002	0.1	0.0002
108	1594	0.080	0.001	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.1	0.0000	0.1	0.0001	0.1	0.0001	0.1	0.0001
112	114	0.006	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0002
113	331	0.017	0.001	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.1	0.0002	0.1	0.0002	0.1	0.0003	0.1	0.0004
114	723	0.036	0.002	0.0	0.0000	0.0	0.0001	0.1	0.0001	0.1	0.0002	0.2	0.0002	0.2	0.0003	0.3	0.0004
115	968	0.049	0.005	0.1	0.0001	0.1	0.0001	0.2	0.0002	0.3	0.0003	0.4	0.0004	0.5	0.0005	0.6	0.0006
122	143	0.007	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001
125	18	0.001	0.000	0.0	0.0001	0.0	0.0002	0.0	0.0004	0.0	0.0007	0.0	0.0009	0.0	0.0011	0.0	0.0013
126	1032	0.052	0.077	0.8	0.0007	1.5	0.0015	3.1	0.0030	4.6	0.0044	6.1	0.0059	7.6	0.0074	9.2	0.0089
128	632	0.032	0.028	0.3	0.0004	0.6	0.0009	1.1	0.0018	1.7	0.0027	2.2	0.0035	2.8	0.0044	3.4	0.0053
129	732	0.037	0.003	0.0	0.0000	0.1	0.0001	0.1	0.0002	0.2	0.0002	0.2	0.0003	0.3	0.0004	0.3	0.0005
132	451	0.023	0.001	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.1	0.0001	0.1	0.0002	0.1	0.0002	0.1	0.0003
136	122	0.006	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0002
138	919	0.046	0.179	1.8	0.0019	3.6	0.0039	7.1	0.0077	10.7	0.0116	14.2	0.0155	17.8	0.0193	21.3	0.0232
139	745	0.038	0.105	1.0	0.0014	2.1	0.0028	4.1	0.0056	6.2	0.0083	8.3	0.0111	10.4	0.0139	12.4	0.0167
140	627	0.032	0.006	0.1	0.0001	0.1	0.0002	0.2	0.0004	0.3	0.0005	0.5	0.0007	0.6	0.0009	0.7	0.0011
144	751	0.038	0.010	0.1	0.0001	0.2	0.0003	0.4	0.0005	0.6	0.0008	0.8	0.0011	1.0	0.0013	1.2	0.0016
148	708	0.036	0.105	1.0	0.0015	2.1	0.0030	4.2	0.0059	6.3	0.0089	8.4	0.0118	10.5	0.0148	12.5	0.0177
149	1498	0.076	0.263	2.6	0.0017	5.2	0.0035	10.4	0.0070	15.7	0.0105	20.9	0.0139	26.1	0.0174	31.3	0.0209
150	2062	0.104	0.152	1.5	0.0007	3.0	0.0015	6.0	0.0029	9.0	0.0044	12.1	0.0059	15.1	0.0073	18.1	0.0088
151	2458	0.124	0.048	0.5	0.0002	0.9	0.0004	1.9	0.0008	2.8	0.0012	3.8	0.0015	4.7	0.0019	5.7	0.0023
155	988	0.050	0.007	0.1	0.0001	0.1	0.0001	0.3	0.0003	0.4	0.0004	0.6	0.0006	0.7	0.0007	0.9	0.0009
158	459	0.02	0.001	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.1	0.0001	0.1	0.0002	0.1	0.0002
Sum	19,828			10		20		40		59		79		99		119	

Continued on next page.

Table 7.18. Cont.

MFA	Average bycatch rate gillnet SESSF (seals/km net-lift)															
	0.007		0.008		0.009		0.010		0.015		0.020		0.030		0.040	
	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
101	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.1	0.0004	0.1	0.0006	0.1	0.0008
102	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.0	0.0004	0.1	0.0006	0.1	0.0008
103	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.1	0.0002	0.1	0.0003	0.1	0.0004	0.2	0.0006
104	0.1	0.0008	0.2	0.0009	0.2	0.0010	0.2	0.0011	0.3	0.0017	0.4	0.0023	0.6	0.0034	0.8	0.0046
105	0.1	0.0007	0.2	0.0008	0.2	0.0009	0.2	0.0010	0.3	0.0016	0.4	0.0021	0.6	0.0031	0.9	0.0042
106	0.1	0.0004	0.1	0.0004	0.1	0.0005	0.1	0.0005	0.2	0.0008	0.2	0.0011	0.3	0.0016	0.5	0.0021
107	0.1	0.0002	0.2	0.0003	0.2	0.0003	0.2	0.0003	0.3	0.0005	0.4	0.0007	0.6	0.0010	0.8	0.0013
108	0.2	0.0001	0.2	0.0001	0.2	0.0001	0.2	0.0001	0.4	0.0002	0.5	0.0003	0.7	0.0004	0.9	0.0006
112	0.0	0.0002	0.0	0.0003	0.0	0.0003	0.0	0.0004	0.1	0.0005	0.1	0.0007	0.1	0.0011	0.2	0.0014
113	0.1	0.0004	0.2	0.0005	0.2	0.0006	0.2	0.0006	0.3	0.0009	0.4	0.0012	0.6	0.0019	0.8	0.0025
114	0.3	0.0004	0.3	0.0005	0.4	0.0005	0.4	0.0006	0.6	0.0009	0.9	0.0012	1.3	0.0018	1.7	0.0024
115	0.7	0.0007	0.8	0.0009	0.9	0.0010	1.0	0.0011	1.6	0.0016	2.1	0.0021	3.1	0.0032	4.1	0.0043
122	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0003	0.0	0.0003
125	0.0	0.0016	0.0	0.0018	0.0	0.0020	0.0	0.0022	0.1	0.0033	0.1	0.0045	0.1	0.0067	0.2	0.0089
126	10.7	0.0103	12.2	0.0118	13.7	0.0133	15.3	0.0148	22.9	0.0222	30.5	0.0296	45.8	0.0444	61.0	0.0591
128	3.9	0.0062	4.5	0.0071	5.0	0.0080	5.6	0.0089	8.4	0.0133	11.2	0.0177	16.8	0.0266	22.4	0.0355
129	0.4	0.0005	0.4	0.0006	0.5	0.0007	0.6	0.0008	0.8	0.0012	1.1	0.0015	1.7	0.0023	2.2	0.0031
132	0.1	0.0003	0.2	0.0004	0.2	0.0004	0.2	0.0005	0.3	0.0007	0.4	0.0009	0.6	0.0014	0.8	0.0018
136	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.0	0.0004	0.1	0.0005	0.1	0.0008	0.1	0.0010
138	24.9	0.0270	28.4	0.0309	32.0	0.0348	35.5	0.0386	53.3	0.0580	71.1	0.0773	106.6	0.1159	142	0.1545
139	14.5	0.0195	16.6	0.0223	18.7	0.0250	20.7	0.0278	31.1	0.0417	41.5	0.0556	62.2	0.0835	82.9	0.1113
140	0.8	0.0013	0.9	0.0015	1.0	0.0016	1.1	0.0018	1.7	0.0027	2.3	0.0036	3.4	0.0054	4.6	0.0073
144	1.4	0.0019	1.6	0.0022	1.8	0.0024	2.0	0.0027	3.0	0.0040	4.0	0.0054	6.1	0.0081	8.1	0.0108
148	14.6	0.0207	16.7	0.0236	18.8	0.0266	20.9	0.0295	31.4	0.0443	41.8	0.0591	62.7	0.0886	83.6	0.1181
149	36.6	0.0244	41.8	0.0279	47.0	0.0314	52.2	0.0349	78.4	0.0523	104.5	0.0697	156.7	0.1046	208.9	0.1395
150	21.1	0.0102	24.1	0.0117	27.1	0.0132	30.2	0.0146	45.2	0.0219	60.3	0.0293	90.5	0.0439	120.6	0.0585
151	6.6	0.0027	7.6	0.0031	8.5	0.0035	9.5	0.0039	14.2	0.0058	19.0	0.0077	28.4	0.0116	37.9	0.0154
155	1.0	0.0010	1.2	0.0012	1.3	0.0013	1.4	0.0015	2.2	0.0022	2.9	0.0029	4.3	0.0044	5.8	0.0058
158	0.1	0.0002	0.1	0.0003	0.1	0.0003	0.2	0.0003	0.2	0.0005	0.3	0.0007	0.5	0.0010	0.6	0.0013
	139		159		178		198		297		397		595		793	

Table 7.19. Hypothetical NZFS bycatch scenarios in the SA RLF. Average (1970-2004) annual fishing effort per MFA, the proportion of fishing effort and expected proportion of NZFS bycatch per MFA is presented. A range of possible bycatch scenarios are presented, ranging from an average of 0.005 to 0.500 seals per 1,000 pot-lifts/year, with individual MFA catch bycatch rates are also given for each scenario.

SA Rock Lobster			Prop. seal bycatch	Average bycatch rate SA Rock Lobster Fishery (seals/1,000 pot-lift)																													
				0.005		0.010		0.020		0.030		0.040		0.050		0.06		0.070		0.080		0.090		0.100		0.200		0.300		0.400		0.500	
MFA	Fishing effort (1,000 lifts)	Prop. fishing effort		No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatc h rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate	No.	MFA bycatch rate
7	11.5	0.005	0.001	0.0	0.0007	0.0	0.0013	0.0	0.0026	0.0	0.0039	0.1	0.0052	0.1	0.0065	0.1	0.0078	0.1	0.0091	0.1	0.0104	0.1	0.0118	0.2	0.0131	0.3	0.0261	0.5	0.0392	0.6	0.0522	0.8	0.0653
8	22.9	0.010	0.000	0.0	0.0002	0.0	0.0005	0.0	0.0010	0.0	0.0014	0.0	0.0019	0.1	0.0024	0.1	0.0029	0.1	0.0034	0.1	0.0039	0.1	0.0043	0.1	0.0048	0.2	0.0096	0.3	0.0144	0.4	0.0193	0.6	0.0241
10	7.5	0.003	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0002	0.0	0.0005	0.0	0.0007	0.0	0.0010	0.0	0.0012
15	60.6	0.027	0.005	0.1	0.0010	0.1	0.0020	0.2	0.0040	0.4	0.0060	0.5	0.0080	0.6	0.0099	0.7	0.0119	0.8	0.0139	1.0	0.0159	1.1	0.0179	1.2	0.0199	2.4	0.0398	3.6	0.0596	4.8	0.0795	6.0	0.0994
18	3.4	0.001	0.000	0.0	0.0000	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.0	0.0004	0.0	0.0005	0.0	0.0005	0.0	0.0006	0.0	0.0007	0.0	0.0008	0.0	0.0015	0.0	0.0023	0.0	0.0030	0.0	0.0038
27	26.7	0.012	0.001	0.0	0.0002	0.0	0.0004	0.0	0.0009	0.0	0.0013	0.0	0.0017	0.1	0.0022	0.1	0.0026	0.1	0.0030	0.1	0.0035	0.1	0.0039	0.1	0.0043	0.2	0.0087	0.3	0.0130	0.5	0.0174	0.6	0.0217
28	107.4	0.048	0.112	1.3	0.0117	2.5	0.0233	5.0	0.0467	7.5	0.0700	10.0	0.0933	12.5	0.1167	15.0	0.1400	17.5	0.1633	20.1	0.1867	22.6	0.2100	25.1	0.2333	50.1	0.4667	75.2	0.7000	100.3	0.9333	125.3	1.1666
39	111.3	0.049	0.454	5.1	0.0456	10.2	0.0912	20.3	0.1824	30.5	0.2736	40.6	0.3648	50.8	0.4560	60.9	0.5472	71.1	0.6384	81.2	0.7296	91.4	0.8208	101.5	0.9120	203.0	1.8241	304.5	2.7361	406.0	3.6482	507.5	4.5602
40	48.0	0.021	0.008	0.1	0.0019	0.2	0.0039	0.4	0.0077	0.6	0.0116	0.7	0.0154	0.9	0.0193	1.1	0.0231	1.3	0.0270	1.5	0.0308	1.7	0.0347	1.8	0.0385	3.7	0.0770	5.5	0.1155	7.4	0.1540	9.2	0.1925
44	3.0	0.001	0.000	0.0	0.0003	0.0	0.0006	0.0	0.0011	0.0	0.0017	0.0	0.0023	0.0	0.0028	0.0	0.0034	0.0	0.0040	0.0	0.0046	0.0	0.0051	0.0	0.0057	0.0	0.0114	0.1	0.0171	0.1	0.0228	0.1	0.0285
45	6.4	0.003	0.000	0.0	0.0001	0.0	0.0002	0.0	0.0003	0.0	0.0005	0.0	0.0006	0.0	0.0008	0.0	0.0010	0.0	0.0011	0.0	0.0013	0.0	0.0014	0.0	0.0016	0.0	0.0032	0.0	0.0048	0.0	0.0064	0.1	0.0080
46	1.9	0.001	0.000	0.0	0.0000	0.0	0.0000	0.0	0.0001	0.0	0.0001	0.0	0.0002	0.0	0.0002	0.0	0.0003	0.0	0.0003	0.0	0.0004	0.0	0.0004	0.0	0.0005	0.0	0.0009	0.0	0.0014	0.0	0.0019	0.0	0.0023
48	42.9	0.019	0.142	1.6	0.0370	3.2	0.0740	6.4	0.1480	9.5	0.2220	12.7	0.2960	15.9	0.3700	19.1	0.4440	22.2	0.5179	25.4	0.5919	28.6	0.6659	31.8	0.7399	63.5	1.4799	95.3	2.2198	127.1	2.9597	158.8	3.6996
49	54.6	0.024	0.220	2.5	0.0451	4.9	0.0903	9.9	0.1805	14.8	0.2708	19.7	0.3611	24.6	0.4513	29.6	0.5416	34.5	0.6318	39.4	0.7221	44.3	0.8124	49.3	0.9026	98.5	1.8053	147.8	2.7079	197.0	3.6105	246.3	4.5132
50	19.7	0.009	0.001	0.0	0.0006	0.0	0.0013	0.0	0.0025	0.1	0.0038	0.1	0.0050	0.1	0.0063	0.1	0.0076	0.2	0.0088	0.2	0.0101	0.2	0.0113	0.2	0.0126	0.5	0.0252	0.7	0.0378	1.0	0.0504	1.2	0.0630
51	144.6	0.064	0.004	0.0	0.0003	0.1	0.0006	0.2	0.0013	0.3	0.0019	0.4	0.0025	0.5	0.0032	0.5	0.0038	0.6	0.0044	0.7	0.0050	0.8	0.0057	0.9	0.0063	1.8	0.0126	2.7	0.0189	3.6	0.0252	4.6	0.0315
55	588.8	0.261	0.025	0.3	0.0005	0.6	0.0010	1.1	0.0019	1.7	0.0029	2.2	0.0038	2.8	0.0048	3.4	0.0057	3.9	0.0067	4.5	0.0076	5.1	0.0086	5.6	0.0095	11.2	0.0191	16.9	0.0286	22.5	0.0382	28.1	0.0477
56	539.4	0.239	0.010	0.1	0.0002	0.2	0.0004	0.4	0.0008	0.7	0.0012	0.9	0.0016	1.1	0.0021	1.3	0.0025	1.6	0.0029	1.8	0.0033	2.0	0.0037	2.2	0.0041	4.4	0.0082	6.7	0.0124	8.9	0.0165	11.1	0.0206
58	452.6	0.201	0.015	0.2	0.0004	0.3	0.0007	0.7	0.0015	1.0	0.0022	1.3	0.0030	1.7	0.0037	2.0	0.0044	2.3	0.0052	2.7	0.0059	3.0	0.0067	3.4	0.0074	6.7	0.0148	10.1	0.0222	13.4	0.0297	16.8	0.0371
Sum	2253			11		22		45		67		89		112		134		156		179		201		223		447		670		894		1117	

The levels of overall NZFS bycatch in the SARLF fishery estimated to place any subpopulation in the *endangered* category was very high, with the lowest thresholds not being reached until total bycatch levels exceed 8,249 seals per annum.

Discussion

Study limitations

This study has compiled and synthesised a considerable amount of information on the demography, size, foraging ecology and extinction risk for South Australia's ASL and NZFS subpopulations and the historical spatial distribution of fishing effort in the SESSF gillnet sector and SA RLF in order to provide an assessment of the risk to SA seal populations from bycatch in these fisheries. This has been done in the absence of any quantitative data on pinniped bycatch levels in these fisheries. A task such as this inevitably has to make many assumptions and deal with data deficiencies that can impact on the outcomes of analyses, and the degree of certainty placed on the findings. As such, we address the major limitations first, so the broad findings can be viewed in an appropriate context.

Seal population data

For ASL, although the relative size of subpopulations is generally understood, the quality of data on the pup production of different subpopulations is typically poor. There are a number of reasons for this (McKenzie et al. 2005, Shaughnessy et al. 2005). Firstly, because of the asynchronous and non-annual breeding cycle the timing of breeding is not well understood for the majority of ASL subpopulations. Secondly, the species has a protracted (5-7 month) breeding season that means that by the end of the season, some pups will have died, moulted and/or dispersed, making it difficult to determine total pup production. Thirdly, pup production estimates (the only mean of estimating subpopulation size) are typically based on the maximum number of live pups seen on single or multiple counts made during a breeding season, and where possible, cumulative numbers of dead pups are added to produce a final estimate. There is uncertainty about the accuracy of these counts, because current methods do no provide estimates of confidence or error. For this reason, the limited time series data available for subpopulations are difficult to interpret and provide little confidence about trends in abundance. This is in contrast to data available for NZFS, where breeding is annual, highly synchronous and pups are born over a relatively short period, after which their numbers can be accurately estimated using mark-recapture methods that provide estimates with confidence limits. In addition, in SA waters NZFS are concentrated at five sites, making it logistically feasible to conduct regular surveys. As a consequence, subpopulation status and trends are well known in NZFS compared to ASL. This is especially so for the numerous small breeding sites that make up the majority of ASL subpopulations.

The demographic models used to estimate the size of seal subpopulations were constructed based on limited data from both species, and a number of assumptions based on data from closely related species. The main model used for the ASL assumed that all subpopulations were stable (equilibrium survival and birth rates), and that the vital rates for all subpopulations were identical, regardless of size. This is almost certainly not the case, because trend data for three subpopulations (The Pages, Seal Bay and Dangerous Reef) indicate a spectrum of increasing, decreasing and potentially stable populations. The demographic models assumed density dependence not to be a significant factor regulating the size of subpopulations. Although there may be some basis to this assumption (eg. species below their carrying capacity following significant range and population reductions, as discussed above), it may be an important factor, which could be limiting the recovery of some subpopulations. Similarly, Allee effects were not incorporated into demographic models, primarily because of their unknown role in regulating pinniped populations. The resultant models used are therefore relatively conservative (ie. presenting more positive growth), because density dependence would reduce the rate at which subpopulations can grow, while Allee effects would tend to reduce the growth potential of small and declining subpopulations.

The uncertainties detailed above in terms of the size and demographic structure of subpopulations impact on the ability to undertake realistic population viability analyses (PVAs), and this procedure has been criticised, because there are often large uncertainties involved in predicting the probability of extinction of populations or species (Taylor 1995, Ludwig 1999, Ellner et al. 2002). Because of this, it is important to examine and evaluate (where possible) the major sources of error.

Foraging models and fishing effort

The foraging effort models used were overly simplistic because they did not incorporate differences within and between subpopulations in the direction (and in some cases distance) of travel. Direction of travel was only estimated for NZFS subpopulations, as a consequence, the area included in the foraging effort in ASL was likely to be widely spread and therefore may have incorrectly incorporated some areas. For example, foraging data for subpopulations of ASL in the Nuyts Archipelago indicate a marked variability in the distribution of foraging effort between colonies, with animals in some colonies feeding inshore in shallow waters and some offshore, while adjacent subpopulations, which are separated by small distances display marked differences in foraging habit (Goldsworthy et al. unpublished data). Based on the marked variability in foraging habit, the only way to resolve this is through additional tracking studies at a range of subpopulations.

Because the fishing effort data used here were recorded in spatially broad MFAs (approximately 1˚ x 1˚), the analysis of spatial overlap and risk of interactions with seals was also analysed at this scale. Although both the SESSF gillnet sector and SARL fisheries concentrate fishing effort inshore, the presentation of fishing effort in MFAs distributes effort over a larger area, and as a consequence reduces the degree of overlap with foraging effort of seals, which also concentrate their foraging effort inshore. Greater spatial precision, in both seal foraging effort and fishing effort, would produce more realistic estimates of interaction and risk probabilities.

Assessment of risks to Australian sea lions

PVA assessment of subpopulations

Our PVA analysis provides the most sophisticated assessment of quasi-extinction risk for ASL subpopulations. These analyses provide strong support for the recent listing of the species as *Threatened* (*Vulnerable* category) under Commonwealth *EPBC Act*. This study has estimated total SA pup production of approximately 2,674 per breeding cycle and a total SA population size of about 10,905. Almost 70% of this population is accounted for by six breeding sites, which make up 16% of known SA breeding localities. As a consequence there are large numbers of breeding sites where few pups are born, with 60% of sites producing fewer than 30 pups (42% with fewer than 20). The median pup production for SA colonies is only 25.5. Depending on which population trajectory model was being used (*decreasing*, *stable*, *increasing*), PVA results indicated that up to 71% of subpopulations could be classed as *endangered* without any additional (anthropogenic) mortality. Very small increases in mortality resulted in quasi-extinctions, with an additional mortality of 2 pups per subpopulation per year resulting in the quasi-extinction of 71% of subpopulations in 30 years in the decreasing population model, or 42% of subpopulations (in <38 years) in the stable population model. Furthermore, if mortalities were directed at older, recruiting age females, rates of decline could increase by more than three-fold compared with similar mortality rates directed at pups.

All of the PVA simulations indicate that in absence of any anthropogenic mortality, some ASL subpopulations are likely to become *quasi-extinct*. With low levels of additional (anthropogenic) mortalities, many other small subpopulations are expected to become *quasi-extinct*, and negative growth will become a feature of even the largest subpopulations for the species. However, because the status and trends in subpopulations, their stage-specific survival and fecundity rates, and the actual rates of anthropogenic mortality are unknown, it is not possible to know whether any of the population scenarios are plausible.

One of the many challenges facing management of the species is that the majority of subpopulations are small (and possibly depleted). In the worst-case scenario, most of these subpopulations could be in decline and heading for extinction. If this is the case, we may be seeing a range of subpopulations at different stages in the process of extinction, and other (unknown) subpopulations may have recently gone extinct. The difficulty in detecting declines in subpopulations that have been reduced to low levels, has been identified as a major problem for population managers (Staples et al. 2005). The possibility that the high numbers of small subpopulations have resulted from systemic subpopulation declines is a pressing hypothesis that needs to be addressed. Similarly, the potential that fishery bycatch in gillnet and trap fisheries is the principal cause for subpopulation declines is another critical hypothesis that needs urgent attention.

Evaluating the risk posed by each fishery

SESSF gillnet sector

Some level of bycatch of ASL occurs in the gillnet sector of the SESSF in SA, but its incidence and spatial occurrence are unknown, because rates of bycatch appear to be under-reported. This study has indicated almost complete overlap between the distribution of effort in the fishery and the spatial extent of foraging effort by all age/gender classes of ASL. Further, fishing effort tends to be focused inshore (in shallower waters) in areas of high ASL foraging effort, and there is evidence for relatively high incidence of entanglement of ASL in demersal gillnet material, at least in parts of their range (see Page et al. 2004). This fact, plus the considerable fishing effort averaging about 20,000 km of net-set per year in SA MFAs, point to there being a high potential for interactions with ASL.

Page et al. (2004) reported 19 individual ASL entangled in monofilament gillnet at Seal Bay (Kangaroo island) over a 15-year period, or about 1.3 entangled seals/year. Most of this subpopulation is monitored daily by SA Department for Environment and Heritage (DEH) staff, providing unique opportunities to monitor the nature and extent of entanglement in fishing gear (Page et al. 2004). The population is currently declining by about 0.7% per year (Shaughnessy et al. 2006). It is impossible to estimate what proportion of the entire population are entangled in demersal gillnets, free themselves and reach ashore wearing the gillnet material. Fowler (1987) and Fowler et al. (1990) undertook a study of entanglement in northern fur seals (*Callorhinus ursinus*), and determined that entangled seals were less likely to be observed on land because, a) an unknown number drown during or shortly after entanglement; b) entangled seals will be encountered less often on shore because of their lower survival, and c) entangled seals spend longer periods at sea foraging because of the additional drag of entangling material. Fowler et al. (1990) suggested that because of these factors, entanglement-related mortality of juvenile northern fur seals was 35 times that of onshore entanglement rates (ie. entangled seals ashore represent 2.9% of all animals entangled).

Based on the probability of interactions between ASL and gillnet SESSF calculated for all ASL subpopulations in SA, we estimate that about 11.4% of the fishery bycatch would be from the Seal Bay subpopulation. Given this, 1.3 entangled seals ashore/year at Seal Bay would imply a total annual SA bycatch of 23 seals if entangled seals ashore represent 50% of all those entangled, 114 seals (if entangled seals ashore represent 10% of all those entangled), 227 seals (if entangled seals ashore represent 5% of all those entangled), and 376 seals (if entangled seals ashore represent about 3% of all those entangled), as in the study of Fowler et al (1990). If entangled seals ashore represent between 1-10% of all ASL that become entangled, then annual bycatch rates for SA and adjacent waters could number between 100-300+ seals/year.

By combining PVAs with subpopulation fishery interaction probabilities, this study has identified the subpopulations and fishery MFAs that are at most risk from gillnet sector SESSF bycatch, population reduction and quasi-extinction. This analysis identified that subpopulations from two regions were most at-risk. Firstly, the top seven subpopulations at greatest risk were all in the Nuyts Archipelago and Streaky Bay regions off the western Eyre Peninsula in MFA 108 (Olive Island, East Franklin Reef, West Island, Purdie Island, West Franklin Reef, Lounds Islands and Breakwater Reef), with the next three at-risk subpopulations occurring south and east of Kangaroo Island in MFAs 149 and 144 (Seal Bay, the Seal Slide and The Pages). Annual bycatch levels of between 260-400 seals per year would be required for quasi-extinction of these populations in about 50 years. These equate to average bycatch rates of 0.01 –0.02 seals per/km net-lift/year (1-2 seals per 100kms of net-lift averaged across all SA MFAs). However, even lower levels of bycatch (between 100-150 seals/year, 0.004-0.005 seals/km/net-lift, 0.4-0.5 seals per 100km net-lifts) would cause many subpopulations to decline. These analyses suggest that even with modest levels of bycatch, the extent and distribution of fishing effort could have significantly impacted the viability of numerous ASL subpopulations.

SA RLF

As with the gillnet sector SESSF, an unknown level of bycatch of ASL occurs in the SA RLF. Because bycatch involves entrapment and drowning of seals in pots, impact of the fishery is likely to be limited to small seals that can physically fit in pot-openings. The SA RLF is concentrated in the south-east of SA, between the south cost of Kangaroo Island and the lower Eyre Peninsula, and along the west coast of the Eyre Peninsula. As a consequence of the restricted spatial distribution of the fishery, 36% of ASL foraging effort is estimated to occur outside regions where SA RLF catches have been reported. Further, probabilities of interaction are low in the major fishing MFAs (southern zone) of the fishery (55,56 and 58), which account for over 75% of effort in the SA RLF (about 1 million pot-lifts•yr^{-1}). Most interactions were predicted to occur in the northern zone of the SA RLF, which accounts for about a third total fishing effort of the fishery (about 500,000 pot-lifts/year).

By combining PVAs with ASL interaction probabilities in the SA RLF, the colonies at highest risk were more spatially spread compared with the risk posed by gillnet SESSF. The ten highest risk subpopulations where distributed across four main regions and MFAs: Price Island (southern Eyre Peninsula, MFA 28) was the most at-risk population, followed by subpopulations in southern Spencer Gulf (Peaked Rocks, North Island, Albatross Island, Lewis Island and South Neptune Island, MFA 39), western Eyre Peninsula (West Waldegrave and Jones Island, MFA 15) and Kangaroo Island (Seal Bay and the Seal Slide, MFA 49). Low levels on annual bycatch (13+ seals, 0.025+ seals/1,000 pot-lifts in MFAs where seals occur) were enough to place some subpopulations into the *vulnerable* category, 40+ seals (0.076+ seals/1,000 pot-lifts) into the *endangered* and *critical* category and 120+ to *quasi-extinct* (0.228+ seals/1,000 pot-lifts). These rates of bycatch are higher than those reported for ASL in the western rock lobster fishery in WA (Campbell et al. 2004). Campbell et al. (2004) estimated annual bycatch rates at about 0.003 seals per 1,000 pot-lifts, but these may be underestimates, because they are based on phone and logbook surveys, and include fishing effort in areas where ASL may not forage. Because bycatch probabilities are a function of fishing effort and seal foraging effort, it is difficult to compare rates of interaction between sites, unless differences in the level of fishing and seal foraging effort can be quantified.

Assessment of risks to New Zealand fur seals

PVA assessment of subpopulations

Based on an increasing population size scenario, which has strong empirical support, PVA of NZFS subpopulations in SA provided outcomes in marked contrast to results from the PVA of ASL subpopulations. The six largest NZFS subpopulations in SA that account for 99% of the State's pup production, all produce more than 600 pups annually and had very low risks of extinction, with very high levels of mortality required to place them at risk. The most vulnerable subpopulations were those off the west coast of Eyre Peninsula, which have comparatively low annual pup production (between 7-57 per year), and collectively account for a 1% of the State's pup production. Little Hummock and Greenly Island subpopulations were the most vulnerable, with low quasi-extinction thresholds (4-8 additional pre-recruit female mortalities/year) in as little as 12 years.

Evaluating the risk posed by each fishery

Based on the combination of PVA outputs, spatial analysis of overlap in SESSF gillnet sector and SA RLF fishing effort and spatial analysis of NZFS foraging effort, the overall potential risks to individual NZFS subpopulations from bycatch in these fisheries was evaluated. Outcomes indicated that unless bycatch levels in both fisheries were high, the level of risk, even to those subpopulations identified as most at risk in PVA outcomes, was low. This was in part due a substantial proportion of foraging effort occurring outside the MFAs for each fishery, and the relatively low level of fishing effort in regions with the most vulnerable NZFS populations. Recent tracking studies undertaken at North Neptune and Liguanea Islands, and at Cape du Couedic, indicate that adult female fur seals may concentrate their foraging effort in oceanic waters (Baylis et al. unpublished data), much further away than estimated in this study. As such, the interaction probabilities given here may be over-estimated to some degree.

Potential to develop risk management tools

The study has made considerable progress toward developing spatial tools to assess the potential risk-reduction (risk of extinction) benefits that could arise from a range of spatial management options in both the gillnet SESSF and SA RLF. Such tools could be useful in the gillnet SESSF, where bycatch mitigation options related to gear modification are limited. Spatial management of fishing effort, which could reduce risks to particular subpopulations, is attractive because it provides immediate risk reduction to the targeted subpopulation or region, with minimal impact on fishery catch. For example, the seven most at-risk ASL subpopulations identified in the gillnet SESSF were located in MFA 108, which accounted for about 5% of the total fishery effort and about 8.5% and 3.9% of the catch of gummy and school shark for SA MFAs (based on catch data for 2004). Spatial management options could be investigated to assess how such effort and catch could be reallocated to reduce the impact on high-risk ASL subpopulations.

Enhanced spatial tools for risk assessment will be required if spatial management of fishing effort is to become a major management strategy for mitigating ASL bycatch in the gillnet sector SESSF. Such tools would provide a simple approach for policy makers and managers, enabling them to evaluate the benefits and costs of different spatial allocations of fishing effort, in terms of increasing or decreasing the risk to sea lion subpopulations. However, further development of such tools is required, because current models are limited by the absence of data on the foraging movements of sea lions in some high risk regions, as well as the absence of accurate fishing effort data at appropriate spatial scales. Satellite tracking of ASL subpopulations identified as high-risk should be undertaken to improve the accuracy of spatial foraging models. In addition, because the gillnet sector SESSF fishers now record the positions of each net-set, the spatial resolution of bycatch probabilities could be improved and with them, the risk assessment for each subpopulation.

Such spatial allocations of fishing effort would also need to include the actual rates of ASL bycatch in the fishery, because spatial closures would need to be underpinned by estimates of bycatch rates in targeted regions. With these data the benefits of spatial closures (in terms of reduced bycatch), could be estimated and compared to the costs to industry. This could be achieved by targeting specific fishing areas for independent observer coverage.

Conclusions and recommendations

This study assessed the risk of bycatch of ASL and NZFS in two fisheries that occur off the coast of SA: the gillnet sector of the SESSF and the SA RLF.

A major constraint in the assessment of the risk of bycatch to seal subpopulations is the absence of quantitative data on bycatch rates in both fisheries.

Risks were assessed based on overlap in the spatial distribution of fishing effort and the estimated spatial distribution of seal foraging effort. The probability of interactions are a function of the extent to which fishing effort and seal foraging effort overlap in space and time. As such, interaction probabilities will change with spatial and temporal variability in fishing and seal foraging effort, and changes in seal population sizes.

Of the two pinniped species investigated, Australian sea lions showed the higher risk of significant depletion and quasi-extinction of SA subpopulations as a result of fishery bycatch. In contrast, the risk that SA subpopulations of NZFS would be significantly depleted was very low.

Population viability analysis of ASL subpopulations reinforced the recent Australian Government listing of the ASL as a *threatened* species, by identifying that many subpopulations of the species are presently vulnerable to extinction. PVA simulations suggest that in absence of any anthropogenic mortality, some ASL subpopulations will likely become *quasi-extinct* and, in the face of sustained but small additional mortalities (eg. from fishery bycatch), many other small subpopulations will likely become *quasi-extinct*, and negative growth will become a feature of even the largest subpopulations for the species.

The large proportion of small ASL subpopulations may be attributable to declines in their size, and fishery bycatch in gillnet and trap-fisheries may be the principal cause for these declines. These are challenging hypotheses that need urgent attention.

Of the two fisheries investigated (SA component of gillnet sector SESSF and SA RLF), the more significant in terms of bycatch of ASL is likely to be the gillnet SESSF. There are three main reasons for this :

- there is almost complete spatial overlap in fishing effort with the foraging effort of ASL in SA,
- fishing effort is substantial in SA and adjacent waters (about 20,000 km of net-set per year), occurs year-round and in close proximity to most ASL subpopulations,
- bycatch can potentially impact all age-sex classes.

The impact from SA RLF is likely to be less because:

- there is less overlap in fishing effort with seal foraging effort, because about two-thirds of the fishing effort occurs in areas with little ASL foraging,
- fishing is restricted to eight months of the year,
- bycatch is likely to be restricted to pups and juvenile seals.

Although this study investigated the bycatch risks posed to seal subpopulations by the gillnet SESSF and SA RLF, the potential additive and interactive impacts posed by combined bycatch in these fisheries have not been investigated, but they could be significant, especially to ASL.

The combining of PVA outcomes with bycatch scenarios based on interaction probabilities has identified the subpopulations, regions and fishery MFAs that are likely to be most significant in terms of bycatch in each fishery. In the gillnet SESSF, the seven ASL subpopulations at greatest risk occurred in one MFA, highlighting the potential significance of spatial management of fishing effort to mitigate bycatch risk in this fishery. In contrast, the ASL subpopulations at greatest risk were spread over a number of MFAs.

The two fisheries investigated here lend themselves to different mitigation approaches to addressing seal bycatch issues. In the gillnet SESSF, gear modification options are limited, with the possible exception of acoustic deterrent devices (‘pingers’). Spatial management of fishing effort could provide a range of risk-reduction options to management, but this would need to be coupled with independent observer effort to demonstrate and justify the benefits. In contrast, there is significant scope for gear modification options in the SA RLF, with pot-protection devices already used to reduce the incidence of seal bycatch in some parts of the fishery. Quantitative testing of these pot-protection devices and alternate protection measures (as is taking place in the WA WRLF), and industry-wide adoption of best-mitigation practices may eliminate seal bycatch, without the need for a large and costly independent observer program.

A number of recommendations arise from this study:

1. An independent observer program in the gillnet sector of the SESSF should be implemented to assess the significance of ASL bycatch in the high-risk regions identified in the study.

2. The spatial risk assessment approach developed in this study should be improved using higher resolution fishing effort data (lat/long location of effort in the gillnet SESSF and depth-stratified data in the SA RLF) coupled with higher resolution spatial foraging data in ASL (utilising satellite telemetry) to produce a spatial risk-management tool, which policy makers/managers can use to assess the risk and benefits of different spatial management scenarios.

3. Investigate options for gear modification (such as acoustic deterrents) to reduce the incidence of seal bycatch in the gillnet sector of the SESSF. Of those options that may be feasible, undertake trials to assess their efficacy.

4. Undertake quantitative trials to assess the efficacy of different pot-protection devices at eliminating seal bycatch in the southern rock lobster fishery. These trials should include testing the impact of different protection measures on catch and size selectivity. Once developed, seal excluding/pot-protection devices should be adopted throughout the southern rock lobster fishery, to address broader seal interactions issues in other States (eg. Victoria and Tasmania).

5. Methods and guidelines for measuring and evaluating the performance of systems for monitoring, assessing and mitigating interactions between the fisheries and seals needs to be developed. This would include improving industry reporting of seal interactions, and developing performance indicators to assess the level and effectiveness of risk reduction following implementation of mitigation options.

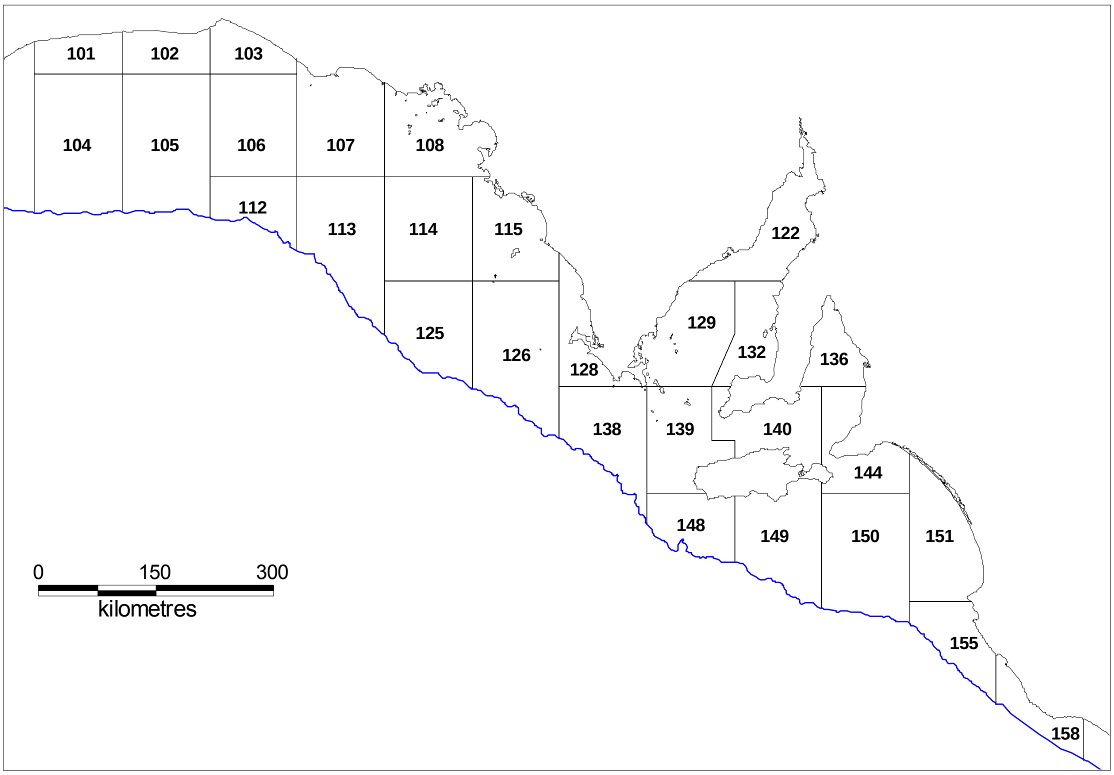


Figure 7.1. Gill-net sector SESSF Marine Fishing Areas (MFAs) off South Australia for which catch and effort data have been recorded since 1973.

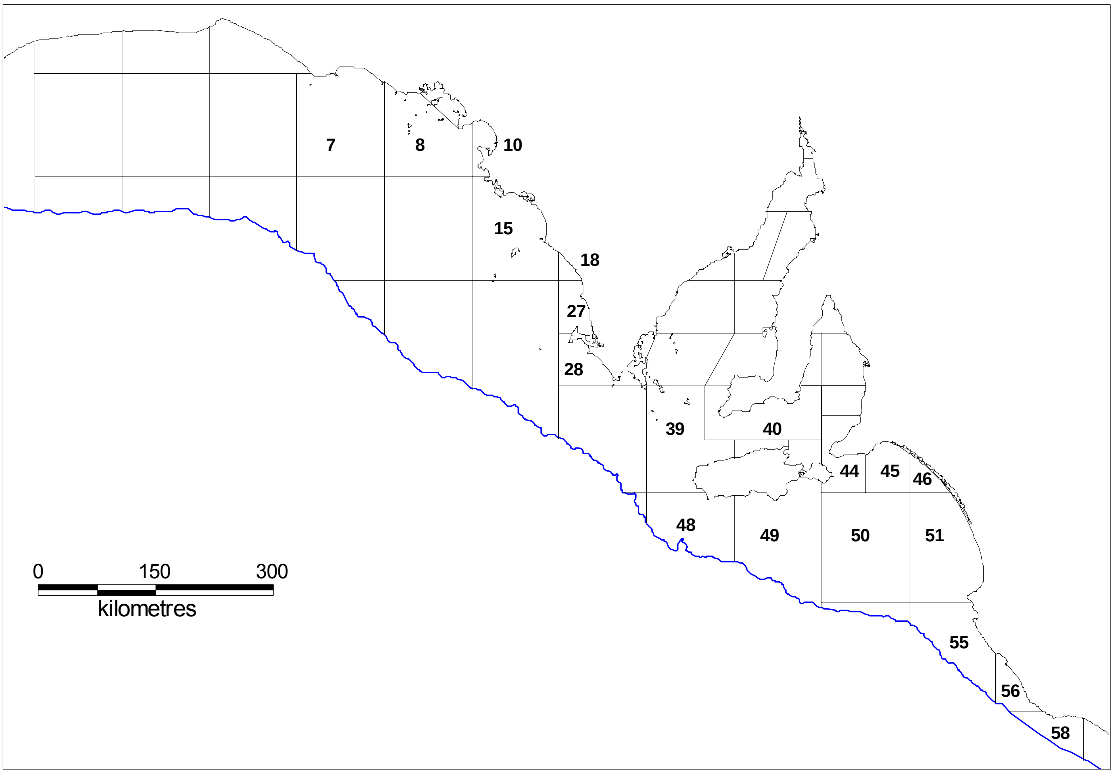
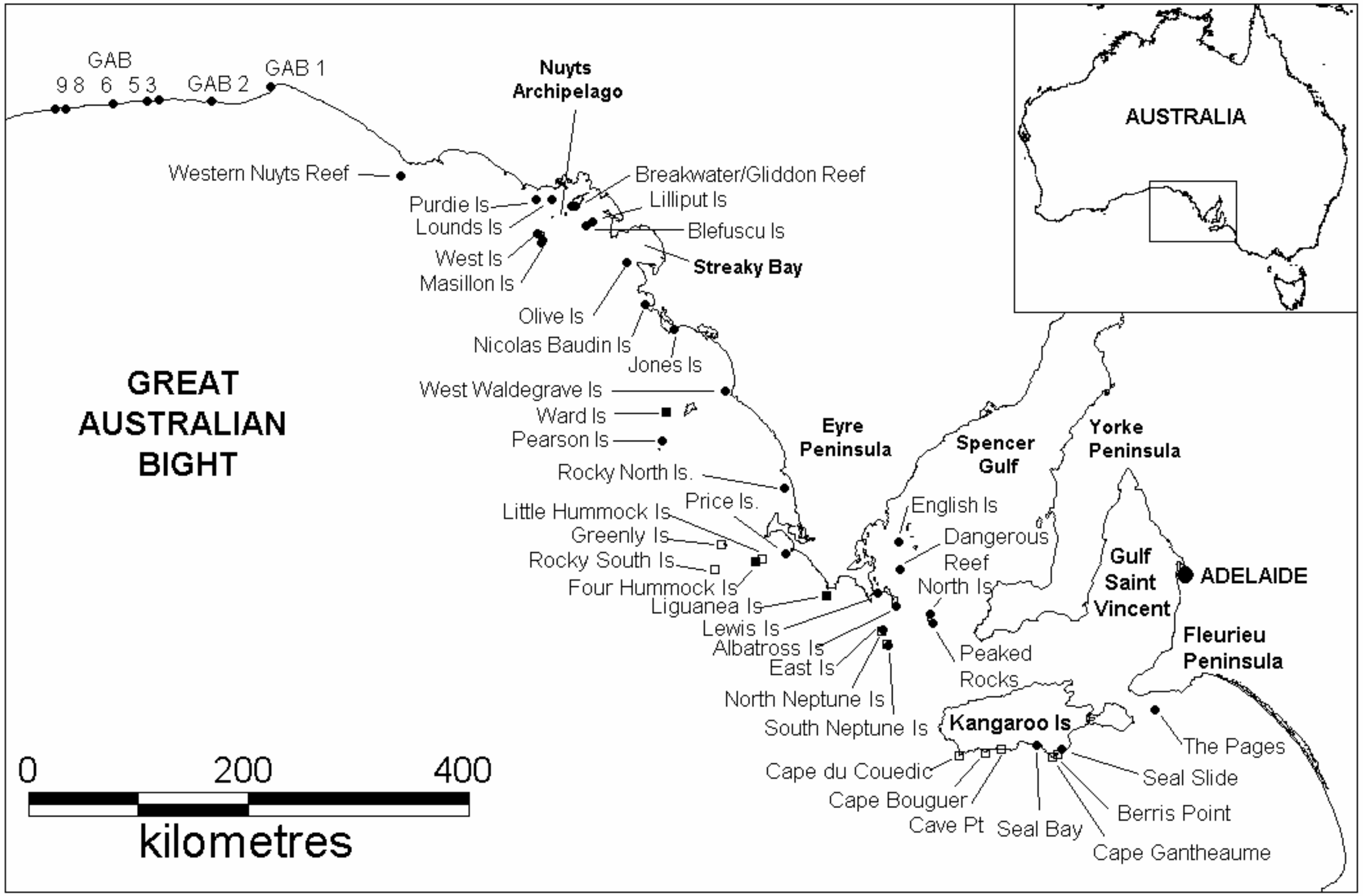


Figure 7.2. SARLF fishery Marine Fishing Areas (MFAs) off South Australia for which catch and effort data have been recorded since 1970.

Figure 7.3. Map of South Australia and the eastern Great Australian Bight (GAB) indicating the location of Australian sea lion (closed circles) and New Zealand fur seal (open squares) breeding sites. Black squares indicate sympatric breeding locations.



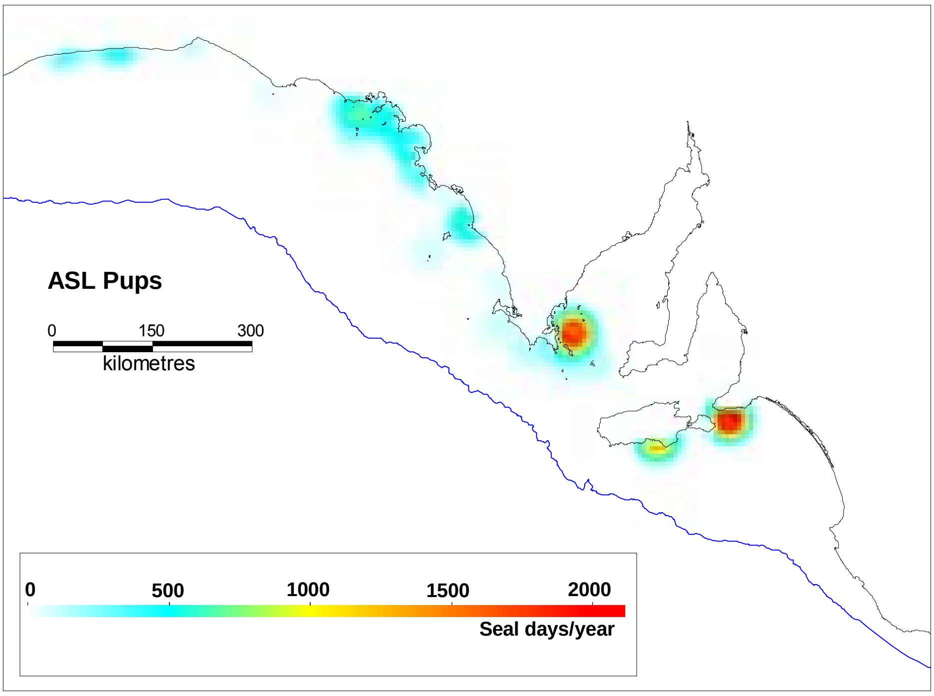


Figure 7.4a. Estimated distribution of foraging effort (seal days.year^{-1}) of ASL pups in South Australia. The blue line indicates the edge of the continental shelf (200m).

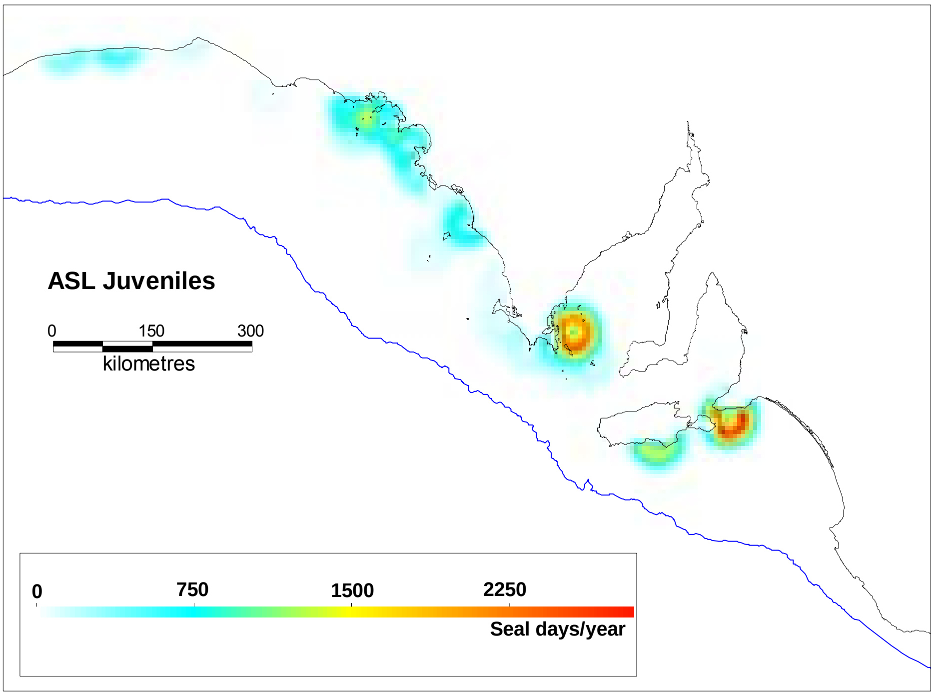


Figure 7.4b. Estimated distribution of foraging effort (seal days.year^{-1}) of ASL juveniles in South Australia. The blue line indicates the edge of the continental shelf (200m).

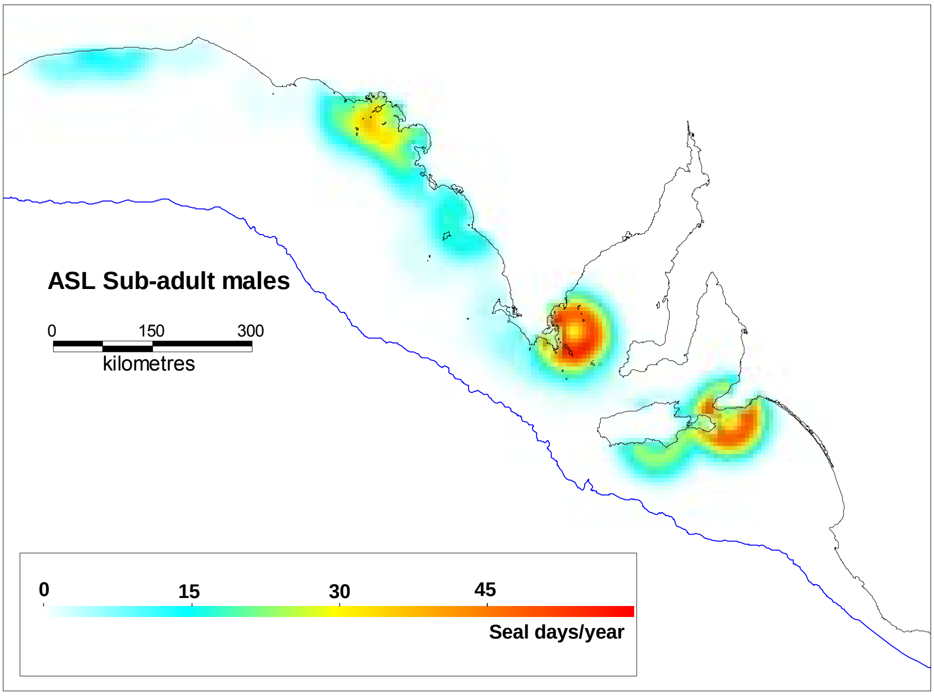


Figure 7.4c. Estimated distribution of foraging effort (seal days.year^{-1}) of ASL sub-adult males in South Australia. The blue line indicates the edge of the continental shelf (200m).

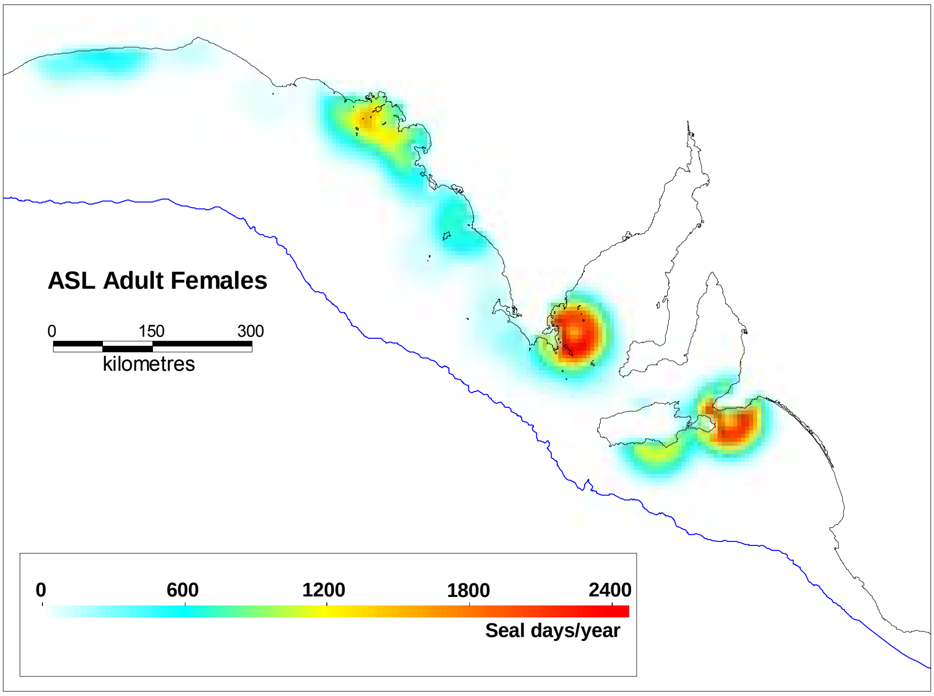


Figure 7.4d. Estimated distribution of foraging effort (seal days.year^{-1}) of ASL adult females in South Australia. The blue line indicates the edge of the continental shelf (200m).

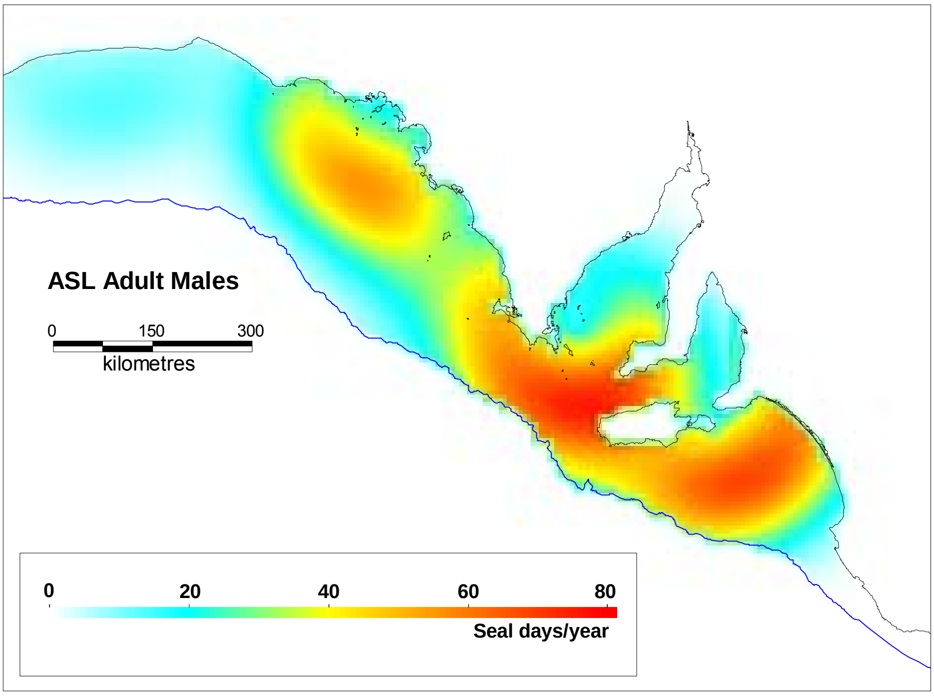


Figure 7.4e. Estimated distribution of foraging effort (seal days.year^{-1}) of ASL adult males in South Australia. The blue line indicates the edge of the continental shelf (200m).

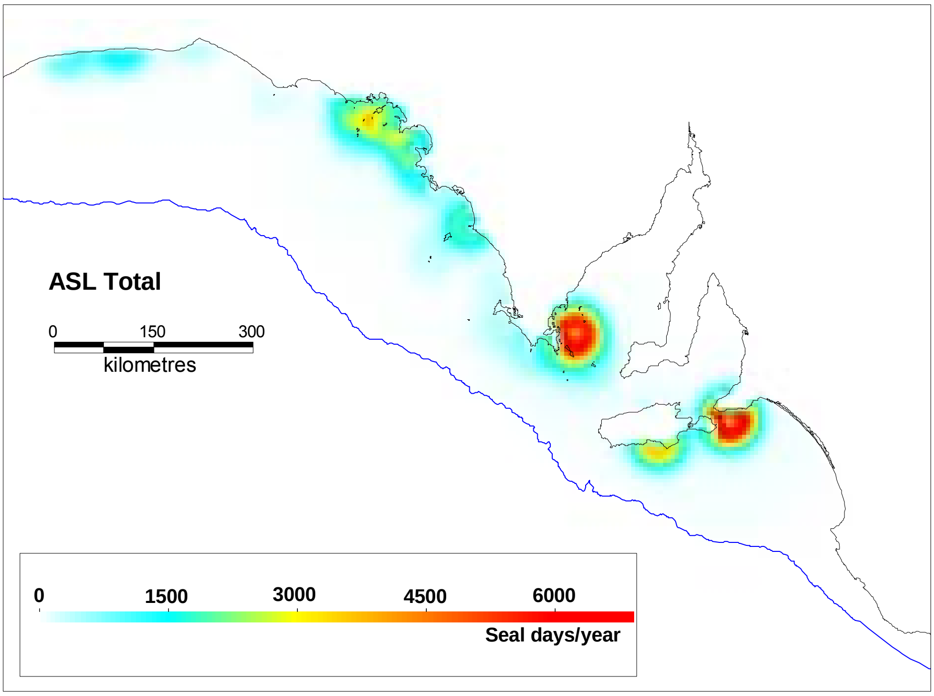


Figure 7.4f. Estimated total distribution of foraging effort (seal days.year^{-1}) of ASL (age/gender groups combined) in South Australia. The blue line indicates the edge of the continental shelf (200m).

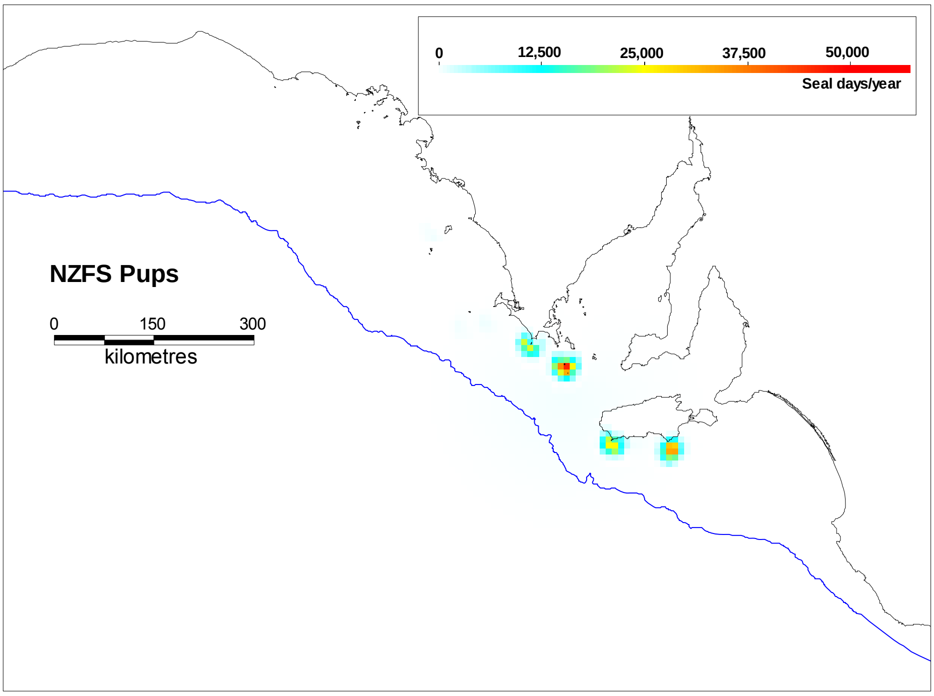


Figure 7.5a. Estimated distribution of foraging effort (seal days.year^{-1}) of NZFS pups in South Australia. The blue line indicates the edge of the continental shelf (200m).

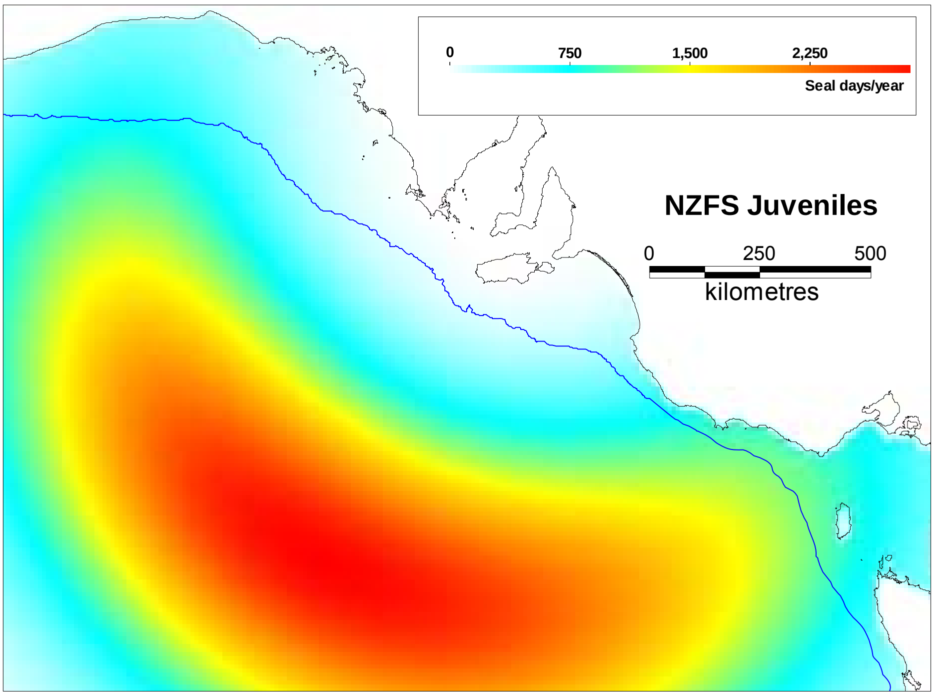


Figure7. 5b. Estimated distribution of foraging effort (seal days.year^{-1}) of NZFS juveniles in South Australia. The blue line indicates the edge of the continental shelf (200m).

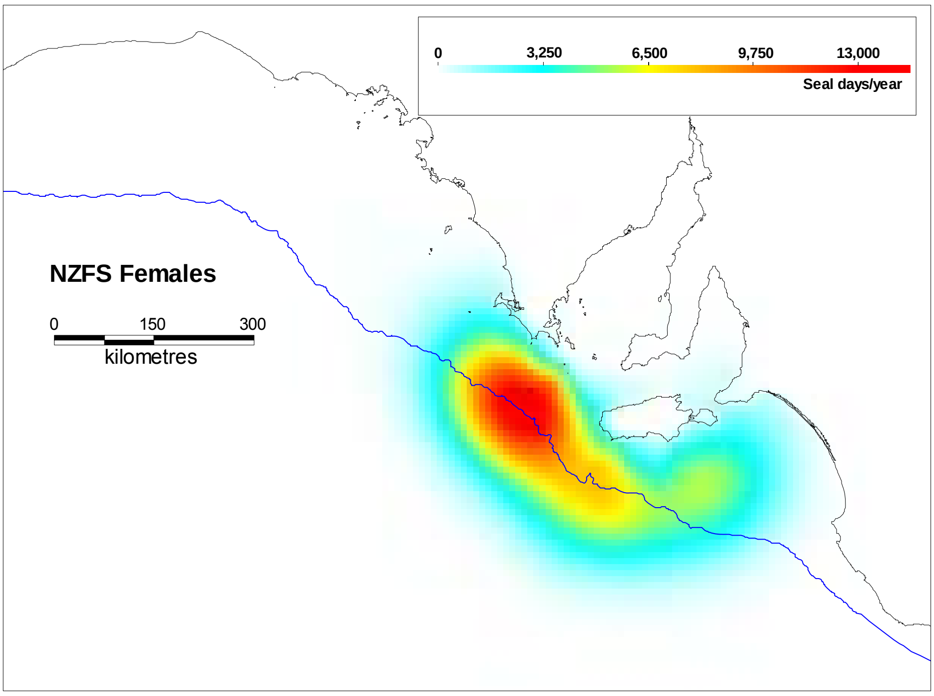


Figure 7.5c. Estimated distribution of foraging effort (seal days.year^{-1}) of NZFS adult females in South Australia. The blue line indicates the edge of the continental shelf (200m).

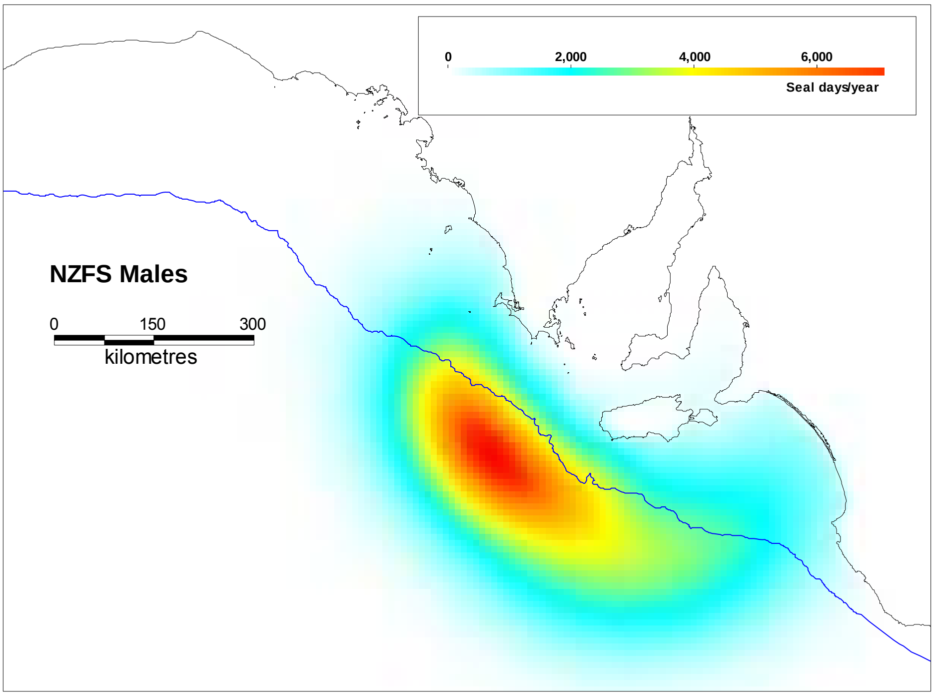


Figure 7.5d. Estimated distribution of foraging effort (seal days.year^{-1}) of NZFS adult males in South Australia. The blue line indicates the edge of the continental shelf (200m).

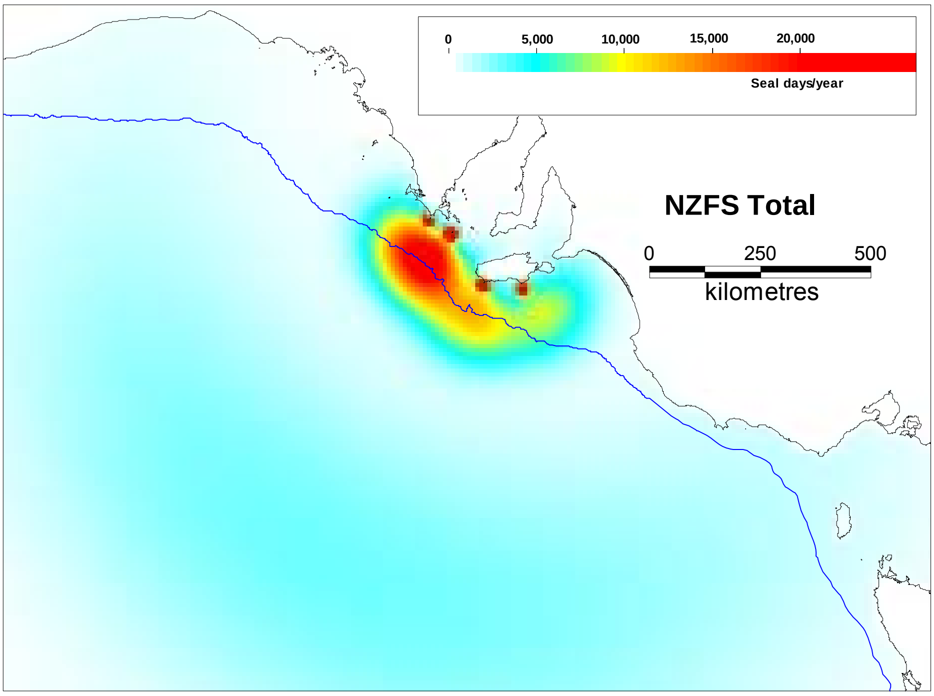
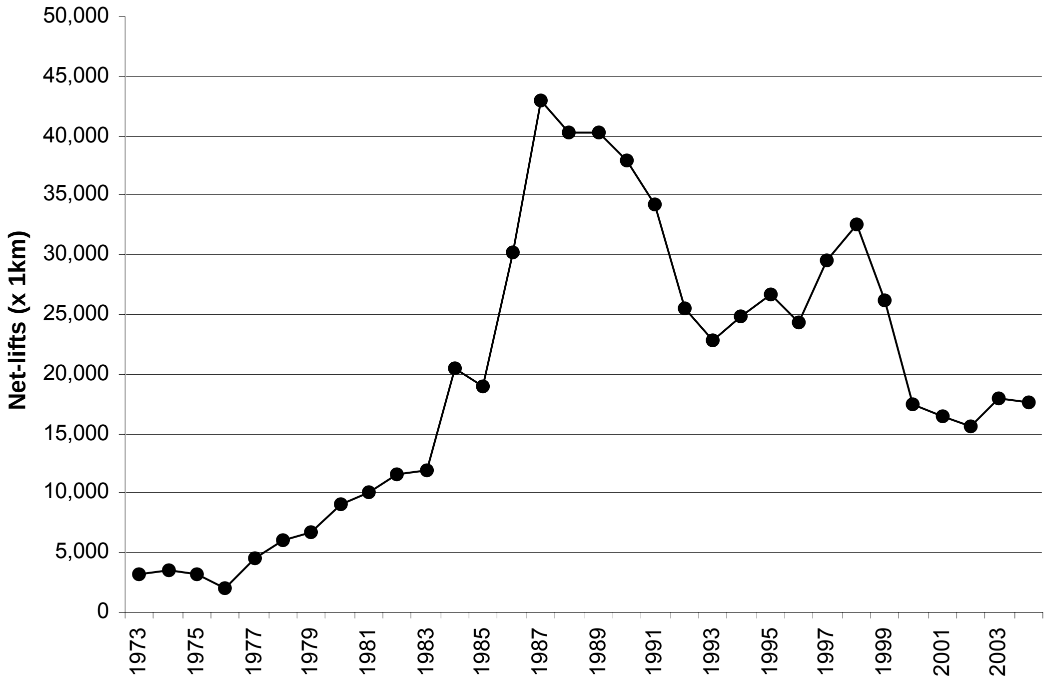


Figure 7.5e. Estimated total distribution of foraging effort (seal days.year^{-1}) of the NZFS (age/gender groups combined) population in South Australia. The blue line indicates the edge of the continental shelf (200m).

A



B

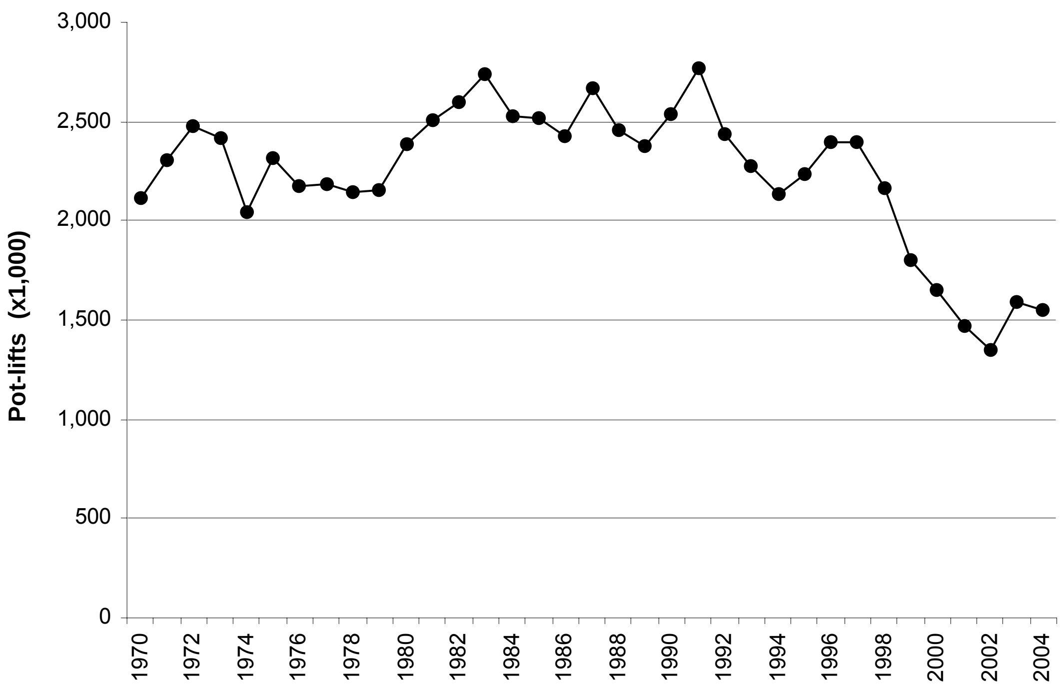


Figure 7.6. Temporal variation on total fishing effort in SA and adjacent Commonwealth waters in the gillnet sector of the SESSF between 1973-2004 (A), and SARLF (B) between 1970-2004

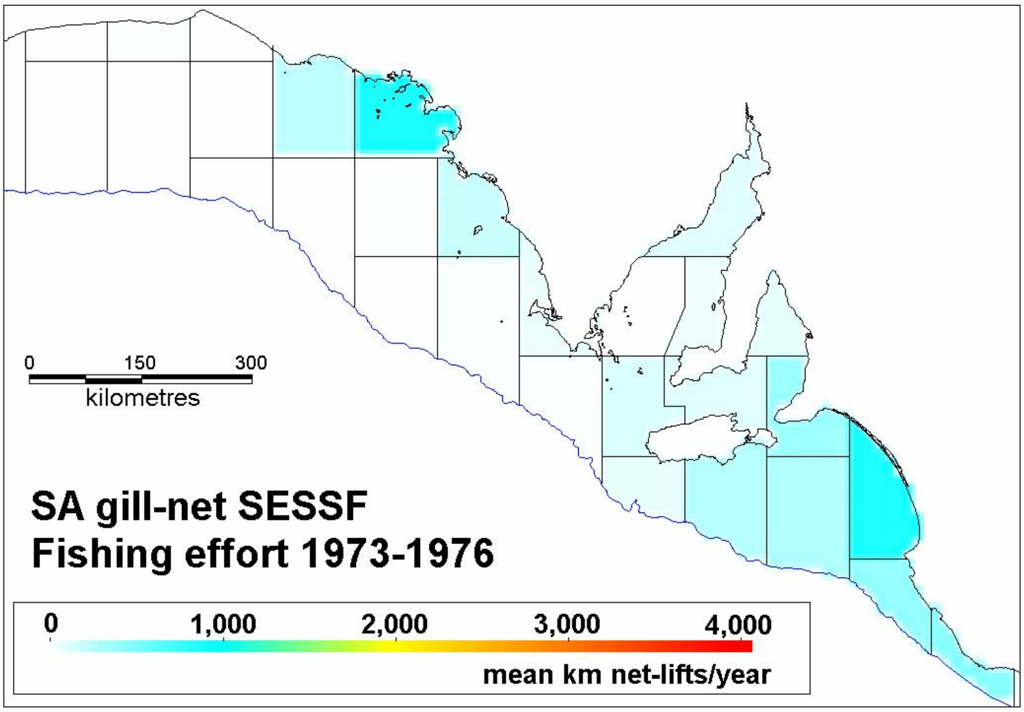


Figure 7.7a. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1973-76.

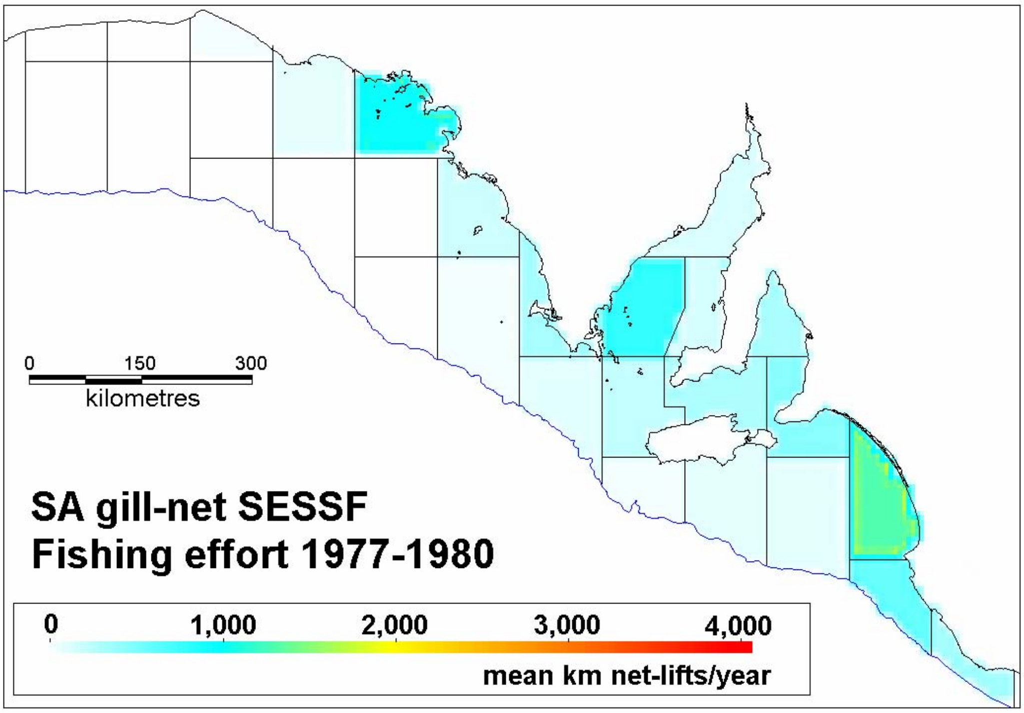


Figure 7.7b. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1977-80.

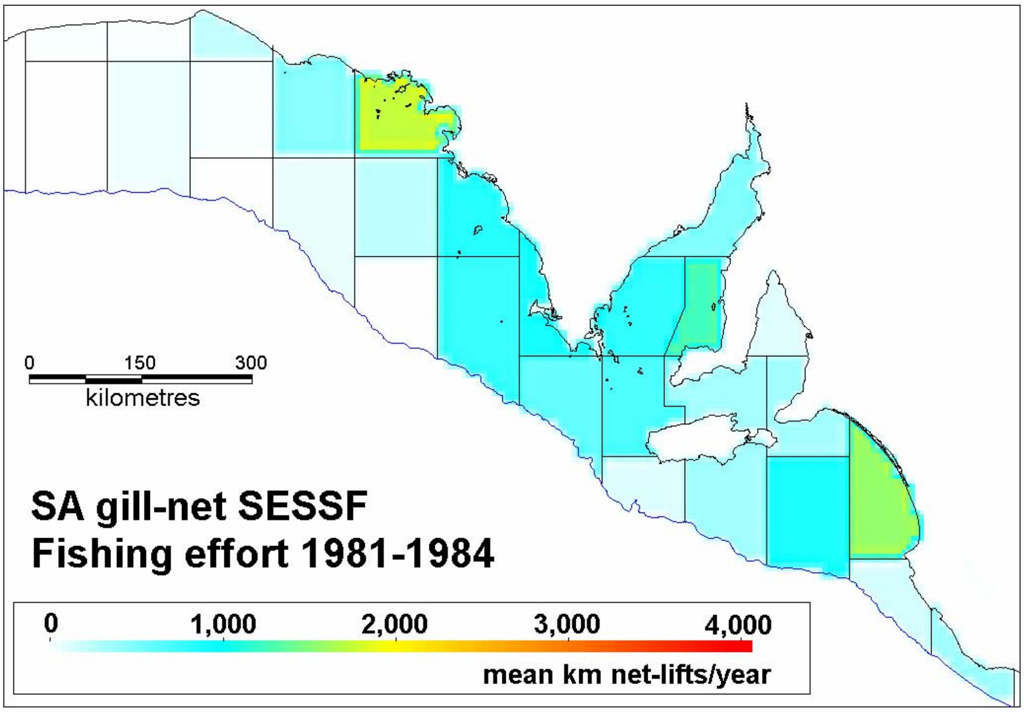


Figure 7.7c. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1981-84.

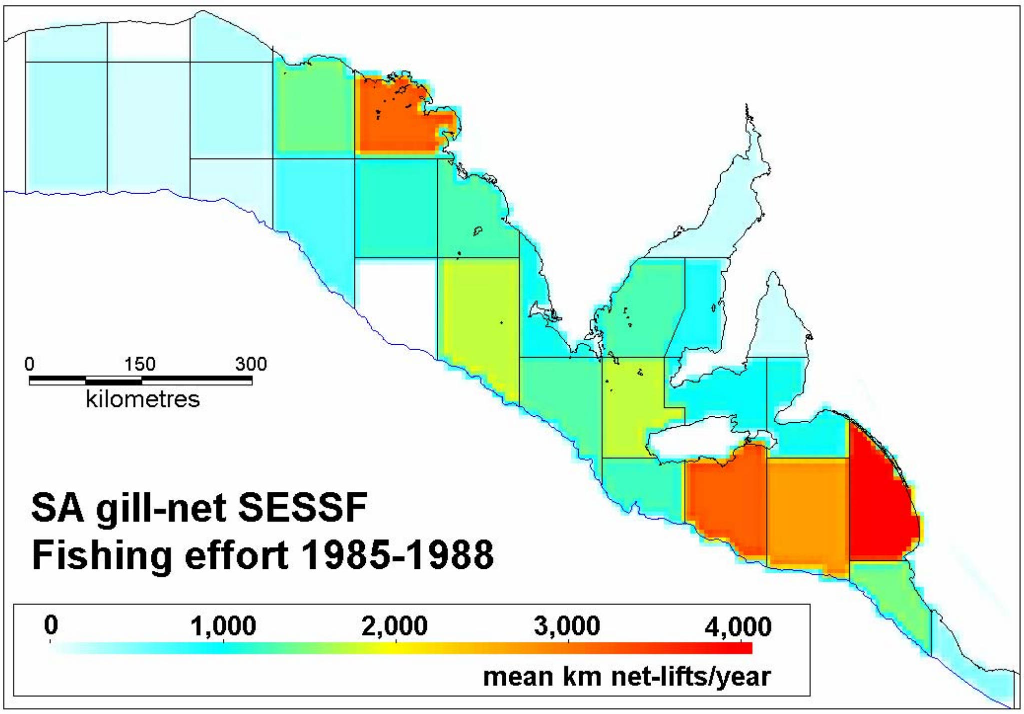


Figure 7.7d. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1985-88.

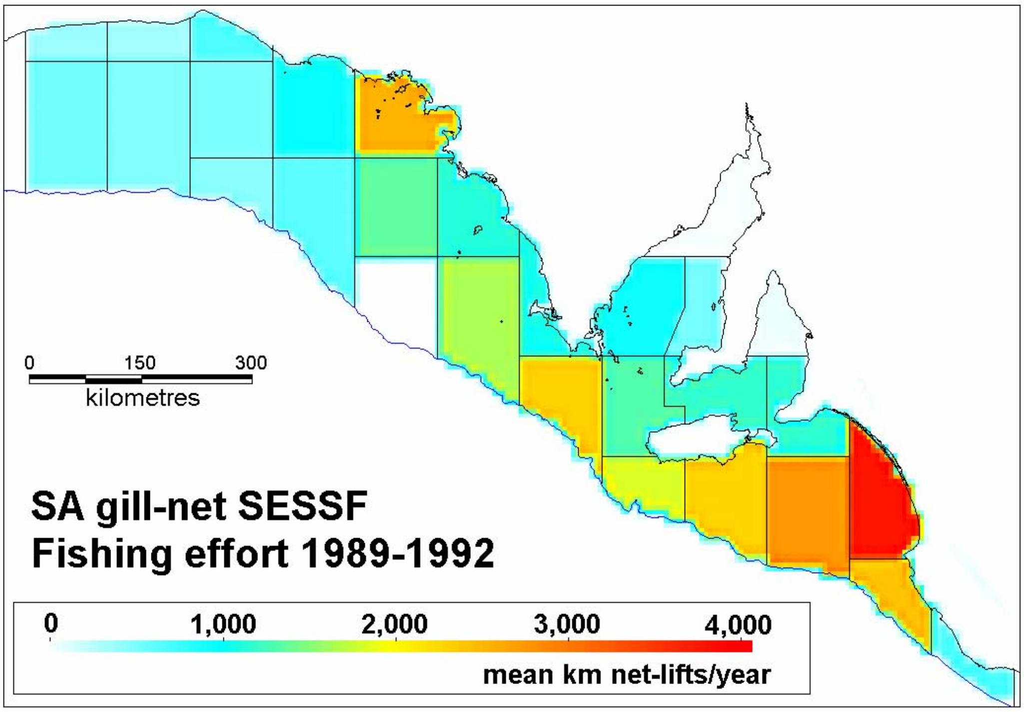


Figure 7.7e. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1989-92.

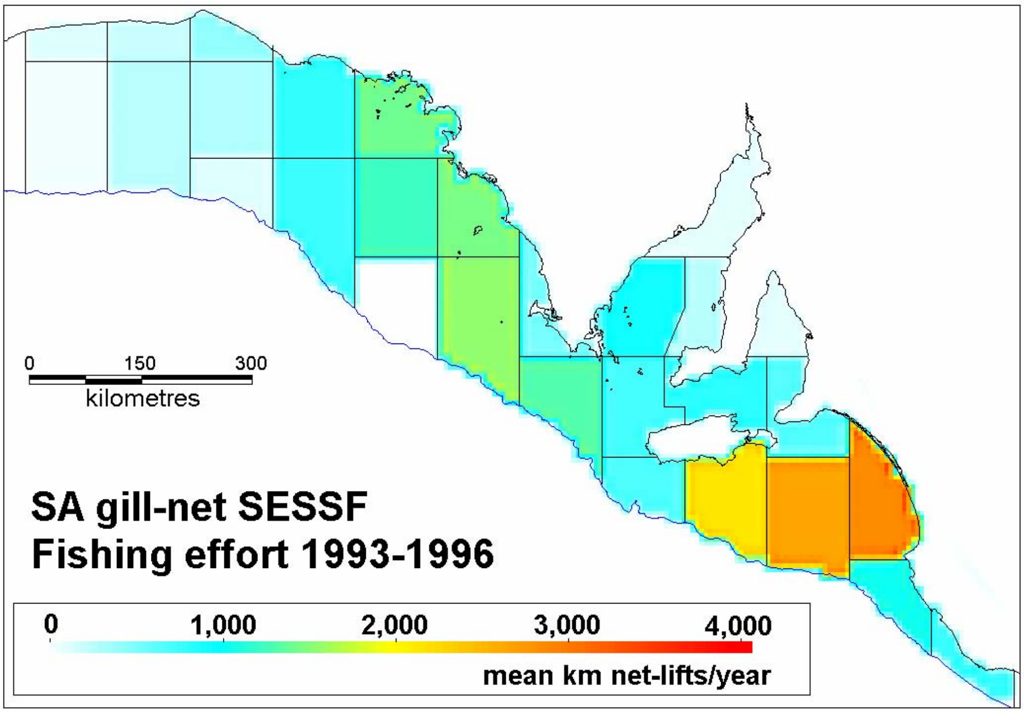


Figure 7.7f. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1993-96.

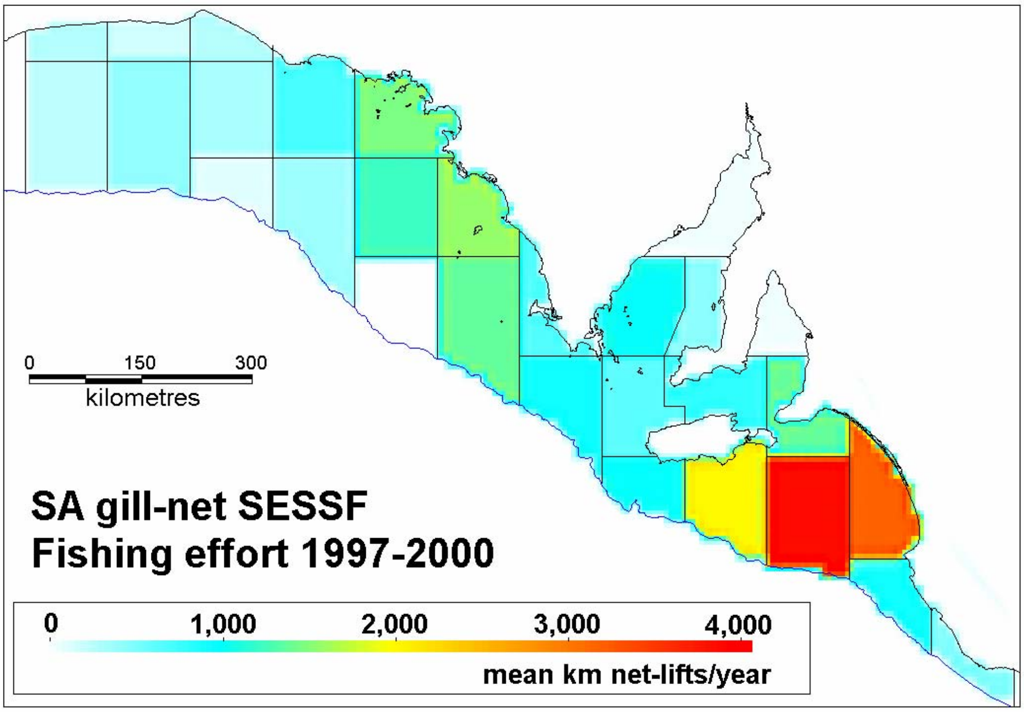


Figure 7.7g. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1997-00.

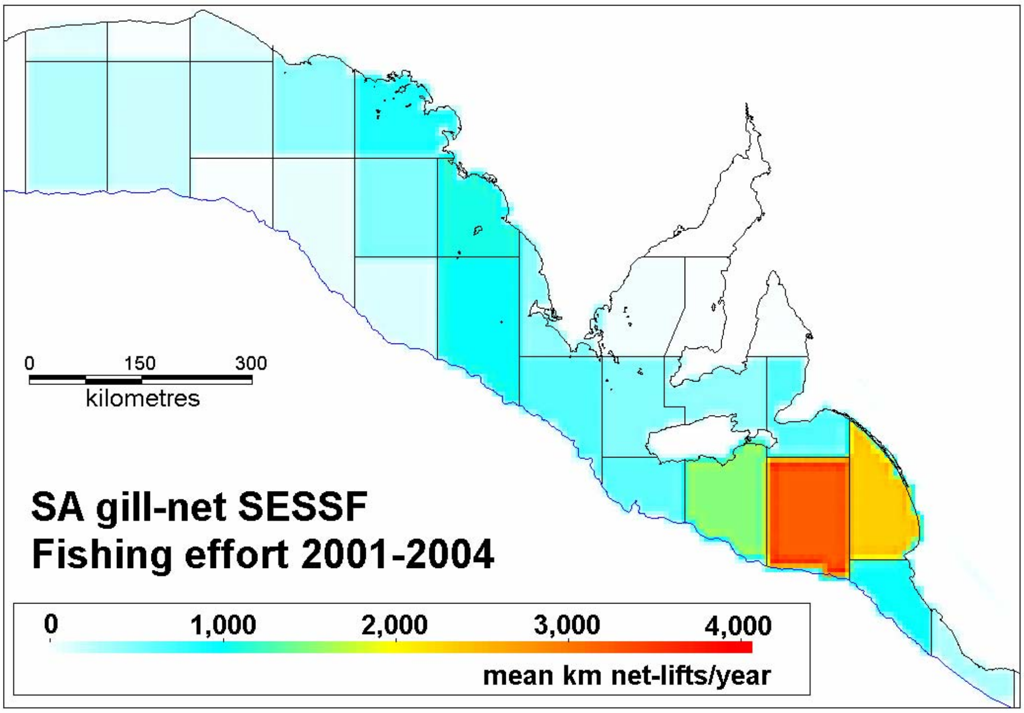


Figure 7.7h. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 2001-04.

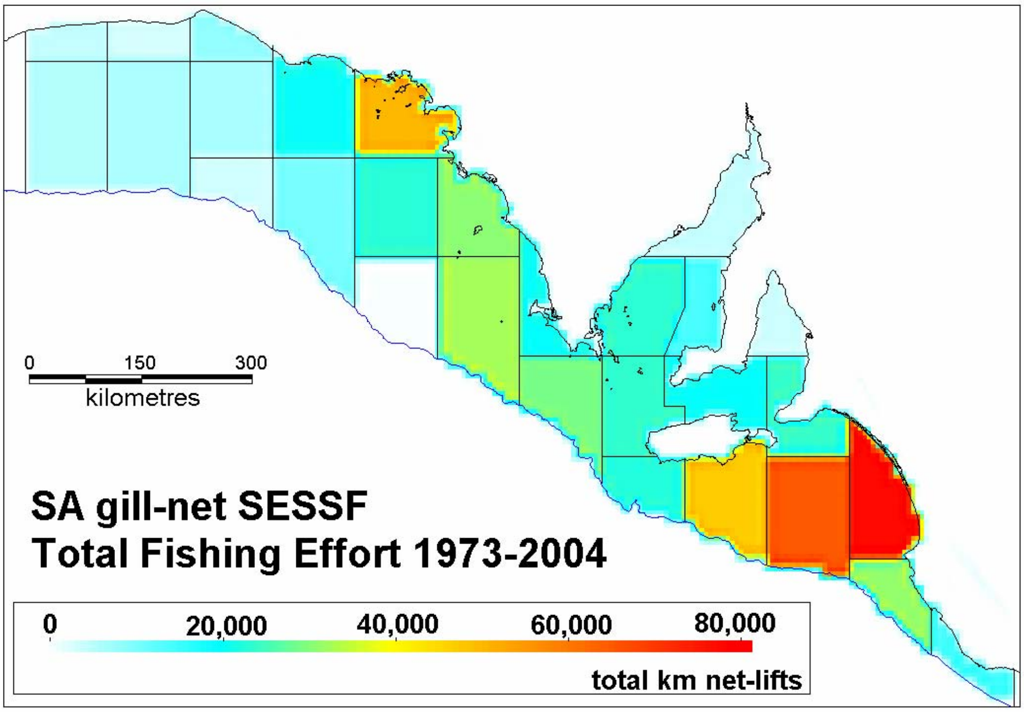


Figure 7.7i. Distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1973-2004.

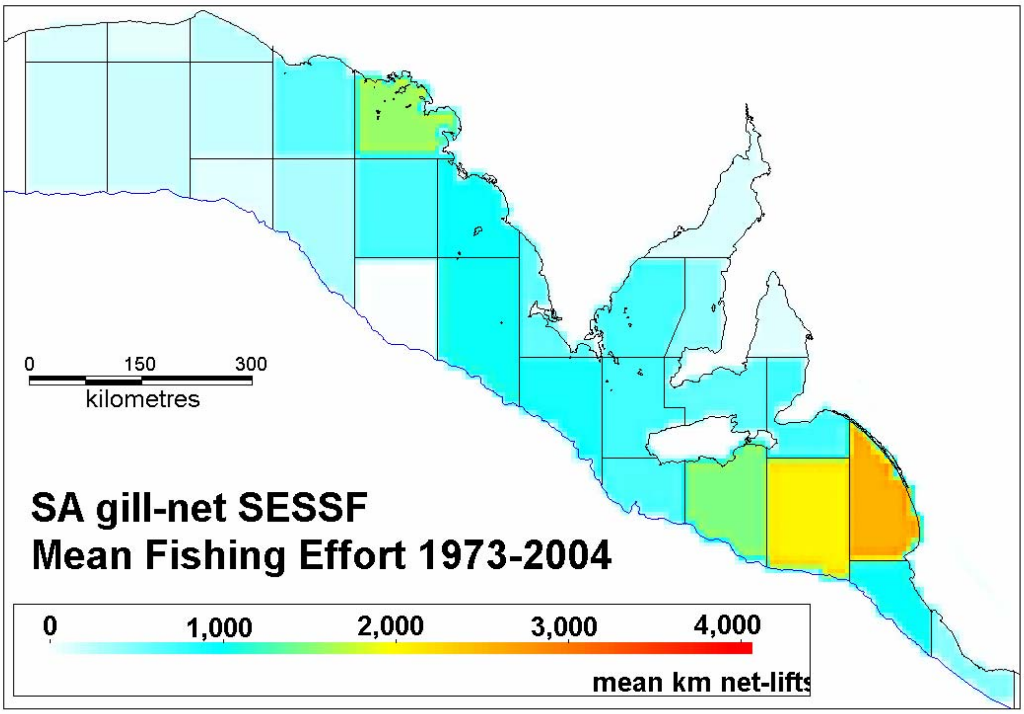


Figure 7.7j. Mean annual distribution of fishing effort in the SA component of the gill-net sector of the SESSF, 1973-2004.

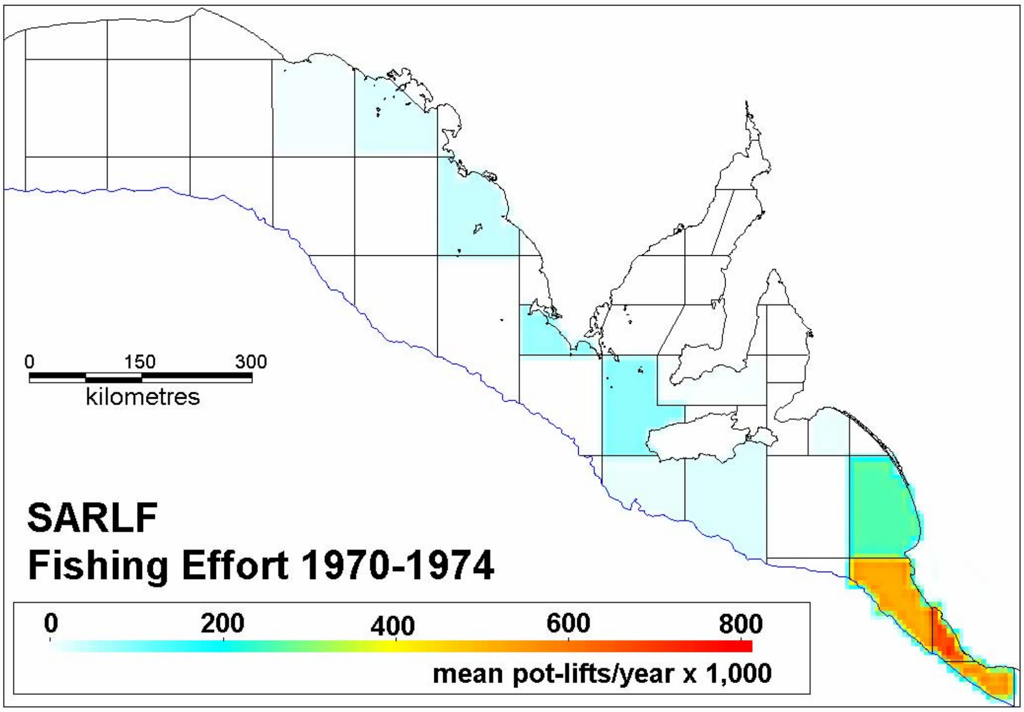


Figure 7.8a. Mean annual distribution of fishing effort in the SARLF, 1970-74.

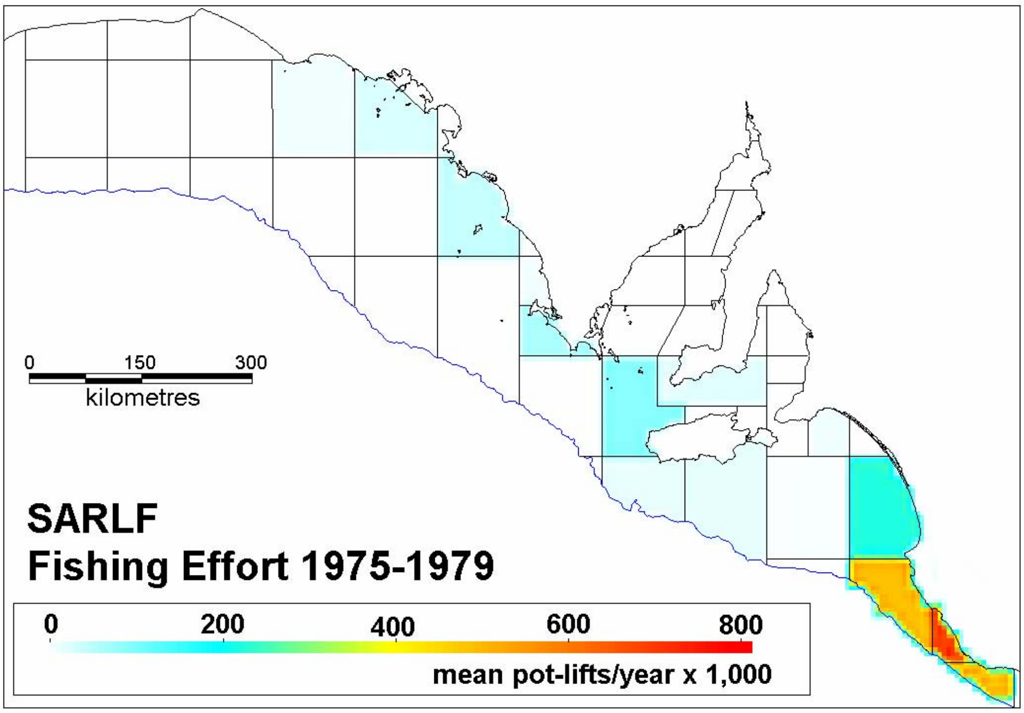


Figure 7.8b. Mean annual distribution of fishing effort in the SARLF, 1975-79.

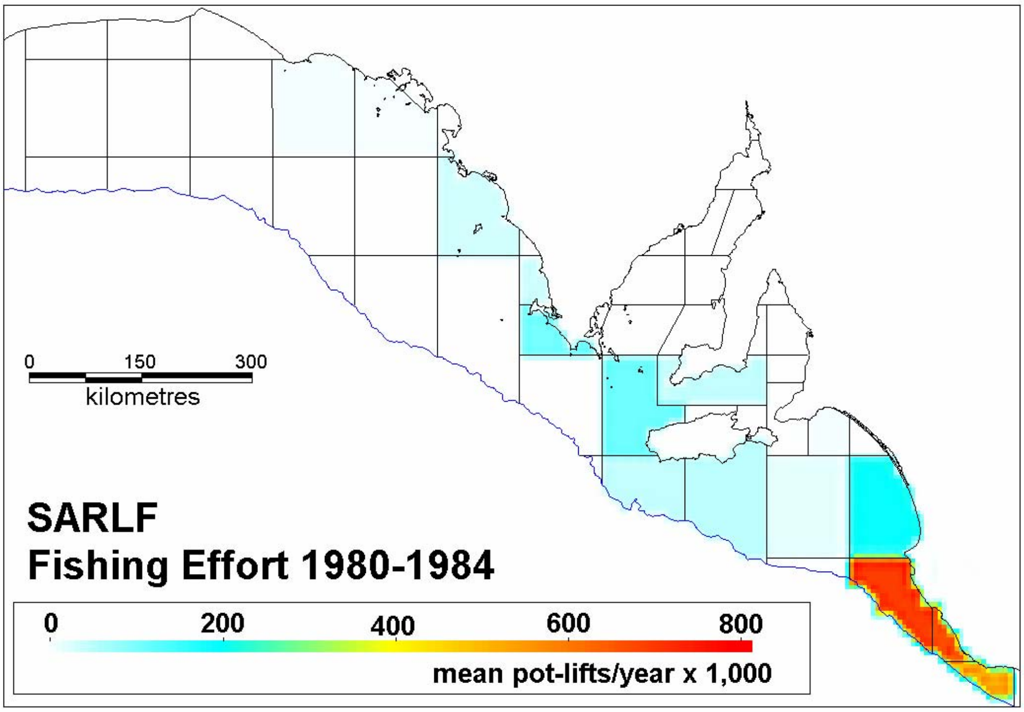


Figure 7.8c. Mean annual distribution of fishing effort in the SARLF, 1980-84.

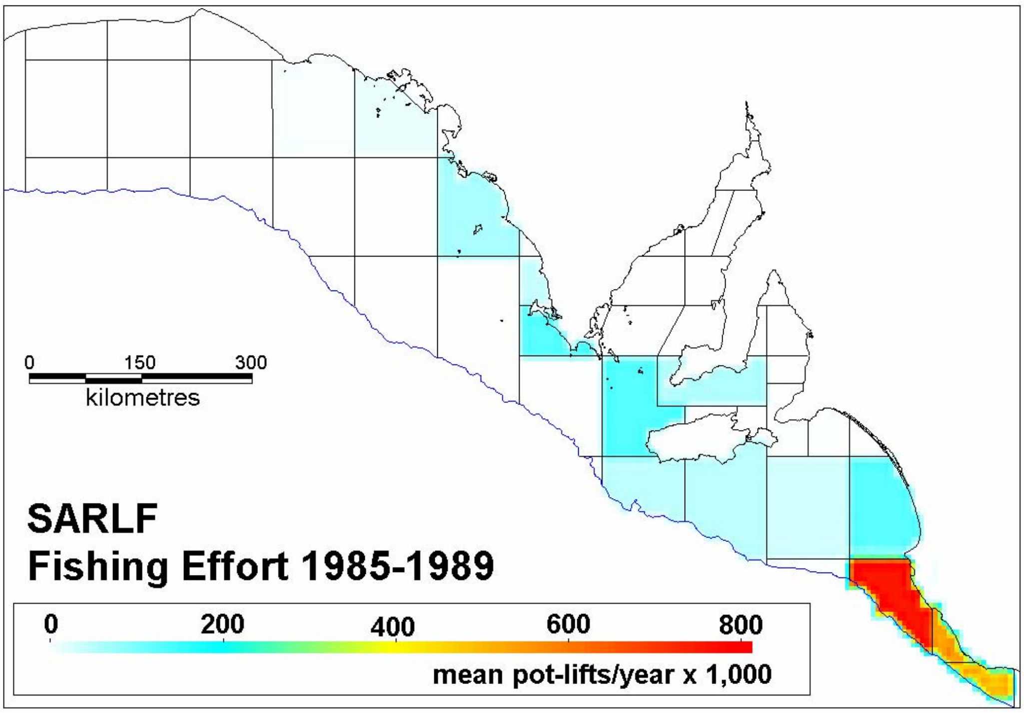


Figure 7.8d. Mean annual distribution of fishing effort in the SARLF, 1985-89.

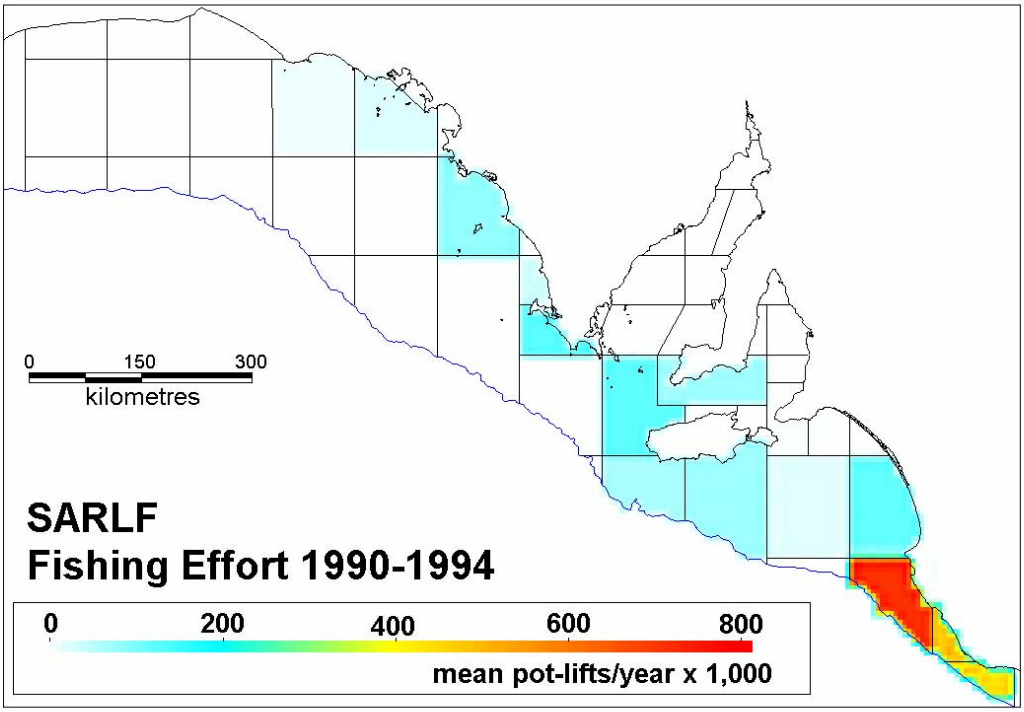


Figure 7.8e. Mean annual distribution of fishing effort in the SARLF, 1990-94.

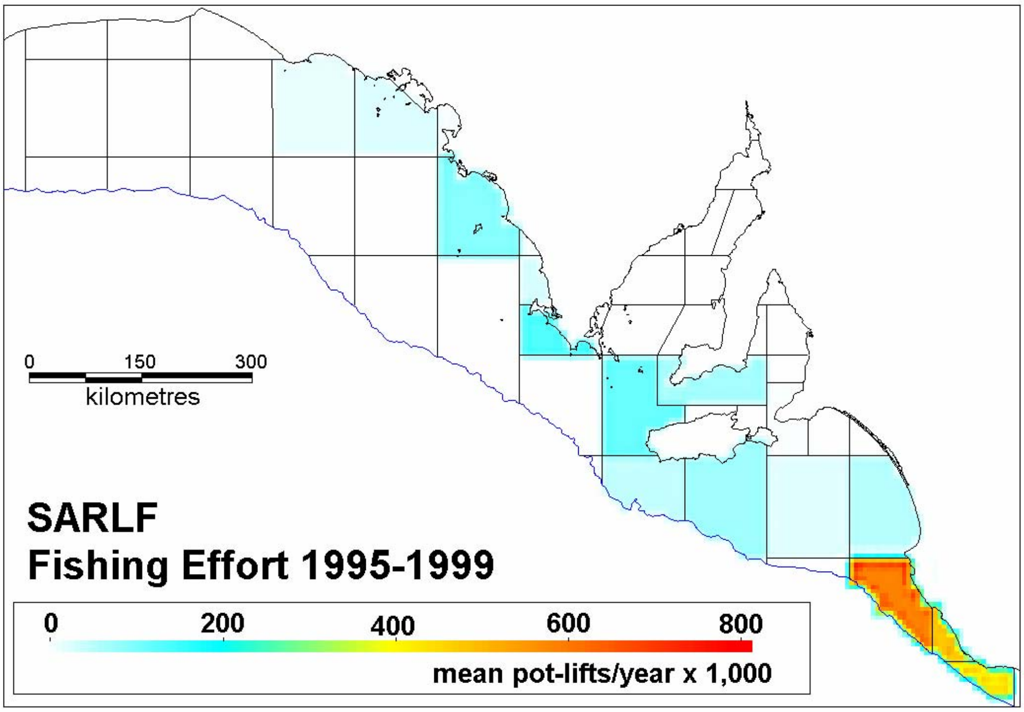


Figure 7.8f. Mean annual distribution of fishing effort in the SARLF, 1995-99.

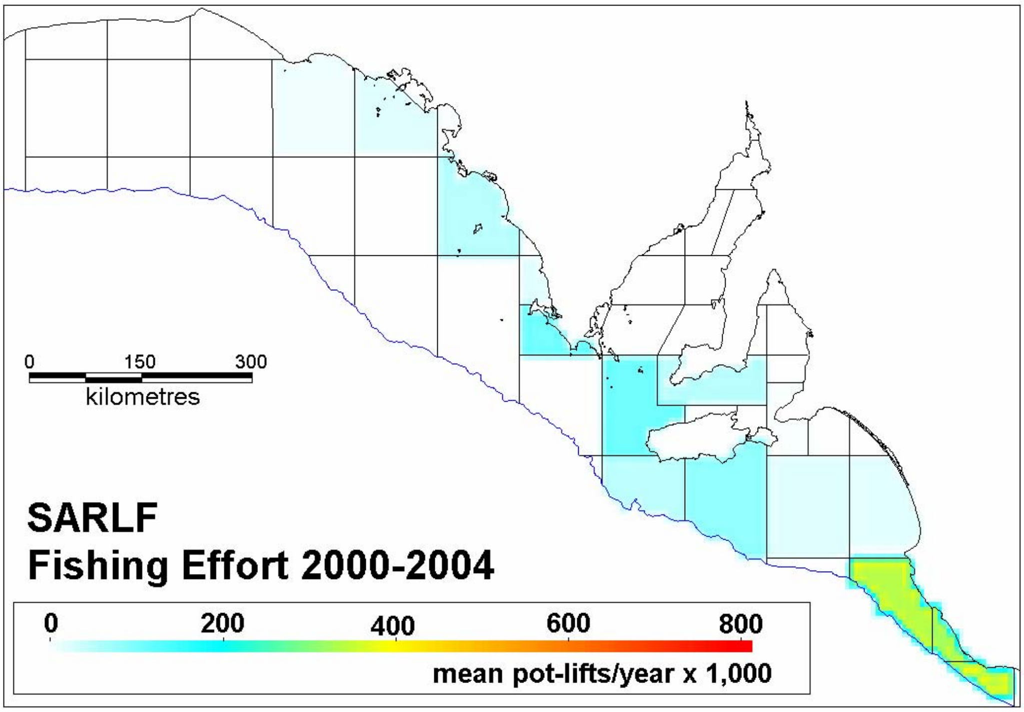


Figure 7.8g. Mean annual distribution of fishing effort in the SARLF, 2000-04.

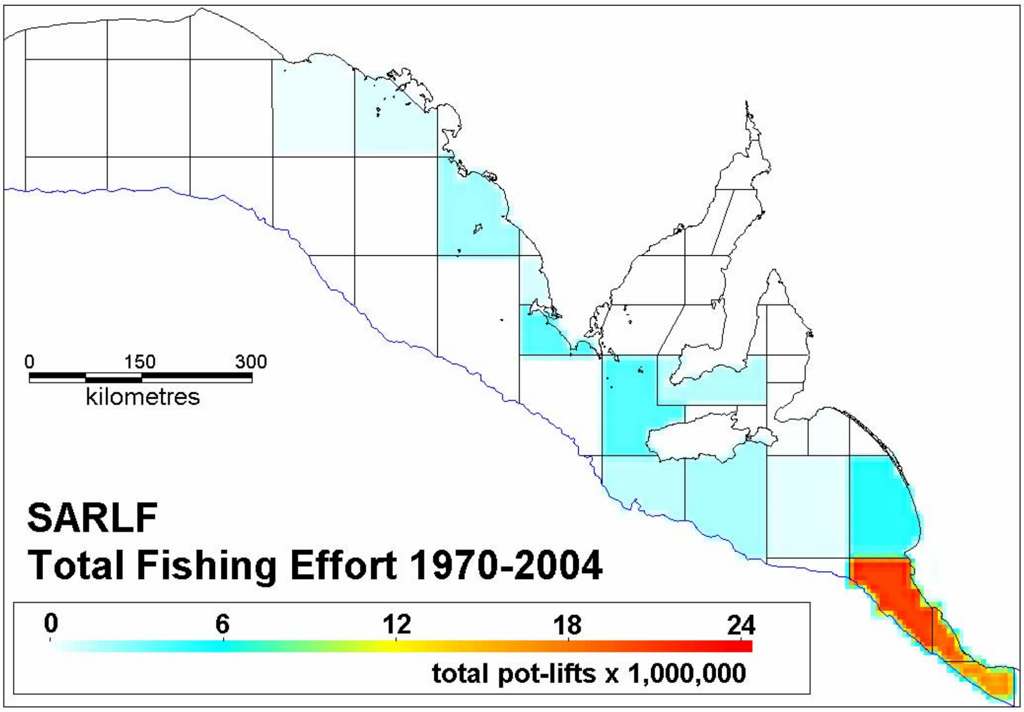


Figure 7.8h. Distribution of total fishing effort in the SARLF, 1970-2004.

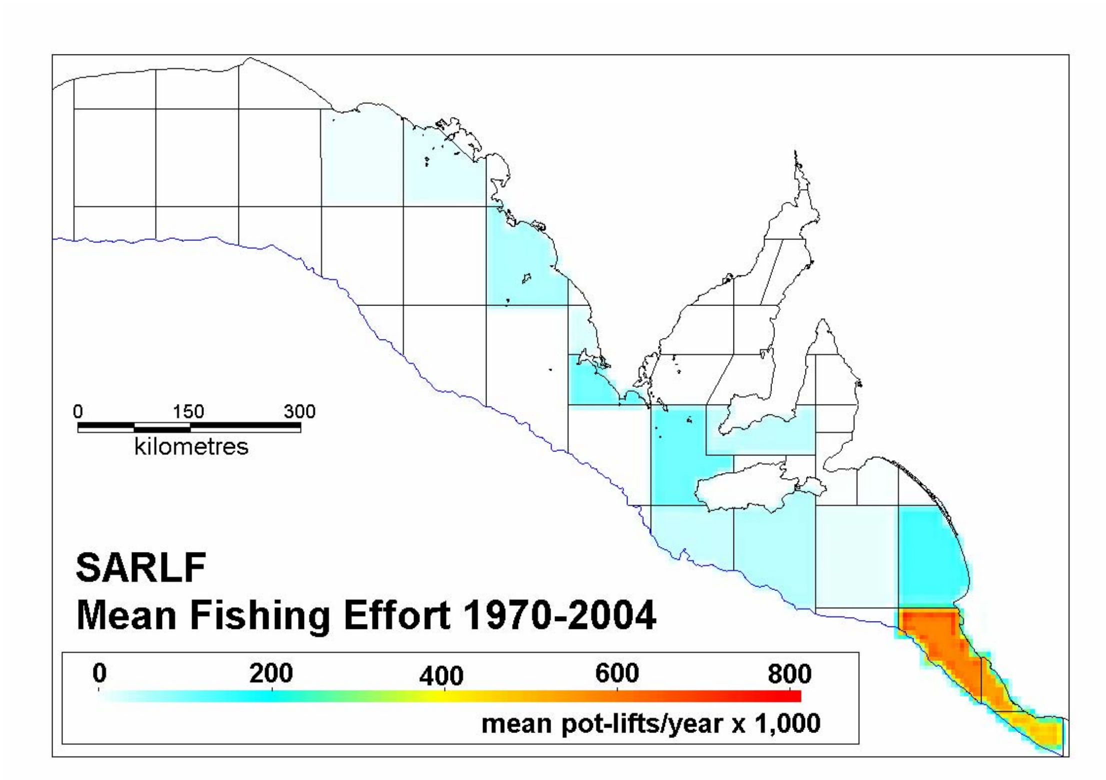


Figure 7.8i. Mean annual distribution of fishing effort in the SARLF, 1970-2004.

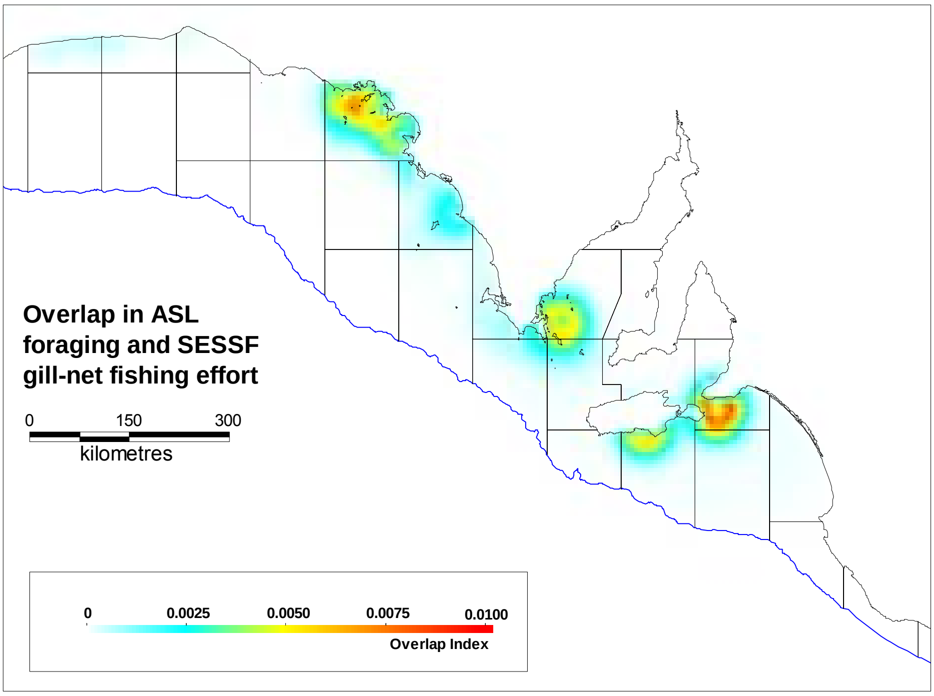


Figure 7.9a. Overlap index in ASL foraging effort and SESSF gill-net fishing effort.

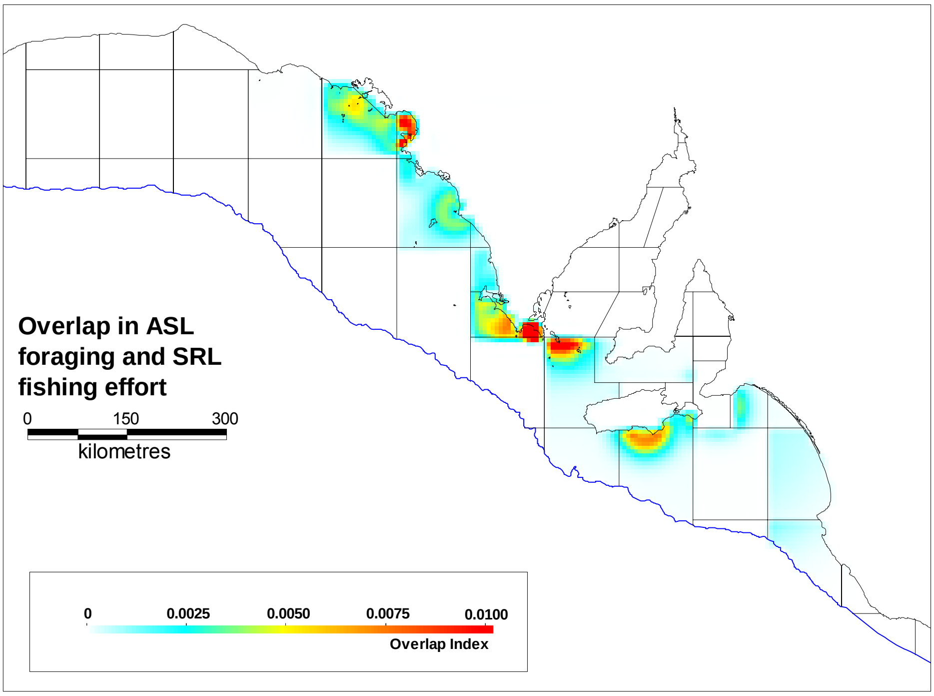


Figure 7.9b. Overlap index in ASL foraging effort and SARLF fishing effort.

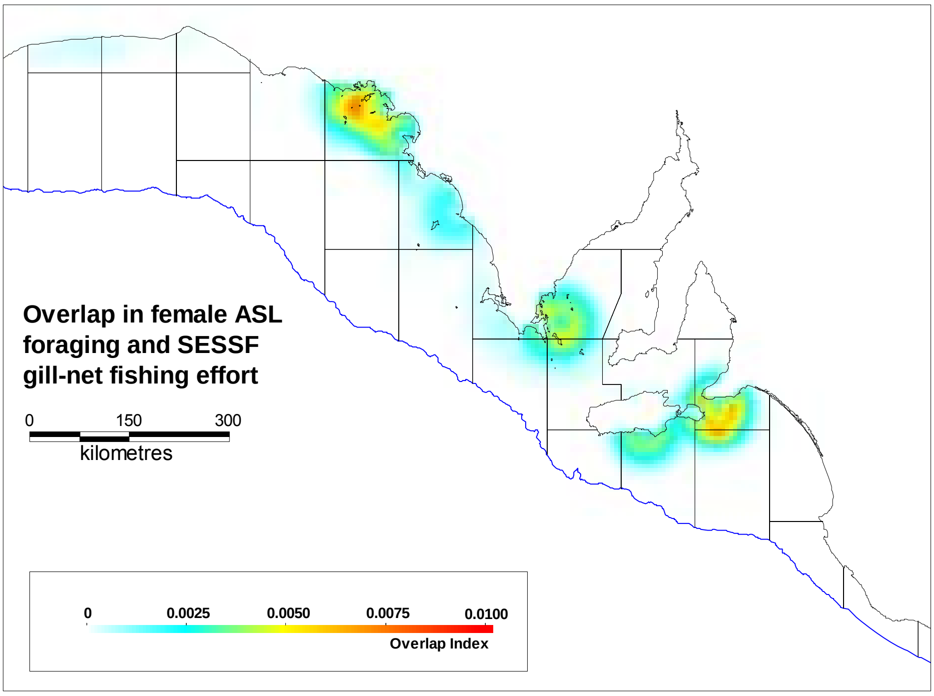


Figure 7.9c. Overlap index between adult female ASL foraging effort and SESSF gill-net fishing effort.

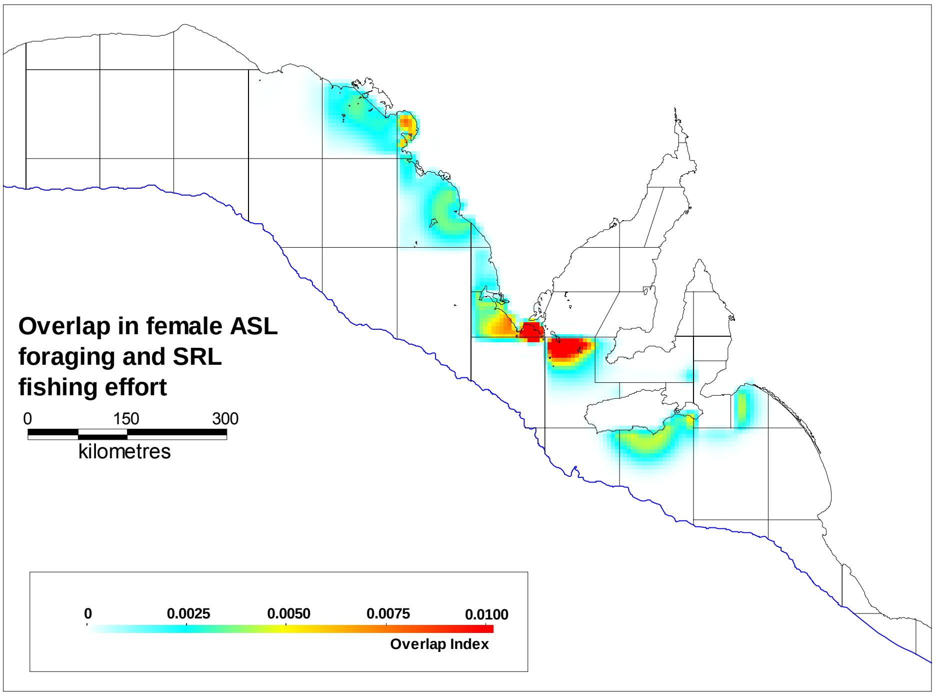


Figure 7.9d. Overlap index between adult female ASL foraging effort and SARLF fishing effort.

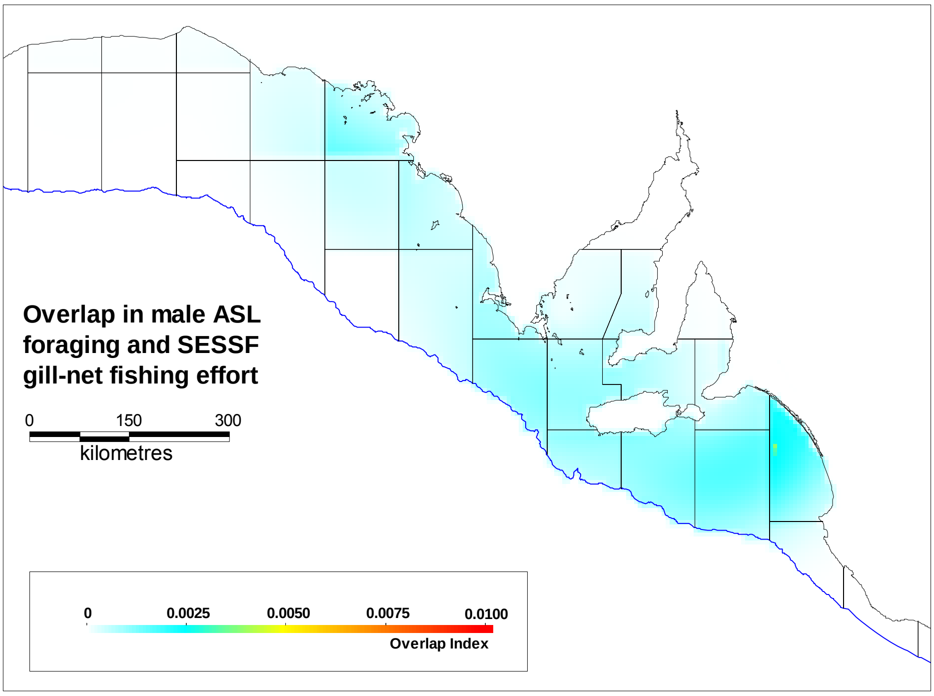


Figure 7.9e. Overlap index between adult male ASL foraging effort and SESSF gill-net fishing effort.

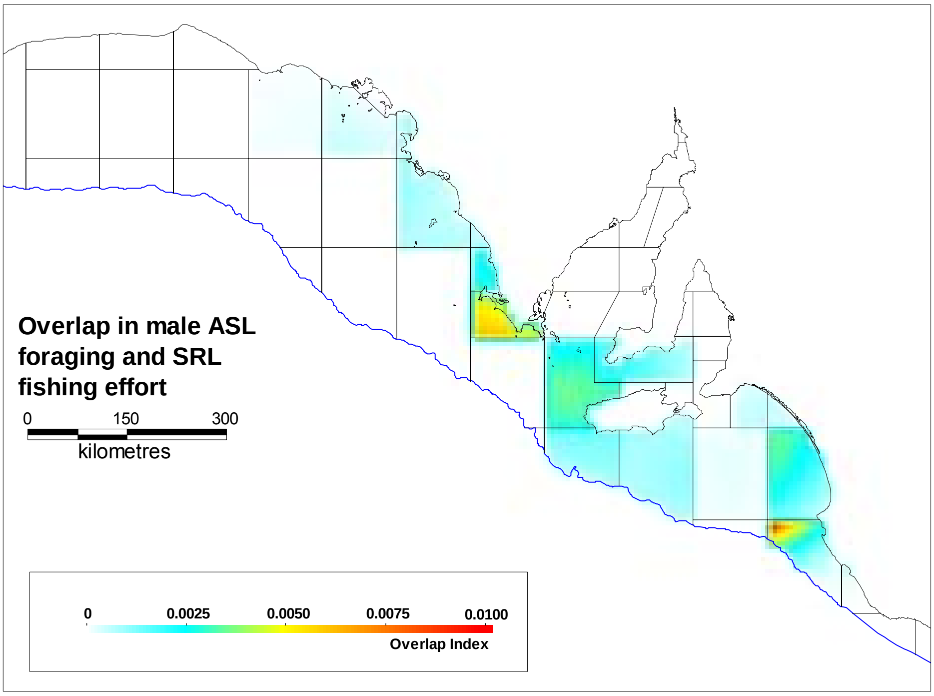


Figure 7.9f. Overlap index between adult male ASL foraging effort and SARLF fishing effort.

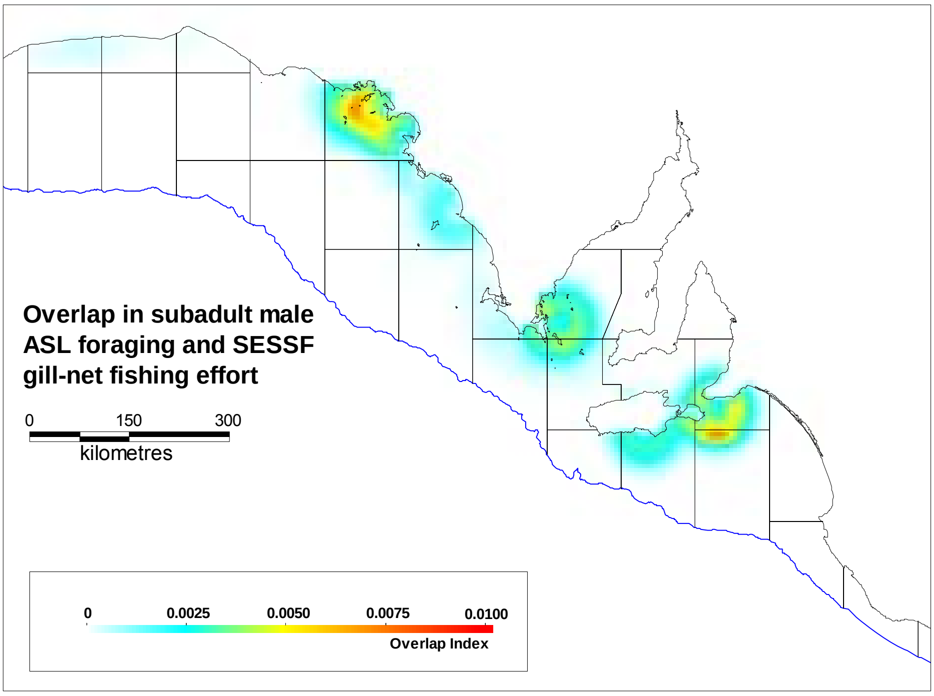


Figure 7.9g. Overlap index between sub-adult male ASL foraging effort and SESSF gill-net fishing effort.

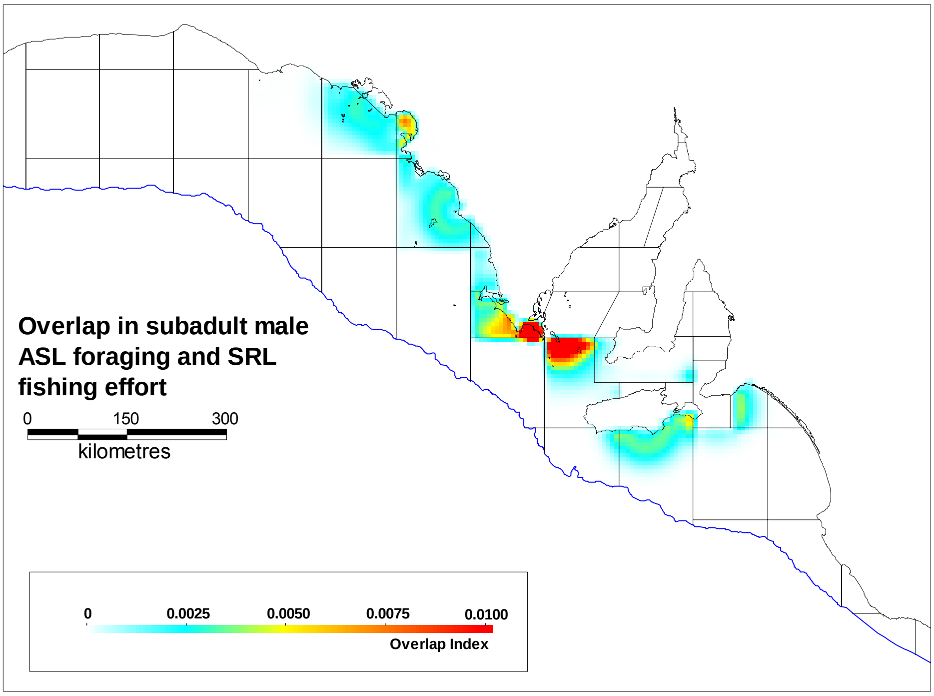


Figure 7.9h. Overlap index between sub-adult male ASL foraging effort and SARLF fishing effort.

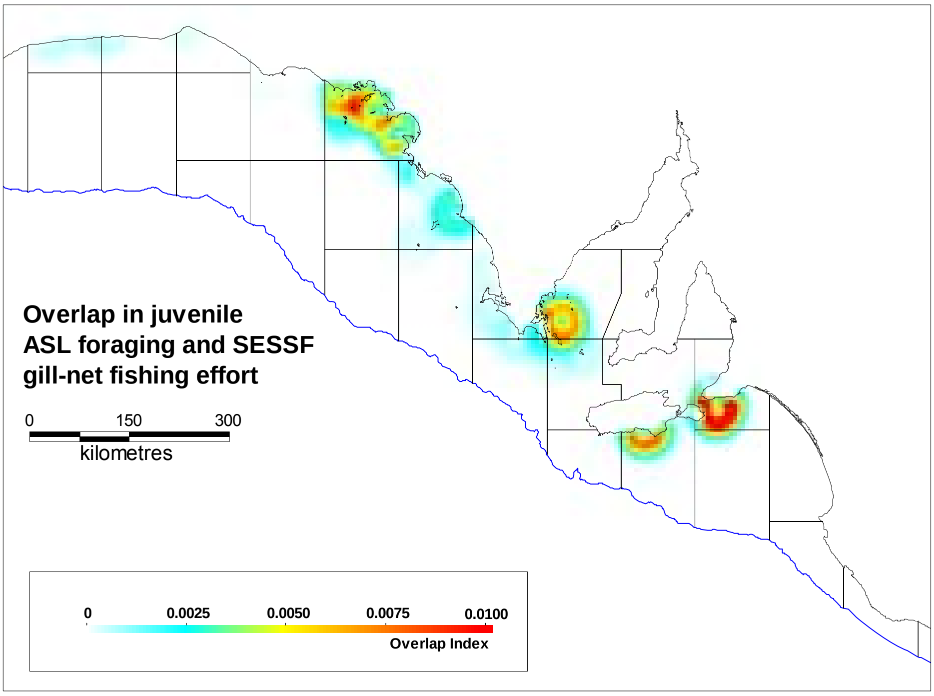


Figure 7.9i. Overlap index between juvenile ASL foraging effort and SESSF gill-net fishing effort.

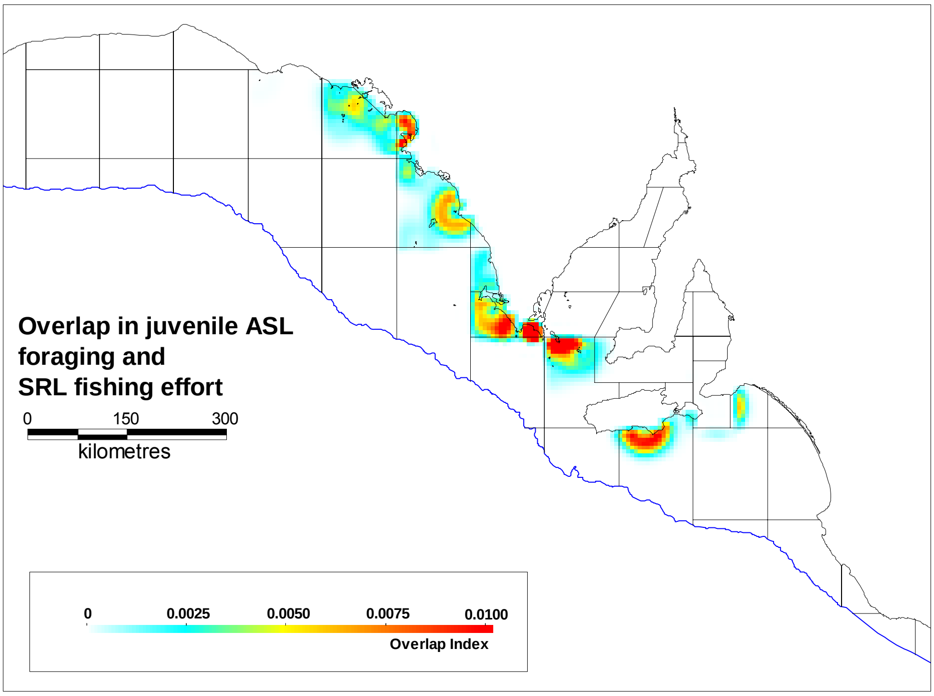


Figure 7.9j. Overlap index between juvenile ASL foraging effort and SARLF fishing effort.

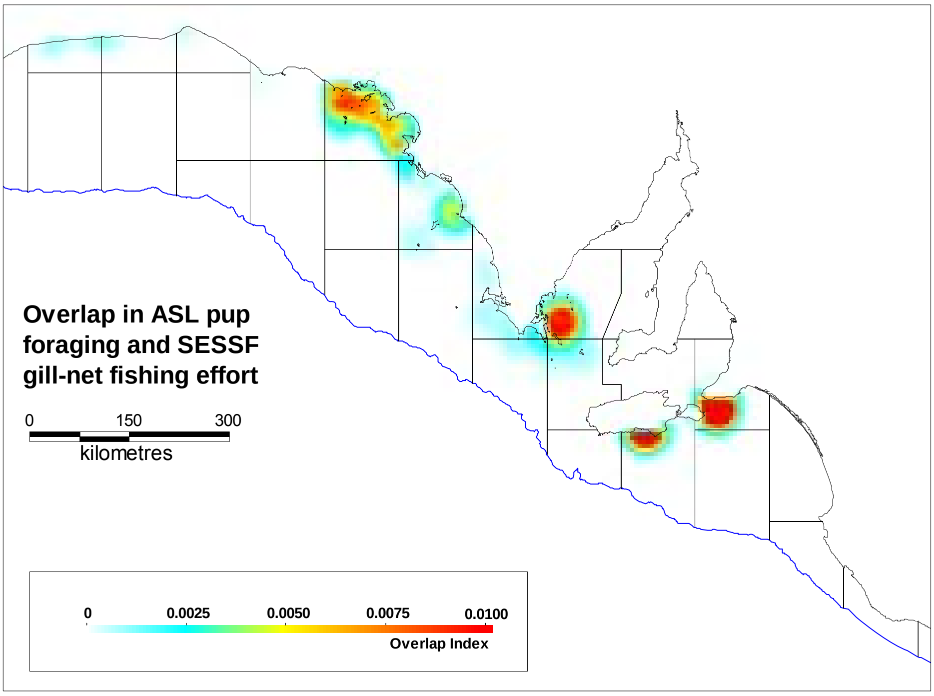


Figure 7.9k. Overlap index between ASL pup foraging effort and SESSF gill-net fishing effort.

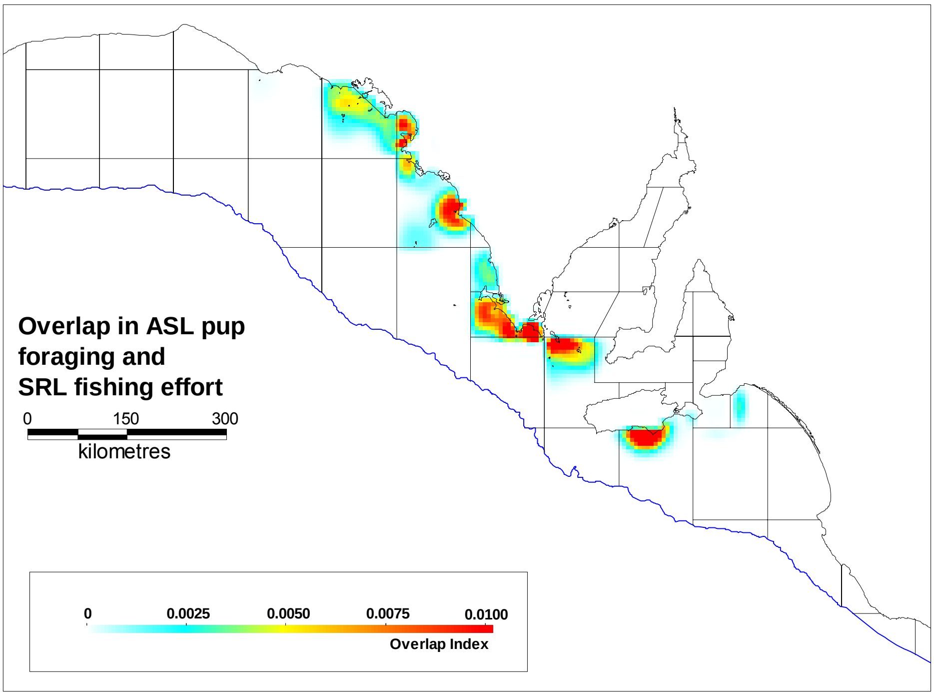


Figure 7.9l. Overlap index between ASL pup foraging effort and SARLF fishing effort.

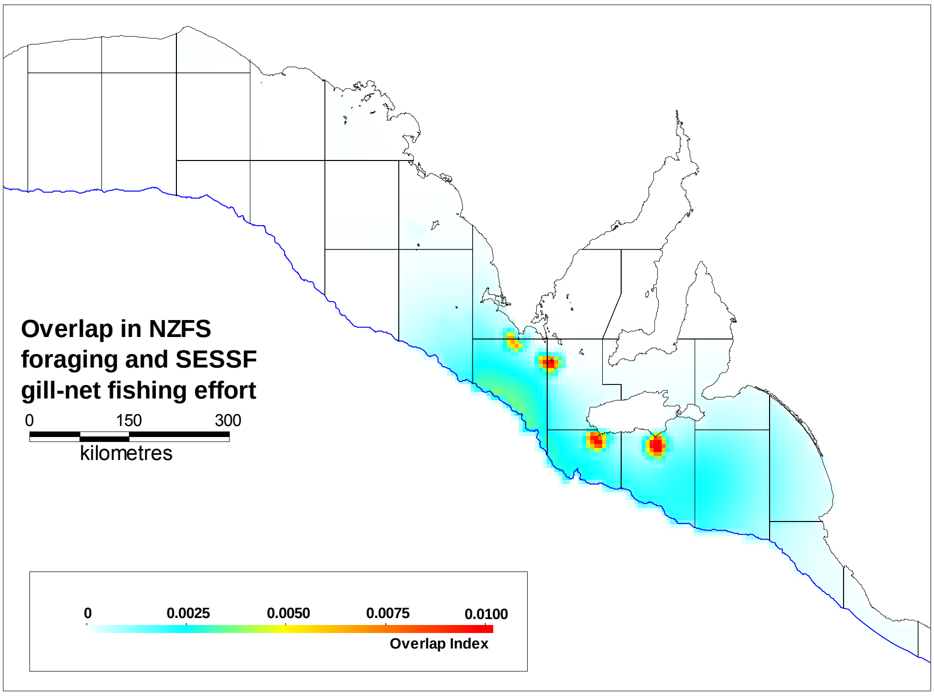


Figure 7.10a. Overlap index between NZFS foraging effort and SESSF gill-net fishing effort.

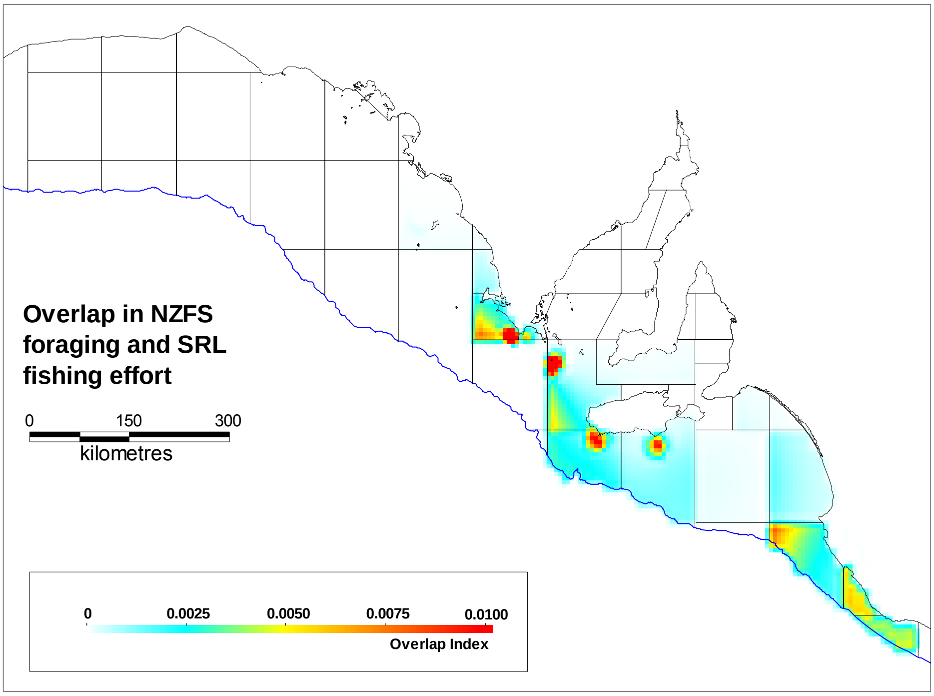


Figure 7.10b. Overlap index between NZFS foraging effort and SARLF fishing effort.

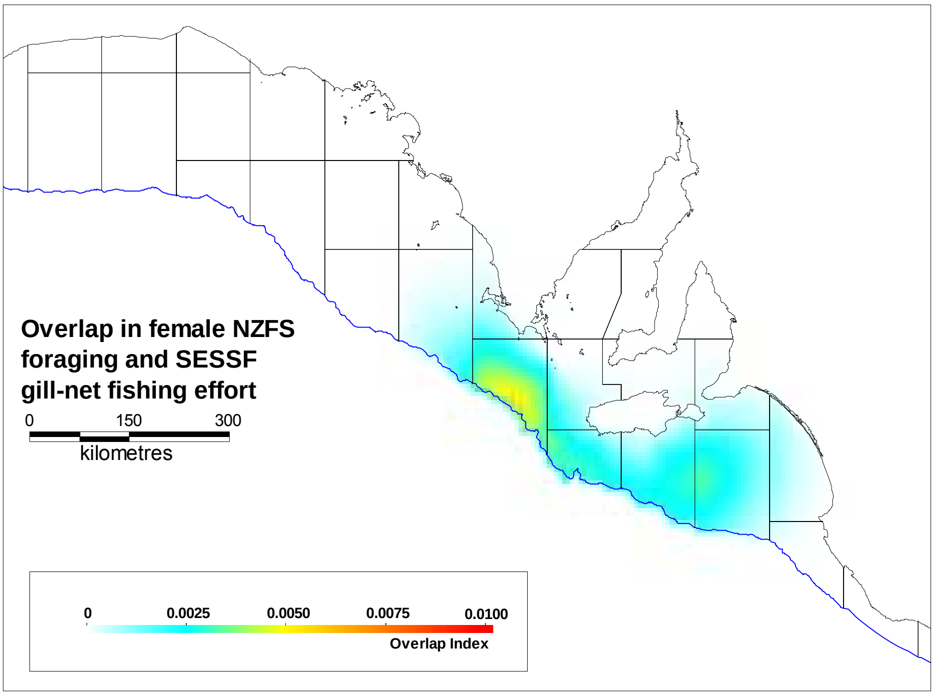


Figure 7.10c. Overlap index between adult female NZFS foraging effort and SESSF gill-net fishing effort.

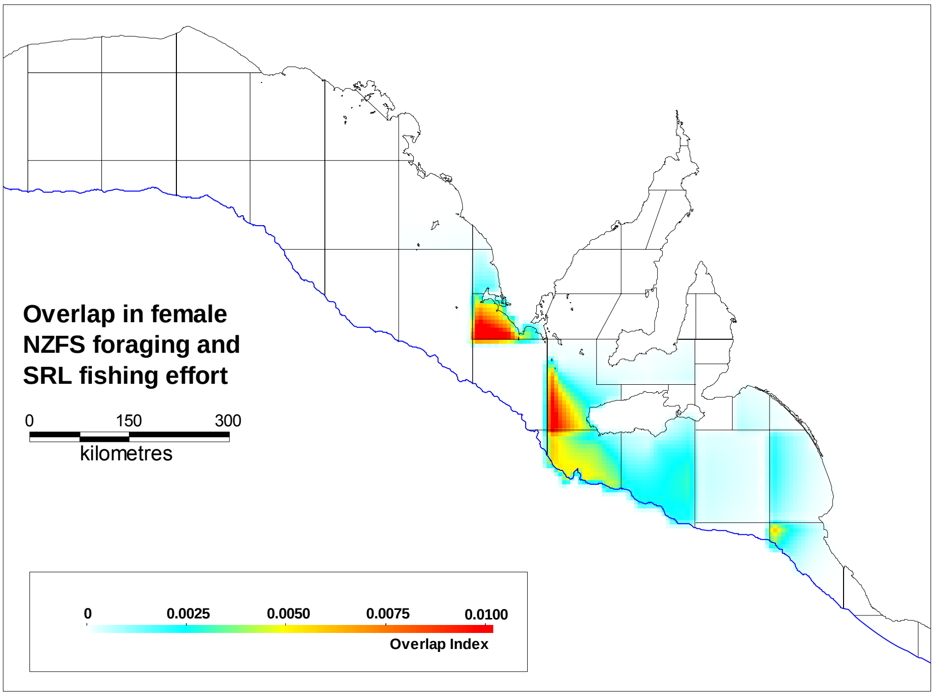


Figure 7.10d. Overlap index between adult female NZFS foraging effort and SESSF gill-net fishing effort.

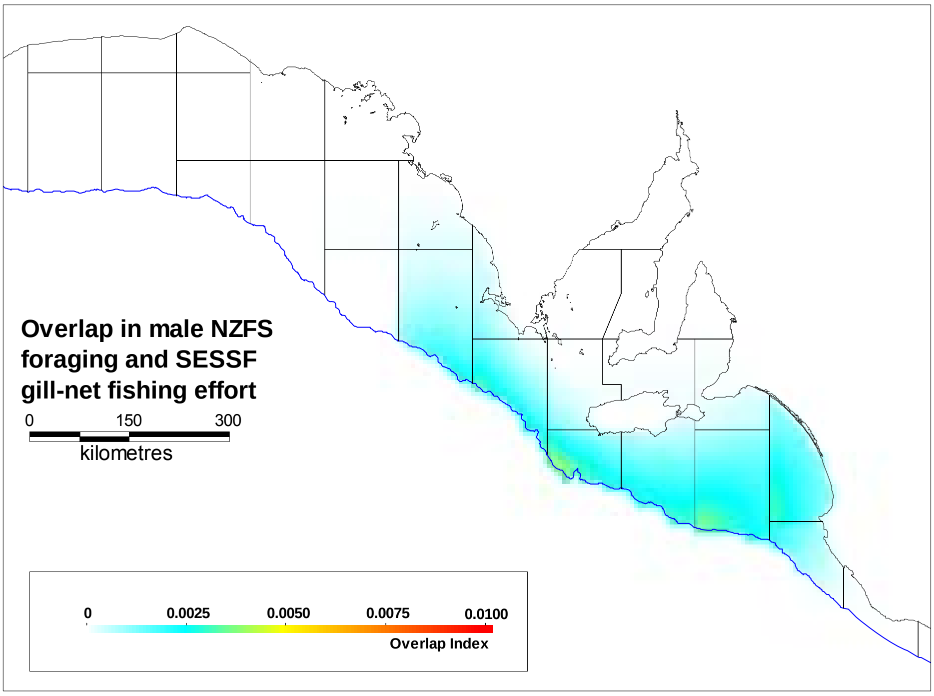


Figure 7.10e. Overlap index between adult male NZFS foraging effort and SESSF gill-net fishing effort.

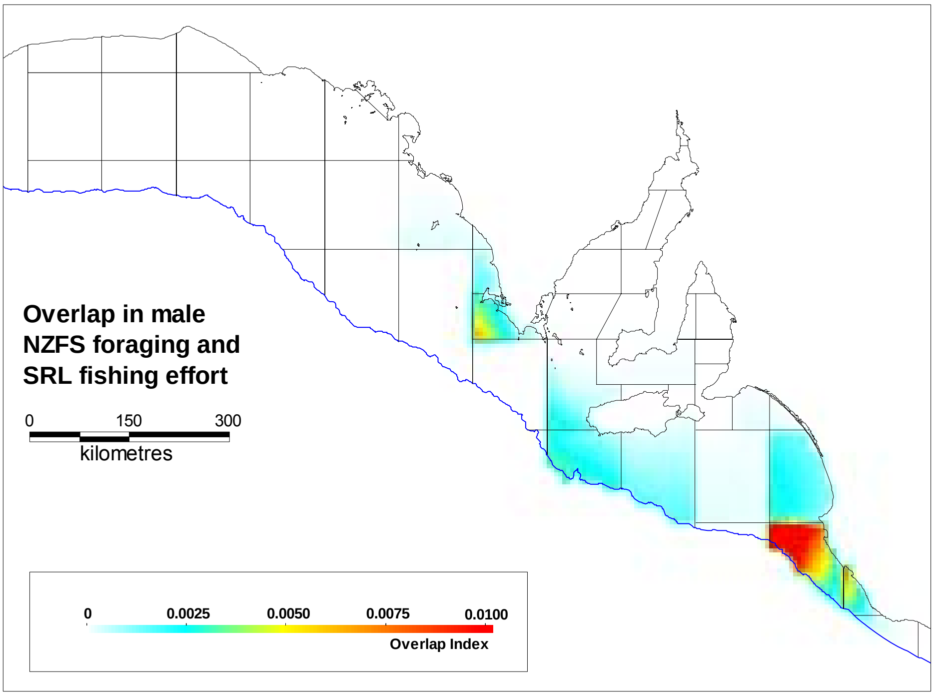


Figure 7.10f. Overlap index between adult male NZFS foraging effort and SESSF gill-net fishing effort.

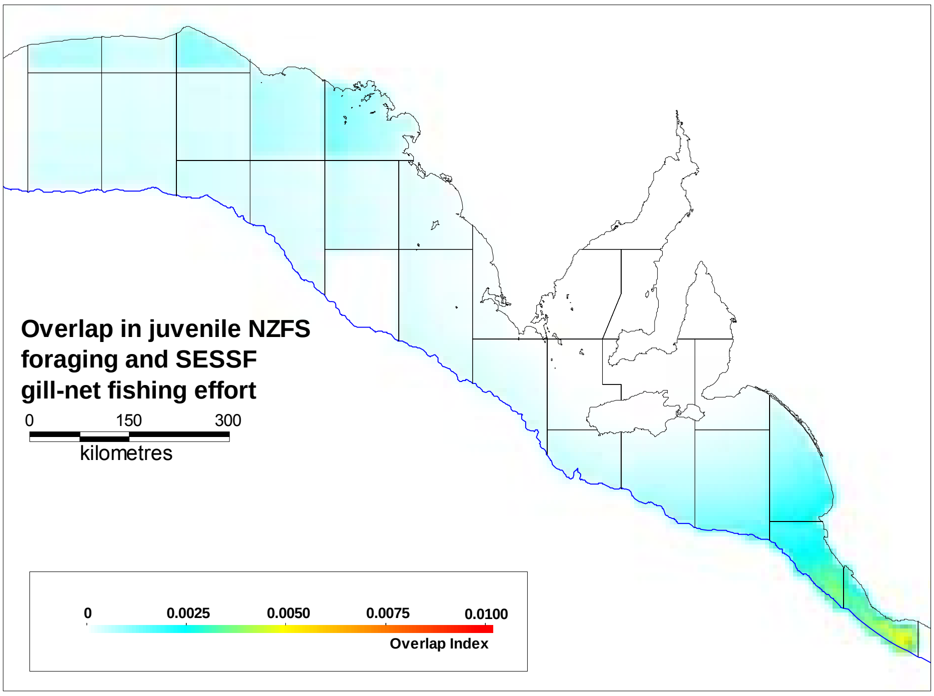


Figure 7.10g. Overlap index between juvenile NZFS foraging effort and SESSF gill-net fishing effort.

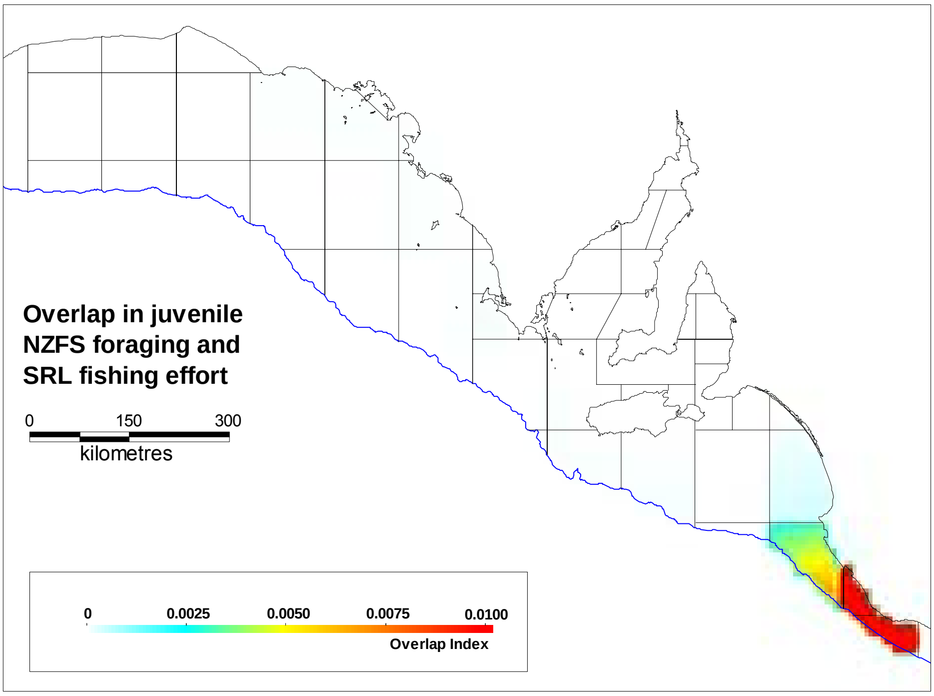


Figure 7.10h. Overlap index between juvenile NZFS foraging effort and SARLF fishing effort.

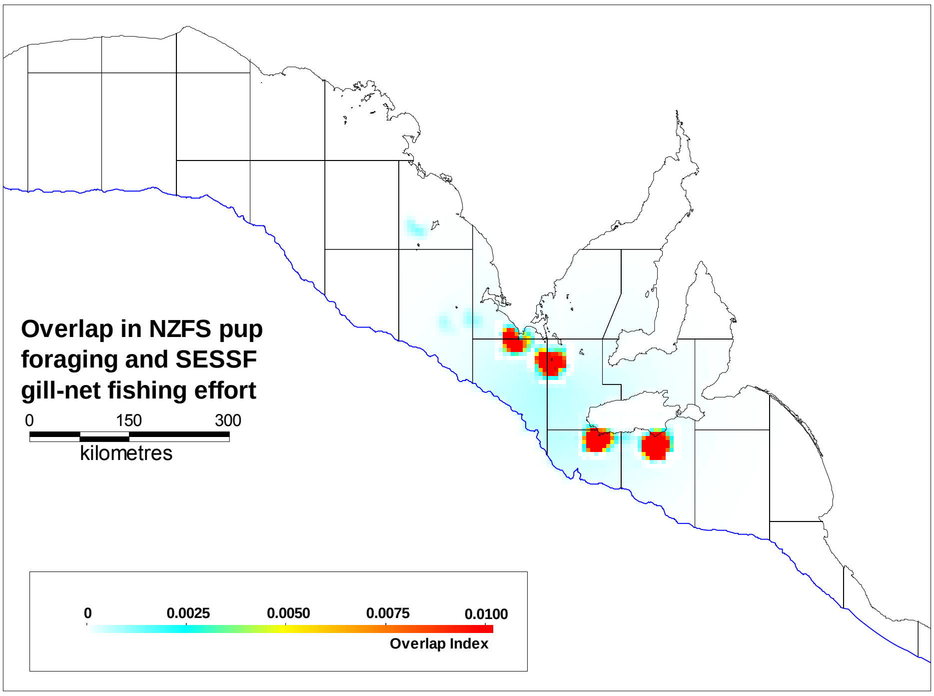


Figure 7.10i. Overlap index between NZFS pup foraging effort and SESSF gill-net fishing effort.

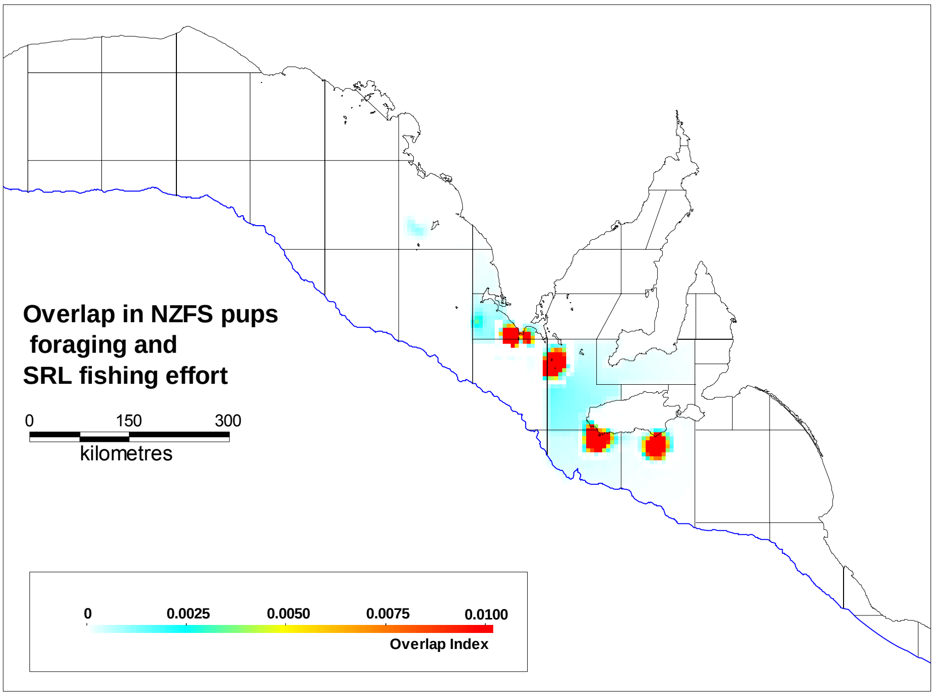


Figure 7.10j. Overlap index between NZFS pup foraging effort and SARLF fishing effort.

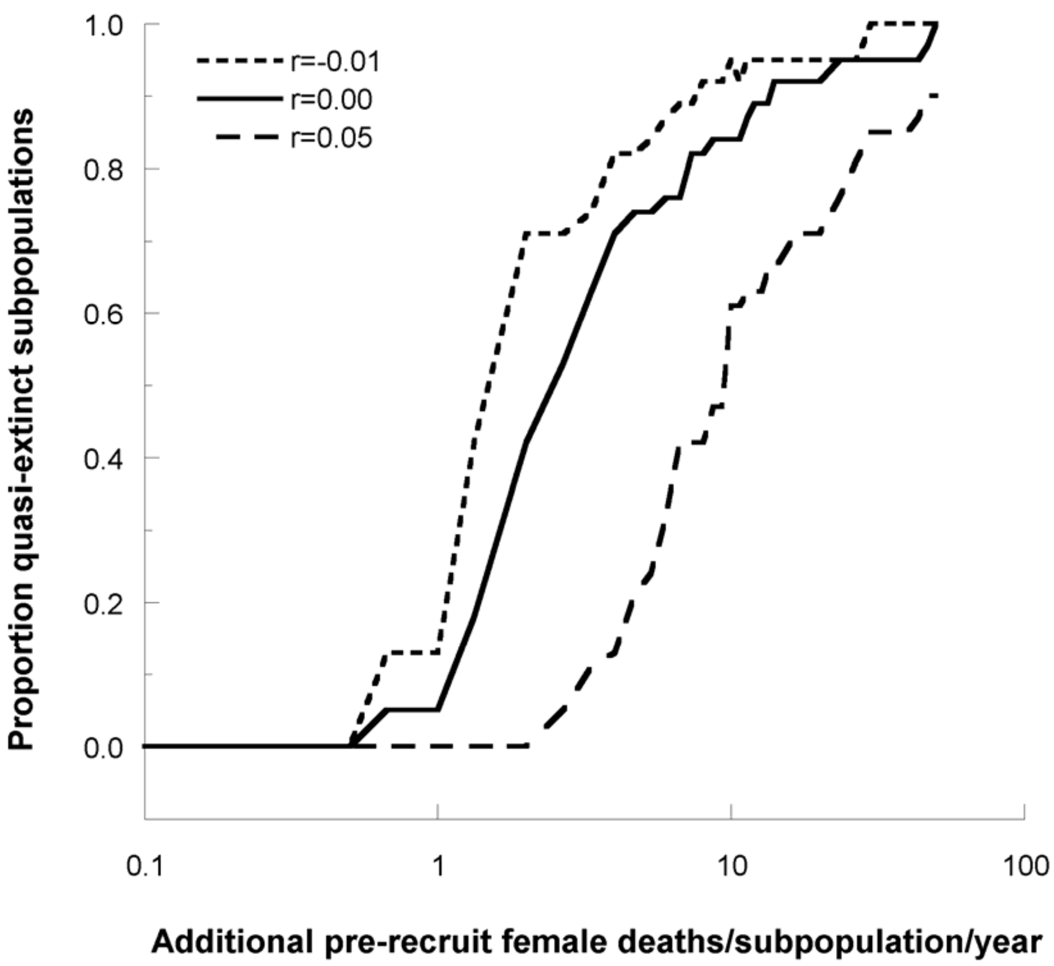


Figure 7.11. Estimated proportion of ASL subpopulations that achieve quasi-extinction as a function of the number of additional pre-recruit female mortalities/subpopulation/year. Three scenarios are given, based on the increasing (r=0.05), stable (r=0.00) and declining (r=-0.01) population models.

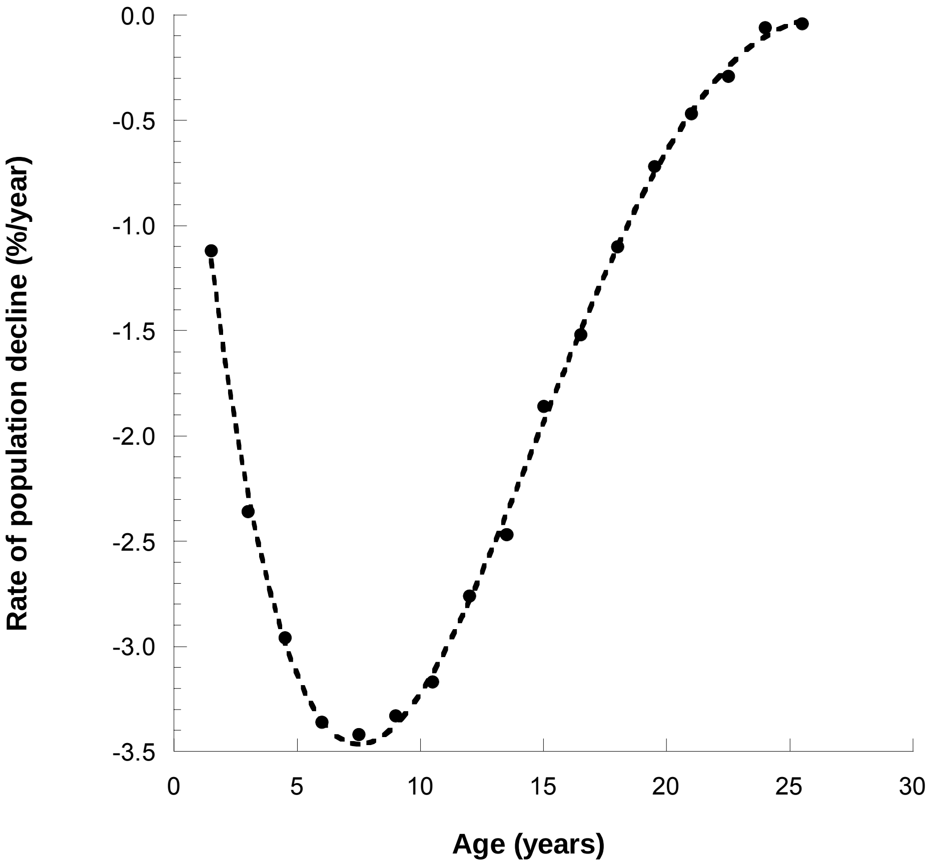


Figure 7.12. Simulated exampled of how the stage (age) at which mortalities are taken affects the rate of population change. In this example a subpopulation of 1,000 female ASL has 20 females removed from a particular age-group each year for 50 reproductive cycles (75 years), using the stable population model (r=0). The rate of population decline resulting from each scenario is presented, fitted with a 4th order polynomial curve. The example demonstrates how the rate of decline is affected by the age-group of females removed from the population. The greatest rates of decline are achieved when 4.5-6, 6-7.5 and 7.5-9 age-group females are removed.

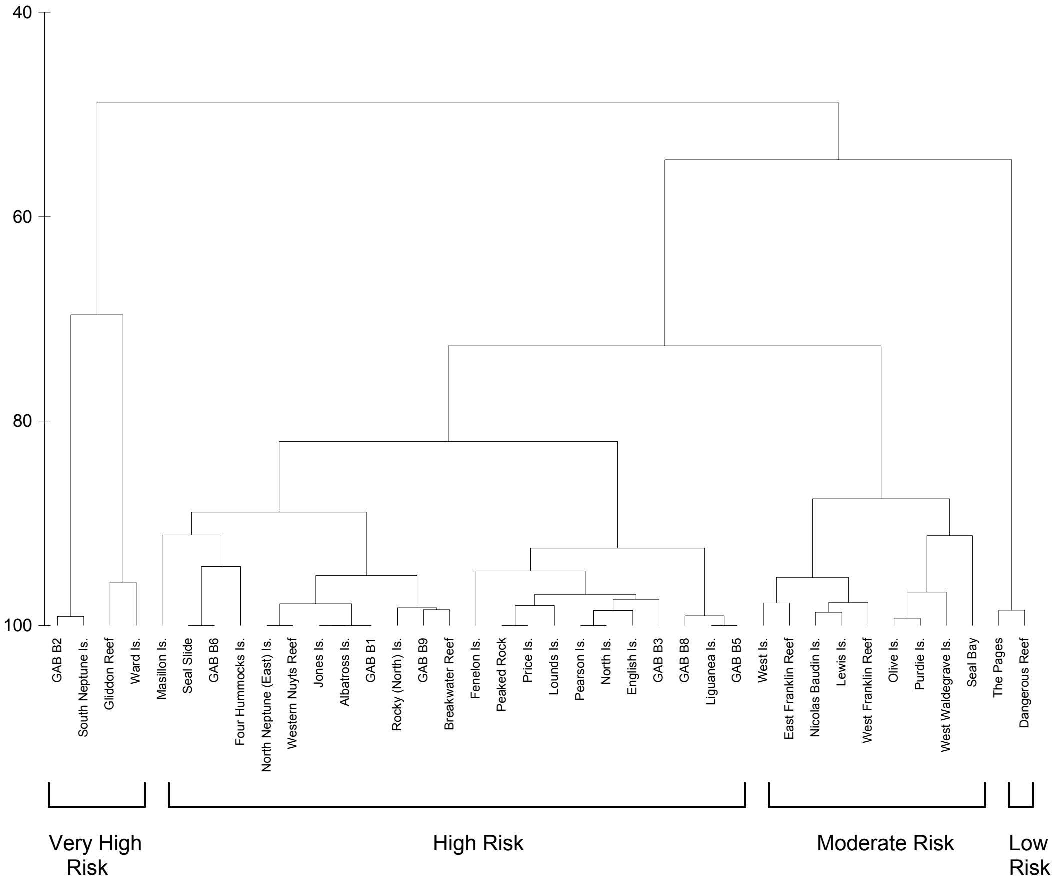


Figure 7.13. Bray-Curtis similarity matrix dendrogram of SA ASL subpopulations, which are clustered according to percentage similarity of quasi-extinction risk (from PVA outputs). Four main groups are identified as the different Risk Categories (dendrogram produced using Primer V5.2.2).

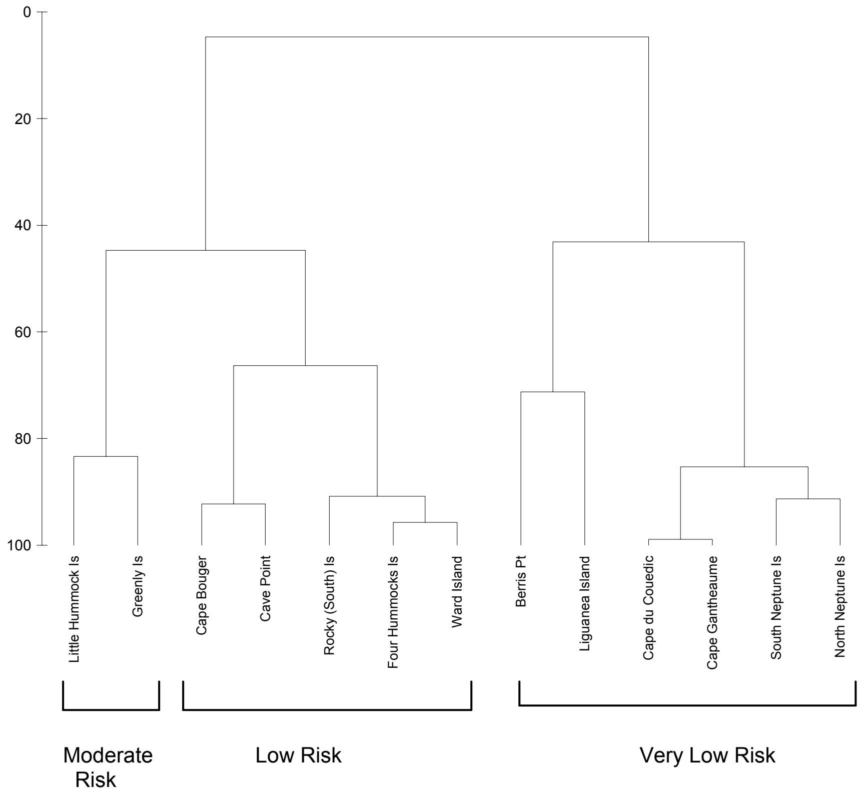
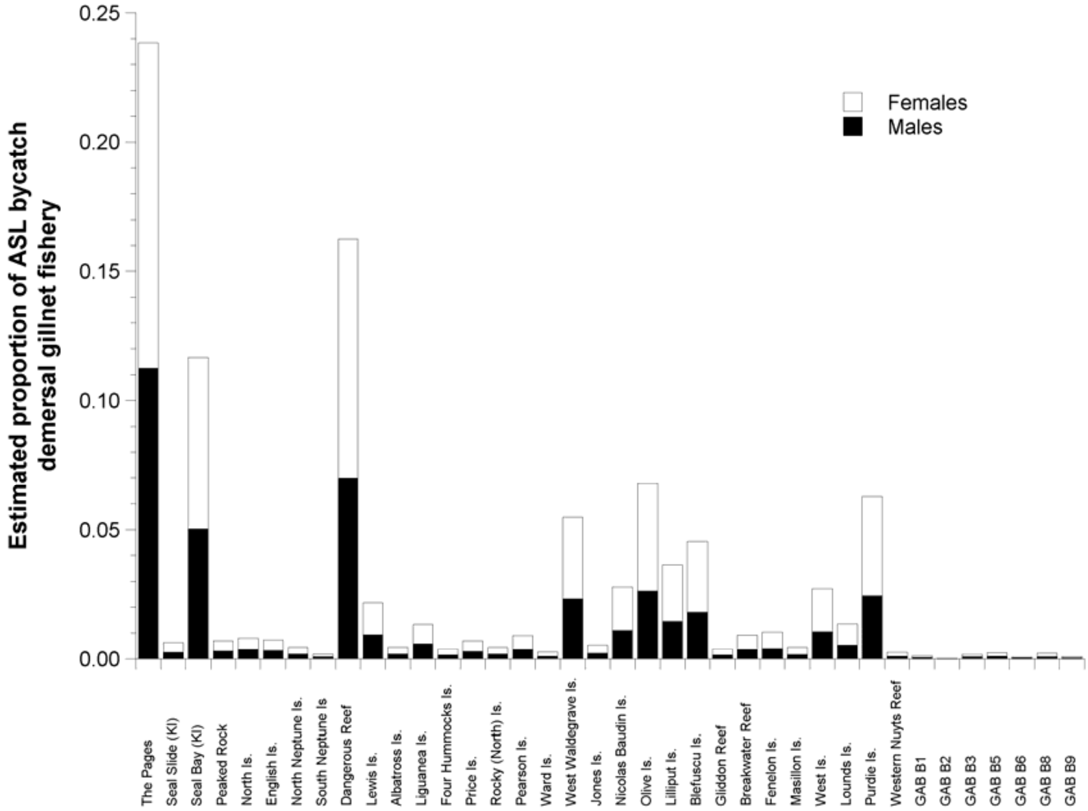


Figure 7.14. Bray-Curtis similarity matrix dendrogram of SA NZFS subpopulations, which are clustered according to percentage similarity of quasi-extinction risk (from PVA outputs). Two main groups are identified (dendrogram produced using Primer V5.2.2).

A.



B.

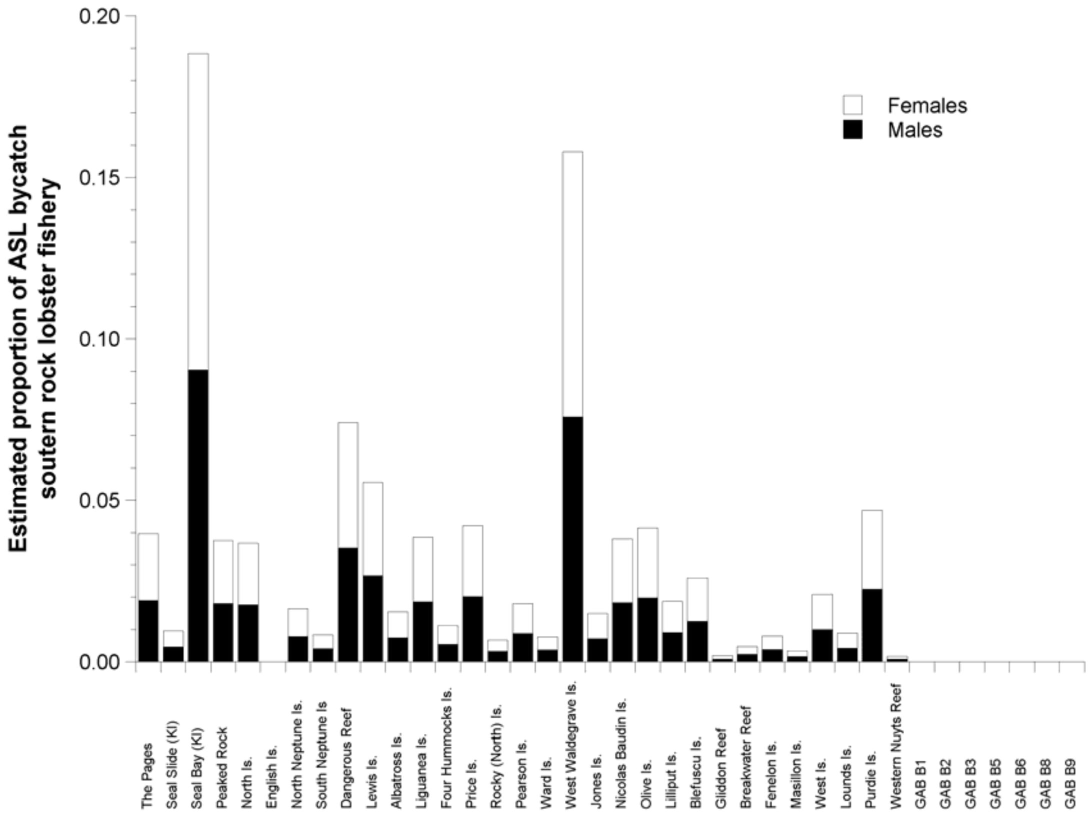


Figure 7.15. Estimated proportion of historic bycatch (broken down by seal sex) accounted for by each SA ASL subpopulation in the SESSF gillnet sector (A) and the SASRLF (B).

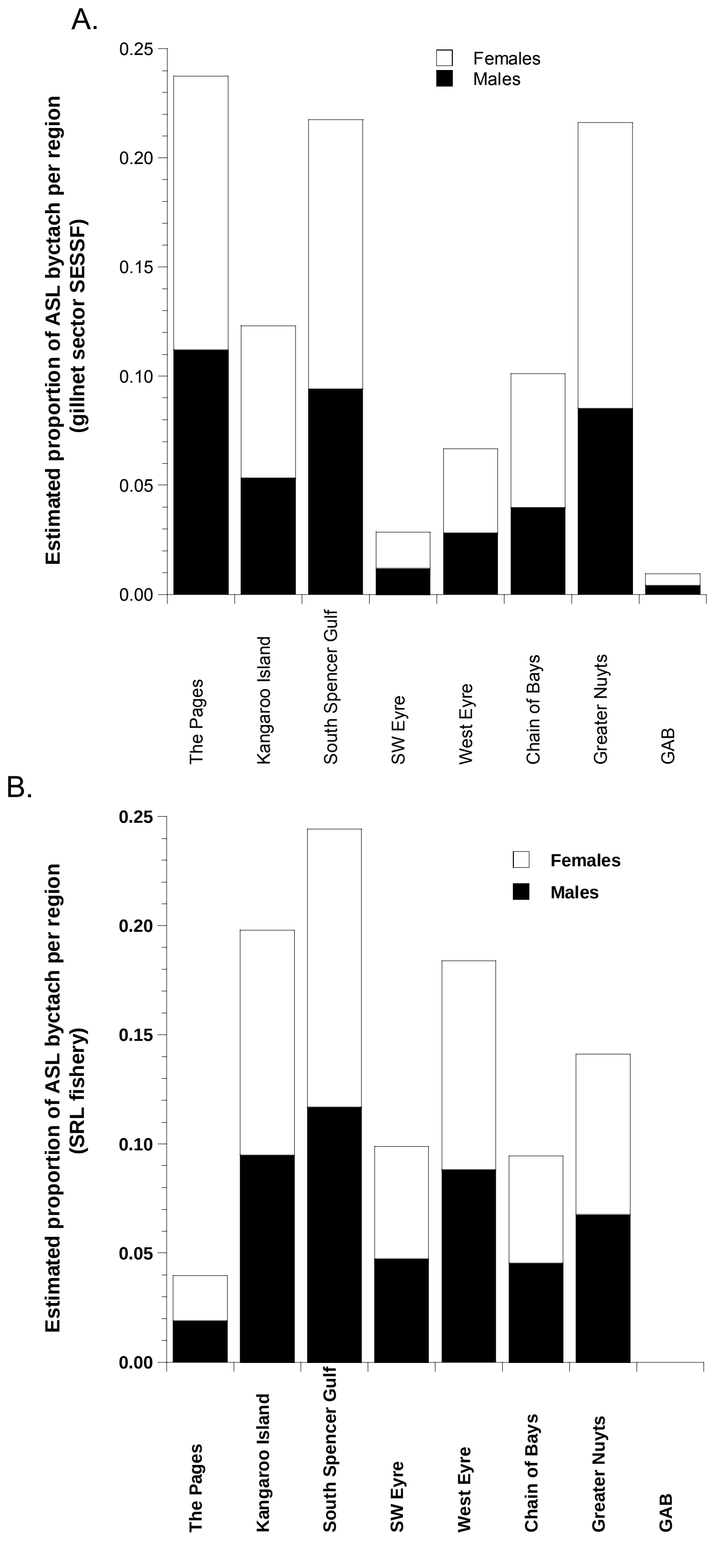
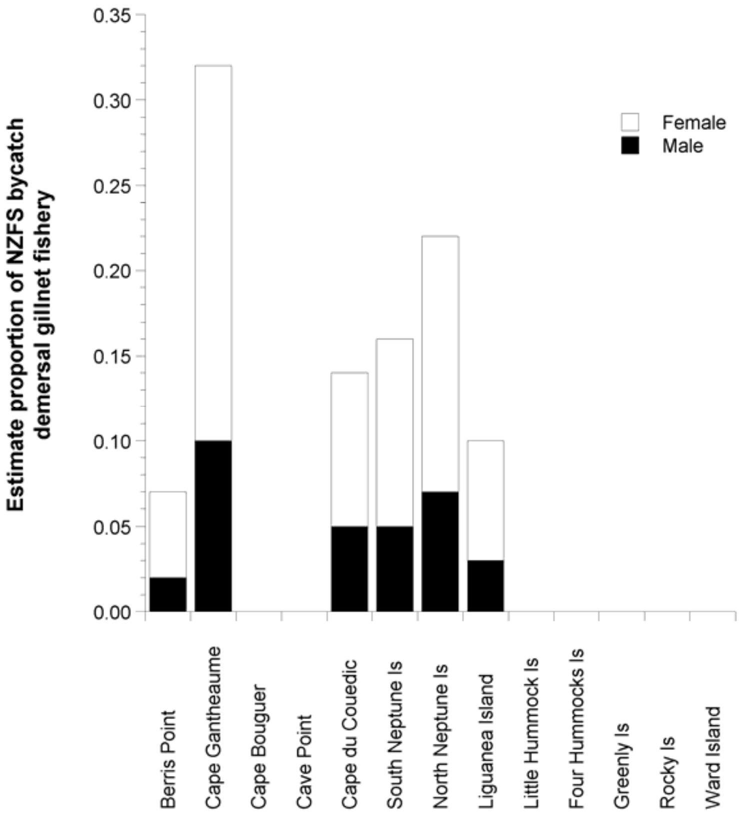


Figure 7.16. Estimated proportion of historic bycatch (broken down by seal sex) accounted for by regional groupings of SA ASL subpopulations in the SESSF gillnet sector (A) and the SARLF (B).

A.



B.

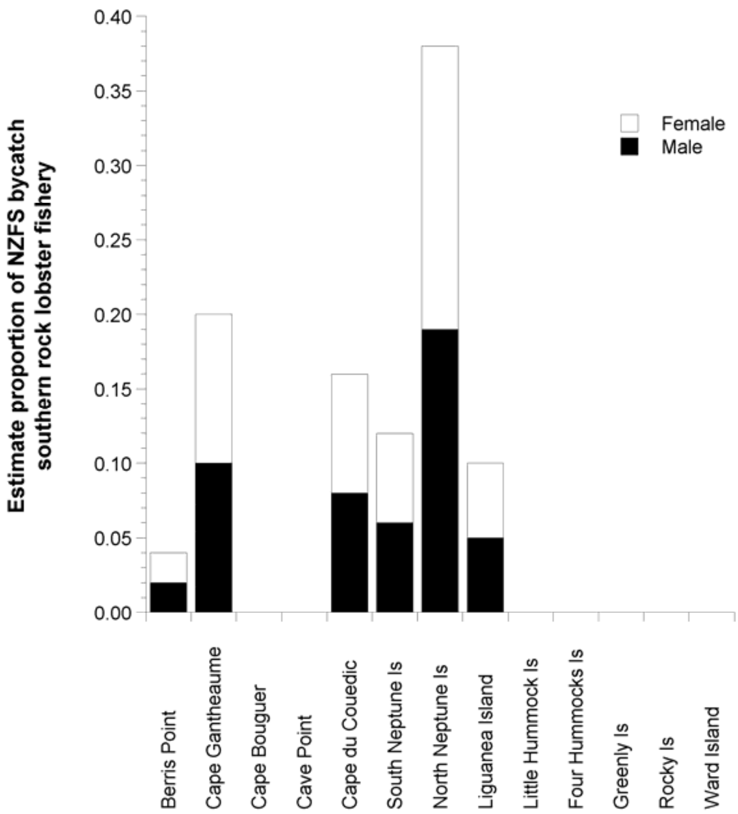


Figure 7.17. Estimated proportion of historic bycatch (broken down by seal sex) accounted for by each SA NZFS subpopulation in the SESSF gillnet sector (A) and the SARLF (B).

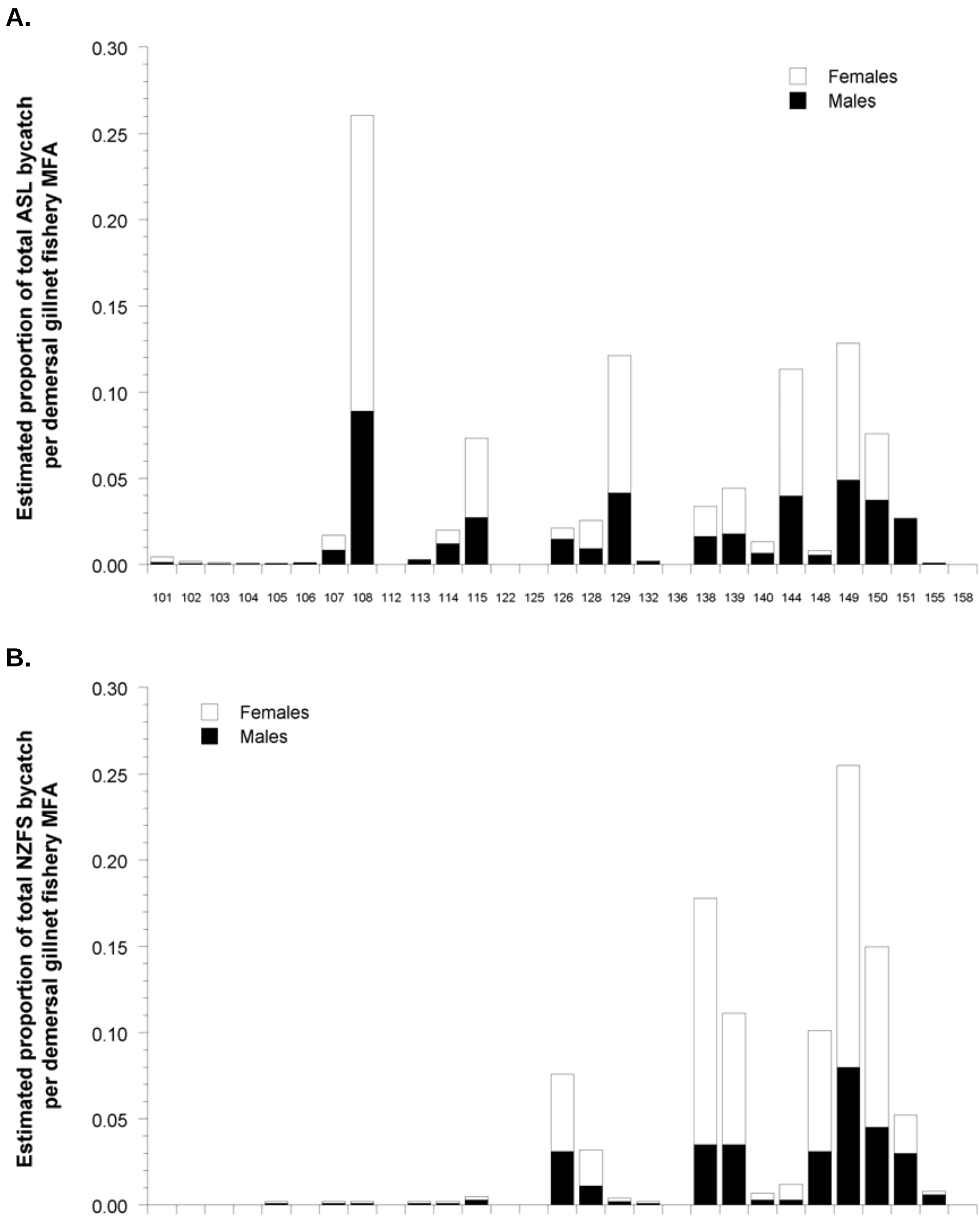
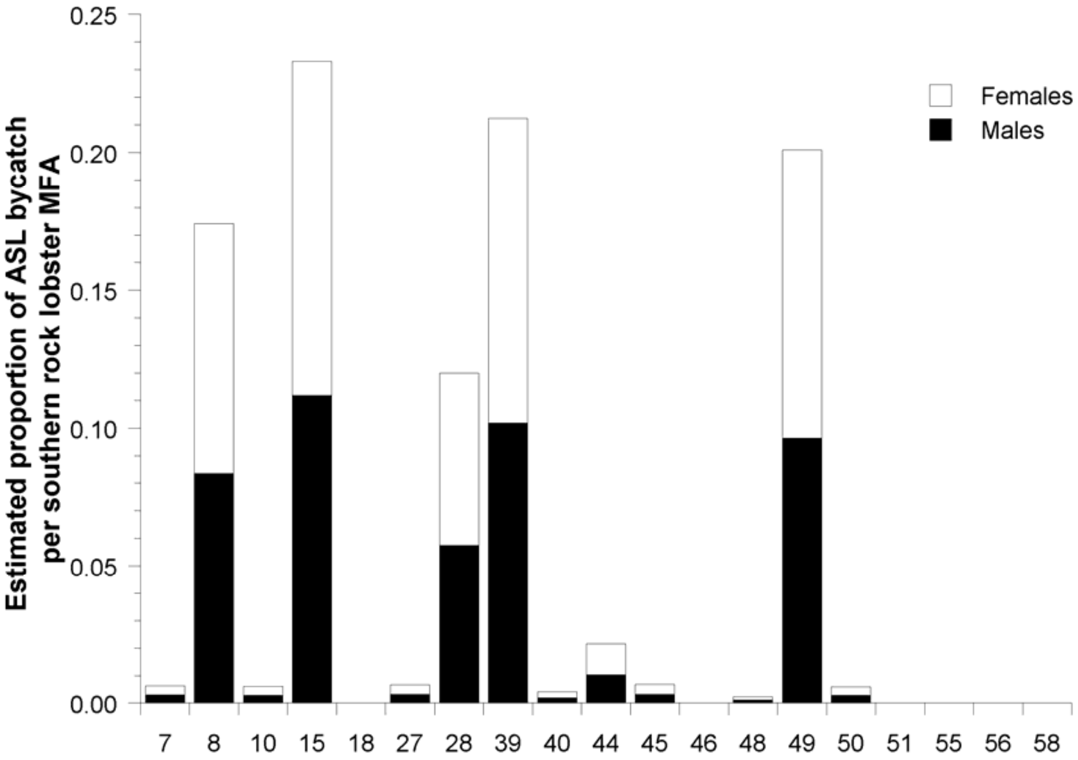


Figure 7.18 Estimated proportion of historic bycatch (broken down by seal sex) (1973-2004) in SA for (A) ASL and (B) NZFS accounted for by each SESSF gillnet sector MFA.

A.



B.

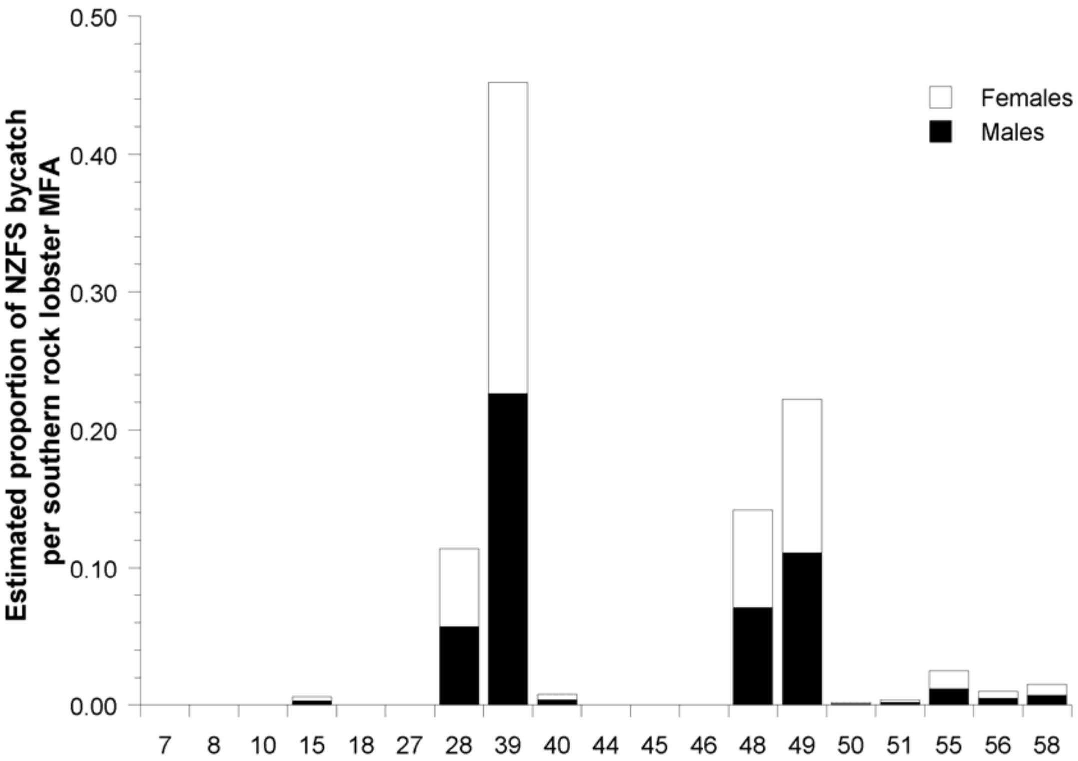
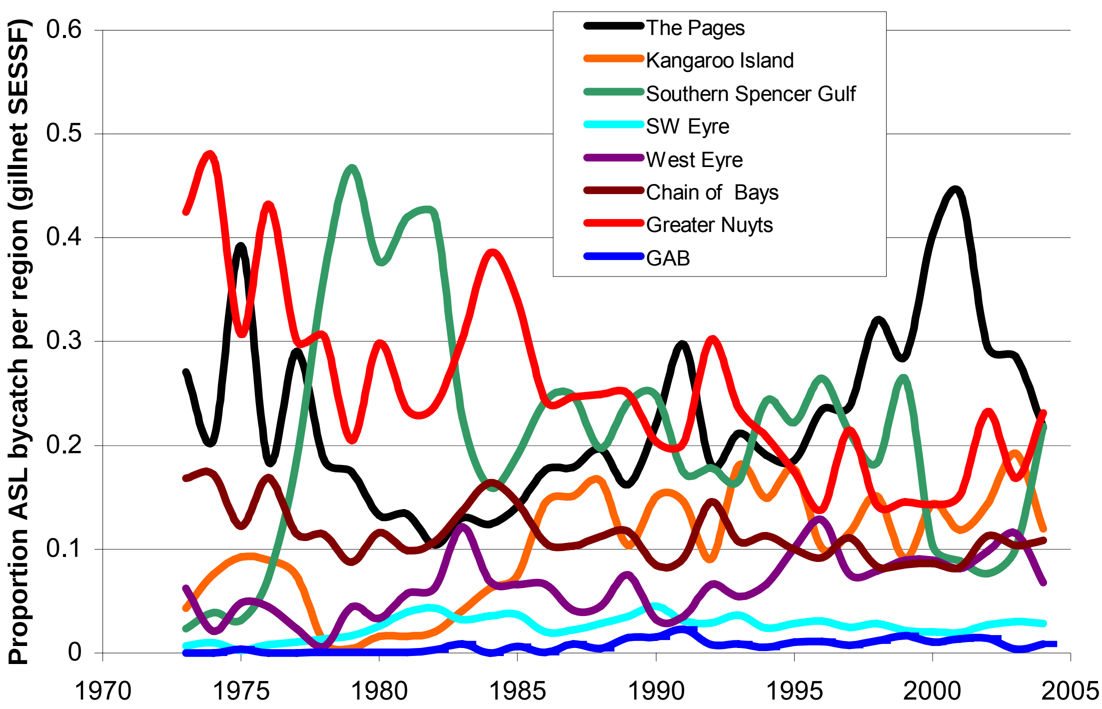


Figure 7.19. Estimated proportion of historic (1970-2004) bycatch (broken down by sex) in SA for (A) ASL and (B) NZFS accounted for by each SA RLF MFA.

A.



B.

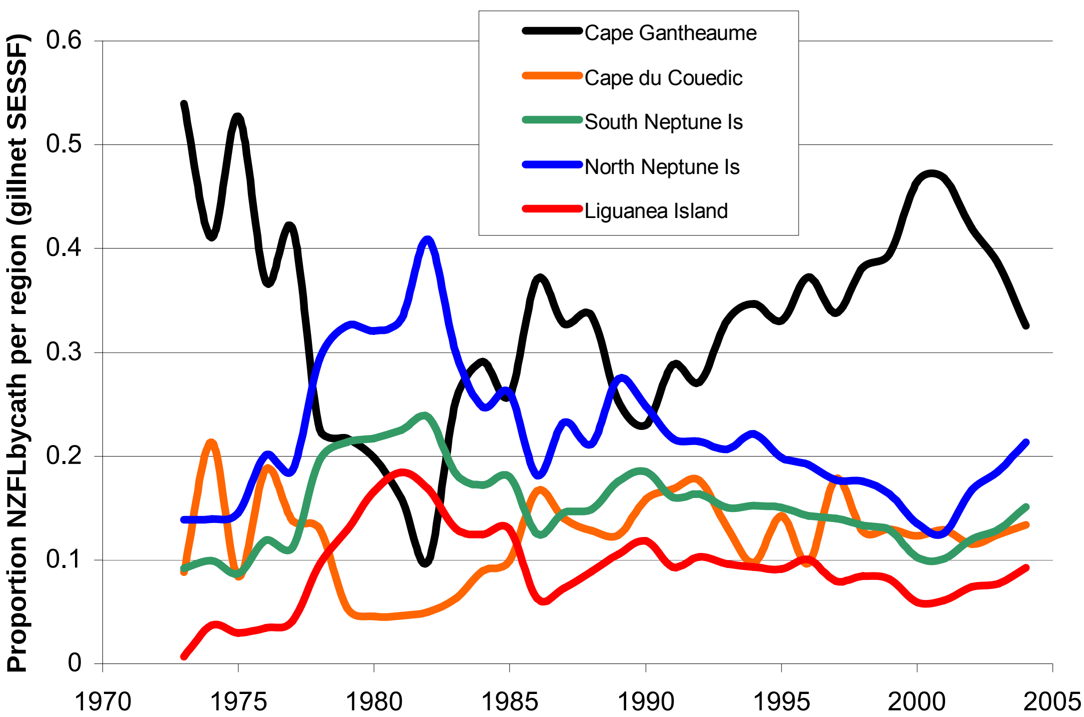
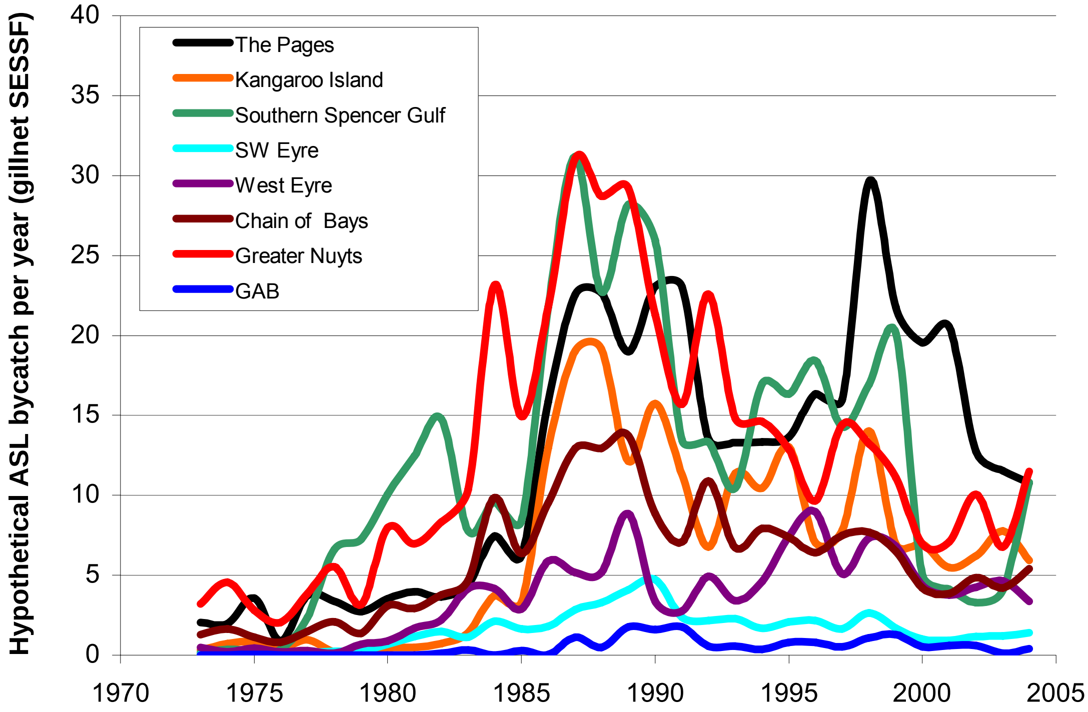


Figure 7.20. Estimated temporal change in the proportion of historic (1973-2004) SA SESSF gillnet sector bycatch, of (A) ASL from different geographic regions and (B) NZFS subpopulations.

A.



B.

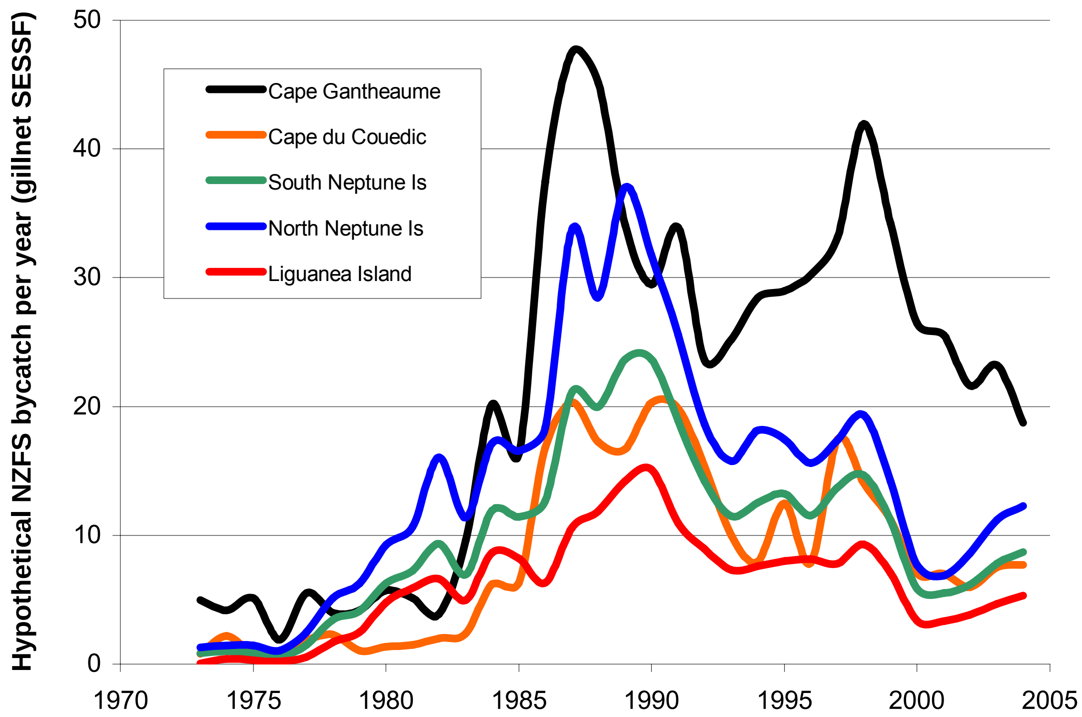
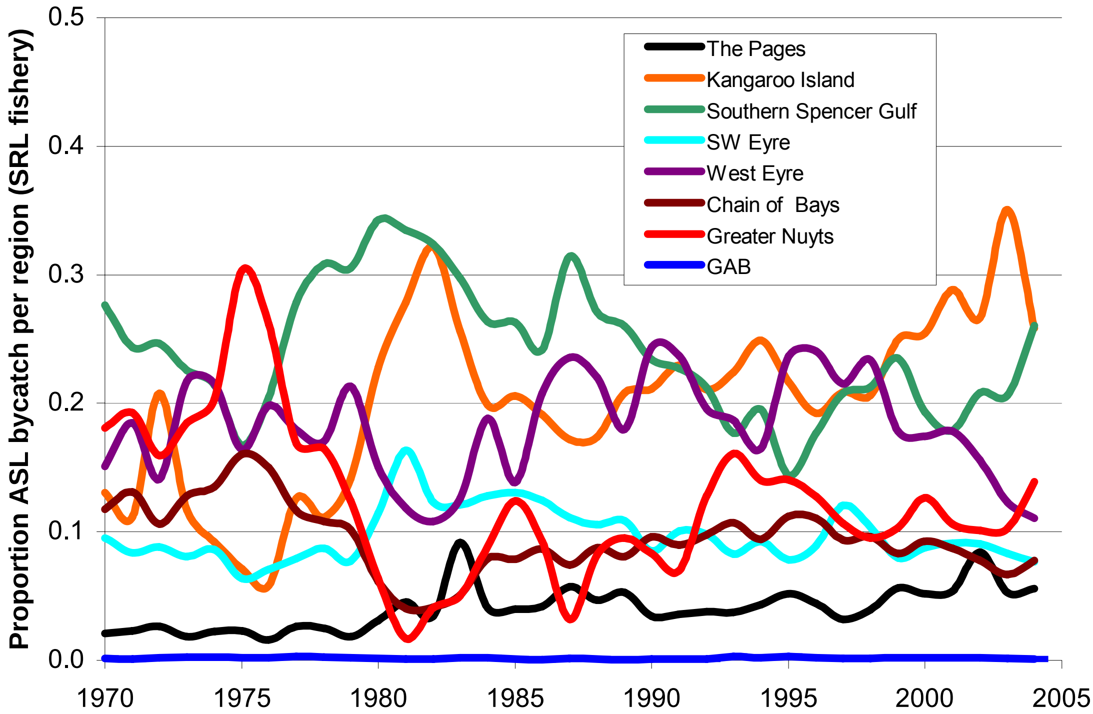


Figure 7.21. Hypothetical temporal change in the numbers of historic (1973-2004) SA SESSF gillnet sector bycatch, of (A) ASL from different geographic regions and (B) NZFS subpopulations. Numbers based on a hypothetical bycatch rate of 0.005 seals/km of net-lift.

A.



B.

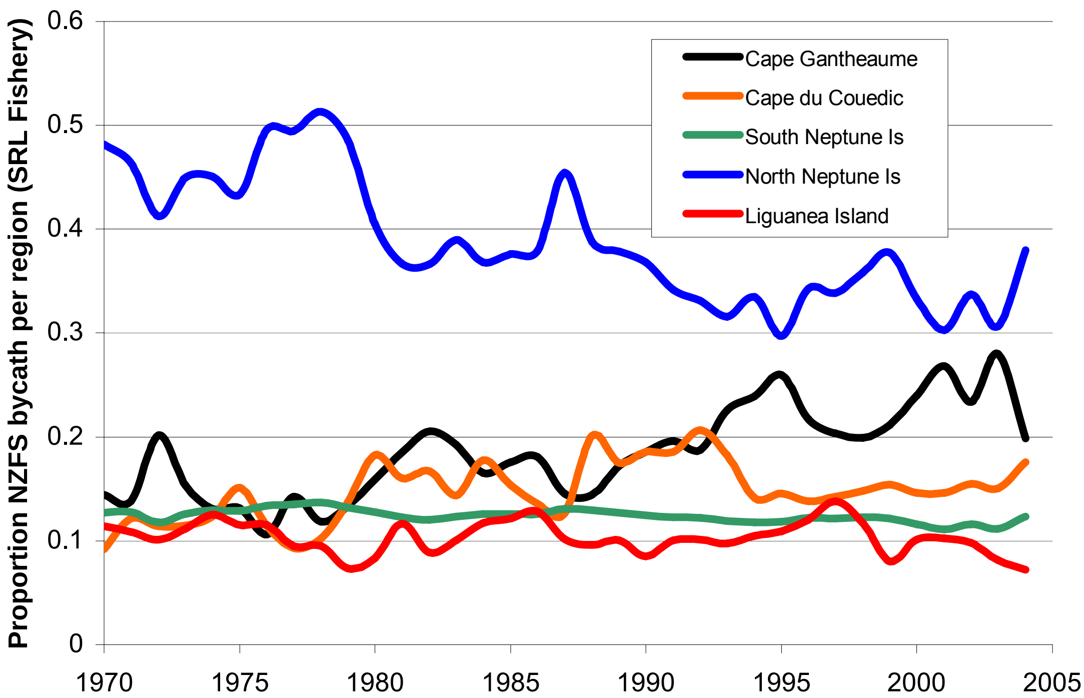
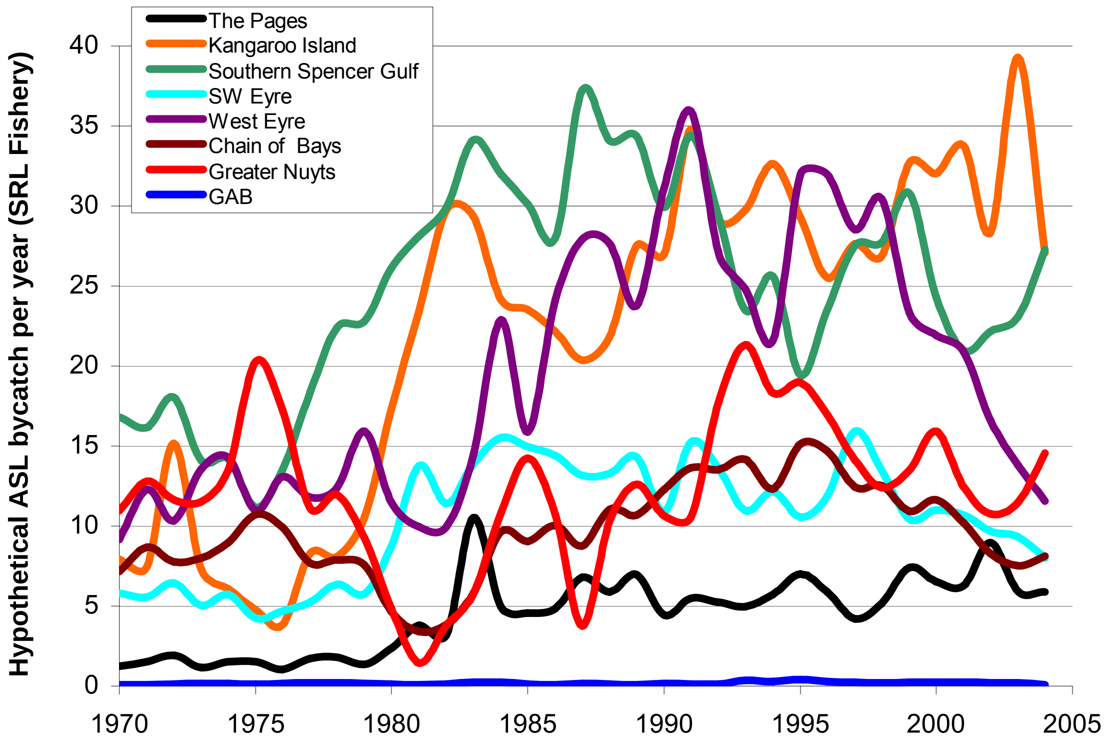


Figure 7.22. Estimated temporal change in the proportion of historic (1970-2004) SA RLF bycatch, of (A) ASL from different geographic regions and (B) NZFS subpopulations.

A.



B.

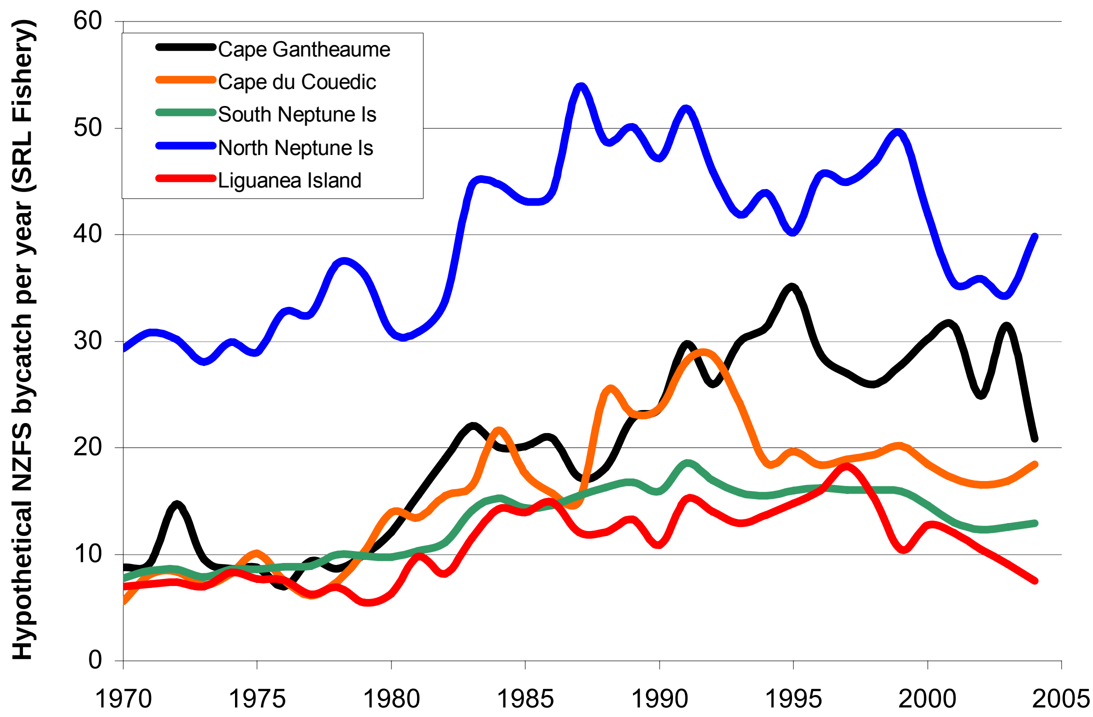
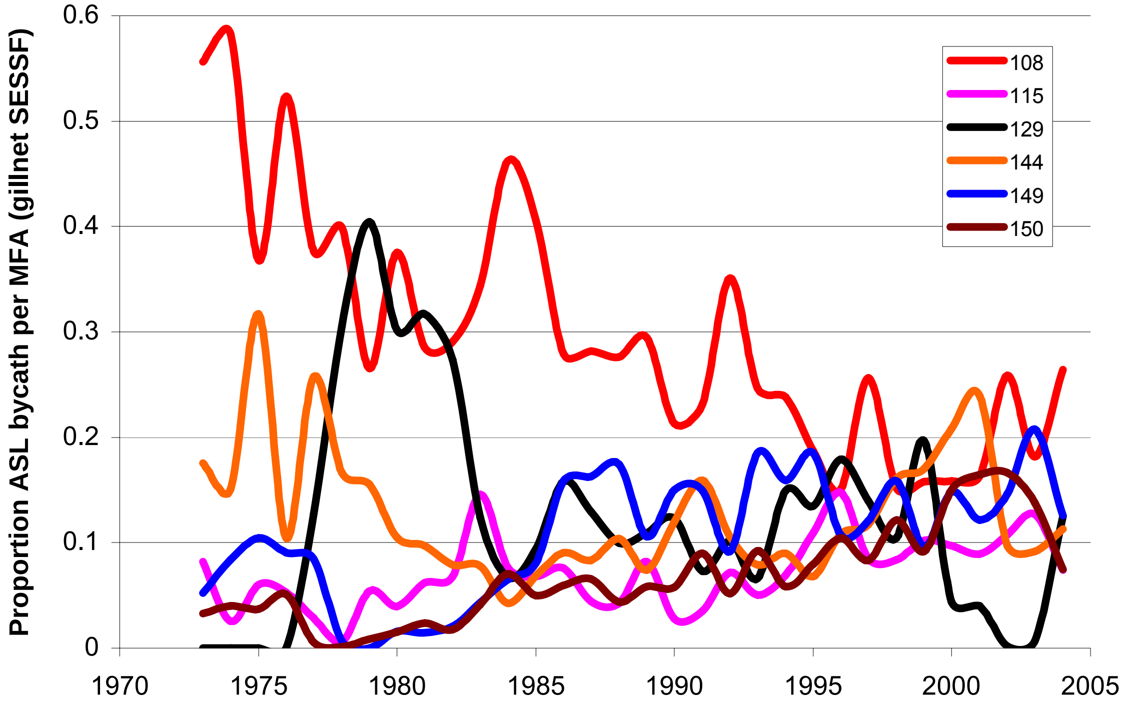


Figure 7.23. Hypothetical temporal change in the numbers of historic (1970-2004) SA RLF sector bycatch, of (A) ASL from different geographic regions and (B) NZFS subpopulations. Numbers based on a hypothetical bycatch rate of 0.2 seals/1,000 pot-lifts.

A.



B.

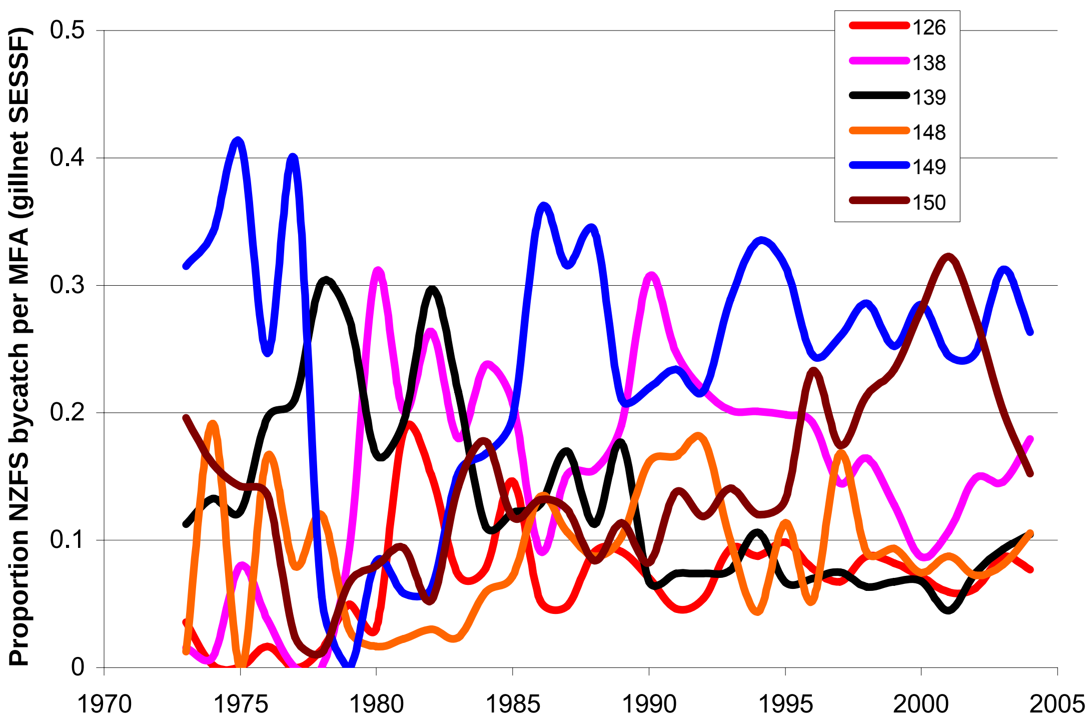
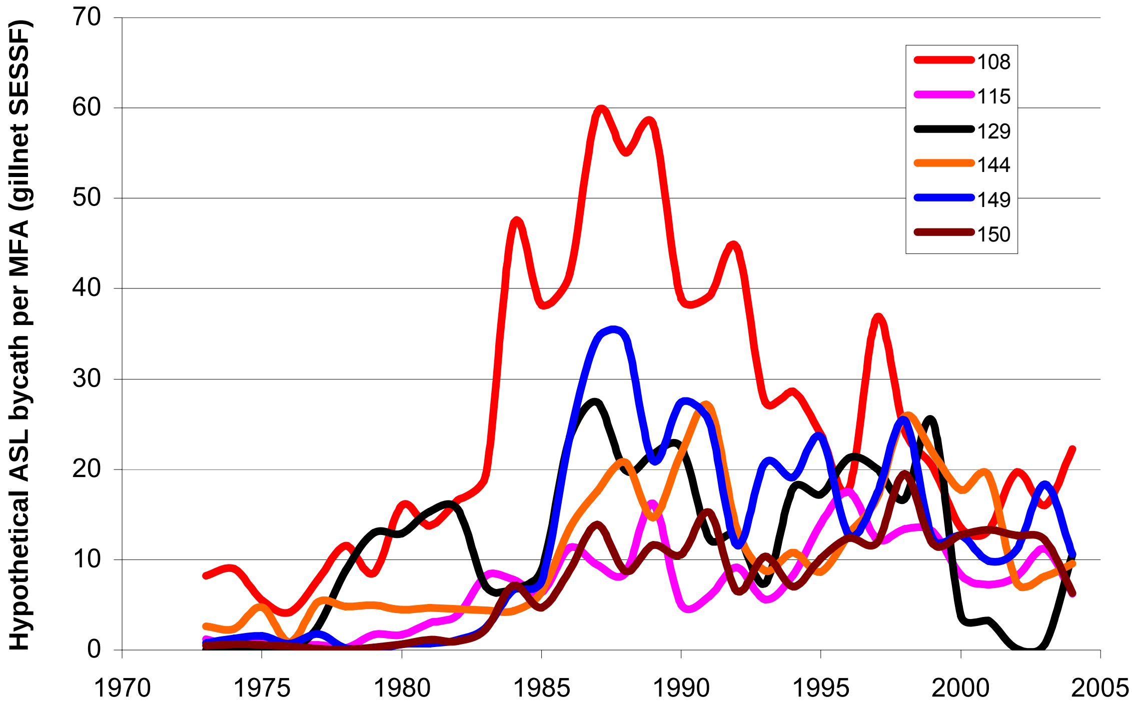


Figure 7.24. Estimated temporal change in the proportion of historic (1973-2004) SA SESSF gillnet sector bycatch, from the six major contributing MFAs for (A) ASL and (B) NZFS.

A.



B.

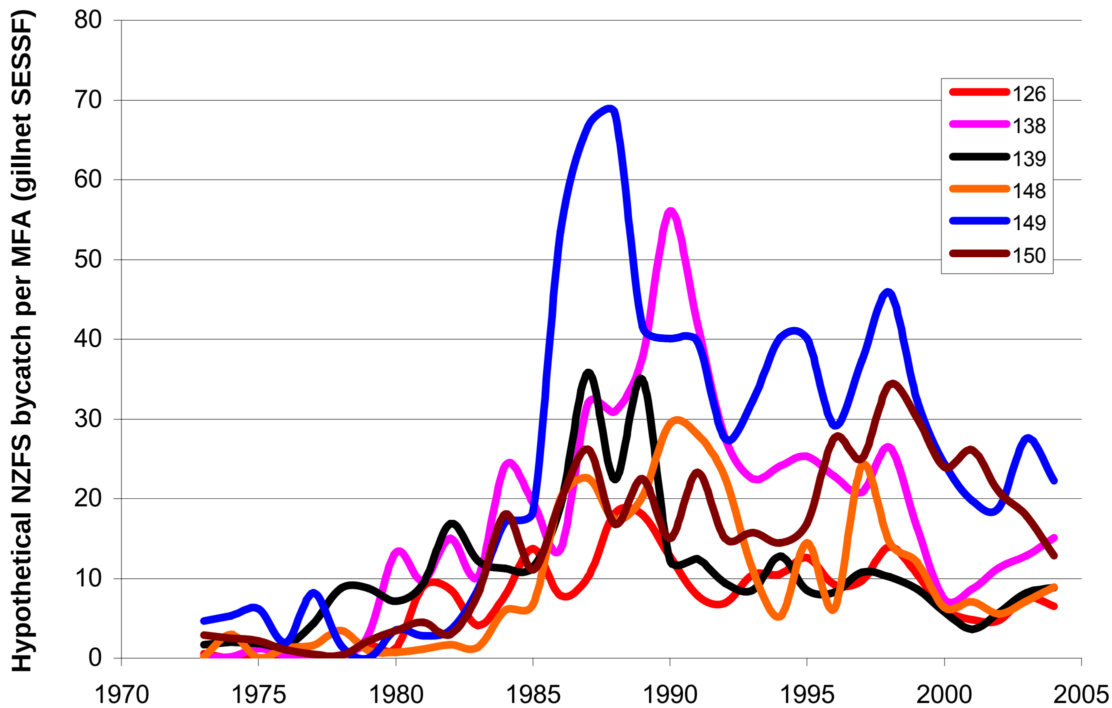
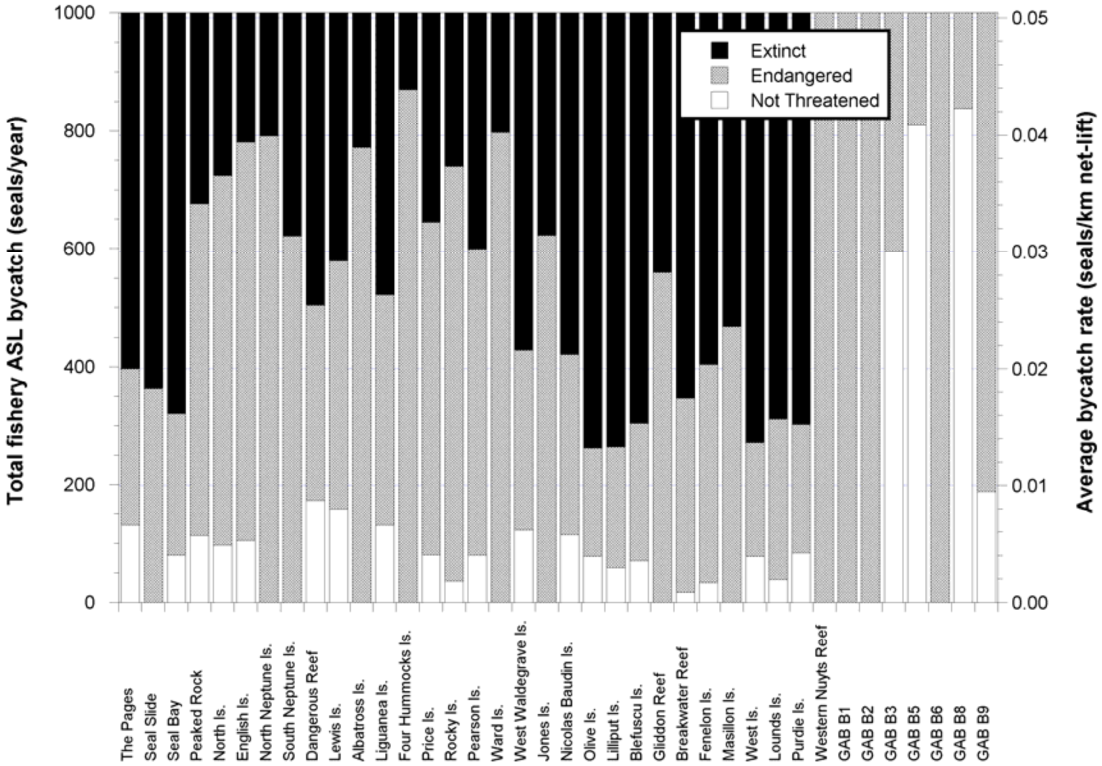


Figure 7.25. Hypothetical temporal change in the numbers of historic (1973-2004) SA SESSF gillnet sector bycatch, from the six major contributing MFAs for (A) ASL and (B) NZFS. Numbers based on a hypothetical bycatch rate of 0.005 seals/km of net-lift.

A.



B.

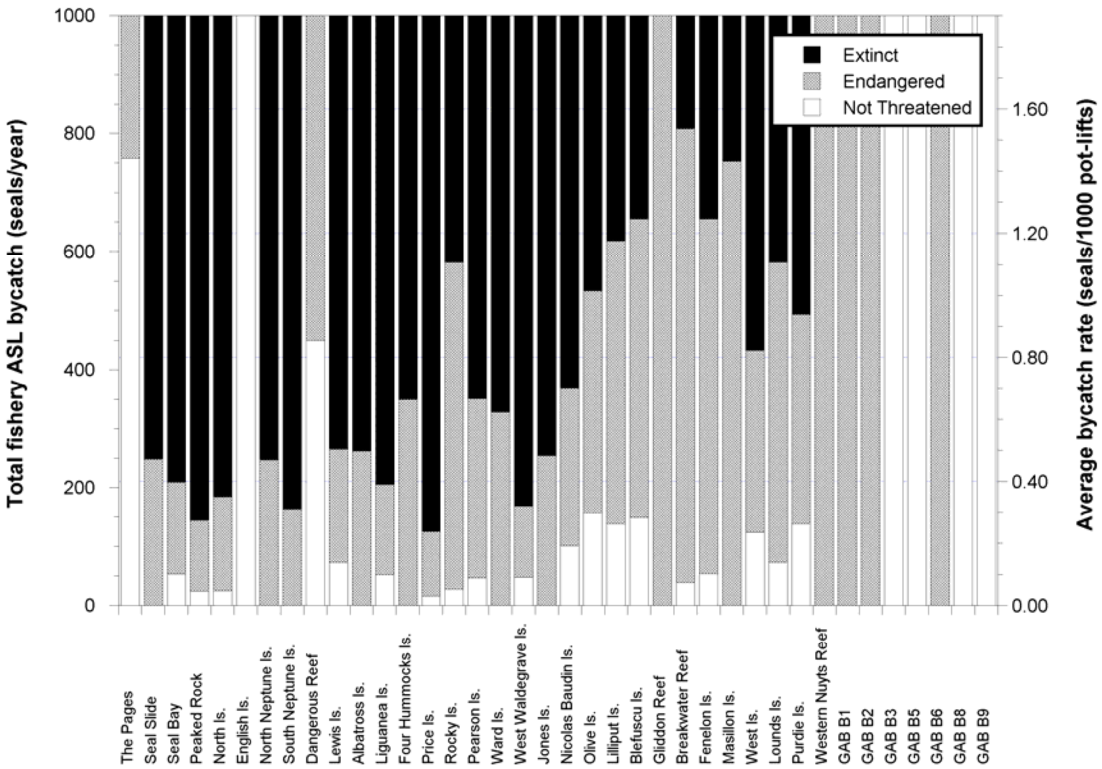
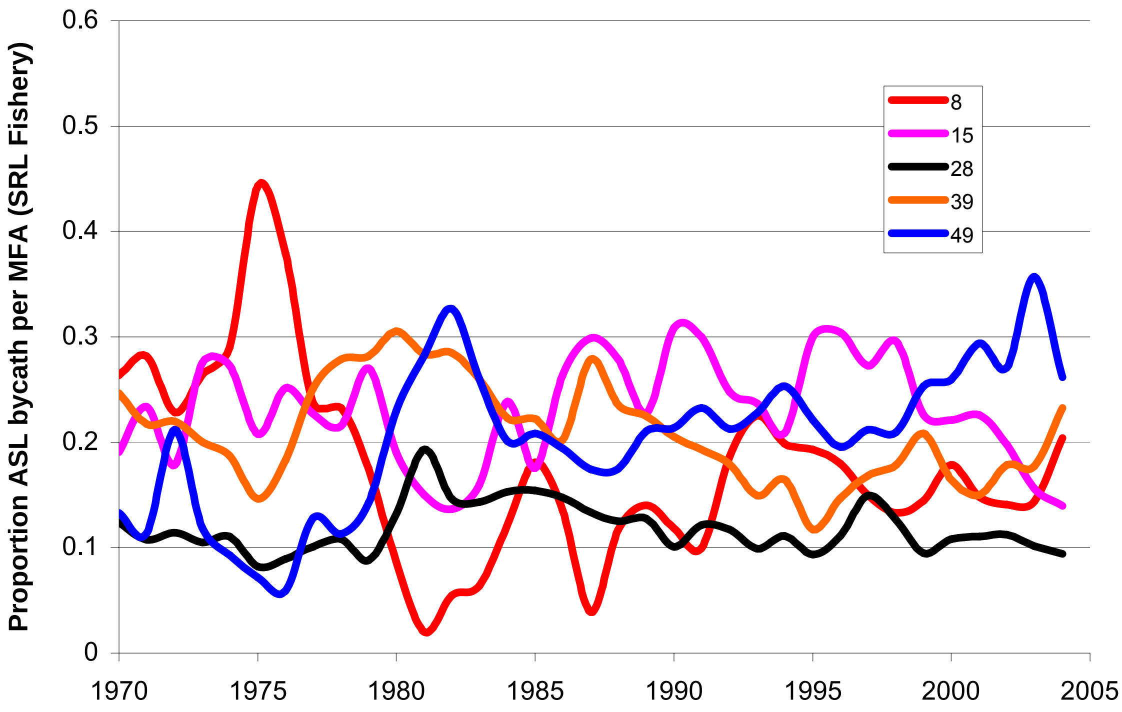


Figure 7.26. Estimated total number of ASL and average bycatch rate required to place different ASL subpopulations into different risk categories in SA component of (A) the SESSF gillnet sector (1973-2004 mean fishing effort) and (B) the SA RLF (1970-2004 mean fishing effort). The bycatch number refers to the total number seals caught per year, of which about 52% are female, which are apportioned among the 38 subpopulations based on fishery-seal interaction probabilities.

A.



B.

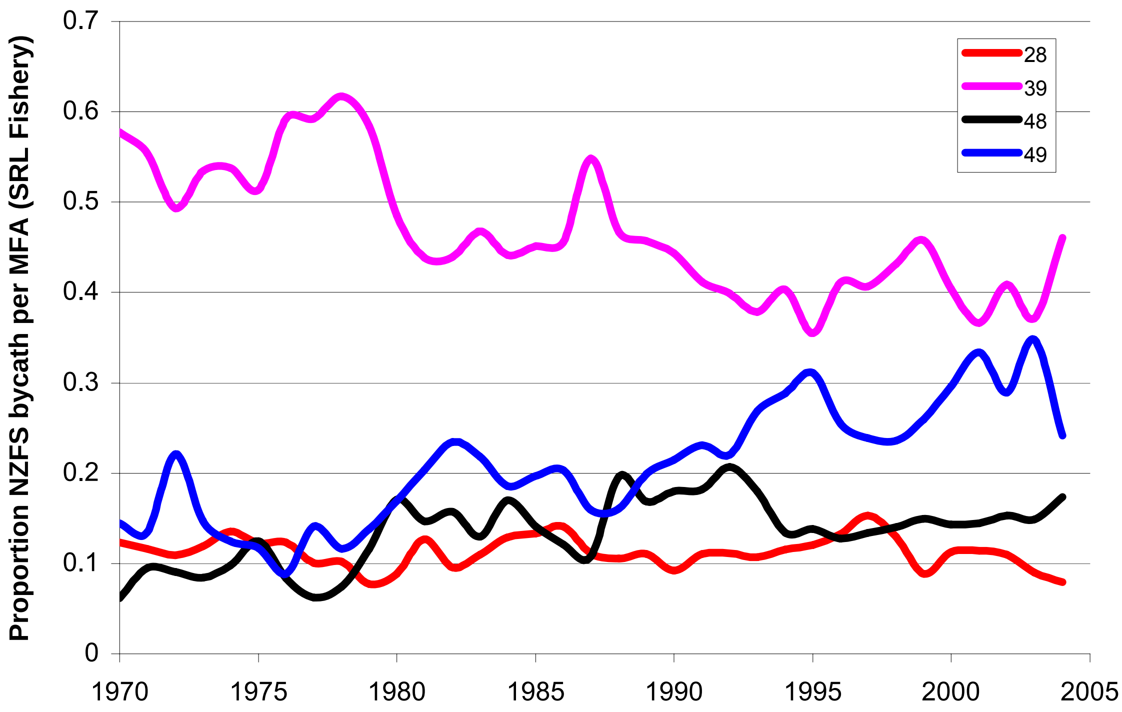
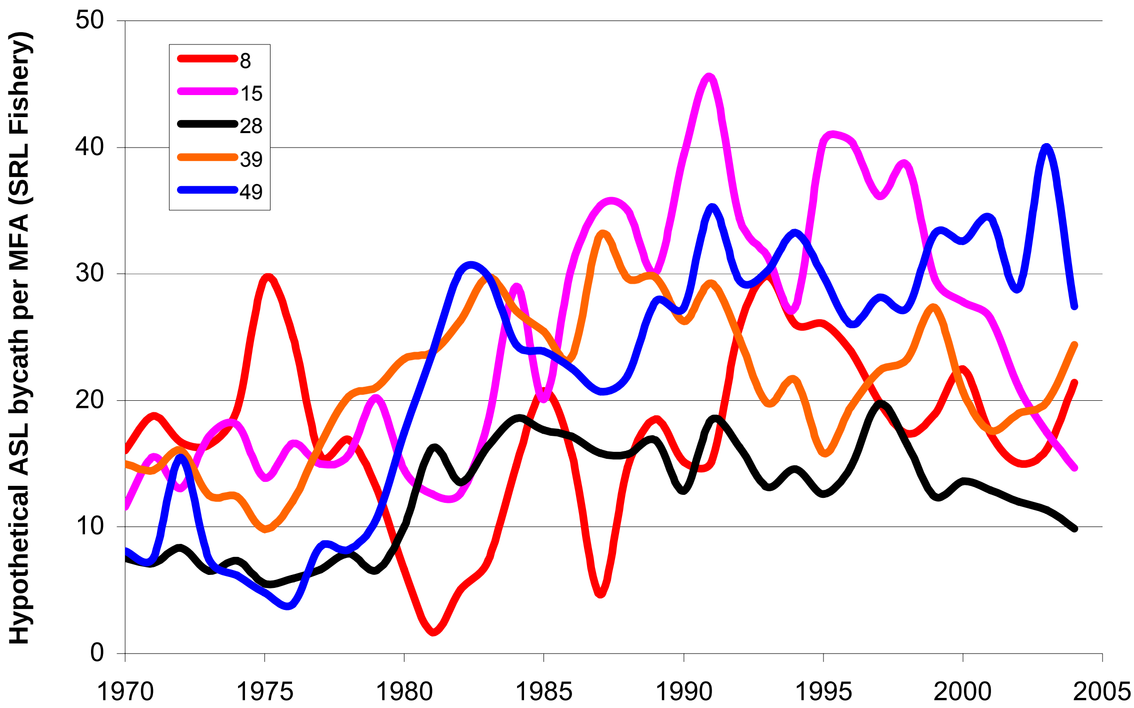


Figure 7.27. Estimated temporal change in the proportion of historic (1970-2004) SARLF bycatch, from the major contributing MFAs for (A) ASL and (B) NZFS.

A.



B.

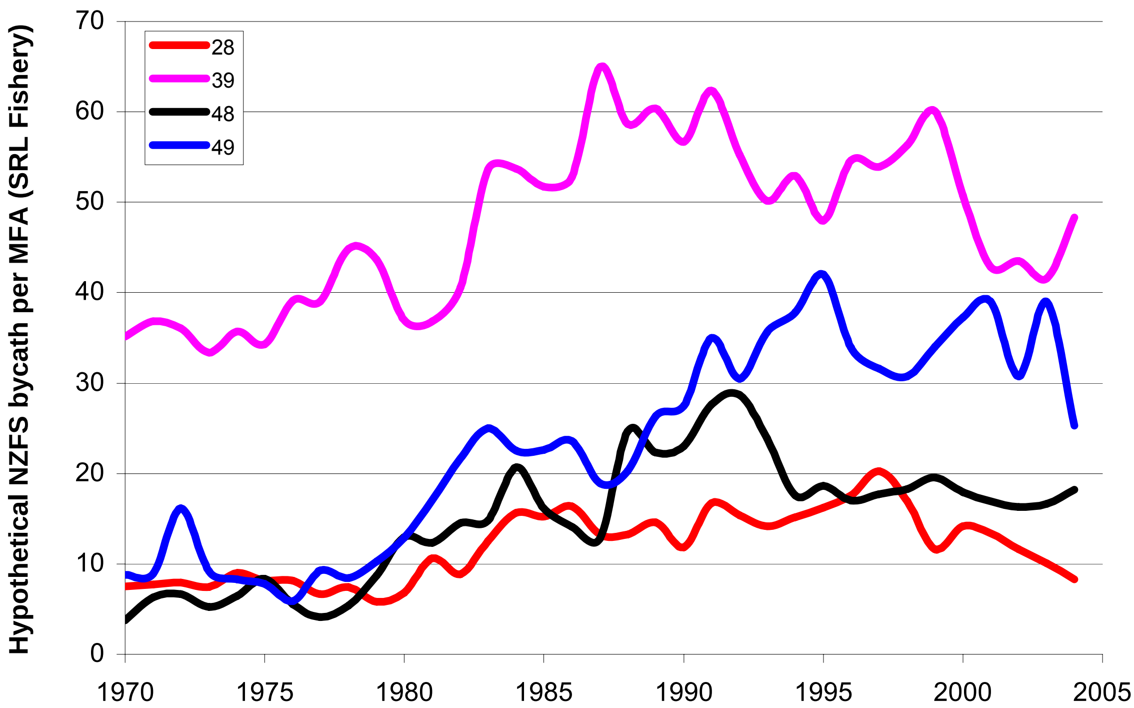
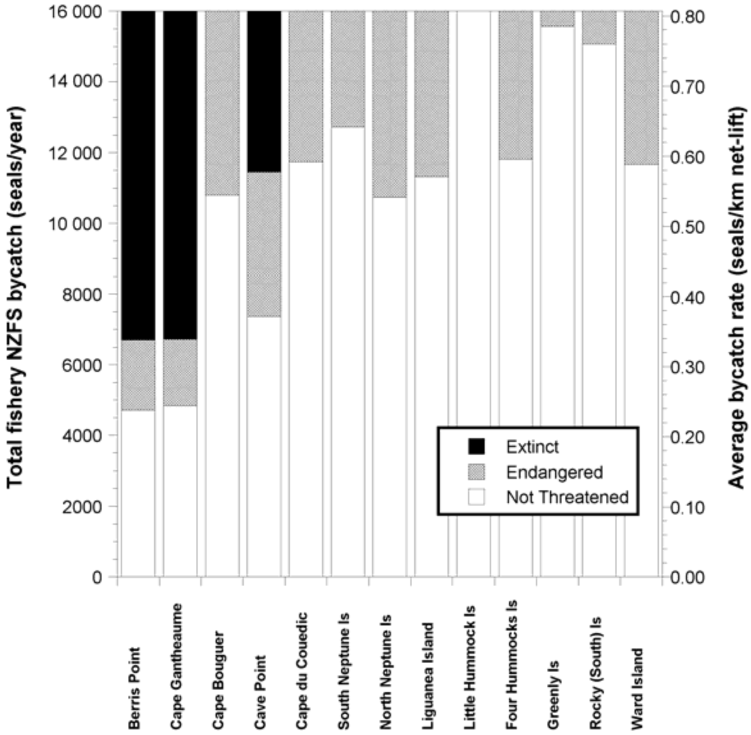


Figure 7.28. Hypothetical temporal change in the numbers of historic (1970-2004) SA RLF bycatch, from major contributing MFAs for (A) ASL and (B) NZFS. Numbers based on a hypothetical bycatch rate of 0.2 seals/1,000 pot-lifts.

A.



B.

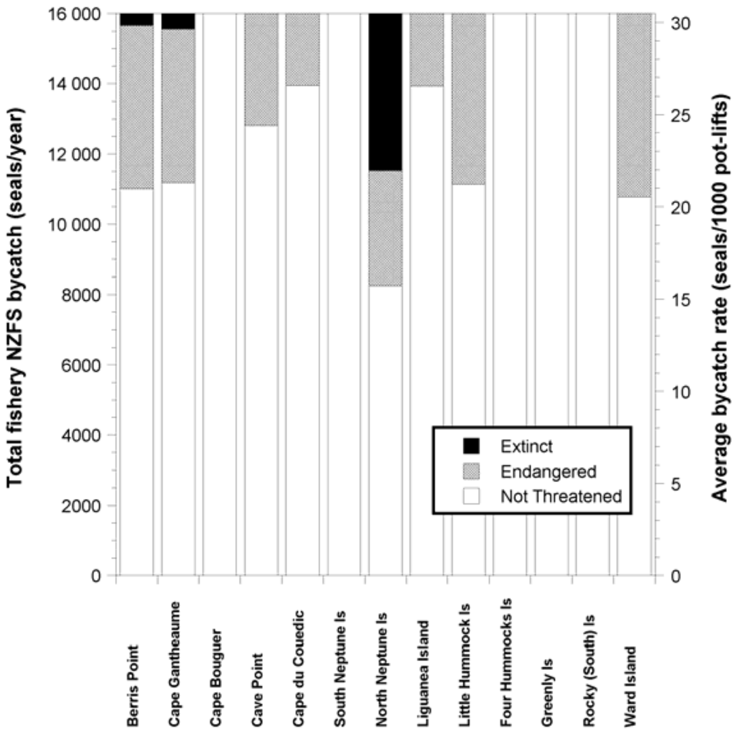


Figure 7.29. Estimated total number of NZFS and average bycatch rate required to place NZFS subpopulations into different risk categories in the SA component of (A) the SESSF gillnet sector (1973-2004 mean fishing effort) and (B) the SA RLF (1970-2004 mean fishing effort). The bycatch number refers to the total number seals caught per year, of which about 56% are female, they are apportioned among the 13 subpopulations based on fishery-seal interaction probabilities.

8 REVIEW OF THE MANAGEMENT RESPONSES RELATED TO SEAL-FISHERY INTERACTIONS

Derek Hamer

Operational interactions between commercial fisheries and non-target species are heightened when both groups simultaneously target the same resources (Hamer and Goldsworthy 2006, Read et al. 2006, Northridge 1991, Wickens 1995). Fisheries-induced mortality of protected species may impact on marine mammal populations in particular, because of their low intrinsic rate of increase, low fecundity and protracted parental investment (Campbell 2002, Bache 2003, Marsh et al. 2003). As a result, these bycatch issues have stimulated the need to manage fisheries to ensure ecological sustainable development, typically involving the adoption of an ecosystem-based approach to the management of fish stocks (Butterworth et al. 1995, Dayton et al. 1995, Fletcher et al. 2002, Punt and Butterworth 1995, Hall et al. 2000, Goldsworthy et al. 2003, Marsh et al. 2003).

The recovery of seal populations and the increase in fishing pressure over the last five decades have contributed to the increase in the incidence of protected species interactions with commercial fisheries (Beverton 1985, Alverson 1992, Wickens 1995, Lavigne et al. 1999, Shaughnessy et al. 2003, Hamer and Goldsworthy 2006). The increasing extent of the problem at a global scale has been identified, with 16 seal species involved in operational interactions with fisheries in the early 1980s, increasing to 36 in the early 1990s (Northridge 1984, Woodley and Lavigne 1991, Wickens 1995). Typically, mitigation of seal-fishery interactions involves changes to fishing practices in the form of *input* controls (limitations on the type of gear used, and when and where fisheries are permitted to operate) and *output* controls (limitations on catch or landings) (Wilkinson et al. 2003). Modified fishing practices, bycatch quotas, incentive programs and education have also been suggested as tools for reducing seal-fishery interactions (Alverson, 1999).

In general, the management responses used to mitigate seal-fishery interactions fall into four main categories: 1) bycatch quotas or limits; 2) spatial closures; 3) modification of fishing gear; and 4) modification of fishing practices. These are reviewed below.

Bycatch quotas or limits

Bycatch limits placed on protected species are typically determined by the status and trends in subpopulations and on the level of protection afforded by their conservation status. One such tool designed to take these aspects into account is the setting of bycatch or Potential Biological Removal (PBR) limits for species or subpopulations, particularly in the absence of sufficient quantifiable data (Barlow et al. 1995, Wade 1998, Wilkinson et al. 2003). Under this management regime, actions are then taken after the predetermined number of individuals of the protected species has been removed, which is termed the trigger point.

The U.S. *Marine Mammal Protection Act* (MMPA) defines the PBR mechanism as *"the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population"*. The PBR is calculated using the following formula (Barlow et al. 1995, Wade 1998, Wilkinson et al. 2003):

$$PBR = (N_{MIN})(0.5R_{MAX})(F_R)$$

Where:

N_{MIN} = Minimum population estimate.
R_{MAX} = Maximum rate of increase.
F_R = Recovery factor.

The minimum population estimate is defined as "an estimate of the numbers of animals in a stock that: (a) is based on the best available scientific information; and (b) provides a reasonable assurance that the stock size is equal or greater than the estimate" (Barlow et al. 1995). A number of uncertainty assumptions related to the model have been considered, with an acceptable N_{MIN} being defined as the level of the lower 20% of the distribution of the abundance estimate (Barlow et al., 1995; Wade, 1998). Therefore, when a direct count is not possible, the minimum population estimate can be calculated using the following formula (Barlow et al., 1995):

$$N_{MIN} = N/\exp(Z(1n(1+CV(N)^2))^{1/2})$$

Where:

N = Population estimate.
CV(N) = Coefficient of variation of the population estimate.
Z = 0.842 (stabilising constant).

PBR limits have been established to ensure acceptable levels of New Zealand sea lion (*Phocarctos hookeri*) bycatch in the arrow squid (*Nototodarus sloanii*) trawl fishery off the Auckland islands in New Zealand, and remain the most notable use of this management tool. The New Zealand sea lion is endemic to the Auckland Islands in New Zealand and has a population of 12,000-14,000 animals, which primarily breed at three sites (Gales 1995, Gales and Fletcher 1999). The species was classified as *Threatened* under the New Zealand *Threatened Species Act 1978* in 1997, and *Vulnerable* (D2) in the International Union for the Conservation of Nature (IUCN) red data book in 1996 (Wilkinson et al. 2003).

An Operation Plan was established to manage interactions between New Zealand sea lions and the squid trawl fishery using *output controls*, which were underpinned by a Maximum Allowable Level of Fishing Related Mortality (MALFIRM). The MALFIRM was based on the PBR approach. The MALFIRM was first implemented to limit sea lion mortalities in waters adjacent to the Auckland Islands, where the main breeding colonies of New Zealand sea lions are located. The first MALFIRM was set at 16 females in 1992, but was increased to 32 females (and 63 New Zealand sea lions in total) the following year (Baird 1994). In 1996, the maximum rate of increase (R_{MAX}) values in the PBR model was reduced from 0.12 to 0.08 to more accurately represent the maximum rate of increase in the New Zealand sea lion population (Wilkinson et al. 2003). In addition, the recovery factor (F_R) was increased from 0.1 to 0.15 and the minimum population estimate (N_{MIN}) increased due to an increase in the estimate of pup production (Gales and Fletcher 1999). The MALFIRM was subsequently set at 73 and 79 during the 1997 and 1998 fishing seasons, respectively.

Since the introduction of the MALFIRM, the fishery has been closed three times (1996, 1997 and 2000), because it exceeded the MALFIRM and two times as a result of voluntary withdrawals (1995 and 1998). The 1998 withdrawal was in part due to a 20% in-season reduction in MALFIRM to allow for additional non-fishery mortality of adult females as a consequence of an epizootic that resulted in the mortality of more than 50% of pups and an unknown mortality of adult females (Wilkinson et al. 2003). The 20% reductions in MALFIRM were maintained throughout the 1999 and 2000 seasons because the effects of the mortality event on the status of the sea lion population were unclear (Wilkinson et al. 2003).

Bycatch quota systems used for the purpose of limiting pinniped bycatch can only work if closures occur immediately when limits are reached, to ensure that they are not exceeded (Wilkinson et al. 2003). However, the first voluntary withdrawal in 1995, plus the 1996 and 1997 statutory closures occurred after MALFIRM limits were considerably exceeded, due to delays in receipt and processing of industry logbooks. Therefore, implementation of the MALFIRM in the squid trawl fishery in New Zealand has been met with varied success.

Performance indicators for PBR (or MALFIRM) success not only include the ability of a fishery to reliably report mortalities to management authorities and to stay within the limits imposed, but also the change in status of subpopulations likely to be affected by the fishing activity. Combined pup production estimates of New Zealand sea lions at Auckland Island indicate that the population has remained relatively stable throughout the last 30 years. This is encouraging and supports the use of PBR limits as a bycatch and conservation management tool. The applicability of this approach in Australia is questionable, as the application of quotas or limits on protected species bycatch may not appear permissible under the EPBC Act.

Spatial closures

Spatial closures aim to redistribute fishing effort to areas where operational interactions with non-target or bycatch species are less likely to occur (Bache 2003). They are most effective when the species to be avoided is not evenly distributed across its range (Hall 1996). Spatial closures are of particular use when aiming to mitigate interactions with protected species, especially those that are suspected of being vulnerable to declines due to fishery related mortalities.

In locations where reserves or Marine Protected Areas (MPAs) prohibit fishing activity, there are likely to be benefits to the structure of the benthos and conservation of flora and fauna within it (Roberts 2000). Area closures have also been used to reduce fishery bycatch of the Hawaiian monk seal (*Monachus schauinslandi*), which breed on the Northwestern Hawaiian Islands (Regan and Lavigne 1999). Pup production for the species was estimated at 175 in 1995, and is thought to have declined by about 60% over the last four decades (Regan and Lavigne 1999). Management steps were first introduced in 1981, with an exclusion zone proclaimed for the waters around pupping and haul-out sites, out to the 18 m isobath (Lavigne 1999). The depth limit was extended to the 37 m isobath in 1988. In 1986, drift-netting was banned within 50 nautical miles of pupping and haul-out sites and long-line vessels were prohibited within 100 nautical miles. In order to fish in the remaining portion of the fisheries conservation zone (between 100 and 200 nautical miles offshore), long-line vessels were required to submit effort plans, obtain permits, report catch and effort data, carry observers and report interactions with Hawaiian monk seals (Lavigne 1999). The US National Marine Fisheries Service (NMFS) later amended the 50 nautical mile protected species zone to prohibit all long-line fishing and create transit corridors between islands to allow unhindered movement of animals without the risk of encountering commercial fishing vessels (Lavigne 1999). It has been suggested that the proclamation of a permanent area of fishing prohibition within a certain distance of several breeding colonies is responsible for stemming the continued decline in the population.

Spatial closures may also have a temporal component and be utilised to protect marine mammals that are present for only a part of the year. This is the case in the Marine Mammal Protection Zone in the Great Australian Bight Marine Park (GABMP) in South Australia, which is closed between 1 May and 31 October each year to protect migratory cetaceans that move into the region to give birth and breed (Natural Heritage Trust 2004).

Fishing activity may also be prohibited in areas when operational interactions and bycatch of non-target species exceed prescribed limits. This management response is often referred to as a ‘trigger point’, whereby specific management options are considered once a predetermined level of bycatch is reached. The use of PBR limits for protection of the Zealand sea lion at the Auckland Islands in New Zealand provide a mechanism for setting a trigger point, with an area closure around the Auckland Islands being the preferred management response, effectively prohibiting squid-trawl fishing activity within the area for the remainder of the fishing season (Wilkinson et al. 2003).

Permanent closures to fishing activity may be considered if acceptable bycatch limits or triggers are exceeded consistently, resulting in the prohibition of fishing activity within areas identified to contain higher bycatch levels. For protected species that are known to be vulnerable to fisheries related mortalities, such prohibitions may assist in their recovery. Closing areas formally fished by a gill-net fishery in California and a shrimp trawl fishery in the western Gulf of Mexico is thought to have improved the conservation prospects of pinniped and cetacean species and the Kemp’s ridley turtle (*Lepidochelys kempii*) (Julian and Beeson 1998, Lewison et al. 2003).

Management authorities have preferred to consider socio-political aspects when setting trigger points, especially when determining acceptable bycatch limits for marine mammals, which typically attract negative public attention. The bycatch of Australian fur seals by factory trawlers targeting blue grenadier (*Macruronus novaezelandiae*) off the west coast of Tasmania provides a good example of this, whereby AFMA set a limit of 15 mortalities per fishing vessel, based on negotiations with the Tasmanian Department of Primary Industries, Water and Environment (DPIWE) (Tilzey et al. 2006, Hamer and Goldsworthy 2006). The bycatch was determined to comprise almost exclusively males (Tilzey et al. 2006), suggesting that the bycatch recorded prior to setting limits was unlikely to impact negatively on the conservation of the species, especially when considering that the species appears to be increasing across its range (Kirkwood et al. 2005).

Although considered to be a last resort in most instances, buyback schemes may be considered if the bycatch of threatened species is thought to be unsustainable, and other mitigation options have failed or been impractical. Such schemes have only been used in situations where harvesting of the target stock has been unsustainable and the impact of fishery closure may have serious social impacts (Weniner and McConnell 2000).

Modification of fishing gear

There have been considerable efforts to mitigate pinniped interactions and bycatch mortalities through gear modification and some of these have shown promising results (Kemper and Gibbs 2001, Stone et al. 1997, Gosliner 1999, Johnston 2002, Wilkinson et al. 2003, Tilzey et al. 2006, Hamer and Goldsworthy 2006). Gear modifications are made to mitigate interactions or to facilitate the escape of animals from fishing gear. There are considerable differences in the types of gear currently used among fisheries, and these influences the likelihood of interactions and the options to modify gear to mitigate them (Northridge 1984). As such, gear modifications for the mitigation of protected species interactions are often specialised and industry-specific. Trap fisheries lend themselves to gear modification and several examples are given below.

Seal Exclusion Devices for lobster pots

A study of the Cape fur seal (*Arctocephalus pusillus pusillus*) in South Africa examined its interactions with the rock lobster (*Jasus lalandii*) fishery (Wickens

1995). Seals were present during 67% of fishing operations, but no evidence of damage to the catch or equipment was reported, indicating that seals were unable to enter the pots. However, an estimated 10% of undersized rock lobsters were predated on by seals when returned to the sea (Wickens 1995).

A recent study investigated operational interactions between Australian sea lions and the Western Rock Lobster Fishery (WRFL) (Campbell 2004). Australian sea lion bycatch in rock lobster pots comprised animals between 6 and 24 months of age (pups and juveniles) (Campbell 2005). Sea lion mortality events occurred in water depths shallower than 20 m and within 25 km of breeding colonies (Campbell 2005).

The WRLF implemented pot modifications, known as Sea Lion Exclusion Devices (SLEDs). Four pot modifications were trialled, being 1) a steel bar through the neck of the pot, 2) a lengthened neck, 3) a T-bar extending from the base of the pot and 4) a cup-head bolt extending from the base of the pot (Campbell 2004). The steel bar through the neck design and the T-bar design proved to be more effective than the lengthened neck design, possibly because of the increased flexibility in the plastic neck, which allowed seals to distort it and gain access to rock lobsters (Campbell 2004). A cup head bolt design was trialled as a potential alternative to the T-bar due to concerns about the potential for pot rope entanglement in the latter (Campbell 2004).

The catch rate and size distribution of rock lobster was significantly reduced for both legal sized and undersize rock lobster in pots with a bar-SLED (Campbell 2004). The T-bar SLED also significantly reduced the catch rate of legal sized rock lobster, but only in waters deeper than 20 metres (Campbell 2004). The Western Australian study of sea lion interactions with the WRLF has not concluded, with further exclusion trials for the cup-head SLED design and further analyses to be completed (Campbell 2004).

Acoustic deterrents and harassment devices

Underwater acoustic devices have been used widely in efforts to mitigate marine mammal interactions with fishing gear and operations and can broadly be divided into two groups: acoustic deterrent devices (‘pingers’) and acoustic harassment devices (AHDs) (Reeves et al. 2001). Pingers are electronic devices that are designed to emit low intensity acoustic pulses to warn marine mammals of the presence of fishing gear in order to reduce the likelihood of entanglement (Northridge et al. 2004). The devices are typically used in fixed net configurations, such as gill-nets for the mitigation of dolphin bycatch (Stewardson and Cawthorn 2004). In contrast to pingers, electronic AHDs aim to frighten animals away from fishing equipment and operations by causing pain, discomfort or irritation via high intensity acoustic pulses (Northridge et al. 2004). They have been used to discourage seals from predating on caged fish at mariculture facilities (Reeves et al. 2001). There are a number of other categories of AHDs on the market, including pyrotechnics and shock wave generators (Stewardson and Cawthorn 2004).

Pingers are thought to reduce bycatch of marine mammals in most cases, although in some cases the effect is short-term (Mate and Harvey 1987, Kraus et al. 1997, Trippel et al. 1999, Yurk and Trites 2000, Barlow and Cameron 2003). Successful use of acoustic pingers has typically been reported for interactions with cetaceans. Gill-net fishing vessels targeting swordfish and shark off the coast of California (where the bycatch was concentrated) have been required to place a pinger every 91 m on the cork-line and lead-line, in an attempt to mitigate marine mammal bycatch (Barlow and Cameron 2003). Nets were approximately 1.8 km long. The incidence of seal bycatch in gill-nets with pingers attached was one third the amount caught by nets without pingers (Barlow and Cameron 2003). Catch rates of target species were not affected by the presence of pingers (Barlow and Cameron 2003).

Although pingers reduced Californian sea lion bycatch in the drift gill-net fishery off the coast of California (Barlow and Cameron 2003), they did not deter South American sea lion (*Otaria flavescens*) from feeding on fish caught in gill-nets off the coast of Argentina (Bordino et al. 2002). In the latter case, damage of fish was significantly greater in nets with active pingers. The mitigating effects of pingers and AHDs are thought to diminish with time as seals become habituated (Mate and Harvey 1987). Seals are also thought to use the sound emitted from these devices as a ‘dinner bell’, thus having the opposite effect to that desired (Bordino et al. 2002, Northridge et al. 2004).

Modification of fishing practices

Fishing codes of practice are typically industry-initiated programs for addressing a number of issues, such as safety and environmental policy, which have traditionally fallen behind compared with other industries. They are a demonstration or acknowledgement by the fishery that operational procedures and activities require improvement in order to meet standards that society, endowed with growing awareness, requires to be best practice.

From a fisheries perspective, a code of practice identifies activities that may impact on the broader marine environment and demonstrates a commitment through long-term objectives for mitigating their impact (South East Trawl Fishing Industry Association 2000a). In addition, fishing codes of practice take into account the social, economic and cultural needs of stakeholders (South East Trawl Fishing Industry Association 2000b).

While a growing number of fisheries in Australia and other developed countries are now developing a code of practice, there are few examples that specifically address mitigating interactions with pinnipeds. Factory trawlers targeting blue grenadier off western Tasmania (and within the South East Trawl Fishery - SETF) developed a code of practice with the aim of reducing seal interactions, bycatch and mortality (South East Trawl Fishing Industry Association 2000b, Hamer and Goldsworthy 2006). Following the introduction of the fishing code of practice there was a decline in seal bycatch, but the decline may have been a result of a reduced number of seals entering nets, rather than the code altering fishers' behaviour (Hamer 2004). The squid trawl fishery in New Zealand has a fishing code of practice, which was introduced at the same time as sea lion exclusion devices (SLED) on trawl nets, to minimise bycatch and mortality of New Zealand sea lions (Moors 2005). The rate of sea lion mortality decreased following the implementation of the code of practice, but SLEDs were introduced simultaneously, again preventing the ability to establish the real benefit of the code of practice with respect to bycatch mitigation.

In both the Tasmanian and New Zealand cases, the effectiveness of this aspect of the code of practice is impossible to determine, because performance assessment measures were not used to establish if pinnipeds were less likely to interact or die as a result of fishing activity. A recently introduced code of practice for the South Australian Pilchard Fishery (SAPF) is being trialled and assessed by comparing the rate of encirclements and mortalities of protected species before and after introduction of the code of practice, using a number of assessment criteria during fishing operations. Although the investigation has not yet been completed, the use of assessment criteria and comparisons between data collected before and after the operational changes associated with the code of practice will provide sufficient evidence to establish its effectiveness.

Concluding remarks

There a number of management approaches that could be adopted to mitigate interactions between commercial fisheries and pinnipeds, although a range of factors including the nature of the fishery, the type of gear used, its location, plus the pinniped species interacting with it will determine the most appropriate suite of mitigation options. For example, the nature of interactions between Australian sea lions and the SESSF gill-net sector and the SARLF are likely to differ significantly, and as a consequence, approaches to mitigate interactions will differ (see Section 7). Most of the suitable options available, are input controls. Output controls such as quota adjustments would be of limited benefit from a pinniped bycatch perspective, particularly when aiming to maintain the viability of the fisheries concerned. Rock lobster pots used by the SARLF lend themselves to extensive structural modification for preventing entry by seals, as has been demonstrated in the WRLF (Campbell 2004). On the other hand, there is limited scope for modification of gill-nets used by the SESSF gill-net sector, and as indicated in Section 7, this fishery may lend itself to more appropriate spatial management.

Although there are apparent benefits associated with the provision of measures for mitigating pinniped interactions with both the SARLF and the SESSF gill-net sector, the ability to measure the benefits is also critical. Appropriate measures would include a comparison of interaction and mortality rates both before and after the implementation of mitigation measures in each fishery, plus monitoring the change in trends of pinniped pup production at breeding sites adjacent to areas of high fishing activity. In the apparent absence of reliable and complete industry-based records on interaction and mortality rates of pinnipeds to date, a short-term observer program may be necessary for verification of these rates and to provide initial advice to industry to ensure an appropriate standard of reporting is reached. At the very least, an improvement on the current standard and mechanism of logbook record keeping is necessary, both from an industry and management perspective. Other options include industry-wide use of onboard video monitoring systems as is being trialled in the gillnet sector SESSF. Such an approach may provide the only option for a quantitative performance measure of protected species interactions. Monitoring of pup production should continue at sites that have historically been monitored and should commence at subpopulations identified as high-risk, so that any change in the trajectory of pup production can be detected. Positive outcomes from the performance measures would be maintenance of low levels or reductions in bycatch rates below a predetermined level (as identified in the PVA analysis in section 7), and a positive adjustment to the current trends in pup production at monitored sites.

9 RECOMMENDATIONS FOR FURTHER RESEARCH

This section addresses Objective 4 of the study, which was to ‘Develop a proposal for a comprehensive study to assess the level and nature of interactions between seals and the SA Rock Lobster and Commonwealth shark fisheries, including the development of guidelines for measuring the performance of systems for monitoring, assessing and mitigating interactions between the fisheries and seals.’

As detailed in previous sections, results from this risk assessment clearly demonstrate that the potential risk to Australian sea lions from bycatch in the gillnet sector of the SESSF and the SARLF are significant and needs to be mitigated. Section 7 outlined the key recommendations for further research following the risk assessment process, and these have been addressed in a draft FRDC application recently submitted to SA FRAB. A full draft FRDC application was developed and submitted to the FRDC in 2006, and was approved for funding in 2007 (2007/041 – ‘Mitigating seal interactions in the SRLF and gillnet SESSF in SA’). The PRP of this full FRDC application is provided in the following pages.

SOUTH AUSTRALIAN FISHERIES RESEARCH ADVISORY BOARD

Preliminary Research Proposal Format 2007/08 Funding Round

PROJECT TITLE

Seal interactions in the RLF and gillnet sector SESSF in South Australia

FRDC PROGRAM IDENTIFICATION

1. Natural Resources Protection

PRINCIPAL INVESTIGATOR CONTACT DETAILS

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COMMENCEMENT AND COMPLETION DATE

Commencement date :1 Jul 07
Completion date :30 Jun 09

NEED

ESD assessments of both the gillnet sector of the SESSF and SA rock lobster fishery (RLF) fisheries have identified interactions with seals as a significant issue. These assessments make at least seven recommendations to address protected species interactions (including seals), but little if any progress has been made to address these. In order to have southern rock lobster taken from South Australian waters placed on the list of exempt native specimens for export under Part 13 and 13(A) of the *EPBC Act*, there is an imperative to address these ESD recommendations, as failure to do so may jeopardise current and future export exemptions.

In February 2005, Australian sea lions (ASL) were listed as a threatened species under the Commonwealth *EPBC Act*, and a draft recovery plan has identified bycatch from bottom-set gillnet and rock lobster fisheries as the most significant anthropogenic contributor to the species' lack of recovery. As such the development of measures to mitigate interactions with sea lions forms the most pressing ESD issues for these fisheries.

South Australia contains 80% of the endemic ASL population, where substantial fishing effort in the gillnet sector SESSF (~17,000 km net-lifts/year) and SA RLF (~1.5 million pot-lifts/year) increase the risk of fatal interactions. A recent risk assessment has identified significant overlap between sea lion foraging and fishing effort in these fisheries, with 40% of colonies at risk of extinction from very low levels of bycatch (1-2 additional female deaths/year over a 20-25 year period).

OBJECTIVES

This project aims to address the recommendations for mitigating interactions between seals and the gillnet SESSF and the SA RLF as detailed in their respective ESD assessments. Specifically this will involve:
1. Assess the level of sea lion bycatch in the gillnet sector SESSF.
2. Develop and assess methods for mitigating sea lion interactions with demersal gillnets.
3. Develop and assess methods for mitigating sea lion interactions with SRL pots.
4. Develop spatial tools based on seal foraging and fishing effort to evaluate different risk-management scenarios for reducing sea lion bycatch in both fisheries.
5. Develop performance indicators to evaluate the effectiveness of the different mitigation options developed for each fishery.

STAKEHOLDER CONSULTATION AND COLLABORATION

A pilot (risk assessment) study for this project was funded by FRDC in 2005 (2005/077), and involved consultation with industry and management during its development. Seal interactions with the gillnet sector SESSF were developed in consultation with AFMA fisheries managers and is ongoing. In the SARLF fishery, the project has been developed in consultation with Mr

Sean Sloan (Senior Fisheries Manager, PIRSA) and with support from the SA Rock lobster FMC (see attached letters of support). The findings of the risk assessment pilot study and this proposal will be presented at forthcoming FMC meetings. Ongoing consultation with DEH regarding the ASL Recovery Plan is also taking place.

DIRECT BENEFITS AND BENEFICIARIES

The project will ensure that the SA RLF and gillnet SESSF are managed according to ESD principles, and that ESD recommendations with respect to interactions with seals are measured, assessed and mitigated.

The outcomes of these achievements will be:
- maintenance of *EPBC Act* export exemptions in the SA RLF.
- a potential reduction in pot-robbing by sea lions following pot-protection development that may significantly improve catch and effort ratio in the SA NZ RLF.
- a significant reduction in seal bycatch in these fisheries assisting the recovery of the *Threatened* ASL.

PROJECT DESIGN AND METHODOLOGY

1. Assessment of the level of sea lion bycatch in the gillnet sector of the SESSF

The scope for gear modification to reduce bycatch in the gillnet fishery is limited (but see 2 below). Hence, the main mitigation option available in this fishery is spatial management/closures. It will therefore be essential to assess real interaction/bycatch rates to determine the need and benefits from spatial closures within particular MFAs. This can only be achieved through an independent observer program. This will be implemented targeting regions identified as high risk (in FRDC 2005/077), and will monitor the level (extent) and nature of interactions and the level of observer effort required to quantify and monitor the extent of interactions. This will provide a basis for determining maximum potential effects on populations and provide data for assessing the level of observer coverage that is needed to monitor interaction rates. In addition, we aim to assist in the development of vessel video monitoring systems being developed for the SESSF by AFMA, which may provide additional data on bycatch rates. There will be a high level of transfer and extension in this phase that will result from working both with industry and managers.

2. Development and assessment of methods for mitigating sea lion interactions with demersal gillnets

There has been some recent success in the use of acoustic deterrents or ‘pingers’ on demersal gill nets to reduce the incidence of seal bycatch in some northern hemisphere fisheries. No comparable data exists for assessing the appropriateness of this method for reducing the incidence of seal bycatch in southern fisheries or with fur seals and sea lions. We will undertake controlled experiments to assess the efficacy of ‘pingers’, and follow up with industry trials if they produce promising results. Again, technology transfer and extension will be enhanced through direct collaborations with industry and managers.

3. Development and assessment of methods for mitigating sea lion interactions with RLF pots

The aim here is to follow a similar approach used in the development of pot-protection devices for the western rock lobster fishery. We will initially asses the nature of seal/lobster-pot interactions using underwater video trials at sea lion colonies, and follow-up these with trials to test the effectiveness a range of pot-protection/bait protection options. We will then incorporate these into industry trials to assess how different protection systems may effect size selectivity and catch rates. The aim is to develop an effective and cheap pot-protection system that eliminates seal bycatch and seal poaching of catch and bait, does not impact on size selectivity or catch rates and can be effectively transferred and extended to industry. Technology transfer and extension with industry will be enhanced by undertaking pot-trials with industry collaboration.

4. Development of spatial tools based on seal foraging and fishing effort to evaluate different risk-management scenarios for reducing sea lion bycatch in both fisheries

The pilot risk assessment study (2005/077) went some way in developing generic spatial tools to assess the potential risk-reduction (risk of extinction) benefits that could arise from a range of spatial management options in both the gillnet SESSF and SA RLF. Further development is required to, as current models are limited by the absence of detailed data on the foraging movements of sea lions in some high risk regions, as well as the absence of depth stratified fishing effort data at an appropriate spatial scale. Satellite tracking of sea lion subpopulations identified as high-risk will be undertaken, to improve the accuracy of spatial foraging models. These will be analysed at finer spatial resolutions with depth-stratified fishing effort data, to produce enhanced spatial tools for risk assessment. Such tools will provide a simple spreadsheet approach for policy makers and managers enabling them to evaluate the benefits and costs of different spatial allocation of fishing effort, in terms of increasing or decreasing the risk from extinction of sea lion subpopulations as a consequence of fishery bycatch.

RESEARCH CAPABILITY AND EXPERIENCE

Identify up to 5 notable publications.

Hamer, D.J., and Goldsworthy, S.D. (2006) Seal-fishery interactions: identifying the environmental and operation aspects of a trawl fishery that contribute to bycatch and mortality of Australian fur seals (*Arctocephalus pusillus doriferus*). *Biological Conservation* 130: 517-529

Shaughnessy, P. D., McIntosh, R. R., Goldsworthy, S. D., Dennis, T. E., and Berris, M. (2006). Trends in abundance of Australian sea lions, *Neophoca cinerea,* at Seal Bay, Kangaroo Island, South Australia. In 'Sea Lions of the World'. (Eds A. Trites, S. Atkinson, D. DeMaster, L. Fritz, T. Gelatt, L. Rea and K. Wynne). pp 37-63. (Alaska Sea Grant College Program, University of Alaska: Fairbanks, Alaska). pp. 325-351.

Goldsworthy SD (2006) Maternal strategies of the New Zealand fur seal: evidence for interannual variability in provisioning and pup growth strategies. *Australian Journal of Zoology* 54(1): 31-44.

Goldsworthy SD, Bulman C, He X, Larcombe J, and Littnan C (2003) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales N, Hindell M, and Kirkwood R. (eds) Marine Mammals and Humans: Fisheries, tourism and management. CSIRO Publications. Pp. 62-99.

Goldsworthy, S. D., He, X. Lewis, M. , Williams, R. and Tuck, G. (2001) Trophic interactions between Patagonian toothfish, its fishery and seals and seabirds around Macquarie Island. *Marine Ecology Progress Series.* 218: 283-302

Identify up to 5 of the most recent research grants.

2006 - National Heritage Trust/Marine Species Recovery Protection. Foraging Ecology and diet analysis of Australian sea lions. Goldsworthy, Hamer, Peters ($81,763).

2006 - National Heritage Trust/Marine Species Recovery Protection. Developing population monitoring protocols for Australia sea lions. Goldsworthy, Shaughnessy, Page, McIntosh, McKenzie, Dennis ($44,000).

2005 - Fisheries Research Development Corporation (FRDC) - Establishing ecosystem-based management for the SA pilchard fishery: developing ecological performance indicators and reference points to assess the need for ecological allocations. Ward, Goldsworthy, Okey ($799,999).

2005 - Fisheries Research Development Corporation (FRDC). Interactions of the South Australian southern rock lobster and Commonwealth southern shark fisheries with fur seals and sea lions. Goldsworthy, Ward, Linnane, Sloan & Hamer ($19,999).

2004 - Fisheries Research Development Corporation (FRDC). Innovative solutions for aquaculture planning and management: addressing seals interactions in the finfish aquaculture industry. Goldsworthy, Cartwright & Shaughnessy ($494,479).

Grants received: 80 career grants, totalling over $3.45 million.
Publications: 50 published papers, 7 published reports, 50 conference papers
Students supervised: 15 PhD (5 completed, 1 submitted, 9 current), 10 Honours (9 completed all 1st class).

10 BENEFITS AND ADOPTION

This project forms a pilot study for a previous proposal submitted to the FRDC, and a proposal recently approved (2007/041). The pilot study has been useful in identifying the key seal/fishery issues associated with the SARLF and gillnet sector of the SESSF, and these form the basis of the FRDC funded project 2007/041. This project is primarily focused on Australian sea lions, and specifically on

- developing and assessing gear modification options for mitigating bycatch in both fisheries, on
- identifying the levels of bycatch in high-risk MFAs of the gillnet sector SESSF, on the
- development of spatial management tools to assess the different risk-reduction options in the gillnet sector of the SESSF, and in the
- development of performance measures to assist evaluation of the effectiveness of bycatch mitigation options developed.

The benefits of adopting the recommendations detailed in this report and in supporting future research will be:

- o the development, and industry and management adoption of mitigation options to reduce seal bycatch in both the SARLF and gillnet sector of the SESSF,
- o addressing the outstanding ESD recommendations detailed in fishery ESD assessments,
- o mitigation of the key threatening process identified in the Australian sea lion Draft Recovery Plan
- o recovery of the Australian sea lion, and potential future delisting of the species as *Threatened*.

In addition, as the southern rock lobster fishery in Victoria and Tasmania also has seal interactions issues (primarily with Australian fur seals), pot-protection measures developed as part of this research will be transferable to these sectors of the fishery.

The major beneficiaries will be the gillnet sector SESSF and SARLF, natural resources managers (PIRSA Fisheries, AFMA, Commonwealth DEH, SA DEH), fisheries and marine mammal biologists and the Australian community. All will benefit from the knowledge of the significance and role of fishery bycatch on seal populations. Furthermore, future development of mitigation methods and technologies will greatly assist in implementing ESD objectives in the southern rock lobster and southern shark fisheries, will assist environmental accreditation to enhance market opportunities for the fisheries, assist in the recovery of the Australian sea lion and assist in achieving benchmarks in ecosystem-based fisheries management.

11 FURTHER DEVELOPMENT

An FRDC proposal developed from the findings of the pilot study has recently been approved for funding (2007/041). It will form a comprehensive research and development program to develop mitigation options to manage seal bycatch issues in the SARL and gillnet SESSF fisheries.

The proposal was developed with extensive stakeholder consultation. Findings of the pilot study, and the objectives and details of the aims of the FRDC project being developed were presented to both the southern and northern zone FMCs of the SARLF, and to the GHATMAC. Ongoing consultation is progressing with PIRSA Fisheries, AFMA, Commonwealth and SA DEH and SharkRAG.

12 PLANNED OUTCOMES

The projects outputs have contributed to the planned outcomes by undertaking a pilot study to identify the research required to ensure that SA rock lobster and the gillnet sector SESSF fisheries are managed according to ESD principles, and that interactions with protected species (in this case seals) are measured, assessed and mitigated.

This pilot study has achieved this:

1. assessing the nature and extent of seal-fishery interactions based on fishery logbook and other information sources; by
2. undertaking a desktop risk-assessment based on historical catch and effort data, and information on the location and size of seal populations;
3. reviewing of the management responses related to the protected species interactions with similar species and fisheries on a global scale; and
4. developing an FRDC research proposal based on findings of the pilot study that has recently been approved for funding (2007/041).

13 CONCLUSIONS

Recent ESD assessments of the SARLF and SESSF fisheries have identified interactions with protected species (particularly seals), as one of the key bycatch issues. These issues are especially pertinent in SA waters where the majority Australia's New Zealand fur seals (NZFS) and endemic and *threatened* Australian sea lion (ASL) populations occur, and where un-quantified interactions between seals and the SARLF and gillnet sector of the SESSF are known to occur. Recommendations from fishery ESD Assessments, fishery Bycatch Action Plans, and a recently drafted Recovery Plan for the ASL, have all identified the importance of assessing and mitigating interactions between seals and commercial fisheries. In response to these, the objectives of this study were to:

1.Synthesise and review the PIRSA and AFMA fishery logbooks for the SARLF and gillnet sector SESSF fisheries for reports of interactions with seals.

2. Undertake a desktop risk assessment of seal-fishery interactions in the SA Rock lobster and gillnet sector SESSF fisheries, based on distribution of catch and effort in proximity to seal populations.

3. Review the management responses related to protected species interactions with similar species and fisheries on a global scale.

4. Develop a proposal for a comprehensive study to assess the level and nature of interactions between seals and the SARLF and gillnet sector SESSF fisheries, including the development of guidelines for measuring the performance of systems for monitoring, assessing and mitigating interactions between the fisheries and seals.

A review of the PIRSA and AFMA fishery logbooks identified the major constraint to the assessment of bycatch risk to seal subpopulations; this was the absence of quantitative data on bycatch rates in both the gillnet sector SESSF and SARLF. Anecdotal evidence and entanglement data suggest there has been significant under-reporting of seal interactions in these fisheries.

Population viability analysis (PVA) was undertaken on subpopulations of both seal species. Results for ASL subpopulations reinforce the recent listing of the ASL as a *threatened* species, by identifying that large numbers of subpopulations have very low pup production and are vulnerable to extinction. PVA simulations suggest that in the absence of anthropogenic mortality, a number of ASL subpopulations will become *quasi-extinct*, and in the face of sustained but small additional anthropogenic mortality (eg. fishery bycatch), most other small subpopulations will become *quasi-*

extinct, and negative growth will become a feature of even the largest subpopulations. That the large number of small ASL subpopulations are a consequence of systemic subpopulation declines, that may be attributable to fishery bycatch in gillnet and trap-fisheries is a hypothesis that requires urgent attention.

The risk of bycatch to both ASL and NZFS subpopulations were assessed based on estimates of the probability of interaction with each fishery. These risks were a function of the extent to which fishing effort and seal foraging effort overlap in space and time. ASL showed the highest risk of significant depletion and quasi-extinction as a result of fishery bycatch. In contrast, the risk that SA subpopulations of NZFS would be significantly depleted was very low. By combining PVA outcomes with bycatch scenarios based on interaction probabilities, this study has identified the subpopulations, regions and fishery MFAs that are likely to be most significant in terms of bycatch in each fishery.

Of the two fisheries investigated, the most significant in terms of bycatch of ASL is likely to be the gillnet SESSF, because of 1) almost complete spatial overlap in fishing effort with ASL foraging effort, 2) a year-round fishery with relatively high fishing effort, that 3) can potentially target all ASL age-classes. The impact from SA RLF is likely to be less because 1) there is less overlap in fishing effort with ASL foraging effort, 2) fishing is restricted to eight months of the year, and 3) bycatch is likely to be restricted to pups and juvenile seals. However, the potential additive and interactive impacts posed by combined bycatch in these fisheries could be significant, especially for ASL.

Results from this study suggest the two fisheries investigated lend themselves to different mitigation approaches to address seal bycatch issues. In the gillnet SESSF, gear modification options are limited, but spatial management of fishing effort may provide a range of risk-reduction options to management. This would need to be coupled with independent observer effort to demonstrate and justify the benefits from different closure options. In contrast, there are significant options for gear modification in the SARLF, with pot-protection devices already used in some parts of the fishery. Quantitative testing of these and alternative protection measures (as is taking place in the WA WRLF), and industry wide adoption of best-mitigation practices may eliminate seal bycatch, without the need for an expansive and costly independent observer program. Recommendations for future research are presented, along with a preliminary research proposal for follow-up FRDC funding (2007/041).

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16 LIST OF ACRONYMS

AFMA	Australian Fisheries Management Authority
ASL	Australian sea lion
DEH	Department of the Environment and Heritage
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
ESD	Ecologically Sustainable Development
MFA	Marine Fishing Area
NZFS	New Zealand fur seal
PIRSA	Primary Industries and Resources South Australia
PVA	Population Viability Analysis
SA	South Australia
SARLF	South Australian Rock Lobster Fishery
SESSF	Southern and Eastern Scalefish and Shark Fishery

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