INNOVATIVE SOLUTIONS FOR AQUACULTURE PLANNING AND MANAGEMENT

PROJECT 2004/201

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Government of South Australia
Primary Industries and Resources SA

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Addressing seal interactions in the finfish aquaculture industry

Innovative solutions for aquaculture planning and management: addressing seal interactions in the finfish aquaculture industry

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1 NON TECHNICAL SUMMARY

2004/201	Innovative solutions for aquaculture planning and management: addressing seal interactions in the finfish aquaculture industry

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OBJECTIVES

1. Assess the nature and extent of interactions between seals and finfish farms in the Port Lincoln region, to provide a baseline against which future changes can be assessed.
2. Determine the distribution of foraging effort of seal populations in proximity to existing finfish aquaculture farms off the southern Eyre Peninsula.
3. Determine the distribution of foraging effort of seals, relative to the distribution of breeding and haulout sites off the west coast of the Eyre Peninsula in regions currently zoned for finfish farms, but where none currently exist.
4. Develop strategic GIS tools to assist in planning finfish aquaculture sites to minimise the costs of interactions to industry, and risks to seal populations and make specific recommendations on the positioning of finfish farms relative to seal colonies, seal haulout areas and seal foraging grounds.

OUTCOMES ACHIEVED

This report provides information on the behaviour of Australian sea lions (ASL) and New Zealand fur seals (NZFS) that breed in close proximity to current or proposed aquaculture lease sites. Information on the behaviour of ASL at these sites is needed to manage the South Australian aquaculture industry in accord with the principles of Ecologically Sustainable Development (ESD). Information will be used to minimise the incidence of interactions between ASL and aquaculture operations. Specifically, the information will assist in the zoning, placement and management of finfish aquaculture developments in South Australia.

The broad aims of this study were to provide information on the foraging zones of seals, and the location of breeding colonies and haulout locations in the Eyre Peninsula region of South Australia, to assist in the zoning, appropriate placement and management of future finfish aquaculture developments in South Australia. In addition, the study aimed to evaluate the nature and extent of seal/fish-farm interactions through observation and satellite tracking; assess the nature and extent of interactions between seals and finfish farms in the Port Lincoln region to provide a baseline against which future changes can be assessed; and to provide information on the foraging behaviour of Australian sea lions (ASL) in the Nuyts Archipelago where, at the commencement of the study, finfish aquaculture was proposed, but none existed. The project provides recommendations on how finfish farmers may minimise interactions between seals and their farms, information and recommendations to assist management and policy, and to guide future research.

Objective 1

Tuna farmers participated in a questionnaire to determine the types of equipment used on farms to deter seals and assess the nature and extent of seal interactions. A questionnaire survey of tuna farmers confirmed that operational interactions with seals were a continuing problem, although there were opposing views on whether interaction rates were increasing or decreasing. The most significant outcome from seal attacks at finfish cages was the death of stock, followed by stress and damage to fish and associated financial losses. Australian sea lions were considered to be responsible for most attacks on tuna and for most interactions that caused stress. New Zealand fur seals (NZFS) were seen frequently around cages and within them and resting on the pontoons. Fur seals were not considered a threat to farmed tuna, because they were mostly juveniles and therefore too small to attack them successfully. They were most likely taking advantage of baitfish fed to the tuna, were targeting smaller scavenger fish at the cages, or were concentrating their efforts on attacking farmed kingfish or mulloway within Boston Bay. To mitigate against seal attacks, finfish farmers use seal fences (1.8–1.9 m high) constructed of nylon netting hung from stanchions attached the polar circle pontoons. Electric fences were used by some farmers since 1996, but few are used now.

Surveys were undertaken at finfish cages during the day and at night to determine the rates of seal sighting, and to provide a baseline against which changes in the abundance and activity of seals around finfish cages can be assessed. Some finfish farmers provided mortality records of stock recovered by divers and in many cases were able to determine if the cause of death was due to seal attack. These records suggested that the impact from seal attacks varied considerably among companies, with up to 14 % of yearly mortalities attributable to seals.

Objectives 2, 3 and 4

Based on satellite tracking studies of ASL at Dangerous Reef, near Port Lincoln, there was limited spatial overlap in the major areas used by seals and the tuna farming zone. Sea lions utilised a large and diverse range of marine habitats, and there was evidence for some seasonal difference on the distribution of foraging effort. Data from juveniles, adult females and males were collected. Extensive tracking was also undertaken in the Nuyts Archipelago from six colonies all with a 40 km radius. There were marked inter-colony differences in foraging behaviour, and evidence for two broadly different foraging ecotypes, shallow inshore and deep offshore foragers. Results suggest that universal parameters of foraging are unlikely to be appropriate in this species, due to the high-level of inter-colony variation and specialisation identified. The presently recommended aquaculture buffer zones around ASL (15 km for large and 5 km for small colonies) represented a small fraction of foraging space of populations, and may be of limited value in reducing the potential prevalence of aquaculture interactions and in protecting critical foraging habitats of ASL populations.

The study provides the most comprehensive appraisal of the status of ASL populations in southern Spencer Gulf and the Nuyts Archipelago, and identifies several new breeding populations.

Summary of recommendations

This study provides several management recommendations. Procedures for minimising finfish mortality from seals should be included in the management plans of tuna farms and other finfish species. These should include:

- incorporation of seal fences on pontoons
- regular and frequent net maintenance, including repair of holes
- regular and frequent removal of tuna carcasses (these may attract seals).

Efforts should be made to improve procedures for recording causes of death of farmed finfish. This could be done through a training scheme for divers so that attacks by seals are properly identified in a consistent manner across industry. In addition, animal husbandry standards at finfish farms should be improved to reduce fish mortality. The process of reporting back to industry by PIRSA Aquaculture should include an indication of how companies are progressing with regard to managing mortalities attributable to seal attacks. Mortality assessment is probably the most cost-effective performance measure to monitor changes in the level of seal attacks, the effectiveness of mitigation procedures that are written into management plans and the costs associated with seal interactions. It would provide a means to monitor variation in the rates of seal interactions among regions, lease sites and companies.

New technologies for caging kingfish and mulloway should be investigated. Options for consideration should include the use of heavy duty net material, steel cages (particularly for the raceways, where fish are held prior to harvesting), and incorporation of stainless steel ‘rub rings’ in the nets through which the feed-cage ropes pass (to prevent formation of holes caused by chafing).

With respect to management recommendations for the future siting of finfish farms relative to seal colonies, tracking results across many different colonies and age/sex categories indicate that universal proximity recommendations may be inappropriate, and where possible, colony based assessment of critical foraging habitat and movement corridors should be undertaken.

Recommended research includes:

- fish mortality forensics and industry training to assist accurate identification of seal caused mortality of fish, and the development of industry and management performance indicators;
- assessment of the risk of new farm systems to threatened ASL (eg. sea cage technology for abalone),
- use of seal traps and new GPS tracking technology to target seals that interact with finfish farms.

KEYWORDS: Australian sea lion, *Neophoca cinerea*, finfish aquaculture, marine planning, southern bluefin tuna, yellowtail kingfish, mulloway, aquaculture management

2 BACKGROUND

Innovative Solutions for Aquaculture Planning and Management

Finfish aquaculture is the single most valuable sector of South Australia's aquaculture industry, and is likely to see continual growth in the near future. Southern bluefin tuna (*Thunnus maccoyii*) farming is well established in the Port Lincoln region, and there is currently provision for expansion of the farming of yellowtail kingfish (*Seriola lalandi*) and mulloway (*Argyrosomus hololepidotus*). In response to this the Aquaculture Primary Industries and Resources SA has been revising the management plans for a number of present and potential aquaculture areas.

The Fisheries Research and Development Corporation and Primary Industries and Resources SA coordinated several Innovative Solutions for Aquaculture Planning and Management projects, with a significant amount of that research aimed to benefit the seafood industry in Port Lincoln. Innovative Solutions for Aquaculture Planning and Management has delivered results through research findings being integrated into the decision-making processes that are associated with aquaculture zoning, parasite control and managing interactions with protected wildlife species.

Seal finfish aquaculture interactions

Given the growth in the finfish aquaculture industry, considerable efforts have been made to address zoning issues, particularly with respect to farm placement in relation to sensitive marine habitats and areas of significant biodiversity that may form part of future Marine Protected Areas. The south and west coasts of Eyre Peninsula are highly significant in terms of seal populations, with about 45 % of the world-wide population of the Australian sea lion (ASL) (*Neophoca cinerea*) (Australia's only endemic seal species), and 46 % of Australia's New Zealand fur seal (NZFS) (*Arctocepahlus forsteri*) population occurring in the region (Goldsworthy et al. 2003). As a consequence, the area has the highest concentration of seal colonies in Australia (25 ASL and 10 NZFS colonies).

Finfish aquaculture farms are known to pose a risk to seals in terms of entanglement, and their interactions with farms (damage to gear and stock predation) can also pose significant economic costs to operators (Kemper and Gibbs 1997, Kemper et al. 2003, NSSG and Stewardson 2007). In the Pacific Northwest of the USA, finfish aquaculture farms have been exposed to heavy predation by seals that have resulted in significant losses and reduced market value of fish (Nash et al. 2000). In addition, operators have had to incur significant financial costs from the development of anti-predator nets and increased maintenance and labour. The aquaculture industry in the Pacific Northwest reported that seals became less fearful of humans, which has resulted in more damage to servicing facilities (Nash et al. 2000). Globally, the aquaculture industry suffers an estimated 2–10 % loss in gross production due to predation by marine mammals, with 12 % of insurance claims related to predation and damage caused by seals (Morris 1996, Nash et al. 2000, Sunderland Marine Mutual Insurance Company Limited 2000).

In Australia, most of the information on seal-fish farm interactions is available from salmonid farming in Tasmania, but some information is available for tuna farming in South Australia. Seal interactions were common in Tasmania four years after the salmonid farming industry had become established and by the late 1980s, were estimated to cost individual lease holders between $10,000–175,000 per year (Pemberton and Shaughnessy 1993, Kemper et al. 2003). These interactions included direct predation of farmed fish, loss of fish through torn nets, stress-related reduced feeding rates of stock due to seal presence, entanglements (Pemberton and Shaughnessy 1993, Kemper et al. 2003) and injury to personnel (one incident in 2000,). These interactions involved almost exclusively male Australian fur seals (*Arctocephalus pusillus doriferus*), with most attacks occurring at night.

Vulnerability of salmonid farms in Tasmania was initially strongly influenced by distance to fur seal haulout sites, with sites within 20 km having ten-fold the number of attacks as those 40 km away. However, after industry expansion in the mid-1990s, distance to seal haulout location from farms ceased to influence the number of seal attacks (Pemberton and Shaughnessy 1993, Kemper et al. 2003). There is currently little documented information about the nature and extent of seal interactions with tuna farms at Port Lincoln. From anecdotal reports, most seals interacting with the farms appear to be ASLs, but NZFS are also sighted (Pemberton 1996, NSSG and Stewardson 2007). In addition, most (86 %) seal carcasses retrieved from farms in the Port Lincoln region since finfish aquaculture was established have been ASL (Kemper and Gibbs 1997). New Zealand fur seals have previously been thought to be the main species responsible for predation attempts on farmed tuna because of their ability to climb over handrails and enter cages (NSSG and Stewardson 2007). Like seal interactions in Tasmania, seal activity around the finfish farms at Port Lincoln became more common about four years after the industry was established (Pemberton 1996). The relationship between seal activity around farms and their proximity to seal colonies, haulout areas and important feeding grounds is unclear. There is currently no data available to indicate whether the number and type of seal interactions have changed since finfish aquaculture was introduced to the Port Lincoln region in the early 1990s.

The study by Pemberton and Shaughnessy (1993) has often been used as an argument against finfish farms in South Australia. Based on the Tasmanian study, some groups suggested that there must be high levels of interactions and a pattern of increased interactions relative to proximity to farms. As such it has often been argued that finfish farms should not be located within 20 km of seal colonies. However, anecdotal evidence from finfish farms in South Australia suggests that the nature and extent of interactions described by Pemberton and Shaughnessy (1993) in Tasmania are not typical of the South Australian situation. This may not be surprising given the significant improvements to finfish farming practices since the 1980s when Pemberton and Shaughnessy (1993) undertook their investigation, as well as differences in the 2 situations. These include:

- Improved cage technologies (Schotte and Pemberton 2002)
- Different seal species involved (ASL and NZFS compared with Australian fur seals).
- Most finfish farms are stocked for only six months of each year in Port Lincoln, compared with year-round in Tasmania.

Given the differences between the nature and extent of seal interactions within the finfish aquaculture sector in Tasmania and South Australia, management practices used in Tasmania may not be suitable for the South Australian Aquaculture industry. Investigation into the appropriate management strategies to address seal interactions in the South Australian aquaculture industry is therefore required.

This project addresses issues associated with planning for the expansion of the marine finfish farm sector in South Australia, and investigates the foraging behaviour of ASL to inform the aquaculture planning processes. This information may assist in the development of appropriate policies that minimise seal and aquaculture interactions in future. Planning the location of finfish aquaculture developments to take into account the location of seal colonies, haulout areas and important foraging regions could prevent or reduce costly interactions in future. There has been significant effort in recent years to document the location of seal breeding colonies in South Australia and census their populations, but there is still considerable uncertainty in the status and trends of seal populations, particularly for the ASL in the region.

No data are available on the distribution of foraging effort of ASL or NZFS in the Eyre Peninsula region. The extent to which the foraging grounds of these seals overlap with current and planned finfish aquaculture developments is unknown. There is very little data on the nature and extent of seal interactions with existing fish-farms, and on the gear/mitigation technologies and methods that are in use by industry to reduce seal interactions.

Background to seal species

Australian sea lions (ASL)

The ASL is one of five sea lion species in the world. Sea lions form around one-third of species in the otariid family of seals, which includes all of the fur seals and sea lions. Over recent decades there has been growing concern over the status of all five sea lion species. In the North Pacific Ocean, the Steller sea lion, *Eumetopias jubatus*, has been declared endangered in parts of its range and is considered threatened with extinction in other parts (Trites et al. 2007). Although the population of California sea lions *Zalophus californianus* in California is increasing (Carretta et al. 2004), the Mexican stock is in decline (Szteren et al. 2006). There have also been reductions in numbers of the Galapagos subspecies of the Californian sea lion, *Z. c. wollebaeki* (Alava and Salazar 2006) and the Japanese subspecies, *Z. c. japonicus,* is likely to be extinct (Mate 1982). Numbers of South American sea lions, *Otaria flavescens*, have reduced considerably in recent years (Crespo and Pedraza 1991, Reyes et al. 1999, Shiavini et al. 2004), especially in the Falkland Is (Thompson et al. 2004). Numbers of New Zealand sea lions, *Phocarctos hookeri* (Lalas and Bradshaw 2003) and ASL (McKenzie et al. 2005) have not recovered from historic sealing and form the smallest populations of all sea lion species.

The ASL is Australia's only endemic and least-abundant seal species. It is unique among seals in being the only species that has a non-annual breeding cycle (Gales et al. 1994). Furthermore, breeding is temporally asynchronous across its range (Gales et al. 1994, Gales and Costa 1997). It has the longest gestation period of any seal, and a protracted breeding and lactation period (Higgins and Gass 1993, Gales and Costa 1997). The evolutionary determinant of this atypical life-history are not known. Recent population genetic studies have indicated little or no interchange of females among breeding colonies, even those separated by short (20 km) distances (Campbell 2003, Campbell et al. 2007). The important management implication of extreme levels of female natal site-fidelity (philopatry) is that each colony effectively represents a closed population.

There are 73 known breeding locations for ASLs, 47 of which are in South Australia where the species is most numerous (80 % of pups counted), with the remainder (26 colonies) occurring in Western Australia (McKenzie et al. 2005). The species was subject to sealing in the late 18th, the 19th and early 20th centuries, resulting in a reduction in overall population size and extirpation of populations in Bass Strait and other localities within its current range. Total pup production for the entire species during each breeding cycle has been estimated at about 2,500 with an estimated overall population size based on a demographic model developed by Goldsworthy et al. (2003), of around 9,800 (McKenzie et al. 2005). A re-analysis of this demographic model, in conjunction with improved estimates of pup production for some sites, has increased estimates of the SA pup production to about 2,700 per breeding cycle and the size of the ASL population in SA to about 10,900 individuals (Goldsworthy and Page 2007). Based on pup production estimates of 709 for WA sites (Goldsworthy et al. 2003), the total pup production for the species is currently estimated at about 3,400 per breeding cycle, with an estimated overall population estimate of around 14,000 (Goldsworthy unpublished data). The life tables associated with the population model produced population estimates that were 4.08 times that of pup production (Goldsworthy and Page 2007), which is about mid-point of the range expected for seal populations (Harwood and Prime 1978).

There are 39 ASL breeding sites in SA, when the criterion for classification as a breeding colony is set at ≥ 5 pups present per breeding cycle (McKenzie et al. 2005, Fig. 2.1). Of these, only six (16 %) produce more than 100 pups, and these account 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 Is and mainland Australia. The next largest populations are Seal Bay (214 pups) on Kangaroo Is, West Waldegrave (157 pups) and Olive Is (131 pups) off the western coast of the Eyre Peninsula, and Purdie Is (132 pups) in the Nuyts Archipelago (summarised in Goldsworthy and Page 2007). The median pup production for SA colonies is 25.5 per colony, with 60 % of breeding sites producing fewer than 30 pups per season, 42 % fewer than 20 pups, and 13 % fewer than 10 pups (Goldsworthy and Page 2007). These analyses do not take into account at least another 11 breeding sites (termed 'haulout sites with occasional pupping'), where fewer than 5 pups have been recorded at some time (McKenzie et al. 2005).

The ASL is listed under both the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act)* as *Threatened*, in the *'Vulnerable'* category, and as 'rare' under the South Australian *National Parks and Wildlife Act 1972*. The ASL is also protected under the *Fisheries Management Act 2007*. A recovery plan for ASL was drafted by the Australian Government in 2005. The IUCN listed ASL as *Endangered* in October 2005.

Although the pre-harvested population size of the ASL is unknown, the overall population is still believed to be in recovery. Unlike Australian fur seal and NZFS populations, which have been recovering rapidly throughout southern Australia over the last 20 years, there is a general view that recovery of the ASL population has been limited, and it is unclear why.

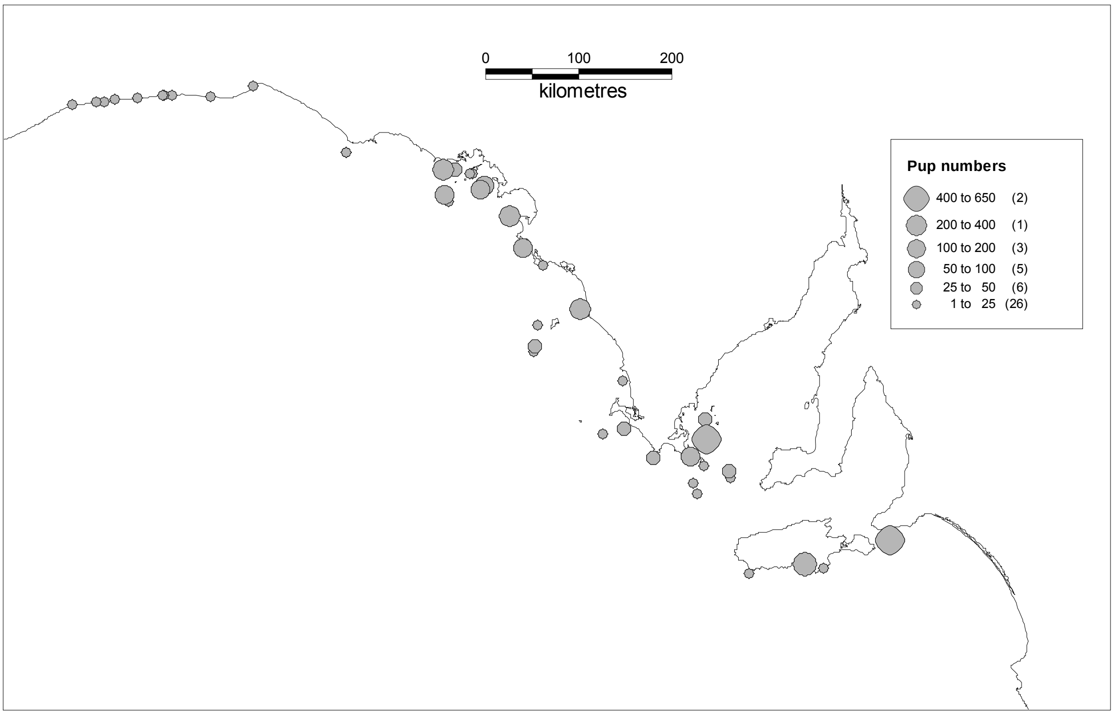

Fig. 2.1. Location and relative size of ASL breeding colonies in South Australia (grey circles are scaled based on pup production per breeding season).

New Zealand fur seals (NZFS)

The NZFS 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 and Shaughnessy 1994; Shaughnessy et al. 1995). Like most other otariid seals, 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 and Shaughnessy 1994). In SA, the median date of pupping is 21 December (Goldsworthy and 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 lasting 1–2 days when pups are nursed (Goldsworthy 2006). On Kangaroo Is, NZFS primarily feed 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. 2005a). Satellite tracking studies undertaken at Cape Gantheaume, Kangaroo Is, 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, but the species has recently begun recolonising the area (Littnan and Mitchell 2002). In Australia, the 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 and Goldsworthy 2007) (Fig. 2.2).

New Zealand fur seals are relatively abundant in SA, with recent censuses estimating over 17,600 pups born over the 2006/07 breeding season (Goldsworthy et al. unpublished data, Shaughnessy and Goldsworthy 2007), representing about 83 % of Australia's total NZFS population. Most pups are born at the Neptune (48 % of SA's total), Kangaroo (40 % of SA's total) and Liguanea Is (12 % of SA's total) (Fig. 2.2 and 2.3). Ongoing surveys of populations of NZFS on Kangaroo Is have shown that between 1988 (when surveys began) and 2006, populations increased exponentially by about 12.3 % per year (from data presented in Shaughnessy and Goldsworthy 2007). There have been fewer surveys undertaken at the Neptune Is, with current data suggesting population growth rates are about 4.1 % per year, which is lower than on Kangaroo Is. Overall, the rate of increase for populations in SA averages about 6.5 % per year (Fig. 2.3).

The NZFS is a protected species under the South Australian *National Parks and Wildlife Act 1972*, and the Australian Government *Environment Protection and Biodiversity Conservation Act, 1999* (*EPBC Act).* The NZFS is also protected under the *Fisheries Management Act 2007*.

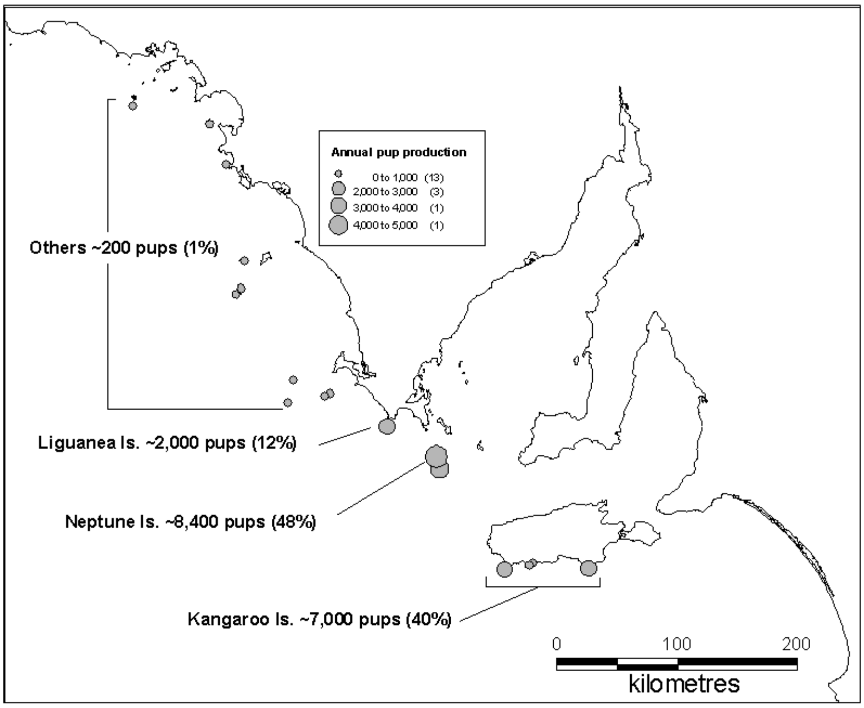

Fig. 2.2. Location and relative size of NZFS breeding colonies (grey circles, based on annual pup production) in South Australia (based on data presented in McKenzie et al. 2005, Goldsworthy and Page 2007, Shaughnessy and Goldsworthy 2007).

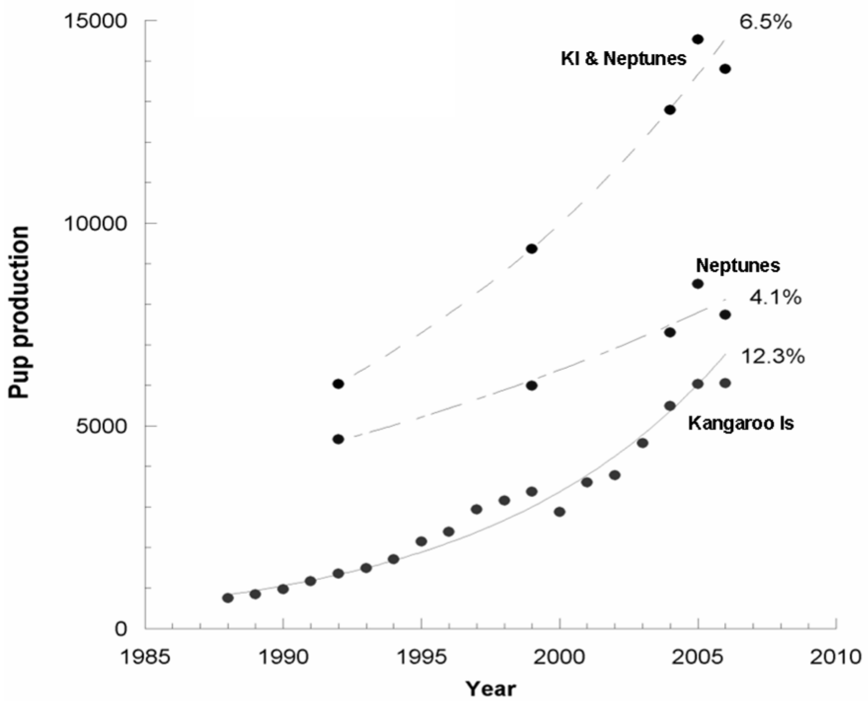

Fig. 2.3. Trends in NZFS pup production on Kangaroo Is (KI) and the Neptune Is between 1988–2006 (trend estimates based on data presented in Shaughnessy and Goldsworthy 2007 and Goldsworthy et al. unpublished data).

Proximity of seal colonies to current finfish aquaculture zones

The approximate distances from the Port Lincoln Tuna Farming Zone (TFZ) to known ASL and NZFS colonies and haulout sites in the southern Spencer Gulf and lower Eyre Peninsula are shown in Fig. 2.4. The figure indicates the occurrence of two haulouts (Donington Reef and Rabbit Is), which are used by both ASL and NZFS, within 10 km of the approximate centre of the TFZ (< 2 km from the nearest lease). The nearest ASL breeding colonies are those at English Is, Dangerous Reef and Langton Is (all 20–30 km from the TFZ). More detailed location information on ASL breeding and haulout sites is presented in Fig. 2.5. There are a number of smaller colonies and haulouts that are located in southern Spencer Gulf between 30–80 km away. The nearest NZFS breeding colony is North Neptune Is (approx 63 km), followed by Liguanea Is (approximately 72 km, shortest straight-line distance) and South Neptune Is (74 km). Collectively, these NZFS colonies produce about 6,500 pups annually (total population ranging from 22,000–29,000), the largest concentration of NZFS in Australia (Fig. 2.2).

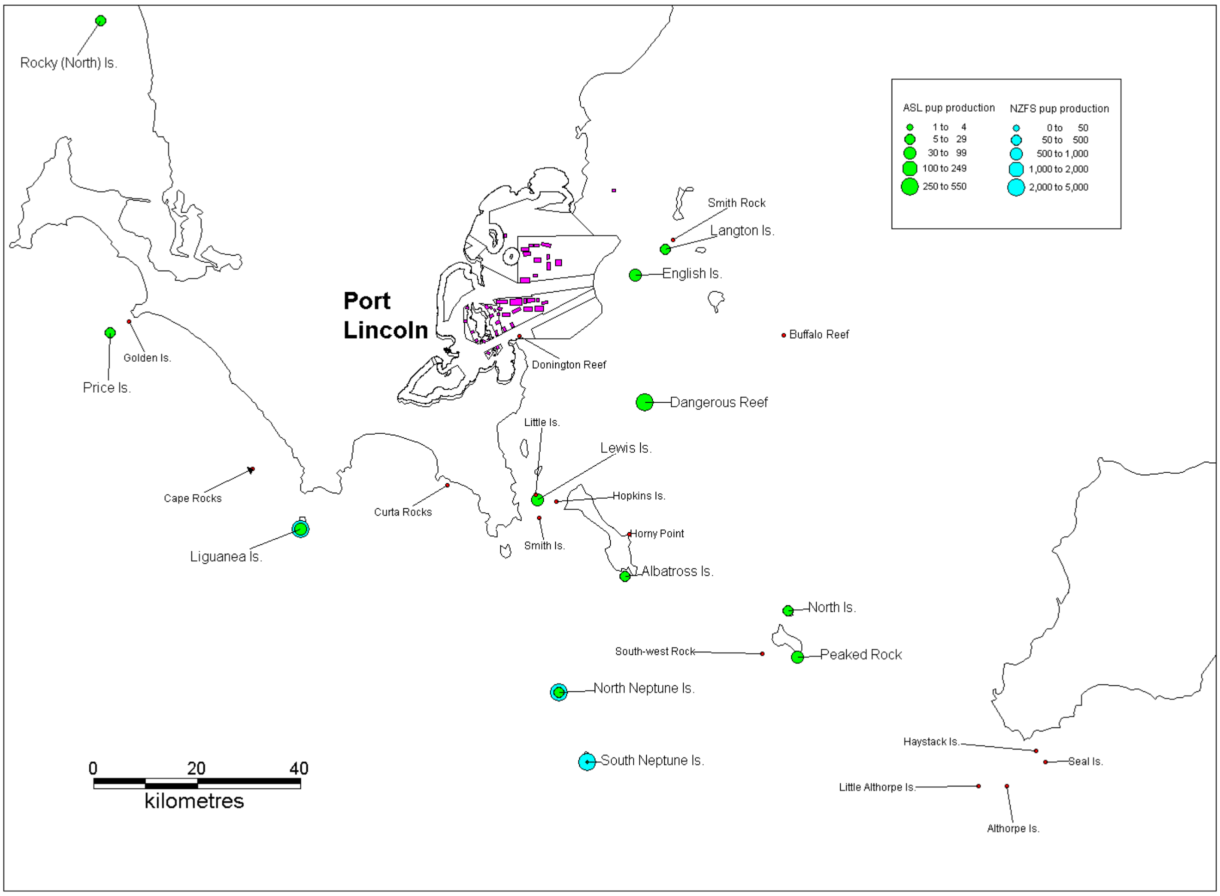

Fig. 2.4. Location and relative size of ASL and NZFS breeding colonies (green circles, based on pup production), and haulout sites (red circles) near the Port Lincoln TFZ. Boundaries of the TFZ are presented as well as the location of lease sites at the time of the study.

Scope of the project

The broad aims of this study were to provide information on the foraging zones of seals, and the location of breeding colonies and haulout locations in the Eyre Peninsula region of South Australia, in order to assist in the zoning and appropriate placement of future finfish aquaculture developments. In addition, the study aimed to evaluate the nature and extent of interactions between seals and marine finfish aquaculture farms through observation and satellite tracking.

This project is explicitly focused at examining the zoning issues for expansion of the marine finfish farm sector in South Australia with respect to seal colonies, haulout areas and foraging regions with the aim of minimising risks to seals and future costs to industry. For the purpose of this study, *seal* refers to NZFS and ASL, unless otherwise stated.

3 NEED

The key needs of this study are as follows:

- Provisions of the Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act)* require assessment of fisheries against the principles of Ecologically Sustainable Development (ESD) including the need to monitor, assess and, if necessary, mitigate the interactions of fisheries with protected species (Fletcher et al. 2002).
- PIRSA Aquaculture Policy Group and the marine finfish aquaculture industries identified a key management need for this industry of improving zoning issues of finfish aquaculture relative to seal colonies and their foraging grounds.
- Marine industry groups expressed a need to reduce and mitigate the negative interactions between seals and finfish aquaculture farms.
- Given the *Threatened* status of the ASL under the Australian Government *EPBC Act and the Endangered* status under IUCN guidelines, community groups such as the Marine and Coastal Community Network have expressed concern about the impacts that marine finfish aquaculture pose to the conservation of seals.
- The South Australian Department for the Environment and Heritage through the Marine Mammal - Marine Protected Areas Aquaculture Working Group, (a sub-committee of the Aquaculture Advisory Group), advise on the policies to allow for appropriate aquaculture development without adversely impacting marine mammals. The research reported here will directly feed into policies involving seal colonies and appropriate aquaculture planning, such as the distance that finfish farms and shellfish farms should be located in relation to seal colonies and important foraging habitats.

- The *National Strategy to Address Interactions between Humans and Seals: Fisheries, Aquaculture and Tourism* (2007), requires government and non-government agencies to:
    - Obtain quantitative and independent data on the nature and extent of human-seal interactions in aquaculture industries
    - Minimise and mitigate adverse interactions between seals and aquaculture industries
    - Develop and implement robust arrangements to report interactions between seals and aquaculture industries
    - Encourage aquaculture industries to embrace stewardship of the marine ecosystem
- Under the Australian Government *EPBC Act*, ASL are listed as *Threatened species* (V*ulnerable category)* and NZFS are listed as *Protected Species*. Both seal species are known to interact with aquaculture operations.

The need is greatest in South Australia, where:

- The majority of populations of ASL occur (~80 % of pup production occurs in this state), and where declining populations have been identified.
- Australia's largest populations of NZFS occur.
- The finfish aquaculture industry is expanding rapidly.

4 AIMS AND OBJECTIVES

The aims and objectives of this project were to:

- Assess the nature and extent of interactions between seals and finfish farms in the Port Lincoln region, to provide a baseline against which future changes can be assessed.
- Determine the distribution of foraging effort of seal populations in proximity to existing finfish aquaculture farms off the southern Eyre Peninsula.
- Determine the distribution of foraging effort of seals, relative to the distribution of breeding and haulout sites off the west coast of the Eyre Peninsula in regions currently zoned for finfish farms, but where none currently exist.
- Develop strategic GIS tools to assist in planning finfish aquaculture sites to minimise the costs of interactions to industry, and risks to seal populations and make specific recommendations on the positioning of finfish farms relative to seal colonies, seal haulout areas and seal foraging grounds.
- Develop recommendations on how finfish farmers may minimise interactions between seals and their farms, and if required, develop a proposal to investigate mitigation options for reducing seal/fish farm interactions.

5 REPORT FORMAT

This report is structured into five sections. Chapter 6 details data gathered on the nature and extent of operational interactions between ASL and NZFS and finfish aquaculture in the Port Lincoln region. Chapter 7 details results from surveys of ASL populations in the above regions. Chapters 8 and 9 provide general descriptions of the movements of ASL. These foraging behaviour chapters detail results from the satellite tracking of ASL, from colonies in proximity to existing and proposed aquaculture sites in southern Spencer Gulf and the Nuyts Archipelago. Recommendations for further research, benefits and adoption, planned outcomes and conclusions are presented in chapters 10–13.

6 OPERATIONAL INTERACTIONS BETWEEN SEALS AND THE TUNA FARMING INDUSTRY IN PORT LINCOLN

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Introduction

Interactions between marine mammals and the tuna farming industry in Port Lincoln were detected soon after establishment of the industry in the early 1990s. They are thought to be a significant contributing factor in the mortality of farmed tuna, and both seals and dolphins have been reported as being entangled and subsequently dying in the netting around tuna farms (Kemper and Gibbs 2001). However much of the information relating to interactions with marine mammals is based on anecdotal reports.

There have been few studies of interactions between seals and finfish farms. The study of seal interactions with the salmon aquaculture industry in southern Tasmania (Pemberton and Shaughnessy 1993) is often referred to in this context, but it is not entirely appropriate to the South Australian situation because the fish species and the seal species differ from those in Tasmania, and there have been significant improvements to finfish farming practices since 1993. The collection and analysis of dolphin and seal carcasses by the South Australian Museum is the only independent source of information relating to marine mammal interactions with tuna aquaculture (Kemper and Gibbs 1997, Kemper and Gibbs 2001). Although specimens collected in that study provided dietary and demographic data, its scope did not include determining the nature and extent of interactions between seals and farmed finfish, or the financial significance of such interactions.

The tuna aquaculture industry evolved to fatten wild-caught stock for export to Japan. Most of the tuna farms are east and northeast of Boston Is. Fish are wild-caught and the growing-out period extends from January/February, when fish are transferred to the cages, until September/October, when harvesting is completed (Fig. 6.1).

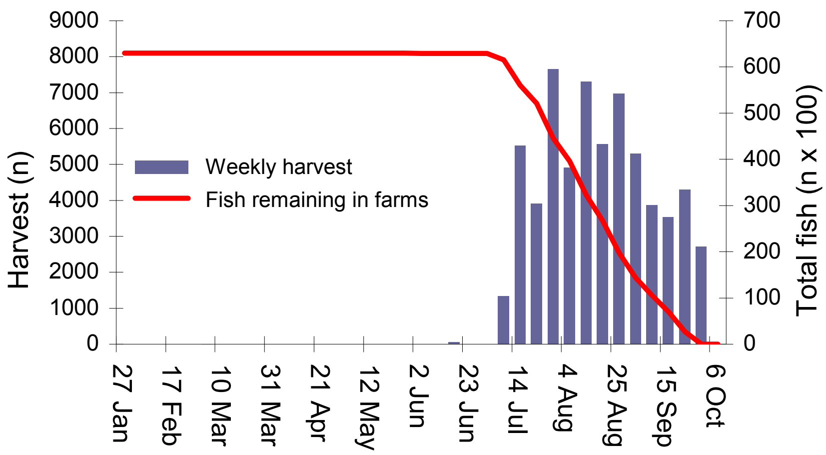


Fig. 6.1. The seasonal trend in the number of tuna held and harvested by one company in the Port Lincoln region during 2005.

More recently, hatchery production and sea-based growing-out of mulloway and yellowtail kingfish for supply to domestic and international market have developed. This form of finfish aquaculture occurs year-round on a smaller scale than tuna aquaculture. It is based primarily at Arno Bay, approximately 120 km northeast of Port Lincoln, although there is one enterprise within Boston Bay, west of Boston Is.

Each year, the finfish aquaculture industry in Port Lincoln experiences financial losses resulting from the death or injury of tuna, kingfish and mulloway before harvesting. Several reasons have been offered to explain these losses, including fatigue and stress related to at-sea translocation to the farm site, starvation, hypoxia, disease, attempted poaching, physical injury caused by the farm structures and interactions with seals. In recent years, as profit margins have reduced, tuna farming companies in the Port Lincoln region have been forced to address causes of mortalities to ensure their companies remain financially viable. In response to the need for better management, techniques for translocation of fish in sea cages have been improved to minimise fish losses due to fatigue, stress and starvation, while stocking densities in farm cages have been reduced to minimise disease, hypoxia and starvation.

The primary structure for containing finfish is a sea cage based on the PolarCirkel design: a nylon mesh net containing the fish is suspended from a single pontoon of large diameter PVC pipe floating at the surface. The tuna cage is approximately 40 m in diameter and between 15–20 m in depth. Various modifications have been made since tuna aquaculture commenced in the Port Lincoln region. In the mulloway and kingfish aquaculture industry, the twin pontoon and plastic upright structures currently used resemble the original design used for farming tuna (Fig. 6.2). Tuna farms have adopted the single pontoon design to withstand harsher environmental conditions experienced in the more exposed waters east and northeast of Boston Is. In recent years, public concern about interactions between seals and aquaculture industries has increased. Aquaculture industries have responded to these concerns by erecting physical barriers such as fences on the pontoons and have improved net maintenance strategies to reduce the likelihood of seals gaining access to fish.

Fig. 6.2. Examples of a typical design used for tuna cages (left – single pontoon with stainless steel 'seal fence' above water) and for mulloway or kingfish cages (right – double pontoon with plastic upright structures). Both examples represent the current designs used by each industry. (Photos: D Hamer).

There are large colonies of both the ASL and the NZFS in the Port Lincoln region (McKenzie et al. 2005, Shaughnessy et al. 1994). The largest ASL colony is at Dangerous Reef, approximately 50 km east of Port Lincoln and about 30 km from tuna farming activity, while the closest NZFS colonies are at the Neptune Is, some 70 km to the south. The finfish aquaculture activities near Port Lincoln are within the foraging range of NZFS and ASL (Page et al. 2006, this report). Although the two seal species have different diets, neither is known to utilise tuna, mulloway or kingfish (Page et al. 2005a, McIntosh et al. 2006). Both seals are likely to be opportunistic foragers and may take advantage of the presence of finfish farming activities in the Port Lincoln region.

The coexistence of finfish aquaculture with large populations of both the ASL and the NZFS provides the potential for 'operational interactions'. Operational interactions typically involve seals and a fishing operation targeting a spatially restricted school of fish (Beverton 1985). In addition, finfish aquaculture provides seals with the opportunity to become habituated to the reliable and continued presence of farmed fish and fish farming operations. The risk of injury or death to seals may not be as great as in active commercial fishing operations, such as trawling (Hamer and Goldsworthy, 2006), because the net of a static finfish cage must be more visible to a seal than a moving trawl net and easier to avoid. Therefore, operational interactions at finfish farms have the potential to result in significant stock losses and an increase in the magnitude of interactions as more individual seals become aware of the benefits of foraging in association with fish-farming operations (Pemberton and Shaughnessy 1993).

During a workshop held with the finfish aquaculture industry at Port Lincoln at the commencement of this study (November 2004), several farm representatives indicated that operational interactions with seals caused significant financial costs to the industry. Anecdotal reports provided at, prior to and since the meeting by industry members suggested that seals harass or directly attack fish in cages, or may simply be present for other reasons within or close to the cages. These interactions may contribute to stress related disease to the fish and to a reduction in growth rates, increased injury or death. The outcome of such interactions may result in a reduction in the number of commercially saleable fish on the international or domestic market, both of which typically demand a high quality, highly presentable product. The high value of individual tuna means that even low levels of attack by seals may result in significant financial costs.

The aims of this project were to: 1) assess the nature and extent of interactions between seals and finfish aquaculture in the Port Lincoln region to provide a baseline against which future changes can be assessed; and 2) develop recommendations on how finfish farmers may minimise seal interactions.

Following the November 2004 workshop with the industry, the aims of this project were approached by:

- Assessing protection measures used at finfish farms.
- Determining industry perceptions of operational interactions between seals and individual farms by means of a questionnaire (Appendix 2).
- Reviewing historical industry records of interactions with seals and fish mortality attributed to seals.
- Assessing the nature and extent of operational interactions with seals, including attacks, based on independent surveys.
- Monitoring the numbers of seals at haulout sites near finfish aquaculture activity to assess their association with the timing of harvesting and their suitability as surrogate indicators of potential operational interactions.

It is unlikely that our current understanding of operational interactions between seals and finfish farms in Port Lincoln is representative, particularly in the absence of quantitative data. In order to provide baseline information and to assist in directing a preliminary quantitative study of the interactions, a questionnaire survey of farms was undertaken (Appendix 2). It was designed to assist in identifying the perceived significance and nature of the problems, what could be done to mitigate them and to seek views on who should be responsible for ongoing monitoring. The last aspect may be particularly important for determining a future framework for assessing the performance of mitigation strategies.

Historical data from industry on the incidence of tuna mortalities due to seal attacks were examined to determine: (i) their geographic distribution, (ii) variation between years or seasons, and (iii) the relative importance of seal attacks in the overall mortality of tuna. In addition to records of seal interactions compiled by industry, an independent observer visited finfish farms to identify the seal species involved and to determine their prevalence. The observer also recorded dolphin numbers for comparison.

In spite of the potential for seals to associate with finfish aquaculture activities in the Port Lincoln region, it is difficult to monitor seasonal movements of the seals. In recent years ASL and NZFS have been noted on Donington Reef at the southern entrance to Boston Bay, between Boston Is and Donington Point. Although this site is near finfish aquaculture, there are no trend data for seal numbers there.

Anthropogenic food sources, such as those provided by finfish farms in the Port Lincoln region, may be important factors in the temporal fluctuations of seal numbers in the region. The tuna industry moves large numbers of wild-caught tuna into the region in January/February. After intensive harvesting, the region is free of tuna from about October until January (Fig. 6.1). The seasonal nature of tuna farming provides an opportunity to investigate the possibility of a relationship between seal numbers and the presence and absence of tuna and with tuna harvesting activity. A positive relationship may imply that seals move into the region to take advantage of the food source offered by the tuna farms.

Methods

Protection measures used at tuna farms

The study focussed on the Port Lincoln finfish aquaculture industry that consisted of 11 companies at the time of the study (2005). Protection measures at farms that aimed to prevent predators (mainly seals) gaining access to fish inside the cages were assessed in two ways. The industry questionnaire (Appendix 2) also provided some historical perspective on how the types of protection measures have changed over time. Secondly, through farm assessments of 46 cages and nets to provide the background of industry-wide use of protection measures.

Questionnaire survey of tuna farm operators

The questionnaire was presented to an official representative (the interviewee) from each of the 11 tuna farming companies based in Port Lincoln during April and May of 2005, after which D. Hamer conducted an interview. There was only one opportunity to conduct a similar interview with a kingfish and mulloway aquaculture company; outcomes of that interview are not considered in this report in order to maintain confidentiality.

The questionnaire addressed the following aspects of operational interactions between seals and the tuna aquaculture industry in Port Lincoln, as perceived by the industry:

- Economic significance
- Temporal trends since tuna farming commenced
- Observed nature of operational interactions, including their effect on the health of tuna, the part of the tuna's body attacked, and the method of cage entry by seals
- Typical outcomes with reference to the growth of tuna and their market value
- Seal species responsible
- Mitigation measures used by industry in the past and at present
- Who should be responsible for coordinating and assessing mitigation strategies.

Each interviewee was asked one or more questions under each of the above categories. The questionnaire was voluntary and each interviewee was given the option to decline commenting on any of the questions. Interviewees were not required to provide their identity, but the responses were considered to reflect the views of the company they represented. Upon completion, each questionnaire with its responses was printed and returned to the interviewee within a week, when amendments and corrections could be provided. A copy of the questionnaire is in Appendix 2.

Seal and dolphin interactions at finfish cages

Counts of seals and dolphins at cages

To record interactions between marine mammals and caged fish, an independent SARDI observer accompanied vessels to farms. For daytime observations, the observer went with randomly selected vessels that were feeding baitfish to caged finfish. Observations of seals and dolphins were made from the highest practicable position on the vessel using the naked eye or 10x50 binoculars. Each cage was observed from as far away as possible while the vessel approached in order to increase the likelihood of detecting marine mammals. Arrival time was recorded when reliable observations began using binoculars. Observations continued while the feed vessel was stationed at a cage. Departure of the vessel toward the next cage marked the end of an observation period.

At tuna cages, there were 489 observation periods during daytime between 23 April and 24 August 2005. Time spent at each cage averaged 18 minutes and varied from 2 to 93 minutes depending on the rate at which tuna were being fed and on other activities.

For night-time observations, the observer accompanied a night security vessel to several tuna farm sites. The vessel was usually stationed close to a cage with its lights off for the entire night, although on a few occasions it moved between farm sites. The vessel typically arrived within the tuna aquaculture area before 1800 hours and departed by sunrise. Between 22 June and 24 July 2005 there were 64 observation periods each of one hour duration. Observations were made with the naked eye, 10x50 binoculars or a night-scope.

At kingfish and mulloway farms, observations were made between 9 December 2005 and 16 February 2006. There were 62 observations, averaging 42 minutes at each cage, and varying from 3 minutes to 2 hours 29 minutes. All but one observation session was during daylight or at twilight.

Numbers of seals and dolphins observed inside and outside cages were recorded for daytime observations. For night-time observations, counting was restricted to outside the cages because the distance of reliable observation was limited. The rate at which animals were observed was calculated and expressed as the number of seals or dolphins per hour. In addition, for daytime observations at tuna farms, the average number of seals observed for each observation period was calculated and numbers inside and outside cages were compared using a paired t-test.

Attacks by seals on caged tuna

After farm representatives completed the questionnaire survey, they were asked to provide historical information on seal-induced tuna mortalities. The data format was not specified in order to minimise inconvenience.

Three of the 11 tuna farming companies provided data about interactions between seals and tuna. One company provided multi-year fish mortality data; they had considered interactions with seals to be very high, but in recent years have viewed the significance of the problem to be low. Previous losses due to seal interactions are likely to have motivated them to keep records in order to detect the performance of mitigation measures. Most of the other companies did not provide this information, because they had not previously quantified the component of fish mortality attributable to seal interactions.

Trends in the abundance of seals near finfish aquaculture

Numbers of ASL and NZFS at Donington Reef were monitored between 22 November 2004 and 17 October 2005 by counting individual animals. Seal numbers were recorded from a small vessel while moving slowly, at approximately 50 m offshore, or opportunistically from tuna feed boats and pilchard purse-seine vessels. The topography of the small islet meant that individual seals were conspicuous and visible from a distance, making it possible to count without having to go ashore.

In addition to total numbers hauled out, animals were grouped into four age/sex categories that are separable on the basis of size and shape: juveniles, adult females, subadult males (SAM, which are similar in size or larger than adult females and are heavier in the shoulders), and adult males (which are much larger). Counts were plotted to detect seasonal variations and regression analysis was conducted to determine the temporal relationship of seal numbers with the number of tuna in the region and with the number of tuna harvested.

Results

Protection measures used at tuna farms

Most tuna cages were 40 m in diameter, with those on one farm being 45 m. Cage depths were 10, 15, 18 or 20 m, and the bottom depth next to the cages varied from 17 to 24 m (average 20.7 m). Nets hung from the pontoons were constructed from nylon. Stainless steel was incorporated in some nylon nets to reduce mesh failure and the associated cost of maintenance and replacement. Seals were thought to take advantage of sub-surface breaches in the mesh, so it was considered that this technology might also reduce the pattern of seal entry at tuna cages. However, this technology proved to be largely unsuccessful, resulting in its subsequent withdrawal from use by most farms.

Seal fences were the major protective measure; they comprised nylon netting attached to stanchions on the pontoons. Mesh size of the netting varied from 4 to 8 inches (102 to 203 mm). Columns on the pontoon that support nylon mesh fences (varied in height from 0.51 to 2.1 m, with most of them being 1.8 or 1.9 m. Some stanchions achieved these heights (1.8 or 1.9 m) with the addition of plastic pipe or metal pipe extensions to the original material. Stanchions were constructed of stainless steel, galvanised iron or moulded plastic. The number of stanchions on a pontoon varied from 31 to 66, with an average of 51. Cage configuration data are summarised in Table 6.1.

Seal fences on three farms were a continuation of the vertical mesh of the cage wall, extending 1.1 to 1.5 m above the pontoon and thus overlapping with the net used specifically for the seal fence. When properly maintained, this design avoided the potential for a gap to form between the top of the cage wall and the bottom of the seal fence. At one farm there were numerous gaps where the cage wall joined the seal fence, which defeated the purpose of the seal fence because the gaps provided seals with opportunities to enter the cage.

Table 6.1. Summary of quantitative data on cages used at finfish farms at Port Lincoln in 2005.

Feature	Mean	Range
Cage diameter	40.7 m	40 – 45 m
Cage depth	15.4 m	15 – 20 m
Water depth	20.7 m	17 – 24 m
Mesh size of cage net	-	102 – 203 mm
Number of stanchions	51	31 – 66
Stanchion height	1.5 m	0.51 – 2.1 m

Note: Stanchions are columns on the pontoon to support a nylon mesh fence, which prevents entry of seals.

Questionnaire survey of tuna farm operators

A summary of each of the questions in the questionnaire is provided in Table 6.2, along with results of the analyses.

Perceived economic significance

The significance of current seal–farmed tuna interactions were graded in seven categories between extremely high and nil. No company considered interactions to be extremely high or nil, although two (18 %) considered them to be very high. Two companies (18 %) thought that interactions with seals were high and two thought they were moderate. Four companies (36 %) indicated that operational interactions with seals at their lease were low although still significant, while one (9 %) thought that interactions were very low. Overall, over half (54 %) of the companies considered operational interactions with seals to be moderate to very high.

Trends over time since tuna farming began

The 11 tuna companies indicated that seal interactions became a problem between 1992 (one company) and 2002 (three companies), with the average year being 1997. Five of the companies (45 %) believed that interactions with seals had increased and five (45 %) perceived a decrease. Only one company (9 %) thought that the level of interactions with seals remained unchanged.

Nature of operational interactions between seals and farmed tuna

Interviewees from each company were asked to identify the nature of interactions between seals and farmed tuna and to rank their relative importance. Seven (70 %) of the 10 respondents considered attacks resulting in death of tuna to be the most significant interaction, followed by stress to the fish and financial loss resulting from stress, damage or death of tuna. Damage to equipment by seals was considered to be relatively rare. While most companies believed that intimidation of farm workers by seals was also rare, five interviewees (45 %) indicated that divers conducting maintenance on cages had reported sub-surface intimidation and harassment by seals.

There are numerous reports and records available indicating that a large number of farmed tuna mortalities are caused by seal attacks. Contract divers provide the majority of these records to the companies in the form of a standardised log sheet. Because accompanying details are rare, it is impossible to determine the accuracy of these reports and the nature of the attack. This is particularly relevant when considering that many of the mortalities are retrieved after a period of at least several hours (often after the fish were dead all night), by which time deterioration caused by lice infestation or scavenging by small fish is likely to have been extensive. In several instances during visits to tuna farms, it was apparent that divers were not fully aware of the nature of the injuries that a seal may inflict on a tuna to cause its death. Instead, divers were using signs that may have been associated with foraging on dead tunas (see below).

Ten of the 11 interviewees (91 %) suggested that attacks on tuna by seals resulted in scarring or flesh removal between the head and first dorsal fin (Fig. 6.3). Attacks behind the first dorsal fin and around the gut region were also noted. There was some speculation and disagreement over whether gut attacks were the actual cause of death, or if they were inflicted post mortem. There was sufficient anecdotal evidence to suggest that both occur, although quantifying the relative proportion of each would be difficult.

The width and depth of bite marks may provide an indication of the age/sex category of the seals responsible for the majority of attacks and for the identity of the species. The broad and deep lacerations on several tuna carcasses that were inspected suggest that large adult male NZFS or adult ASL of either sex may have been responsible. But it is not possible to be more specific in the absence of sufficient data.

Perceptions of mulloway and kingfish farmers were not collected as part of the questionnaire survey, but a number of carcasses that had been attacked by seals were collected. Both fish species appeared to be attacked, predominantly in the gut region (Fig. 6.3). The softer flesh of these two species compared with tuna may make it easier for seals to focus their attack on their gut region. In addition, the narrower width of the bite marks suggests that small seals were involved in the attacks. Workers at mulloway and kingfish farm sites have observed many juvenile NZFS hauled out on the pontoons, which supports this suggestion.

Fig. 6.3. An example of a possible seal attack on tuna (left) and kingfish (right). Most tuna are attacked on the dorsal surface between the head and the first dorsal fin. Attacks are likely to be caused by larger seals, such as adults. In contrast, mulloway and kingfish are typically attacked in the gut region and are most likely targeted by juvenile NZFS. (Photos: D Hamer)

Ten companies (91 %) considered the most common method of seals entering tuna cages to be by jumping over the seal fence, while eight (72 %) believed that seals also gain access to cages via holes in the net close to, but under the surface. Anecdotal reports suggest that the adoption of higher seal fences across the industry (typically from 1.0 m to 1.8 m in the last few years) has assisted in restricting entry to tuna cages by seals (Fig. 6.2). However, there is still the opportunity for seals to jump fences during times of high swell, when the seal fences often become partially submerged.

Table 6.2. Summary of the questionnaire used to seek information from tuna farm lessees on operational interactions with seals, and responses.

Broad aspect of interest	Q #	Abridged detail of the question asked	Categories	Result
				No. respondents in each category
Economic significance	1	Significance of problems associated with seals during daily operations	nil	0
			v. low	1
			low	4
			moderate	2
			high	2
			v. high	2
			exty high	0
				Average response is moderate
				No. respondents in each category
Temporal trends	2	Trend in operational interactions since industry commenced	1= increase	5
			2= same	1
			3= decrease	5
				Average = 2
Nature of operational interactions	3	Rate the relative importance of the following five operational interactions with seals:		Rankings:
		• damage to equipment		least important
		• tuna become stressed		equal 2nd important
		• tuna mortality		most important (7 of 10)
		• financial loss		equal 2nd important
		• harassment of farm workers		almost least important
	4	Bodily location of attacks:		No. respondents agreed (max 11)
		• between head and first dorsal fin		10
		• behind first dorsal		2
		• gut attack, still alive		2
		• gut attack, post mortem		5
	5	Method of cage entry by seals:		No. respondents agreed (max 11)
		• pre-existing holes		3
		• create holes, sub-surface		8
		• create holes, seal fence		5
		• jump over seal fence		10
		• jump over seal fence during high swells		5
		• through hole around feeder rope		4
Outcomes of operational interactions	6	Stress related reduction in growth:		No. respondents agreed (max 11)
		• fish cease feeding		8
		• flighty swimming		5
		• lack of oxygen		4
		• injury		4
	7	Reduction in market value		No. respondents agreed (max 11)
		• premature mortality		11
		• scarring		9
		• pale flesh		6
		• weight loss		7
		• sold as pieces		4
Seal species responsible	8	Australian sea lions		No. respondents agreed (max 11)
		• attack tuna		8
		• stress tuna		6
		• present only		1
		New Zealand fur seal		No. respondents agreed (max 11)
		• attack tuna		2
		• stress tuna		3
		• present only		9
Mitigation measures used by industry	9	Mitigation measures trialled, but not used:		No. respondents agreed (max 11)
		• acoustic deterrent devices		6
		• electric fences		6
		• stainless steel impregnated nylon mesh		3
	10	Mitigation measures currently used:		No. respondents agreed (max 11)
		• high seal fences		11
		• electric fences		6
		• frequent maintenance		11
		• timing of harvest		5
Responsibility for coordinating implementation of and assessing the value of mitigation strategies	11			No. respondents agreed (max 11)
		• SARDI		7
		• company/industry		10
		• both		6
Commitment to assist ongoing monitoring of seal interactions	12			No. respondents agreed (max 11)
				10

Entry to cages by seals might also be gained through holes where structural or feed cage ropes pass through the net. All companies indicated that the overall number of holes in the net was directly related to their individual maintenance strategy. Most interviewees indicated that holes developed a few metres below the surface, where swell movements resulted in net fatigue. Therefore, companies that regularly conduct maintenance on nets are more likely to have relatively low interaction rates with seals and associated mortalities, because of the reduced incidence of cage entry by seals. One company indicated that the cost of using contract divers to conduct net maintenance outweighed the benefits associated with reduced seal related tuna losses, although this view was not supported by the other ten companies.

Typical outcomes of interactions: reduced growth and market value

Each farm manager indicated that all types of seal–farmed tuna interactions resulted in deleterious outcomes. Eight of the companies (72 %) believed that harassment or attacks on tuna, mulloway or kingfish, by seals, or even their presence in or near the cage resulted in the cessation of feeding and the subsequent reduction in growth rates. Although there is very little quantitative evidence, this belief is widespread at all levels within the aquaculture industry at Port Lincoln. Flighty swimming and subsequent lack of oxygen in the water within a cage, plus associated injuries, are all thought to result from seal harassment and to have a negative impact on the growth and conditioning of farmed finfish.

All companies recorded fish mortalities that they attributed to interactions with seals. The losses are likely to be underestimates because causes of death of a substantial number of fish deaths are either recorded incorrectly or cannot be determined. In addition, losses are underestimated when dead fish do not exhibit visible signs (e.g., from stress or lack of oxygen), and are overestimated when contract divers and boat operators incorrectly attribute the cause of death to seals.

Due to the high value of individual tuna, attacks by seals that resulted in death were considered most important in the overall economic framework. Tuna that survive attacks and are scared or otherwise damaged cannot be sold as whole carcasses, due to the market requirement undamaged, whole fish. Blemished carcasses are sold as pieces and fetch a much lower price. The estimated loss in revenue for individual tuna that have been attacked by seals was between 35 % and 100 %.

Seal species responsible

Ten of the 11 farm managers (91 %) were able to visually identify ASL and NZFS as the two species observed at tuna farm cages, although there was some confusion over the common names of each species. The inability to assign the correct name to each species indicates a marked potential for inaccuracy in historical industry records. As a result, it would be impossible to assign accurately the relative proportion of interactions to each seal species from such information.

In spite of the obvious difficulties in differentiating between the two seal species, each interviewee was asked to describe the two species before the nature of the interactions they described was assigned to each. While most farm managers agreed that ASL are rarely observed around tuna farms during the day, they indicated that ASL were responsible for most of the attacks and interactions that caused stress, injury and death of tuna. More specifically, there were indications that ASL have been observed at cages during the evening prior to the recovery of dead tuna or signs of injured and stressed fish being noticed the next day. However, there is no firm evidence that ASL are exclusively responsible for attacks on tuna, and no eyewitness accounts of direct attacks have been reported. Adult ASL are much larger than NZFS and are likely to be more capable of perpetrating a successful attack on a mature tuna.

In contrast, NZFS were not considered to be a threat to farmed tuna by the majority of farm managers, even though they were frequently observed swimming past cages or resting on the pontoons. In addition, most farm managers said that juvenile NZFS were regularly found inside cages. They believed that juvenile NZFS were too small to attack tuna successfully and were most likely taking advantage of baitfish fed to the tuna or were targeting the smaller scavenger fish present at or in cages. In addition, several farm mangers believed that NZFS sat on the pontoons or entered the cages to avoid predators, such as white sharks (*Carcharodon carcharias*).

Mitigation measures no longer used

All companies had attempted to address seal interactions by trialling various mitigation measures. Six had trialled acoustic deterrent devices, but had found them to be ineffective. Two farm managers noted that the devices emitted regular pulses and that seals had been observed jumping out of the water with similar regularity. This led them to believe that seals observed exhibiting this behaviour were actively avoiding the acoustic emission. Although these devices are no longer used, some farm managers indicated that trialling new devices would be warranted if the technology improved sufficiently to avoid such problems.

About half of the companies had trialled but no longer use electric fences above the pontoons, often in conjunction with the current seal fences. The high cost of maintenance and their unreliability in exposed conditions were cited as the principal reasons for removing them. In spite of this, one company currently uses electric fences and believes they are the primary reason for a recorded reduction in seal interactions.

Cages made of heavy-duty nylon mesh impregnated with stainless wire strands were trialled by three companies. The material was expected to reduce maintenance costs by reducing the formation of holes. However, constant wave action close to the surface led to failure of the stainless steel wire strands, with the broken ends chaffing on the nylon sheath, followed by the formation of multiple holes just below the surface (Dave Warland, pers. comm.).

The use of sub-surface predator nets (a second, more robust ‘curtain’ of net that hangs off the pontoon, outside the main cage) to prevent the entry of seals was widespread, but only one company currently uses them. An independent investigation during the mid 1990s found that they entangled and killed dolphins and seals (Kemper and Gibbs 1997, Kemper and Gibbs 2001), resulting in their removal at the majority of farms.

Mitigation measures currently used

All companies have equipment and strategies in place to mitigate interactions with seals. The most important strategies are the use of high (1.8 m) seal fences, frequent and regular maintenance of nets and cages to repair holes that may be used by seals as entry points, and the removal of tuna carcasses because they may attract seals. Farm managers who indicated that seal attacks had reduced in recent years also indicated that they had implemented a program of rigorous net maintenance and tuna carcass removal by contract divers.

All farm managers indicated that the use of high seal fences was responsible for deterring seals from entering cages. Most companies commenced operations without an above-water barrier to seals, but as soon as seal attacks became apparent, stanchions 1.0 m high were erected on the pontoons to support a nylon mesh fence to prevent entry. This structure became known as the ‘seal fence’. Anecdotal and eyewitness reports of NZFS entering farm cages by climbing over these relatively short seal fences prompted companies to increase the height of seal fences to 1.8 or 2.0 m. These higher fences appear to have been more successful. However, seals may still be able to swim or jump over seal fences when the swell is high and fences are partially submerged. In most cases though, seals are unable to climb over the higher fences, particularly if the mesh is slack and they have reduced purchase. All but two companies had installed higher seal fences by July 2005.

Five of the respondents indicated that timing of the tuna harvest could also be used as a strategy to reduce seal attacks. Some respondents believed that companies that stocked their farms first (in early January) were more likely to be specifically targeted by seals while tuna were contained in the cages, although there is no evidence to support this claim.

Responsibility for coordinating and assessing seal interaction mitigation strategies

Most of the tuna farming companies agreed that a collaborative approach should be taken to manage the issues of seal interactions and associated stock losses. One farm manager suggested that this would result in a proactive approach to the problem, and that the reactionary approach currently adopted by several companies is likely to lead to minimal sharing of information, thus slowing progress toward a solution. It was the general sentiment that industry-wide implementation of mitigation gear and strategies would provide a much more efficient means of seal deterrence in the long term. All but one company also made a commitment to participate in the ongoing monitoring of seal interactions, by participating in an industry-based logbook recording program.

Seal and dolphin interactions at finfish cages

Counts of marine mammals at finfish cages

During daytime observations, 22 seals were seen inside tuna cages at 0.15 seals per hour, compared with 91 seals outside the cages at 0.63 per hour (Table 6.3). The incidence of sightings per observation session outside cages was significantly greater than inside ($t = 86.1$, $df = 488$, $P < 0.001$). All seals observed within the cages were NZFS; outside cages, most (86) were NZFS and five were ASL. Most NZFS were juveniles, and there were a few adult females, subadult males and adult males.

Seals within the cages were swimming or floating at the surface, as there was no available structure for them to rest on. Outside the cages, most of the NZFS were resting on the floating pontoons and did not move away when the feed vessel approached. No dolphins were seen inside the cages, but 201 were seen outside the cages, at 0.41 per hour.

In contrast to observations made during the day, all of the 24 sightings made at tuna cages during the night were of ASL. There were no confirmed sightings of NZFS or dolphins. The incidence of 0.39 seals per hour seen outside the tuna cages is lower than for observations made during the day (0.63 seals per hour). More specifically, more ASL were observed at night, compared with daytime observations, suggesting that they were more active at night. These rates are likely to be underestimates and are not directly comparable for two reasons. First, differences in size of the area scanned for seals; many animals must have gone undetected at night, because the maximum observational distance would have been less than 70 m on a calm night and 40 m in rough conditions (with the use of the night-scope), whereas during the day seals were observed at much greater distances. Second, night-time observations were severely restricted by the lack of light; on a few occasions it was impossible to determine the species of seal present, or to distinguish between dolphins and seals, and these observations were not included in the analysis.

At the mulloway and kingfish farms, no seals or dolphins were seen inside the cages, although they were active on the outside: 5 seals at 0.12 per hour of observation and 24 dolphins at 0.56 per hour (Table 6.4). Of the seals, three were identified as ASL and one was a NZFS. These four seals were swimming past while caged fish were being fed. The fifth seal was seen at night in a spotlight and could not be identified; it was swimming around a cage while fish were being harvested. Each of the five seals was alone.

Behaviour was recorded for 23 of the 201 dolphins sighted. Ten were swimming near the cage while fish were being fed, either singly or in groups of up to four. Another dolphin was feeding on baitfish that was being transferred to a cage; it followed the boat to the next cage and repeated its activity. A group of five dolphins approached a cage when the transfer of baitfish began. Fish in the cage reacted by breaching the surface during a burst of increased swimming speed. These dolphins did not remain at the cage, and departed after about two minutes. Transferring activities attracted a pod of three dolphins on one occasion. In another instance, a group of four dolphins was observed feeding on wild fish outside the cage during harvesting activities.

Table 6.3. Marine mammals observed near tuna cages at Port Lincoln from feed boats (daytime) and security boats (night-time).

	Day		Night
No. observation sessions	489		64
Total time observing	145 h 13 m		61 h 27 m
Average time per session	18 min		58.5 min
	Inside cages	Outside cages	Outside cages
No. seals seen	22	91	24
Seals per hour	0.151	0.627	0.391
Seals per session	0.045	0.186	0.375
No. dolphins seen	0	201	-
Dolphins per hour	0	0.411	-
Dolphins per session	0	1.384	-

Table 6.4. Marine mammals observed at mulloway and kingfish cages at Port Lincoln from feed boats.

No. observation sessions	62	
Total time observing	43 h 15 m	
Average time per session	42 min	
	Inside cages	**Outside cages**
No. seals seen	0	5
Seals per hour	-	0.116
Seals per session	-	0.081
No. dolphins seen	0	24
Dolphins per hour	-	0.555
Dolphins per session	-	0.387

Seal attacks at tuna farms

Records from *company 11* indicated that the number of tuna carcasses that exhibited obvious signs of attack by seals declined over a period of eight years (between 1998 and 2005), except for a slight increase in 2000 and a smaller increase in 2004 (Fig. 6.4). Four other farm managers also indicated that the incidence of tuna mortalities associated with seal attacks peaked in 2000 and two others reported experiencing seal attacks for the first time during the same year.

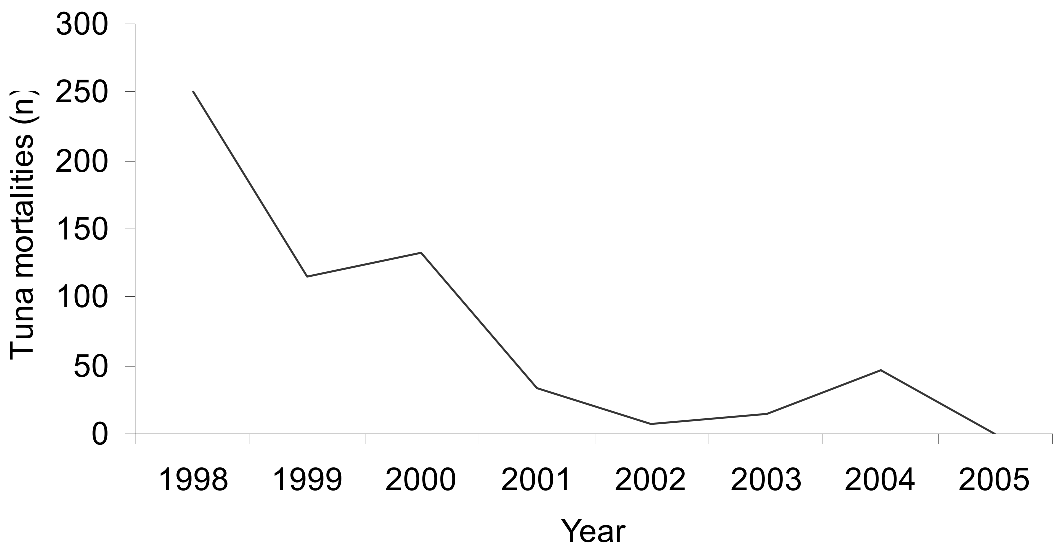


Fig. 6.4. Inter-annual trends in seal attacks resulting in mortality of farmed tuna at *company 11*.

The farm manager of *company 11* attributed their success in reducing seal attacks and the subsequent decrease in tuna mortalities to their proactive policy with regard to mitigating interactions. They have trialled and are currently using a number of mitigation measures. Along with the construction of high seal fences and regular net maintenance, the same farm is also using heavy-duty nylon net material, which has reduced the frequency of hole formation in nets, particularly in the area just below the surface. In addition, they placed stainless steel 'rub rings' in the nets through which the feed-cage ropes pass, thus preventing the formation of large holes caused by chafing. The combination of these mitigation measures with more conventional practices is likely to have assisted in the decline in tuna mortalities due to seal attacks over the eight-year period.

Seasonal data on tuna mortalities attributable to seals from three companies are presented on a monthly basis in Fig. 6.5. The longest data set (provided by *company 11*) covers the eight-year period from 1998 to 2005. It shows a peak in mortalities in August, most of which occurred in 1998, the first year of tuna farming activity by their company. The minor peak in April refers to a large amount of tuna mortality that occurred in 1999. Data from *company 6* covers a complete year (2005) and shows a peak in May. The third data set refers to mortalities in three months of a single year at *company 3*. Overall, mortalities approach zero from October onwards when few tuna remain in the cages.

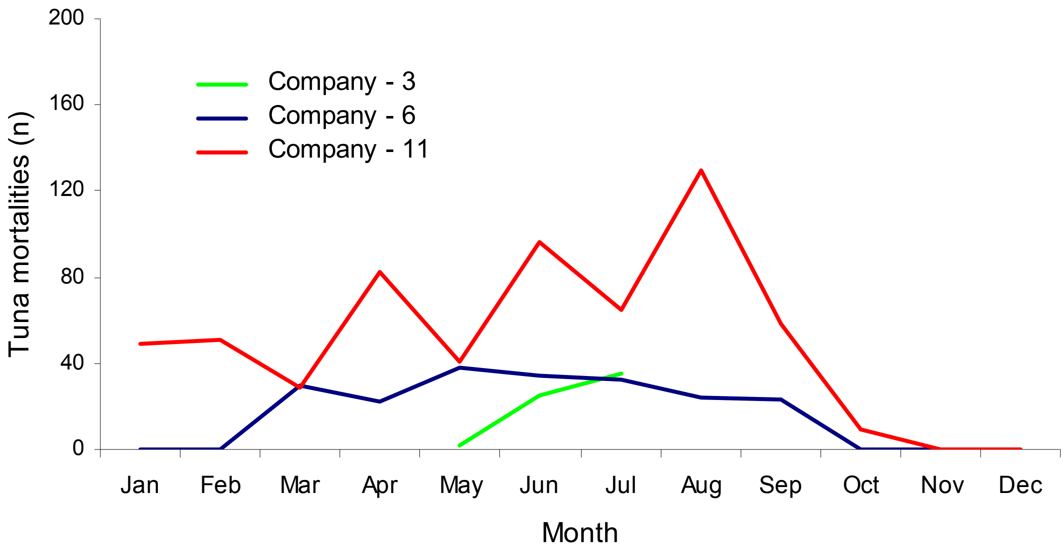


Fig. 6.5. Seasonal trends in mortality of farmed tuna associated with seal attacks at three companies.

Weekly data on tuna mortalities are available from *company 6*, which had a relatively large number of mortality in 2005 (Fig. 6.6). Each tuna mortality was attributed to one of three causes: seals, meshing in the cage net, and undetermined. In the 36 week period from 28 January to 30 September, mortalities attributed to seals and meshing were of similar incidence, with seal attacks being slightly greater by the end of the period. But the cause of most mortality was not determined.

At one farm, 9.3 % of all tuna mortalities for 2005 were attributed to seals. During the containment period, the percentage of mortalities attributed to seals increased markedly and reached a maximum of 88 % in September (Fig. 6.7), a month with little overall mortality.

For *company 3*, seals were thought to be responsible for 14 % of the tuna mortality in 2004, which amounted to 0.47 % of their total stock. In 2005, no mortality attributed to seals had been recorded to the beginning of July.

During 2005, three dead seals were reported to the Department for Environment and Heritage in Port Lincoln by tuna farms. All were NZFS: one drowned in netting of a cage, and two drowned and were removed from between a predator net and the bottom of a cage.

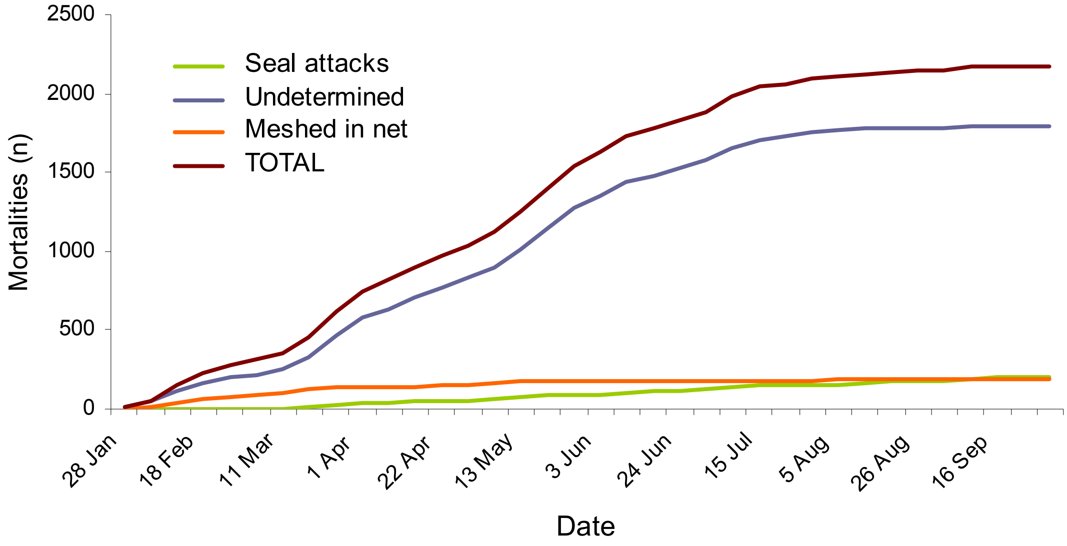


Fig. 6.6. Cumulative numbers of tuna mortalities in 2005 attributable to various sources including seal attacks, based on information from one tuna farm at Port Lincoln, South Australia.

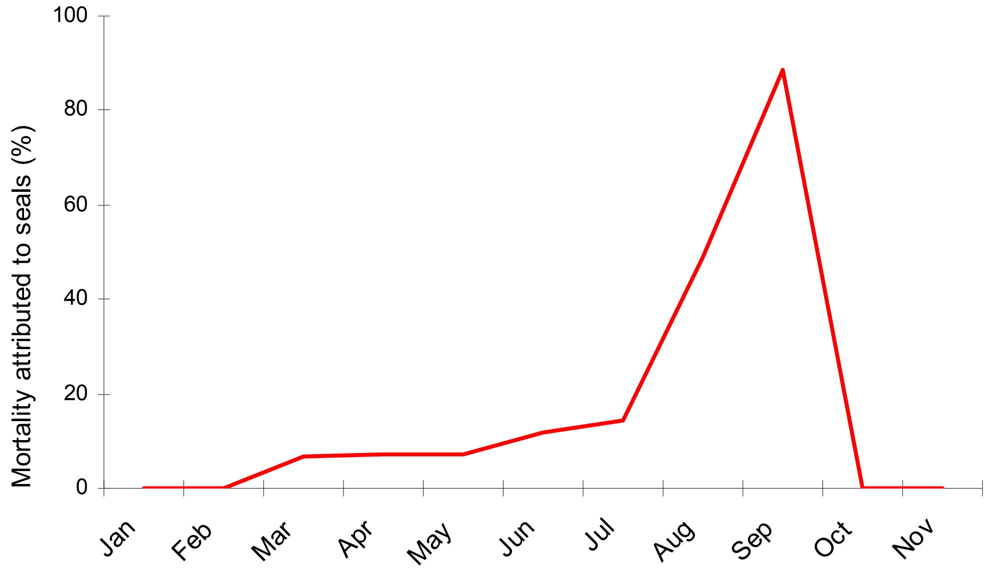


Fig. 6.7. Tuna mortalities attributable to seal attacks during 2005, based on data from one tuna farm.

Trends in the abundance of seals near finfish aquaculture

Australian sea lion numbers for all age classes at Donington Reef were very low and highly variable. Although there appeared to be an increase from mid January until mid October (Fig. 6.8), regression analysis indicated that overall ASL numbers were not associated with the number of farmed tuna in the region ($P = 0.53$, $R^2 = 0.02$), or with the number harvested ($P = 0.19$, $R^2 = 0.08$).

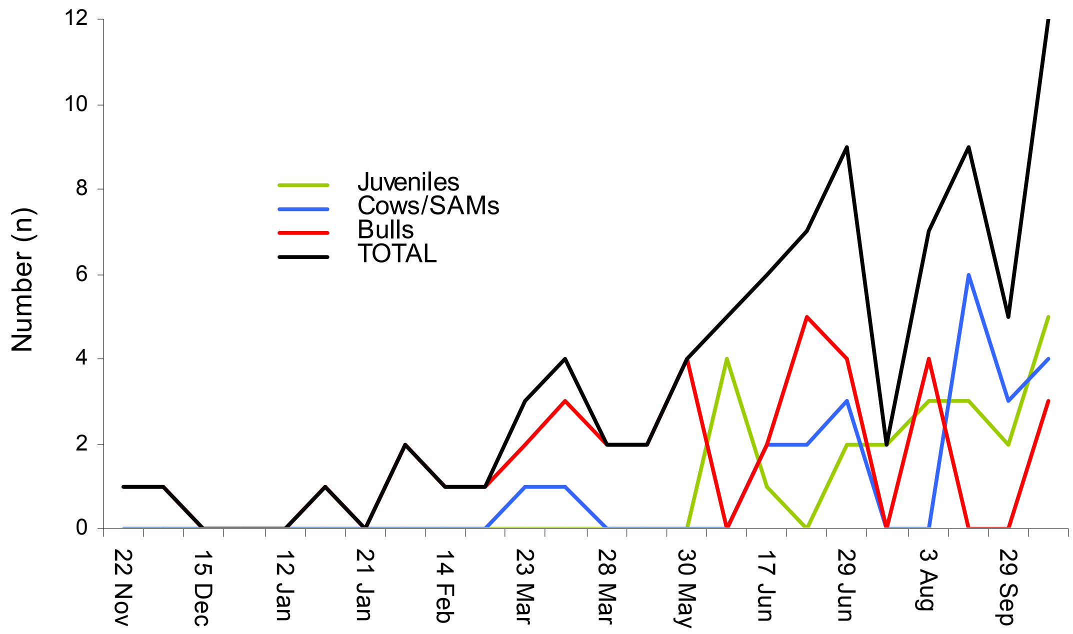


Fig. 6.8. Numbers of ASL at Donington Reef between 22 November 2004 and 17 October 2005.

Fur seals did not appear at Donington Reef until April (Fig. 6.9), some three months after the first tuna arrived in late January, with juveniles being observed first. Overall numbers increased markedly from late May and peaked at 205 in early August. Number of NZFS were an order of magnitude greater than ASL.

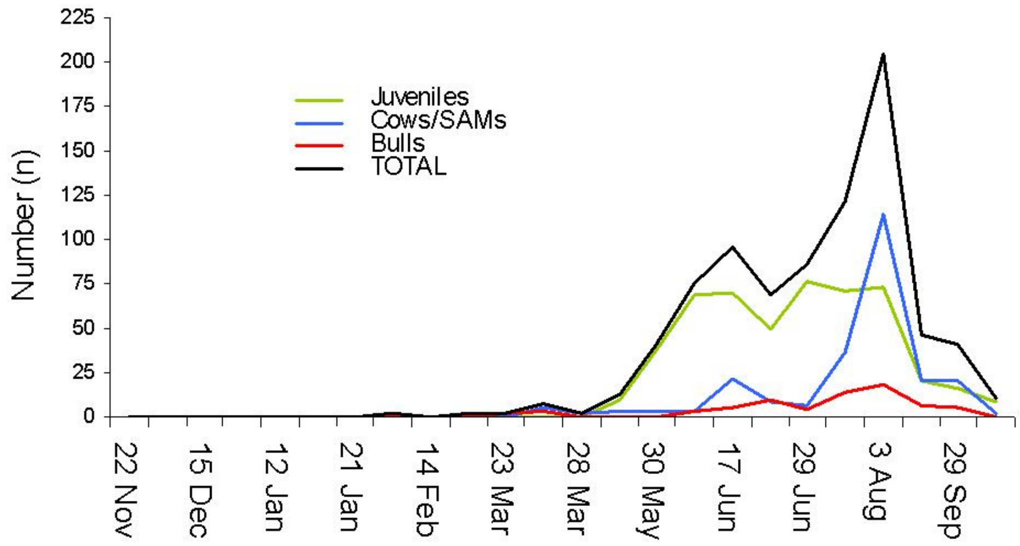


Fig. 6.9. Numbers of NZFS at Donington Reef between 22 November 2004 and 17 October 2005.

Most larger NZFS arrived around early August, particularly adult females and subadult males, and overall numbers soon reached a peak when tuna harvesting was well underway. Numbers of adult males remained comparatively low throughout the study, but also peaked in early August. Overall numbers declined rapidly by mid September and almost no animals remained by mid October.

Regression analysis did not indicate a relationship between the total number of NZFS at Donington Reef and the number of farmed tuna in the region ($P = 0.16$, $R^2 = 0.09$). But there was a strong relationship between the total number of NZFS and the number of tuna harvested ($P < 0.01$, $R^2 = 0.47$), and particularly for the number of adult females and subadult males with the number of tuna harvested ($P < 0.01$, $R^2 = 0.59$).

Discussion

Protection measures used at tuna farms

There has been a gradual evolution of the measures used to deter seals from gaining access to tuna cages. Electric fences were initially installed on pontoons in 1996, but only one tuna farm continued to use them when the survey was conducted in 2005. Each electric fence consisted of a single strand of stainless steel wire, approximately 0.3 m above the pontoon and attached to the seal fence. Extensions to seal fence stanchions to raise their height to 1.8 m or more were generally added in

2002. Predator nets hung outside the cages were popular during the 1990s (Pemberton 1996), but only one of the five farms surveyed in 2005 continued to use predator nets around its cages.

Questionnaire survey of tuna farm operators

Few companies have compiled records of seal activity or interactions at their farms. The lack of such data may explain some of the variation in responses concerning trends that became apparent in the questionnaire survey. A summary of historical records of seal interactions should provide useful insights into spatial, seasonal and inter-annual trends. In addition, many questionnaire interviewees indicated that factors other than interactions with seals were responsible for fish mortalities and that pertinent data were contained in their records. Alternative causes of fish death cited by interviewees included starvation and stress due to translocation after capture, becoming enmeshed in the net, lesions due to net collisions and disease.

Although interviewees were specifically asked to consider the significance of seal interactions in the present context, the nature of some responses indicated that historical interactions might have influenced their answers. For example, companies that had experienced significant interactions in the past thought that the current level was either very high or high. It is also likely that these responses were based on economic impacts, rather than historical trends in the incidence of interactions, although the two are likely to be closely related. In considering this problem, it is difficult to infer the current industry-wide level of interactions with seals and the overall fluctuation of its economic significance since aquaculture activity commenced at Port Lincoln.

Opposing responses to the question concerning trends of seal interactions at tuna farms are likely to have been influenced by a number of historical operational peculiarities between the companies. Firstly, some companies have changed the location or the size of their lease during the course of their existence and have moved closer to seal colonies or haulout sites. Therefore, it is possible that seals now interact more frequently with some farms than previously.

Secondly, there was considerable variation between farms in the year that significant interactions were first detected, ranging from between 1992 and 2000. Because the establishment of tuna farming companies also took place over this period, it is likely that seal interactions were first noted soon after each company began operating. In addition, inter-annual seal activity in the region is likely to have varied due to environmental fluctuations, suggesting that overall interaction rates are likely to have increased or decreased depending on the year the company first commenced operations.

Thirdly, it is likely that the opposing views on the direction of the trend between companies is due to the varying measures undertaken by individual companies to mitigate seal interactions. All companies indicated that they had traditionally withheld information about seal interaction mitigation techniques in order to attain an advantage over competitors, thus resulting in a gradual divergence in equipment modifications and operational improvements. Notwithstanding, several interviewees indicated that information typically became widespread due to the transient nature of employees who moved between companies, thus ensuring the dissemination of recent developments.

Seal and dolphin interactions at finfish cages

Counts of marine mammals

It is unlikely that all seals outside cages were counted, even during daytime observations. The results indicate that seals were not able to move freely in and out of the cages. Australian sea lions were less likely to be observed than NZFS, because they were less likely to approach or remain within the vicinity of human activity. The sighting of four times as many seals outside the cages compared with inside them during the day suggests that mitigation strategies are reducing the likelihood of seals entering farm cages. Farmed tuna typically swim in circles close to the netting wall of cages. Therefore it is possible that some tuna are being attacked from outside the cages, whereby an NZFS or ASL rams the cage to ‘stun’ a tuna, which sinks to the bottom of the cage and is subsequently partially eaten through netting. But an attack of this nature would not result in scarring between the head and the first dorsal fin, as reported for the majority of carcasses that have been attributed to seal attacks. Therefore, ramming of tuna by seals is likely to only account for a small proportion of fish mortalities.

Daytime farm visits coincided with a large volume of boat traffic and activity within the sites. It is possible that seals may be more active and more likely to attack tuna at night when they are less likely to be disturbed by humans.

The exclusive presence of ASL at night compared with the high number of NZFS observed during the day suggests diurnal differences in foraging methods and at-sea movements of the two species. If the ASL is responsible for most attacks, as results of the questionnaire survey suggest, it may be more appropriate to monitor seal activities at night rather than by day. Because problems associated with night-time observing would significantly hinder the effectiveness of such monitoring, observations may need to be undertaken with more advanced night vision equipment than was available during this study. Although improved lighting would increase the area over which observations could be undertaken, the possibility that it may deter ASL from approaching may render its use inappropriate. Once the relative contribution of the two species to fish mortality is determined, it may be appropriate to monitor fluctuations in numbers of animals at Donington Reef and other nearby seal haulout sites. Variations in seal abundance at appropriate haulout sites could be compared with fluctuations in reported seal attacks and interactions, with the aim of providing a means of assessing the performance of mitigation strategies being used at the time. In addition, increases in seal numbers at these sites could act as an indicator that increased interactions with seals may be imminent, thus providing fish farming companies with the trigger to increase the level of protection at their farms.

Seal attacks

Interactions between seals and farmed tuna are likely to result in deaths that do not exhibit physical signs, resulting in some mortality that is incorrectly attributed to other causes. Relatively minor injuries resulting from seal harassment and attacks are unlikely to lead to immediate death. Skin lesions (and blindness in some cases) caused by seal attacks may lead to the development of secondary infections that result in delayed mortality without the original injuries remaining on the carcass. In addition, harassment may lead to stress related reduction in health and growth, because fish generally cease feeding and swim much faster, which increases their metabolic rate. In contrast, direct attacks may not result in obvious physical signs. Fish may become enmeshed in the net and die while attempting to escape an attack. Weight loss associated with seal attacks and with harassment may also occur. Fish may stop feeding, or energy stores may be used to escape attacks. Hypoxia may result when oxygen levels within a cage are depleted; some tuna within a cage may use higher than normal levels of oxygen during times of increased stress or activity. Therefore, the physical outcomes of harassment and attacks are often difficult or impossible to interpret or detect, which is likely to result in misrepresentation of mortalities associated with seal interactions.

Divers visit finfish farm cages frequently to remove carcasses and repair nets, and are in the best position to collect most records of seal attacks. In some cases, bite marks and the removal of flesh are obvious on fresh tuna carcasses, thus providing clues of a direct seal attack (Fig. 6.3). Although divers are highly experienced in the capacity in which they are employed, most companies cautioned that they are not trained to determine causes of tuna deaths. This is particularly relevant when considering that many recovered carcasses have already deteriorated considerably following microbial activity and partial consumption by scavengers. These processes occur rapidly, with carcasses in an advanced state of decay often being removed from cages even though they were cleared as recently as the previous day. Therefore, it is often difficult to establish positively that tuna mortalities result from direct seal attacks.

Seven tuna companies stated that they had not kept historical records on seal interactions and attacks at farms. The industry developed when seal activity was low or absent, and losses due to seal interactions and attacks were perceived to be insignificant and of low priority. Seal activity has increased markedly as seals have moved into the area and have become habituated to the predictable activities of tuna faming and its associated foraging advantages. Although many farm representatives indicated that seal activity peaked in 2000, it is unlikely that tuna farming companies have been aware of the real impact of seal activity throughout the existence of the industry.

Results from this study indicate that the impact of seal interactions varied considerably between companies. It is apparent that there is a need for better record keeping of seal interactions and their effect. Several companies indicated that they would begin to keep records or improve their record keeping during 2006.

Although measures have been taken to reduce the incidence of seal attacks and harassment, documented evidence demonstrating their effectiveness is currently absent and is unlikely to become available considering the current difficulties in monitoring efficacy. This is of particular concern when considering that five of the 11 tuna farming companies that participated in the questionnaire survey indicated that seal attacks have increased. An effective performance indicator would be to relate the number of attacks attributable to seals at several farms with different cage designs or with distance from seal haulout sites.

Trends in the abundance of seals near finfish aquaculture

ASL numbers at Donington Reef remained low throughout this study. The absence of a relationship between ASL numbers and the number of farmed tuna or the number of tuna being harvested coincides with the relatively low level of operational interactions detected with this species. Although this indicates that ASL may not have been targeting farmed tuna as a food source, it does not rule out the possibility that larger ASL (i.e., adult males) may target and attack farmed tuna opportunistically (as in Fig. 6.3), albeit inconspicuously.

In contrast, trends in overall numbers of NZFS at Donington Reef indicated an association with tuna harvesting in the region. Fur seals did not move into the area until four months after the arrival of farmed tuna, suggesting that they may not be directly targeting large fish such as tuna, but possibly feeding on small pelagic fish that have taken up residence around the cage structures. This is a logical explanation, because smaller fish comprise the diet of NZFS (Page et al. 2005a).

The influx of juvenile NZFS to Donington Reef three months before harvesting began suggests the presence of alternative food sources that are more accessible and palatable to them than caged tuna. For example, large volumes of pilchards (*Sardinops sagax*) and redbait (*Emmelichthys nitidus*) are used as feed at tuna farms; these may attract NZFS, which typically forage on small pelagic fish

(Carey 1992, Fea et al. 1999, Page et al. 2005a). In addition, large schools of small fish, such as tommy ruff (*Arripis georgianus*), jack mackerel (*Trachurus declivis*), blue mackerel (*Scomber australasicus*), silver trevally (*Pseudocaranx dentex*) and Degen's leatherjacket (*Thamnaconus degeni*) are present around tuna, kingfish and mulloway cages throughout the farming period and are also likely to be targeted by NZFS. The presence of juvenile NZFS in tuna cages and the apparent lack of associated attacks on tuna suggest that they target these smaller fish rather than the tuna. This is also supported by the general perception of the tuna industry that smaller NZFS do not attack tuna.

In spite of the general perception that NZFS do not target tuna, it may be wise to monitor annual trends in numbers of adult males at Donington Reef, because they are the only age class that is likely to have the capacity to target tuna and they may already be responsible for some attacks. If numbers of adult male NZFS were to increase, appropriate mitigation measures would be needed to deny their access to farmed tuna.

Summary

Large colonies of ASL and NZFS are located near the Port Lincoln tuna farms at Dangerous Reef and Neptune Is, respectively. During an initial workshop held with the tuna aquaculture industry at Port Lincoln in November 2004, farm representatives indicated that operational interactions with seals were a significant financial cost to the industry.

A survey of equipment used on tuna farms indicated that cages used nylon nets 10 to 20 m deep hung from polar circle pontoons of 40 m diameter. Some nets incorporated stainless steel wire to add strength, but this was no longer used. An important measure to prevent seal attacks was the use of seal fences constructed of nylon netting hung from stanchions attached to the pontoons. Most stanchions were 1.8 to 1.9 m high. Electric fences were installed in 1996, but they are not used extensively by the industry. Regular maintenance to reduce holes in cage nets is also thought to reduce seal access.

A questionnaire survey of tuna farmers confirmed that operational interactions with seals are a continuing problem, although there were opposing views on whether they are increasing or decreasing. The most significant effect of interactions was the death of tuna, followed by stress and damage to the fish and the associated financial losses. The part of the tuna's body attacked most frequently was between the head and first dorsal fin. The most frequent entry method used by seals was jumping over the seal fence, even though the seal fence was considered to be the best method to limit seal attacks. Another important method of limiting seal attacks was frequent maintenance of cages to repair holes and remove tuna carcasses because they are likely to attract seals. Australian sea lions were considered to be responsible for most attacks on tuna and for most interactions that caused stress. New Zealand fur seals were seen frequently around cages and within them, and resting on the pontoons. Most NZFS seen were juveniles. Fur seals were not considered a threat to farmed tuna, being too small to attack them successfully. They were most likely taking advantage of baitfish fed to the tuna, were targeting smaller scavenger fish at the cages, or were concentrating their efforts on attacking farmed kingfish or mulloway within Boston Bay.

A program of observations at farms during daylight indicated that all seals inside the cages were NZFS and that most seals outside the cages were ASL. At night, all seals seen were ASL, although the lack of lighting made observations difficult. Because ASL are considered to be responsible for most attacks on tuna, it may be more appropriate to monitor seal activities at night, using improved night vision technology, rather than by day.

Results from this study indicate that the impact of seal interactions varied considerably between companies. Data on seal attacks collected by one company from 1998 to 2005 showed a decrease, except for a slight increase in 2000. The company attributed the overall decline to their proactive policy of mitigating interactions. Data on causes of tuna mortality kept by another company during 2005 indicated that the frequency of attacks by seals was similar to that of tuna becoming enmeshed in nets; but the cause of most mortalities was unknown. At one tuna farm, where tuna mortalities attributed to seals was 9.3 % for 2005, the percentage attributed to seals increased markedly during the growing period and reached a maximum of 88 % in September, a month with relatively little overall mortality.

Seals were counted on Donington Reef at the entrance to Boston Bay from November 2004 to October 2005. Few ASL used the site. Fur seals arrived in April, about three months after farms were stocked with tuna, numbers peaked in August at 2005 and were associated with the tuna harvest.

Recommendations

Management arrangements that are in place to reduce seal interactions with finfish aquaculture industries include:

- Under the current *Aquaculture Act 2001* licensees are required to submit a Seabird and Large Marine Vertebrate Interaction Strategy at the commencement of operations, which satisfies the Minister. The strategy details what procedures the licensee will implement to minimise the risk of interactions and manage incidents of entanglement or entrapment of seabirds and large marine vertebrates. The *Aquaculture Act 2001* should be used to ensure that best practice mitigation measures (such as standard height seal fences and net maintenance regimes) become standard across the industry. Annual review of documented strategies for all existing operations would allow any new or altered mitigation actions to be incorporated across the industry. Minimum mitigation strategies should be established and reviewed in consultation with industry, government and research agencies. Under the existing *Aquaculture Act 2001* operational practices detailed in the documented strategy can be audited, with failure to comply resulting in fines or suspended or cancelled licences.

- Tuna and other finfish aquaculture industries in South Australia have agreed to reduce seal interactions through improved farm management practices. This requires that all reasonable measures must be taken to reduce interactions with wildlife and any interactions must be reported immediately to PIRSA Aquaculture. Incidents must also be reported in annual environmental monitoring reports. Proposed farms in areas where interactions are considered likely will be required to submit and adhere to a Wildlife Interaction Avoidance Strategy as part of their environmental management and monitoring conditions. If wildlife continues to interact with the farm, the operator may be required to use different cage structures.

Procedures for minimising finfish mortality attributable to seals that should be included in management plans of tuna farms are:

- Incorporation of seal fences on the pontoons, with a minimum height of 2m.
- Regular and frequent net maintenance, including repair of holes.
- Regular and frequent removal of tuna carcasses, because they are likely to attract seals.
- Promote and if necessary require the implementation industry-wide of measures that are demonstrated to effectively mitigate adverse interactions.
- Incorporate management measures into regulations with regular auditing requirements.

Develop and establish standard methods of recording and evaluating interactions and impacts of seals on finfish farms including categorising the nature and extent of injury and probable cause of death of farmed finfish. This could be implemented through a training course for divers and farm workers covering aspects such as identification of types of injuries, identifying course of mortality, seal species identification and standard recording and reporting procedures. This would assist in improving industry reporting and assessment of seal-finfish aquaculture interactions and allow development of robust performance indicators to assess the ongoing effectiveness of mitigation measures.

Further research focused on reducing non-seal related causes of mortality and injury of farmed finfish (such as disease) through improved husbandry practices would also assist in reducing the overall cost to industry due to stock loss, injury and loss of condition.

Use data from mortality assessments and seal interactions with finfish farms to investigate spatial and temporal variability in seal predation rates at farms. Relate these results to farm seal-mitigation practices, stocking rates, feeding rates, proximity to other farms and to seal haulouts and colonies. Such information would greatly assist in managing seal-finfish farm interactions.

Monitor the loss of aquaculture equipment and entanglement of marine mammals in connection with aquaculture. This should include any material or equipment used to secure, anchor or mark the position of farm structures and leases.

Undertake robust, quantitative trials to monitor and assess the efficiency and economic benefit of gear and farm management modifications to reduce the incidence of seal-related mortality and injury of farmed finfish. Such trials should include effective height and construction of seal-fences and more robust mesh design to reduce net maintenance. New technologies for caging kingfish and mulloway should be investigated. Options include the use of heavy-duty net material, steel cages (particularly for the raceways, where fish are held prior to harvesting), and incorporation of stainless steel ‘rub rings’ in the nets through which the feed-cage ropes pass (to prevent the formation of holes caused by abrasion). Introduction of new farm systems such as sea-cages for shellfish should be undertaken on a trial basis, with independent observer monitoring, to assess the risk of such systems to marine mammals. Further research is also required to reduce technology costs in an attempt to encourage industry to adopt new technologies that exclude seals from finfish farms.

Improve or develop formal strategies for information exchange between research, government and industry agencies and among individual operators for the distribution and exchange of information on technological advances, assessment of mitigation measures and guidelines and progress of research projects. This would promote industry ownership and stewardship and an effective industry-wide active management regime.

Accreditation of finfish farms should be contingent on implementation of Environmental Management Systems (EMS). The International Standards Organisation (ISO) provides the world’s most recognised EMS framework, which is of particular relevance because most of the farm-harvested tuna from Port Lincoln is for the international market. The ISO 14000 accreditation framework assists in the management of environmental impacts and would provide industry with the opportunity to demonstrate that they are dedicated to mitigating interactions with seals in the most appropriate manner.

7 AUSTRALIAN SEA LIONS IN SOUTHERN SPENCER GULF AND ON THE COAST OF EYRE PENINSULA, SOUTH AUSTRALIA: ABUNDANCE IN 2004 AND 2005

PD Shaughnessy, SD Goldsworthy and B Page

Background

The Australian sea lion (ASL) is an endemic species, restricted to South Australia and Western Australia. Its breeding range extends from The Pages Is in South Australia to Houtman Abrolhos on the west coast of Western Australia. In February 2005 it was listed as a *Threatened* species, *Vulnerable* category under the *Environment Protection and Biodiversity Conservation Act 1999*. It forms the basis of a thriving tourism industry on Kangaroo Is and of smaller tourism ventures elsewhere in South Australia and in Western Australia (Kirkwood et al. 2003, Orsini and Newsome 2005).

Several aspects of the breeding biology of the ASL are unusual. A breeding cycle of 17–18 months was first reported at Kangaroo Is by Ling and Walker (1978) and has been recorded at many other breeding colonies. A consequence of the 17–18 month breeding cycle is that pupping seasons at a particular colony do not occur at the same time each year. For example, one pupping season may include winter months and the next season at that colony will include summer months. Furthermore, timing of pupping seasons is not synchronous between islands (Gales et al. 1994), as it is in some other seals. This adds to the difficulty of locating breeding colonies and in determining the timing of pupping seasons.

The pupping season in this species extends for about 5 months (Gales et al. 1992, Higgins 1990), and is even longer in large colonies such as Seal Bay, Dangerous Reef and The Pages Is (Ling and Walker 1976, Shaughnessy et al. 2005, Shaughnessy et al. 2006). The pupping season for this species is much longer than that of other seal species, many of which extend for only 1 to 2 months. Estimates of the timing of pupping seasons for most breeding colonies in South Australia for the period 1995 to 2005 have been presented by Shaughnessy et al. (2005).

In a recent review of the biology of the ASL, McKenzie et al. (2005) listed 73 breeding sites for this species and another 142 locations where they have been recorded ashore without any evidence of breeding (haulout sites). Based on pup count data, they estimated that a minimum of 2,495 pups were born at those 73 breeding sites per breeding cycle in recent years, with 80 % of the population in South Australia and 20 % in Western Australia. That estimate of overall pup production is less than that of 2,861 reported by Goldsworthy et al. (2003) because the latter estimate was based on extrapolations from pup counts in some colonies. The estimate of McKenzie et al. (2005) is slightly higher than that reported by Gales et al. (1994) of 2,432 based on surveys around 1990, which was also based on extrapolations from pup counts in some colonies; the increase results from the inclusion of data from several colonies that have been discovered since the early survey.

Estimates of the size of the total population require a demographic model to provide an estimate of the proportion of the total population composed of pups, and hence multipliers to convert estimates of pup numbers to estimates of abundance of the whole population. Two such models have been developed for the ASL: Goldsworthy et al. (2003) developed generic otariid life-tables based on mean age-specific survival data from a range of species and Gales et al. (1994) developed a model that assumed a balanced (i.e., stable) population. McKenzie et al. (2005) combined the multiplier 3.93 developed by Goldsworthy et al. (2003) with their own estimate of pup numbers to estimate the overall population size at 9,794.

This part of the project aimed to improve knowledge on the status and abundance of ASL colonies on several islands in southern Spencer Gulf, islands immediately south of Spencer Gulf and on some islands in the Nuyts Archipelago. Information on the status and abundance of ASL underpins the distribution of foraging effort of seal populations in proximity to existing finfish aquaculture farms off the southern Eyre Peninsula and in regions currently zoned for finfish farms, but where none currently exist, off the west coast of the Eyre Peninsula.

Methods

Study colonies

Descriptions of the islands utilise information in Robinson et al. (1996) from the biological survey of offshore islands, as well as our own observations. Geographical positions of the islands are from McKenzie et al. (2005) and are updated in Appendix 3 of this report.

Islands in Spencer Gulf and nearby offshore islands

South Neptune Is (*35.3303 S, 136.1118 E)*

There are three islands in this group: Main Is (with many NZFS), Middle Is (with few NZFS) and Lighthouse Is. Each island is used by ASL. Lighthouse Is includes the marine navigation light, cottages and associated buildings that formerly housed staff of the lighthouse service, and an abandoned emergency airstrip.

North Neptune Is (*35.2301 S, 136.0683 E)*

There are two islands in this group: the larger, West Is, is used by NZFS and both species are found on the smaller East Is. They are separated by 300 m.

North Islet (*35.1207 S, 136.4761 E)*

North Islet forms part of the Gambier group and is 2.3 km north-east of the northern point of Wedge Is. North Islet has a granite base and steep calcareous cliffs. A landing was made in a bay on the north-western side of the Is.

Peaked Rocks (*35.1868 S, 136.4830 E)*

These two steep-sided rocks are also part of the Gambier group and are within a kilometre of the south-eastern extremity of Wedge Is. Both have a granite base with a remnant limestone cap. The two rocks are usually referred to as 'Peaked Rocks (north-east)' and 'Peaked Rocks (south-west)'. Landings on these small rocks are difficult and they were surveyed from a boat in this study.

Albatross Is (*35.0686 S, 136.1814 E)*

Albatross is a low granitic island of 6 ha south of Thistle Is. It is exposed to the prevailing swells and a landing was not possible on it.

Liguanea Is (*34.9984 S, 135.6199 E)*

Liguanea Is, near the southern tip of Eyre Peninsula, is south of Cape Carnot. It has a granite base and a limestone cap, with a steep slope up to the edge of a plateau. It extends 2.3 km in a north-south direction and is 202 ha in area. The breeding area for ASL is primarily on a peninsula at the southern end of the island, which is about 0.5 km long and is cut off from the main island when high seas move through a narrow gulch.

Smith Is (*34.9863 S, 136.0293 E)*

Smith Island is at the southern entrance of Thorny Passage and 1.8 km east of Cape Catastrophe. It has a granite base, steep sides and a limestone cap with much vegetation.

Lewis Is (*34.9570 S, 136.0317 E)*

Lewis Island is in the Thorny Passage, to the north of Smith Is. It also has a granitic base but its limestone cap leads to a more peaked summit than those of nearby islands.

Little Islet (*34.9499 S, 136.0253 E)*

Little Island is a rocky island with a small amount of vegetation. It is located in Thorny Passage north-west of Lewis Is.

Hopkins Is (*34.9675 S, 136.0610 E)*

Hopkins Island is 1.3 km east of the northern end of Thistle Is. It is one of the larger islands in Thorny Passage (162 ha). Most of its coastline is granite. Sea lions favour two sandy beaches on its northern shore.

Dangerous Reef (*34.8170 S, 136.2170 E)*

Dangerous Reef is 35 km south-east of Port Lincoln and forms part of the Sir Joseph Banks Group Conservation Park. It comprises Main Reef with nearby East Reef and West Reef. They cover about 12 ha in area (Robinson et al. 1996). Sea lion pups are born on Main Reef, and some of them move to the West Reef several weeks after birth.

Rabbit Is (*34.6048 S, 135.9858 E)*

Rabbit Island is a small island at the entrance to Louth Bay. Its granite coastline surrounds a sandy, vegetated interior.

Sibsey Is (*34.6450 S, 136.1820 E)*

Sibsey Island is at the south-west end of the Sir Joseph Banks Group of islands.

English Is (*34.6379 S, 136.1958 E)*

English Island is a small rocky island that is primarily granite. It forms part of the Sir Joseph Banks Group and is 1.2 km east-north-east of Sibsey Is.

Langton Is (*34.5971 S, 136.2518 E)*
Langton Island is an oval shaped island with a rocky coastline and is part of the Sir Joseph Banks Group. It has a sandy spit which extends 250 m from its north-eastern corner. Most ASL were near the end of the spit and on its western side, with some of them in the vegetated part of the spit.

Blyth Is (*34.5678 S, 136.2920 E*
Blyth Island is a small, oval shaped island surrounded by a sandy beach backed by a sloping rise 8 m to 10 m high with vegetated dunes in its interior. It is near and south of Reevesby Is, and is one of the largest islands in the Sir Joseph Banks Group. All ASL were on the beach and most of them were in the south-western part of the island.

Islands of the Nuyts Archipelago

NE Franklin Is (*32.4486 S, 133.6685 E) and SE Franklin Is* (*32.4623 S, 133.6392 E)*
These two un-named islets are a few hundred metres from Franklin Is. The north-east islet has a granite coastline with a steep rise to a limestone cap. The south islet is much lower in elevation and has granite boulders and slabs on most of its coastline, with a sandy area and beach on the side closest to Franklin Is. A third islet south-west of the south islet appeared to be wave-washed and unapproachable by boat because of nearby shoals. SE Franklin Is and NE Franklin Is were recently named Blefuscu Is and Lilliput Is, respectively, but these names have not been adapted in this report.

Flinders Reef (*32.387 S, 133.551 E)*
Flinders Reef is between Franklin Is and Goat Is. It is likely to be awash in most sea conditions.

Gliddon Reef (*32.3218 S, 133.5619 E)*
Gliddon Reef is a small island south-east of St Peter Is with granite boulders along its coast and a sandy interior that supports bushy vegetation.

Breakwater Is (32.3217 S, 133.5613 E)
This small island is about 1 km south-east of Goat Is. It is about 400 m long and 200 m wide, and consists mainly of granite boulders and slabs. ASL, including pups, were reported there in early 2003 by a local tour boat operator, Perry Will.

Fenelon Is (*32.5810 S, 133.2817 E)*
Fenelon Island is 5.5 km south of St Francis Is. There is a small sandy beach on the northern coast of Fenelon Is that is used by ASL. They were counted from a boat while it encircled the island slowly. A

landing was then made on the beach and animals counted there and among rocks at both ends of the beach.

Masillon Is (*32.5586 S, 133.2814 E)*

Masillon Island is 2.5 km south of St Francis Is. It is surrounded by “spectacular orange and yellow calcarenite cliffs” (Robinson et al. 1996, p. 161). Access by boat was not possible and ASL were counted during a circumnavigation. Sea lions were on a narrow sandy beach on the northern side of the island at the base of a cliff and on rocks at the eastern end of the beach.

West Is (*32.5108 S, 133.2513 E)*

West Island is 1.5 km west of St Francis Is. It has a deep, narrow embayment on its northern side where boat landings are possible on boulders. Sea lions were spread over its entire coast, with a concentration on the north-eastern side.

Lounds Is (*32.2730 S, 133.3657 E)*

Lounds Island is a steep island with a granite base, a limestone cap and caves in the limestone where it meets the granite. The island’s coastline is usually wave-washed and it is difficult to land there from a boat.

Purdie Is (*32.2698 S, 133.2284 E)*

Purdie Island is in the western-most group of islands in the Nuyts Archipelago. The largest island of this group is used by ASL; it has a granite base and a sandy cap that supports many bushes.

Pup counts

The usual method for monitoring the abundance of ASL is for two or three observers to walk through a colony counting pups and, in some instances, other animals ashore. Pup numbers are chosen as the index of abundance (Berkson and DeMaster 1985) because pups are easily recognisable, most stay ashore when people enter a colony quietly, and they are manageable (if the estimating technique requires handling). In addition, most pups are ashore at one time, unlike other age classes in which a highly variable proportion is ashore at any one time. But in the ASL, the pupping season is extended and some of the pups born early in the season may leave the colony with their mothers before the last pups have been born. Because the pupping season lasts for several months, it is necessary to schedule several visits to record dead pups and a visit to count pups when numbers reach a maximum. Each pup count is likely to underestimate the number of pups born in the pupping season and, unless several counts are made during the season, the pup production can be underestimated seriously.

A timetable of ASL pupping seasons for the period 1995 to 2005 was presented by Shaughnessy et al. (2005). It was used in this study to schedule the first visits to colonies to be near the beginning of a pupping season. The number and size of pups on first visits was then used to refine the estimate of when pupping had begun. For instance, pups aged less than 4 weeks can be recognised by their small size, loose skin folds, and a relative lack of coordination (T. Dennis pers. comm.). In addition, many pups less than 3 weeks of age have a relatively pale crown and dark mask across their face (Ling 1992). After estimating the date of the beginning of a pupping season, a visit calculated to be near the end of the season was scheduled when maximum pup numbers were expected, about 5 months later.

Pups were recorded in three categories based on those used by Gales et al. (1994):
brown pups, live pups in natal pelage or still moulting it; *moulted pups*, live pups that have completely moulted their natal pelage, which occurs in most pups at about 5 months of age (Shaughnessy et al. 2005); and *dead pups*. Numbers of brown pups and moulted pups were combined to form the category *live pups*.

Classifying some young ASL can be difficult because moulted pups can be confused with small juveniles of similar size born in the previous pupping season, which are then older than 1 year. Small juveniles can be recognised by their cranial development, particularly their slightly longer noses. When pups moult their natal coat, they replace it with a silver grey and cream coloured pelage. When juveniles that were born in the previous pupping season are moulting, their newly emerging silver grey coat shows through their aged, ginger coloured outer hair, giving them a different coloration from that of moulted pups.

At Dangerous Reef, pups were counted while we walked around the island, taking care not to disturb animals on the top of the island for fear of them bolting across to the other side and sending pups into the sea, and hence biasing the count downwards. After counting around the periphery of the island, the counters walked through the centre of the island counting pups. For the last two surveys, two people counted pups, working separately but each ensured that pups that were difficult to see were drawn to the attention of the other counter.

Two visits were made to Liguanea Is. On the first visit, ASL were counted on the southern peninsula and then immediately north of it; these are the areas where ASL pups were encountered during the survey in January 1990, when the colony was first reported (Gales et al. 1994). The second visit in the 2004–05 pupping season was made in conjunction with a survey to estimate abundance of NZFS pups. Because most of the ASL had departed from the southern peninsula, the only animals counted were very small pups that were judged to be less than a month of age and hence would have been born since the first visit.

Pup mortality

At each visit to a colony, we recorded the number of dead pups or the number that had died since the previous visit. This enabled an estimate to be made of the number of pups that died during the whole pupping season. It enabled the pup production for the season to be determined more accurately than if dead pups were not recorded or, in the case of Dangerous Reef where pup mortality is high, if they were only recorded on one or two occasions. Pup mortality seems to be greater in large, crowded breeding colonies such as Dangerous Reef than in the smaller, less dense colonies. Consequently, in this study, counts were made more frequently at Dangerous Reef than at the other colonies in order to improve the estimate of dead pups there. To avoid recounting, dead pups were sprayed with paint or covered with rocks when they were counted.

The number of dead pups recorded at each visit was added to the number recorded at previous visits to give the number of ‘Accumulated dead pups’. When that number was added to the number of live pups recorded on that visit, it gave the best available estimate of pup production to that date.

For Dangerous Reef, the incidence of pup mortality is expressed as a percentage and calculated from:

(Dead pups x 100) / (Dead pups + Live pups),

where 'Dead pups' is the accumulated number of dead pups when the sum of it and the number of live pups reaches its maximum for the season. The mean pup mortality over several seasons at Dangerous Reef was taken as the unweighted average, that is, the average of the estimates of pup mortality for each season. For the other colonies, pup mortality was estimated in a similar manner using the available data.

Procedure for estimating pup abundance from counts

The index of abundance for the pupping season was taken as the maximum of the sum of live pups and accumulated dead pups. At Dangerous Reef colony, where three counts were made in the two months after the maximum count, the accuracy of the maximum can be improved. Pups recorded in the count on these visits that were aged less than 4 weeks can be added to the maximum count because they had not been born when that count was made. Methods of identifying such pups were indicated above.

Mark-recapture estimation of pup numbers

A mark-recapture procedure was used to estimate the number of live brown pups on the Main Reef of Dangerous Reef in mid-July 2005. On 13 July, brown pups were marked by clipping hair on the top of their heads. Individual pups were caught and restrained physically. Three people marked pups and worked separately, but in view of a fourth person who recorded the number of pups that were marked. Pups were marked throughout the whole of Main Reef, and we aimed to mark about one third of them spread uniformly across the island.

Five recapture sessions were conducted on 15 July. There were two recapture teams, each of two people, a ‘caller’ and a scribe. Both ‘callers’ used binoculars when looking at the heads of all pups greater than 5 m distant to ensure that the presence or absence of the head mark could be seen clearly. Recapture session began at intervals of about one hour. Because the island is relatively small, only one recapture session was underway at a time in order to avoid the possibility of a second recapture team disturbing pups and causing some to move across the island.

The mark-recapture estimate of pup numbers (N) was calculated using a variation of the Petersen method, with the formula

$$\hat{N} = \frac{(M+1)(n+1)}{(m+1)} - 1,$$

where:
M is the number of marked pups at risk of being sampled during recapture operations
n is the number of pups examined in the recapture sample, and
m is the number of marked pups in the recapture sample.

The variance of this estimate was calculated from

$$V = \frac{(M+1)\,(n+1)\,(M-m)\,(n-m)}{(m+1)^2\,(m+2)}$$

and the 95 % confidence limits were calculated from

$$N \pm (1.96 \times V^{0.5}).$$

Since there were several mark-recapture estimates (N_j), one from each recapture session, they were combined by taking the mean (N) using formulae from White and Garrott (1990, pp. 257 and 268):

$$\hat{N} = \sum_{j=1}^{q} \hat{N}_j / q$$

where q was the number of estimates for the colony (i.e., the number of recapture sessions).

The variance of this estimate was calculated from:

$$\text{Var } \hat{N} = \frac{1}{q^2} \sum_{j=1}^{q} \text{Var}(\hat{N}_j)$$

and its standard deviation was calculated from:

$$[\text{Var}(\hat{N})]^{0.5}$$

At Dangerous Reef, two direct counts of pups were made on 15 July 2005, immediately before the recapture sessions began and their average was calculated. The mark-recapture estimate of pup numbers was compared with the direct count of pups by taking the quotient of the mark-recapture estimate and the direct count. The 95 % confidence limits of this ratio were obtained by dividing the upper and lower 95 % confidence limits of the mark-recapture estimate by the direct count.

Trends in abundance of pups at Dangerous Reef

Sea lion pups have been counted at Dangerous Reef since 1996 with assistance of staff of National Parks and Wildlife SA (NPW SA), Department for Environment and Heritage. Before then, counts were made opportunistically from 1975 by NPW SA staff and by John Ling and colleagues of the South Australian Museum (Ling and Walker 1977, Dennis 2005).

For the seventeen pupping seasons between 1975 and 1999, ten data sets were collated by Dennis (2005). Seven of them were suitable for initial consideration in this study, namely those for 1975, 1976–77 and those for five seasons from 1990 to 1999. Counts made in another three seasons after 1975 were not used because each was based on a single visit and likely to have underestimated pup numbers; the observed maximum in each of those seasons was far less than half of the average pup numbers recorded in the colony. No counts were made in the other seven pupping seasons between 1975 and 1990. Counts are also available for the four seasons from 2000–01 to 2005 (Shaughnessy and Dennis 2001, 2003; Shaughnessy 2004b; this report). Overall, data are available from 11 seasons.

Dead pups were counted in ten of the 11 seasons for which data are available. For the initial consideration of trends, each of the 11 data sets was used; although one of them was based on a single count (363 pups in 1996), it is considered a reasonable estimate because it is near the long-term average (375, see below).

In the discussion on trends in abundance of the Dangerous Reef population, direct counts of pups are used without the addition of pups less than 4 weeks of age that were counted on visits that followed the maximum count (see above), because those data were available only in three of the last four pupping seasons and their inclusion would have interfered with the aim of the trend analysis.

The rate of change in pup numbers was calculated using linear regression of the natural logarithm of the mean estimate of pup numbers against year. The exponential rate of increase (r) is the slope of the regression line. An exponential rate of increase has been demonstrated for other seal species, for example the NZFS on Kangaroo Is (Shaughnessy et al. 1995). It can be expressed as a percentage increase using the following formula:

$$(e^{r}-1) \times 100.$$

In addition, the correlation coefficient, R, of the trend data was calculated.

Classification of sites used by ASL

We follow the classification of ASL colonies used by the National Seal Strategy Group, which refers to surveys conducted in the last 20 years: (1) *breeding colony*, five or more pups recorded in at least one survey, (2) *haulout site with occasional pupping*, one to four pups recorded in at least one survey, (3) *haulout site*, areas frequented by ASL where pups have not been recorded.

Results

Australian sea lion pups at sites in the 2004–05 pupping seasons

Counts of ASL, including pups are presented for the Neptune Is, other islands south of Spencer Gulf and islands of southern Spencer Gulf in Table 7.1, for islands off the west coast of Eyre Peninsula in Table 7.2, and for Dangerous Reef in Table 7.3.

South Neptune Is

Sea lions were counted on the South Neptune Is on 7 February 2005 when 35 were seen, most of which were on Main Is. No pups were seen, although the visit was at the end of the predicted pupping season; small numbers of pups have been seen previously on Main Is (Gales et al*.* 1994; Shaughnessy et al*.* 2005).

North Neptune Is

On 10 February 2005, 24 ASL were counted on East Is of the North Neptune group, including six brown pups. On a later visit (12 May), there were 13 brown pups and a dead pup.

On three visits to East Is in the last 15 years, 20 to 35 ASL have been counted on the island, but pups have not been seen. Those visits were on: 1 February 1990 as part of the overall survey of ASL colonies (Gales et al*.* 1994); 2 February 1993 when a bull was mate-guarding a cow (Dennis 2005), indicating that a breeding season may have begun soon afterwards; and 8 February 2000 (P Shaughnessy, unpublished data). The observations in February 2005 form the first record of pupping on the East Is of the North Neptune group and the estimate of pup numbers for the season is 14. The North Neptune Is were noted as possible breeding localities by Gales et al*.* (1994).

North Islet

On 27 July 2005, 120 ASL were seen at North Islet, including 28 live pups. Previously, small numbers of pups were reported there: eight in November 1975 (Ling and Walker 1976; Gales et al*.* 1994) and one in February 1977 (G. Walker, in Dennis 2005).

Peaked Rocks

During a circumnavigation of Peaked Rocks on 28 July 2005, 15 ASL were seen on the two rocks of Peaked Rocks, including three that may have been pups.

Sea lions were recorded breeding on the north-east island of Peaked Rocks by C. Wickham on 2 April 1990 when 22 live pups and one dead pup were seen (Dennis 2005). This was reported as a count of 24 pups on 29 March 1990 by Gales et al. (1994); the reason for the discrepancy is not apparent.

Albatross Is

Albatross Is was circumnavigated on 27 July 2005 when at least 15 ASL pups were seen. Previously, 12 ASL pups were reported from the island in November 1982 (Gales et al. 1994; Robinson et al. 1996).

Liguanea Is

In the 2004–05 pupping season, Liguanea Is was visited twice. In November 2004, pup numbers were estimated as 41, comprising 37 brown pups and four dead pups. All but one of the pups was on the southern peninsula, and many of them were under or near bushes on the top of the peninsula. No pups or signs of breeding activity were observed from the boat on the eastern shore of the island.

In February 2005, two small pups judged to be younger than two months were seen on the southern peninsula; they were assumed to have been born since our previous visit two months earlier. On the February visit, no pups or signs of breeding activity were observed on the island's coastline other than on the southern peninsula. Therefore the estimate of pup numbers for the 2004–05 pupping season is 43. This exceeds the direct count of 23 pups made in January 1990, based on a single visit when the colony was first reported (Gales et al. 1994) and timing of the breeding cycle there was unknown. It also exceeds the count in November 1995, when only one pup was seen (Shaughnessy et al. 2005).

Smith Is

During a walk around the island in November 2004, 34 ASL were counted but no pups were seen. On two inspections from boats, in June and July 2005, small numbers of ASL were seen, but no pups. Previously, brown pups were reported on the island from an aerial survey in December 1995 (Shaughnessy et al. 2005). Several explanations are possible for the earlier sighting of pups there and their absence in this study: the recent visits may have been outside of the pupping season, but this seems unlikely because we saw pups on nearby islands at similar times in 2004 and 2005.

Lewis Is

Five visits were made to Lewis Is. In November 2004, the island was circumnavigated by boat and 61 ASL were seen, but no pups or signs of breeding. Landings were made on the island during the last four visits and pups were seen on each occasion. On the visit in late June 2005, six small pups were seen and the pupping season must have just begun. By late November 2005, a total of 78 pups had been recorded there, which includes three dead pups seen in September.

Table 7.1. Counts of ASL and NZFS on islands in the southern Spencer Gulf region, South Australia, 2004 and 2005.
A dash (-) indicates that no information is available. Pups less than 1 month of age (in the 7th column) are also included in the column for brown pups and in the total count of ASL; their presence indicates that a pupping season is still underway.

Colony	Date	Bull	Unclassed	Moulted pup	Brown pup	Pups < 1 month	Dead pup	Total ASL	NZFS	Observers [a]
South Neptune	7 Feb 05	11	24	-	0	0	0	35	many	PS
North Neptune, east	10 Feb 05	5	13	0	6	0	0	24	-	SG
North Neptune, east	12 May 05	-	-	0	13	-	1	-	-	SG
North Is, Gambier Is	27 Jul 05	16	76	18	10	-	0	120	4 pups	SG, BP, DH
Peaked Rocks, Gambier Is*	28 Jul 05	0	12	3 (?)	0	0	-	15	0	SG, BP, DH
Albatross *	27 Jul 05	-	-	0	15	0	-	- [d]	-	SG, BP, DH
Liguanea	11 Nov 04	22	67	0	37		4	130	many	JM, PS
Liguanea, nonbreeding area*	11 Nov 04	5	22	0	0	-	0	27	many	JM, PS
Liguanea	10 Feb 05	-	-	-	-	2	0	- [d]	-	PS
Smith, Thorny Pass.	11 Nov 04	5	29 [b]	0	0	0	0	34	0	JM, PS
Smith, Thorny Pass.*	29 Jun 05	0	3	0	0	0	0	3	3	DH
Smith, Thorny Pass.*	28 Jul 05	0	4	0	0	0	0	4	14	SG, BP, DH
Lewis *	11 Nov 04	7	54 [b]	0	0	0	0	61	-	JM, PS
Lewis	29 Jun 05	17	59	0	6	6	0	82	0	DH
Lewis	28 Jul 05	26	116	1	23	1	0	166	-	SG, BP, DH
Lewis	23 Sep 05	-	-	-	43	-	3	-	-	BP, PW
Lewis	30 Nov 05	2	62	-	75	-	0	139	-	DH

Table 7.1 (cont.)

Colony	Date	Bull	Unclassed	Moulted pup	Brown pup	Pups < 1 month	Dead pup	Total ASL	NZFS	Observers [a]
Little	29 Jun 05	0	29	4	0	0	0	33	-	DH
Little *	28 Jul 05	2	23	0	0	0	0	25	-	SG, BP, DH
Hopkins	29 Jun 05	4	62	0	0	0	0	66	0	DH
Hopkins	28 Jul 05	4	56	0	0	0	0	60		SG, BP, DH
Rabbit*	7 Jun 05	2	0	0	0	0	0	2	57	DH
Rabbit*	3 Aug 05	0	0	0	0	0	0	0	102	DH
Rabbit*	17 Oct 05	0	0	0	0	0	0	0	1	DH
Sibsey*	7 Jun 05	1	5	-	-	-	-	6	31	DH
English	7 Jun 05	5	-	0	21	2	3	- [d]	-	DH
English	24 Jun 05	5	-	0	18	3	1	- [d]	-	DH
English	20 Jul 05	-	-	25 [c]	6	-	1	- [d]		DH
Langton	25 Jul 05	14	113	2	0	0	0	129	0	DH
Blyth	25 Jul 05	12	66	0	0	0	0	78	0	DH

Footnotes

[a] Counters were: Simon Goldsworthy, Brad Page (SARDI, Adelaide), Derek Hamer (SARDI, Port Lincoln), Jane McKenzie (DEH, Adelaide), Peter Wilkins (DEH, Port Lincoln), Peter Shaughnessy (CSIRO, Canberra).

[b] Includes cow-juvenile pairs: 4 at Smith Is., 9 at Lewis Is.

[c] Includes 3 pups marked at Dangerous Reef.

[d] Incomplete count.

* Partial count from a boat.

Table 7.2. Counts of ASL and NZFS at sites on the west coast of Eyre Peninsula, South Australia during 2004 and 2005.
A dash (-) indicates that no information is available. Pups less than 1 month of age (in the 7th column) have been included in the column for brown pups and in the total count of animals; their presence indicates that a pupping season is still underway.

Colony	Date	Bull	Unclassed	Moulted pup	Brown pup	Pups < 1 month	Dead pup	Total ASL	Fur seals	Observers [a]
NE Franklin	8 Nov 04	20	87	0	10	-	0	117	4	JM, PS, CZ
NE Franklin	10 Jan 05	14	63	0	30	-	3	110	0	BM, PS, CZ
NE Franklin	10 Mar 05	6	79	4	57	9	3	149	0	MB, BM, CZ
NE Franklin	6 Apr 05	2	62	1	55	0	1	121	0	BM, PS, CZ
SE Franklin	8 Nov 04	19	80	0	16	-	0	115	0	JM, PS, CZ
SE Franklin	10 Jan 05	16	102	3	54	-	1	176	2	BM, PS, CZ
SE Franklin	10 Mar 05	8	91	6	75	4	2	182	4	MB, BM, CZ
SE Franklin	6 Apr 05	8	120	1	62	0	0	191	3	BM, PS, CZ
Flinders Reef *	10 Jan 05	-	6	-	-	-	-	6	-	PS
Gliddon Reef	4 Jun 05	-	23	0	7	0	0	30	0	PS SG BP KP
Breakwater	8 Nov 04	3	19	0	0	-	0	22	0	JM, PS, CZ
Breakwater	10 Jan 05	9	23	0	2	-	0	34	0	BM, PS, CZ
Breakwater	7 Apr 05	2	28	0	15	2	0	45	0	BM, CZ
Breakwater	4 Jun 05	-	-	5	11	0	1	- [d]	0	PS
Fenelon	13 Mar 05	12	40	0	10	1	0	62	19	MB, BM, CZ
Masillon *	13 Mar 05	8	19	0	0	0	0	27	12	MB, BM, CZ
Masillon *	29 May 05	7	18	0	0	0	0	25	5	PS, SG, BP
West	13 Mar 05	17	67	0	36	-	2	122	2	MB, BM, CZ
West	29 May 05	6	55	6	46	-	1	114	2	PS SG BP KP AB
West	5 July 05	-	-	-	-	1	0	- [d]	-	BP
Purdie	31 May 05	9	119	8	121	0	3	260	0	PS, SG

Footnotes
[a] Counters were: Mel Berris (Kangaroo Is), Simon Goldsworthy, Brad Page, Al Baylis, Kristian Peters (SARDI, Adelaide), Jane McKenzie (DEH, Adelaide), Bec McIntosh (La Trobe University, Melbourne), Peter Shaughnessy (CSIRO, Canberra), Cathy Zwick (DEH, Ceduna).
[d] Incomplete count.
* Partial count from a boat.

During an aerial survey in September 1975, seven moulted pups were seen on Lewis Is (Ling and Walker 1976; Dennis 2005). The island was not included in the enumeration of pup numbers in lists of breeding colonies by Robinson and Dennis (1988) or by Gales et al. (1994), presumably the sighting was considered unreliable, because moulted pups are difficult to recognise from a fixed-wing aircraft. It was noted as a possible breeding site by Gales et al. (1994).

Little Islet

About 30 ASL were seen on each of two visits to Little Is in this study. Four moulted pups were sighted on the first visit, in late June 2005. Because they were large enough to have moved there from another island, it is assumed that they were not born on Little Is. Nevertheless, Little Is should be considered a potential breeding site.

Hopkins Is

About 60 ASL were seen on two visits to the beaches of Hopkins Is in this study, but there was no evidence of pups. Nearly all of the animals seen on the second visit (28 July 2005) were juveniles.

Dangerous Reef

Pup counts in the 2005 pupping season

Counts of pups and other ASL at Dangerous Reef in the 2005 pupping season are presented in Table 7.3 and counts of pups are graphed in Fig. 7.1. The largest estimate of live pups and accumulated dead pups was 585 on 27 June, about 5 months after pupping began. Fewer pups were counted on the next two visits to the island, both in mid-July, although the estimated number of pups on the final visit, on 11 August, was 551 and similar to that on 27 June.

On the final visit to the colony, on 17 August, 20 pups aged less than 1 month were seen which would have been born since the previous visit. This indicates that the pupping season was nearly over by then. That number plus the 12 pups seen in mid-July all would have been born since the visit on 27 June when the maximum count was made. When those 32 pups are added to the count for 27 June (585), the best estimate of pup numbers from direct counting for the season is obtained, namely 617 pups. This is the highest recorded estimate of pup production for Dangerous Reef.

Table 7.3. Counts of ASL at Dangerous Reef colony, southern Spencer Gulf, between January 2005 and August 2005.

Date	Live pups	Dead pups [a]	Accumul. dead pups [b]	Estimated pups [c]	Bulls	Other classes	Counters [d]
26 Jan	2	1	1	3	-	-	SG
13 Apr	89	9	10	99	-	-	BP
11 May	207	37	47	254	-	-	SG, BP, DH
27 Jun [e]	403	135	182	585 [k]	58	518	PS, DH, SW
13 Jul [f]	258	56	238	496	44	292	PS DH SW BM
15 Jul [g]	272	10	248	520	-	-	PS, BM, SW
11 Aug [h]	277	26	274	551	33	204	PS, BM, SW

[a] 'Dead pups' refers to those that died since our previous visit to the colony.
[b] 'Accumulated dead pups' refers to the number of dead pups counted in the season up to and including the current count.
[c] 'Estimated pups' is the sum of Moulted pups, Brown pups and Accumulated dead pups.
[d] Counters were: Simon Goldsworthy and Brad Page (SARDI Aquatic Sciences, Adelaide), Derek Hamer (SARDI Aquatic Sciences, Port Lincoln), Sarah Way (DEH, Port Lincoln), Bec McIntosh (La Trobe University, Melbourne) and Peter Shaughnessy (CSIRO, Canberra).
[e] Data for 27 June on West Reef includes 1 pup, 6 bulls and 79 'other classes'; on East Reef it includes 6 bulls and 68 'other classes'.
[f] Data for 13 July on West Reef includes 0 pups, 5 bulls and 67 'other classes'; it was too rough to visit East Reef.
7 pups were less than 1 month of age.
[g] Data for 15 July on West Reef includes 0 pups, 1 bull and 93 'other classes'; it was too rough to visit East Reef.
On Main Reef, the count of 'Live pups' was the average of two counts done simultaneously: 269 and 274.
5 pups had been born since 13 July.
[h] Data for 11 August on West Reef includes 6 pups, 3 bulls and 80 'other classes'; it was too rough to visit East Reef.
On Main Reef, the count of 'Live pups' was the average of two counts done simultaneously: 268 and 273.
20 pups were less than 1 month of age.
[k] 32 brown pups were recorded after the survey on 27 June; with their inclusion, the best estimate for the 2005 pupping season is 617 pups.

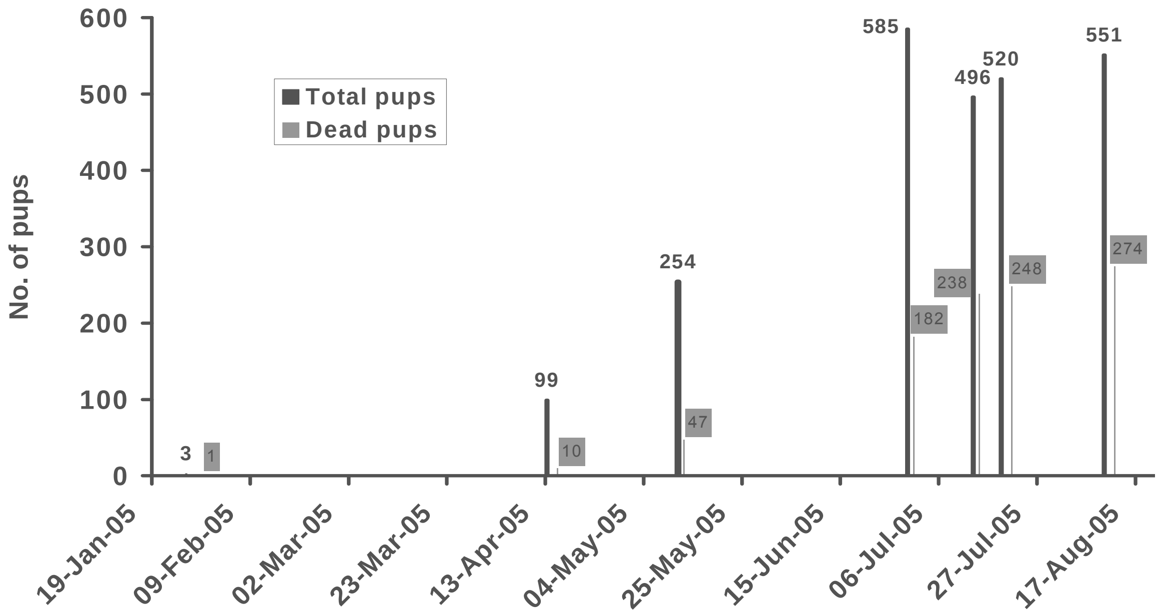


Fig. 7.1. Counts of ASL at Dangerous Reef, 2005.

Mark-recapture estimates of pup numbers and comparison with direct counts

The mark-recapture estimate in this colony was based on 115 marked pups. In the five recapture sessions on 15 July 2005 the proportion of marked pups averaged 0.35. Estimates of the number of live pups ranged from 285 to 361, with mean 326 and standard deviation 7.2 (Table 7.4). The 95 % confidence limits of the mark-recapture estimate were 312 and 340.

The proportion of marked pups sighted by the two ‘callers’ were 0.385 and 0.335. A chi-squared test of homogeneity of the distribution of marked and unmarked pups in the five recapture sessions showed that the data were homogeneous ($\chi^2_{(4)} = 4.29$, $0.3 < P < 0.4$). When the data were amalgamated by combining the recapture data of each ‘caller’, there was no association between the ‘caller’ and the proportion of marked pups ($\chi^2_{(1)} = 2.71$, $0.1 < P < 0.2$). Therefore it is appropriate to combine the data sets from all five recapture sessions.

Table 7.4. Mark-recapture estimates of ASL pups at Dangerous Reef colony on 15 July 2005.

Caller [a]	No. marked pups (M)	No. pups examined (n)	No. marked pups recaptured (m)	Pup population estimate (N)	Standard deviation
BM	115	231	93	285.3	9.9
SW	115	224	71	361.5	21.6
BM	115	246	90	313.9	12.1
SW	115	232	82	324.6	15.2
SW	115	225	75	343.9	18.8
Mean estimate				326	7.2

[a] Recapturers (callers) were: Bec McIntosh (La Trobe University, Melbourne) and Sarah Way (DEH, Port Lincoln.

Numbers of live pups counted on the Main Reef on the day of the recapture sessions were 269 and 274, averaging 272. Thus the mark-recapture estimate was 1.20 times larger than the direct count of live pups, and the 95 % confidence limits of this ratio were 1.15 and 1.25.

Comparisons of mark-recapture estimates of ASL pups with direct counts at Dangerous Reef have now been made three times (Table 7.5). Each time, the mark-recapture estimate was between 1.19 and 1.27 times the direct count of pups, and the 95 % confidence limits of the comparison overlapped, ranging from 1.12 to 1.31. This indicates that the comparisons of mark-recapture estimates with direct counts of pups were similar in the three pupping seasons. The discrepancy between the direct counts and the mark-recapture estimates on each occasion results from the difficulty of sighting all pups in the colony. Pups asleep under rocks or behind rocks that can't be accessed are missed during direct counting.

On the assumption that pups were as likely to be overlooked during the last direct counts as they were on 15 July 2005 when direct counting was compared with the estimate from the mark-recapture procedure, the estimate from direct counting can be adjusted to give an estimate of 740 pups (i.e., 617 x 1.20), with 95 % confidence limits 710 and 771.

Table 7.5. Mark-recapture estimates of the abundance of ASL pups at Dangerous Reef; summary of the results from three seasons.

Date	Direct count of pups	Mark-recapture estimate of pups	Comparison	95 % confidence interval	Source
July 1999	240	285	1.19	1.12 to 1.25	Shaughnessy and Dennis (1999)
Jan 2004	333	423	1.27	1.21 to 1.31	Shaughnessy (2004b)
July 2005	272	326	1.20	1.15 to 1.25	This report

Pup mortality

For the 2005 pupping season at Dangerous Reef, 182 dead pups were recorded by 27 June when the estimated number of births reached a maximum of 585, giving an incidence of pup mortality 31.1 %.

For the last seven pupping seasons at Dangerous Reef (since 1996), the incidence of pup mortality has ranged from 15 % to 45 % (Table 7.6). It was high for pupping seasons that occurred predominantly in winter (30 % in 1996, 42 % in 1999, 45 % in 2002 and 31 % in 2005, with unweighted average 37 %) and lower for pupping seasons that occurred predominantly in summer (15 % in 1997–98, 23 % in 2000–01 and 19 % in 2003–04, with unweighted average 19 %). For this analysis, data for pupping seasons before 1996 have been omitted because insufficient attention had been directed at dead pups.

A generalised linear model was fitted to the pup mortality data in which a binomial distribution was assumed with a logit link. The model was fitted with 'season' (winter and summer) as a two-level factor. The coefficients of regression and the change of deviance associated with this model indicate that there was a highly significant difference in pup mortality between seasons ($P < 0.001$).

A difference in pup mortality between a winter and a summer pupping season was also observed by Gales et al*.* (1992) at islands in the Jurien Bay region on the west coast of Western Australia (namely, North Fisherman, Beagle and Buller Is). They reported high pup mortality in the first five months of a breeding season that included the 1989 winter, averaging 24 % over the three islands. Pup mortality rates were considerably lower (7 %) in the preceding pupping season, which occurred during the summer. The difference in mortality rates between seasons was thought to have been related to timing of the ASL pupping seasons in winter and in summer, respectively.

Causes of the high levels of pup mortality in ASL are not clear, but there is evidence that an important cause is intra-specific aggression. At Dangerous Reef, Marlow (1975) observed ASL in 1967, 1969 and 1970, and noted that for pups, “overt aggression by other ASL was the main cause of death … adult bulls, large juvenile males and adult females all being involved” (p. 224). At Seal Bay, Kangaroo Is, attacks on pups by ASL bulls holding territories were responsible for 19 % of pup deaths (4 of 21 deaths examined) in two breeding seasons (Higgins and Tedman 1990). Evidence from Dangerous Reef and from the islands near Jurien Bay indicates that weather may also have an influence on pup mortality, with higher rates recorded during the colder, wetter winters of these areas.

Table 7.6. Estimated number of births of ASL at Dangerous Reef, South Australia for 11 pupping seasons between 1975 and 2005. The estimated numbers of births are maxima of direct counts for each pupping season. Data are collated from Dennis (2005), Shaughnessy and Dennis (2001, 2003), Shaughnessy (2004b) and this report. The entry for 1994–95 includes an adjustment to account for pup mortality because only live pups (295) were counted in that season.

Pupping season	Accumulated dead pups [a]	Estimated no. of births	Pup mortality (%)	Month of max. count since pupping began
1975	73	356	20.5	5
1976–77	26	262	9.9	4
1990	55	260	21.2	4
1994–95	-	354 [b]	not estimated	6.5
1996	110	363	30.3	-
1997–98	38	248	15.3	4
1999	161	383 [c]	42.0	4
2000–01	90	393	22.9	7
2002	190	426 [d]	44.6	6
2003–04	93	499 [e]	18.6	5
2005	182	585 [f]	31.1	5

[a] 'Accumulated dead pups' refers to the number of dead pups counted through the pupping season to a maximum of 7 months from the first births.
[b] Adjusted for pup mortality using:
"Maximum pup count" x 1.19954, where 0.19954 is the un-weighted average proportion of dead pups in three summer pupping seasons, 1997–98, 2000–01 and 2003–04.
[c] In addition, 23 newly-born pups were recorded on the last two visits; that number plus the previous estimate (of 383) leads to an estimate of pup numbers for the season of 406.
[d] In addition, 29 newly-born pups were recorded on the last visit; that number plus the previous estimate (of 424) leads to an estimate of pup numbers for the season of 453.
[e] In addition, 27 newly-born pups were recorded on the last visit; that number plus the previous estimate (of 499) leads to an estimate of pup numbers for the season of 526.
[f] In addition, 32 newly-born pups were recorded on the last three visits; that number plus the previous estimate (of 585) leads to an estimate of pup numbers for the season of 617.

The pup mortality estimates are based on counts of dead pups in colonies and are likely to be underestimates because, in general, dead pups are more difficult to see than live pups and may be overlooked. In addition, dead pups may disappear before being counted because high tides and storm-driven waves wash them away, older ASL trample them into the ground, and avian scavengers gradually remove them.

Trends in abundance at Dangerous Reef

For the ASL colony at Dangerous Reef, estimates of pup numbers by direct counting for eleven pupping seasons from 1975 to 2005 ranged from 248 to 585 (Table 7.6, Fig. 7.2) and averaged 375 with standard deviation 103.

Because dead pups were not counted in the 1994–95 season, the number of live pups in that season has been adjusted to estimate the number of births. The estimate of pup abundance for this season (351) is the product of the maximum pup count for the season (295 on 27 March 1995) and 1.19954, using the unweighted average proportion of dead pups in three summer pupping seasons from 1997–98 to 2003–04, namely 0.19954 (Table 7.6).

The estimates of pup numbers for most seasons exceed that obtained for this colony in 1990 during the first overall survey of ASL (Gales et al*.* 1994, Table 7.1), in which the count for Dangerous Reef was 250 pups and the estimate was 275 pups. The estimate for 1990 used here is 260 pups (Table 7.6), comprising 205 live pups and 45 dead pups on 28 July 1990, and 10 dead pups from an earlier count in the same season.

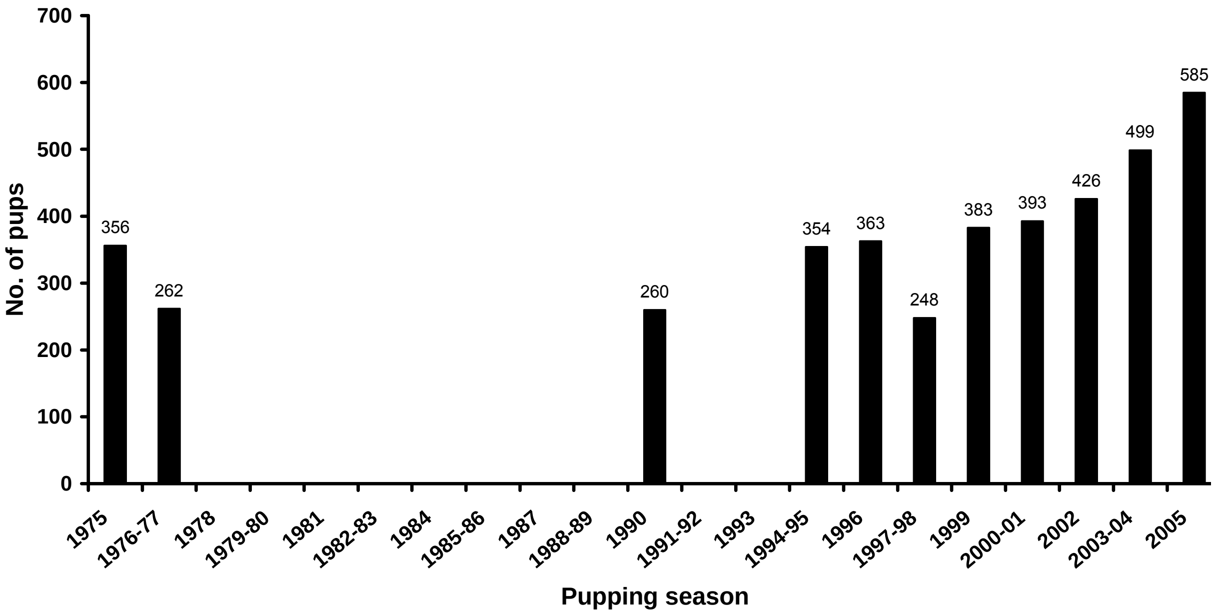


Fig. 7.2. Trends in numbers of ASL pups at Dangerous Reef from direct counting, 1975 to 2005.

The number of pups born at Dangerous Reef over the eleven pupping seasons (Fig. 7.2) increased at an exponential rate of r = 0.024, equivalent to 2.4 % per season, but the trend is not significant ($F_{1,9}$ = 4.96, P = 0.053, R^2 = 0.36).

Of data points for the eleven pupping seasons, three are considerably smaller than the others: 262 pups in 1976–77, 260 in 1990 and 248 in 1997–98. Each of these counts was made in the fourth month after pupping began, whereas maximum counts for all but one of the other seasons were made in the fifth month or later. Counting that ended in the fourth month of a pupping season is likely to underestimate pup production seriously. If data for those three seasons are omitted from the trend analysis, eight sets of data remain, for 1975, 1994–95, 1996, and for the five consecutive seasons from 1999. The rate of increase for these eight pupping seasons is r = 0.018 or 1.8 % per season, equivalent to 1.2 % per annum, ($F_{1,6}$ = 3.93, P = 0.095, R^2 = 0.40). Although this analysis also indicates that the colony has been increasing, the trend is not statistically significant.

Pup count data have been collected more assiduously since 1994–95 than previously, but the data set for 1997–98 was incomplete because counts did not extend beyond the fourth month of the season. If that data point is omitted and data for the other seven pupping seasons from 1994–95 are analysed, counts increased at *r* = 0.066 or 6.8 % per season, equivalent to 4.6 % per annum ($F_{1,5}$ = 26.1, P = 0.004, R^2 = 0.84). This is the best interpretation of these data and the trend is significant.

The increasing trend at Dangerous Reef is contrary to the decline in pup numbers at Seal Bay on Kangaroo Is, where the decrease in numbers of live pups was 12.6 % over 13 pupping seasons at an exponential rate of 1.1 % per season (Shaughnessy et al. 2006).

Finfish aquaculture of southern bluefin tuna (*Thunnus maccoyii*), has operated about 30 km north-west of the Dangerous Reef ASL colony since 1992, initially in Boston Bay, Port Lincoln and, since 1996, outside Boston Bay on the eastern side of Boston Is (Kemper and Gibbs 2001, this report). The caged tuna are primarily fed pilchards (*Sardinops sagax*) and redbait (*Emmelichthys nitidus*). Excess food either sinks to the bottom or is consumed by fish and other species (Kemper and Gibbs 2001). Some of it is taken by silver gulls (*Larus novaehollandiae*); numbers of this species in the area have increased greatly which has been attributed to the extra food resources available (Harrison et al. 2004, 2005). Similarly, opportunistic observations since 1996 of black-faced cormorants (*Phalacrocorax fuscescens*) breeding on Dangerous Reef indicate that the number of nesting birds and the area they occupy has increased (unpublished observations). It is possible that all three species in the area have benefited from the increased food resources available and this may have enabled numbers of ASL pups at Dangerous Reef to increase.

In addition, effort in the bottom-set gill-net fishery for sharks in southern Spencer Gulf in the Marine Fishing Area surrounding Dangerous Reef (MFA 129) decreased in the period after the year 2000 (Goldsworthy and Page 2007, Table 7.9). That timing overlaps with the observed increase in ASL pup numbers at Dangerous Reef. Because that fishery is believed to impact on ASL, which become entangled in the nets (Shaughnessy et al. 2003, Page et al. 2004), it is likely that the lower fishing effort may have enabled ASL numbers to increase.

Rabbit Is

The coastline of Rabbit Is was inspected from a boat three times. Two ASL were seen in June 2005 (both were bulls) and none on the other visits (August and October). Fur seals were ashore each time, with a maximum of 102 in August and only one in October. Fur seals were also reported on the island in 2003 (R. Allen, pers. comm. in Shaughnessy 2004b, p. 11), but none was ashore in February 2004.

Sibsey Is

The single inspection of Sibsey Is did not reveal any indications to suggest that it was a breeding colony. That visit was made in early June 2005, when the pupping season was well underway at nearby Dangerous Reef and English Is.

English Is

English Is was visited on three occasions. In early June, 21 brown pups and three dead pups were seen. In late June, there were 18 brown pups and one dead pup; of the brown pups, three were small and were judged to be less than a week old. In late July there were 31 live pups (25 moulted and six brown) and one dead pup. The 25 moulted pups included three that had been marked by clipping hair on the head a week earlier at Dangerous Reef. Movement of pups from Dangerous Reef to English Is has been suspected (Shaughnessy et al*.* 2005). Pup production at English Is for the 2005 season is estimated at 27, from information from the first two visits: namely, 24 pups in early June plus the three small ones seen on the second visit.

In four pupping seasons from 1998 to 2002, between four and 15 pups were recorded (Shaughnessy et al*.* 2005) and 18 pups were seen in February 1991 (Gales et al. 1994). Hence the count in 2005 exceeds previous counts.

Langton Is

The single inspection of Langton Is revealed 129 ASL, including two moulted pups. This visit was made in late July 2005 when the pupping season was well underway at nearby Dangerous Reef and English Is, and the pups were large enough to have swum there from those nearby colonies. Therefore it is assumed that they were not born on Langton Is. Nevertheless, it should be considered a potential breeding site.

Blyth Is

The single inspection of Blyth Is in late July 2005 revealed 78 ASL but no indications that would suggest that it was a breeding colony.

NE Franklin Is and SE Franklin Is

Both islands were visited on the same days on four occasions during the 2004–05 pupping season. Small numbers of pups were present on the initial visit on 8 November 2004: ten on NE Franklin Is and 16 on SE Franklin Is. Several adult females were aggressive during that visit to the latter island.

The highest pup counts were obtained on the third visit to both islands, on 10 March 2005 about 5 months after pupping began. Pup numbers were slightly lower on the final visit four weeks later indicating that the pupping season had ended. The estimate of pup production for NE Franklin Island is 67, comprising 61 live pups in March and a total of six dead pups. For SE Franklin Is, the estimate of pup production is 84, comprising 81 live pups in March and a total of three dead pups.

The only other estimates of pup numbers for these islands are from a single visit to each in October 1990 when 46 and 75 pups, respectively, were counted. The estimates for the 2004–05 pupping season exceeded those for 1990, presumably because the recent ones were made closer to when peak numbers were in each colony than were the estimates in 1990.

Flinders Reef

This reef was inspected in January 2005 from a vessel during a circumnavigation; six ASL but no pups were seen.

Gliddon Reef

Gliddon Reef was visited on 4 June 2005 when 30 ASL were counted including seven brown pups that were judged to be so small that they would have been born there. This is the first record of breeding by ASL on Gliddon Reef.

Breakwater Is

When we first visited Breakwater Is on 7 February 2003 with charter boat operator Perry Will, there were 23 ASL ashore, including six moulted pups (Shaughnessy and Dennis 2003). Because moulted pups can move between islands and there was no evidence of breeding activity, we were reluctant then to record the site as a breeding colony. The site was visited again in February 2004 and with similar results: 27 ASL with seven moulted pups (Shaughnessy 2004b).

During this study, we visited Breakwater Is four times: in November 2004 and in January, April and June 2005. On the visits in January and April, two and 15 brown pups were on the island, respectively. They were so small that they must have been born there. Sixteen live pups and a dead pup were seen on the island in June. This is the first record of breeding by ASL on Breakwater Is and the estimate of pup numbers for the season is 17, based on the final visit.

Fenelon Is

During our visit in March 2005, ASL (including breeding females and pups) were on the sandy beach on the north coast and on the adjacent rocks beyond the west end of the beach. A few pups on the beach were not visible from the boat and were counted during a foot traverse, as were some animals on the rocks. The rocks west of the beach were not accessible on foot except those near the beach. In all, ten pups were seen, aged between about 10 days and 3 months. A second attempt to visit the island, in May 2005, was thwarted by high swells. Previously, eight pups were counted there in April 1982, 21 in September 1990, nine in August 1995, and 19 in September 2002 (Robinson et al*.* 1996, Gales et al. 1994, Shaughnessy et al*.* 2005, Robinson et al*.* 2003). Fur seals were on rocks at the eastern end of the beach in March 2005: one pup was seen among 19 animals.

Masillon Is

In March and May 2005, the island was surveyed from the boat because no landing site was apparent. No pups were seen among 27 and 25 ASL, respectively. In addition, NZFS were seen ashore on both visits. Nine brown pups and another 18 ASL were reported there in September 2002 by Robinson et al*.* (2003). They were presumably on the beach on the north side of the island where we saw ASL; any pups born there would have a precarious time in high swells because the beach is narrow and the backing cliffs are steep. We wonder if those pups had moved to Masillon from a nearby colony, such as Fenelon Is, where Robinson et al*.* (2003) also reported brown pups on the same day in September 2002.

West Is

This island was visited three times in 2005. In March 2005, the island was circled on foot. Thirty eight ASL pups were recorded including two dead pups. A total of 122 animals was ashore, including 17 bulls; five of them were attending adult females and pups, indicating that pupping was still underway. In late May, a similar number of ASL was counted (114), including 52 live pups and one dead pup. In July, ASL were not counted, but one pup was seen that was estimated to have been less than a month old and hence had been born since the last visit. Therefore in the 2005 pupping season, there were at least 56 ASL pups born on West Is; this includes the three dead pups seen in March and May, and the small pup seen in July. The total of 56 exceeds the number recorded in the previous survey, of 14 in September 1990 (Gales et al*.* 1994).

Fur seals were also seen ashore: two animals but no pups were there on each of the first two visits to the island (March and May 2005).

Lounds Is

We were unable to land on Lounds Is in May 2005 when we visited nearby Purdie Is because of large waves washing ashore. A later visit by helicopter in October 2005 was well after the pupping season had finished and most ASL ashore were large pups and their mothers. A count of pups at that time was not undertaken because it would not have been apparent which pups had been born at the island and which had moved in from other colonies.

Purdie Is

Sea lions on this island were counted on 31 May 2005, when 132 pups were seen, including three that were dead. Eight of the pups had completed their moult, which indicated that the pupping season had nearly finished. Most of the pups were on the top of the island among the vegetation.

This pup count exceeds previous counts at the site: 112 in November 1990, 65 in February 1992, and 32 in August 1995 (Gales et al. 1994, Shaughnessy et al*.* 2005). The differences could indicate an increase or could result from several factors, including counting at different times of each pupping season, environmental perturbations or human disturbances.

Discussion

Classification of aggregations of ASL

The 26 islands with aggregations of ASL inspected in this survey are grouped in Table 7.7, following the criteria used by the National Seal Strategy Group, into breeding colonies (18) and haulout sites (8). No sites qualified as 'haulout sites with occasional pupping' because each site where pups were found had at least five pups and hence qualified as a breeding colony. These colonies are listed in Appendix 4 in accordance with the classifications developed by the National Seal Strategy Group and the Marine Mammal – Marine Protected Area Aquaculture Working Group (2004).

The 26 islands are further divided in Table 7.7 into sites that were listed in the recent compilation of McKenzie et al*.* (2005) and the newly reported sites (Appendix 3). There are four newly reported breeding colonies: North Is, Lewis Is, Gliddon Reef and Breakwater Is. The status of three sites have changed: North Is and Lewis Is changed from haulout sites to breeding colonies, and Breakwater Is changed from a haulout site with occasional pupping to a breeding colony. One new haulout site is reported here, Sibsey Is, and two of the haulout sites can be considered as potential pupping sites because moulted pups were seen there, namely Little Islet and Langton Is.

Table 7.7. Classification of aggregations of ASL on 26 islands in South Australia inspected in this study compared with the list prepared by McKenzie et al. (2005). Refer Appendix 3 for further summaries.

Breeding colonies		Haulout sites	
This survey	McKenzie et al. (2005)	This survey	McKenzie et al. (2005)
North Is. [a]	South Neptune [c]	Sibsey	Smith Is.
Lewis Is. [a]	North Neptune, East		Little
Gliddon Reef	Peaked Rocks		Hopkins
Breakwater [b]	Albatross Rock		Rabbit
	Liguanea		Langton
	Dangerous Reef		Blyth
	English		Flinders Reef
	NE Franklin		
	SE Franklin		
	Fenelon		
	Masillon [c]		
	West		
	Lounds [c]		
	Purdie		
4	14	1	7

[a] Listed as a haulout site by McKenzie et al. (2005).
[b] Listed as a haulout site with occasional pupping by McKenzie et al. (2005).
[c] No pups seen on single inspections in this study; reported as breeding colonies previously.

Recently, several new breeding colonies of the ASL on the west coast of Eyre Peninsula were reported by Shaughnessy et al. (2005): Four Hummocks, Price, North Rocky, West Waldegrave and Nicolas Baudin Is.

Pup counts in breeding colonies from this survey compared with previous estimates

Estimates of abundance of ASL pups at 17 breeding colonies inspected in this survey during pupping seasons are presented in Table 7.8. One of the 18 breeding colonies listed in Table 7.7 has been omitted, namely Lounds Is, because it was visited well after the pupping season had ended. A total of 1,198 pups were seen, of which 52 % were on Dangerous Reef. This total is 1.97 times the total number of pups recorded for these colonies (607) in the first overall survey of the species made about 1990 (Gales et al. 1994).

Five of the 17 breeding colonies were not included in the 1990 survey: North Neptune East, Lewis, Gliddon, Breakwater and Masillon. When they were excluded from the comparison, there were 1,082 pups seen on the survey reported here, which is 1.78 times the number seen in the 1990 survey.

The largest difference between the two surveys is at Dangerous Reef, with 617 pups counted in 2005 compared with 250 in 1990. In the earlier survey, the count at Dangerous Reef was made in the fourth month of the pupping season, before pup numbers had reached their maximum (see above). If Dangerous Reef was also excluded from the comparison, 465 pups were recorded in the remaining 11 breeding colonies in 2004 and 2005, which is 1.30 times the number for the earlier survey (357).

Of the 12 islands for which there are estimates of pup numbers for the two surveys, pup numbers were higher in this study in nine colonies and smaller in three. For two of those three, we were unable to get ashore at the appropriate time in the pupping season (Peaked Rocks and Fenelon Is). At Dangerous Reef, the increase in pup numbers has been substantiated (see above). The most likely reason that larger estimates were obtained at the other breeding colonies in this study was that visits were planned to coincide as close as possible to dates when maximum numbers of pups were expected ashore. In other words, because knowledge of the timing of pupping seasons has improved over the years, timing of visits was planned more strategically. Other possibilities include environmental perturbations or human disturbances during the earlier survey, which might have affected pup numbers adversely.

Recommendations

Monitoring ASL population trends at colonies that are adjacent to existing and proposed sea-cage aquaculture sites provides a key performance measure to assess the potential impact of aquaculture operations.

Table 7.8. Numbers of ASL pups counted at breeding colonies on Neptune Is, islands in the southern Spencer Gulf region and islands on the west coast of Eyre Peninsula, South Australia, from surveys in 2004 and 2005 compared with pup counts for those islands from earlier surveys. Counts from Gales et al. (1994) refer to surveys made in 1990 and 1991, together with some earlier data.

	This study		Other studies		Gales et al. (1994)	
Site	Date [a]	Pups	Date	Pups	Date	Pups
S Neptune, Main Is.	7 Feb 05	0	early 93	6 [b]	11 Oct 91	4
N Neptune, East Is.	12 May 05	14	-	-	-	- [g]
North Is	27 Jul 05	28	-	-	15 Nov 75	8 [c]
Peaked Rocks	28 Jul 05	3*	2 Apr 90	23 [d]	29 Mar 90	24
Albatross Is.	27 Jul 05	15*	-	-	Nov 82	12 [e]
Liguanea Is.	11 Nov 04	43	-	-	30 Jan 90	23
Lewis Is	30 Nov 05	78	14 Sep 75	7 [c]	-	- [g]
Dangerous Reef	27 Jun 05	617	-	-	27 Jul 90	250
English Is	7 Jun 05	27	7 Aug 02	15 [b]	23 Feb 91	18
NE Franklin	10 Mar 05	67	-	-	24 Oct 90	46
SE Franklin	10 Mar 05	84	-	-	24 Oct 90	75
Gliddon Reef	4 Jun 05	7	-	-	-	-
Breakwater Is	4 Jun 05	17	-	-	-	-
Fenelon Is	13 Mar 05	10	24 Sep 02	19 [f]	28 Sep 90	21
Masillon Is *	13 Mar 05	0	24 Sep 02	9 [f]	-	-
West Is	29 May 05	56	-	-	28 Sep 90	14
Purdie Is	31 May 05	132	17 Feb 92	65 [b,d]	27 Nov 90	112
Total		1,198				607

[a] These dates are when the majority of the pups were counted; details are in Tables 7.1, 7.2 and 7.3.
[b] Shaughnessy et al. (2005)
[c] Ling and Walker (1976)
[d] Dennis (2005)
[e] Robinson et al. (1996), Robinson and Dennis (1988)
[f] Robinson et al. (2003)
[g] Noted as a possible breeding colony by Gales et al. (1994)
* Partial count from a boat

8 THE DISTRIBUTION OF FORAGING EFFORT OF AUSTRALIAN SEA LIONS IN SOUTHERN SPENCER GULF AND THE NUYTS ARCHIPELAGO

SD Goldsworthy, B Page, KD Peters, RR McIntosh, D Hamer and AMM Baylis

Introduction

Some species aggregate in great numbers to breed, dramatically increasing the potential for intra-specific competition for resources around colonies. Although coloniality confers selective benefits, such as enhanced mate-choice and defence against predators (reviewed in Andersson 1994), large aggregations of high-order consumers may deplete local food resources (Ashmole 1963, Birt et al. 1987). This may result in the separation of breeding and foraging habitats and an increase in the cost of commuting to provision dependent young, which remain at the central place (Orians and Pearson 1979). In an attempt to reduce this cost, colonies of some terrestrial animals are located in different places from year to year, tracking their dynamic food resources (Brown et al. 1992). However, animals such as seabirds, fur seals and sea lions utilise the marine environment to forage but regularly return to land to breed, rest and nurse their dependent young. The energetic cost of commuting to foraging grounds is therefore a factor that may influence the location of colonies and affect the fitness of breeding seals, as has been demonstrated for seabirds (Hunt et al. 1986, reviewed in Gremillet et al. 2004).

In contrast, non-breeding seals are less constrained in where they can forage, so they would be expected to avoid proximal feeding grounds by conducting longer foraging trips to search out more profitable habitats. Recent studies on seals confirm that non-breeders typically spend more time at sea on each foraging trip and forage further afield than lactating females (Boyd et al. 2002, Sterling and Ream 2004, Ream et al. 2005, Page et al. 2006). Differences in the diet and foraging behaviour of lactating female, male and juvenile NZFS (*Arctocephalus forsteri*) in southern Australia indicate that they utilise different prey and that lactating females typically utilise shallower habitats than males (Page et al. 2005a, 2005b, 2006). Such dietary variation reflects differences in the metabolic requirements and physiological constraints of male and female seals, because lactating females also perform relatively brief foraging trips in order to nurse their dependent pups (Page et al. 2005a). In contrast, a greater diving capacity is thought to be necessary to access the prey that adult males require to maintain their relatively large body size and juveniles are likely limited in their ability to utilise larger prey (Page et al. 2005a, 2005b).

The distribution of different sized prey can influence the habitat utilised by predators, because predator body size may affect the size of prey that can be efficiently captured, killed and consumed (e.g. Ashmole 1968). For air-breathing divers, such as seals, body size is also related to oxygen storing capacity and diving ability, which determine how deeply prey can be accessed (Kooyman 1989). Furthermore, some large predators are thought to be less adept at capturing small prey, so these predators may specialise on larger, less-manoeuvrable and/or cryptic prey, which are typically benthic (e.g. ASL, Gales and Cheal 1992, Costa and Gales 2003, McIntosh et al. 2006). Such predator versus prey size relationships have been found among sympatric tern species and different demographic groups of fur seals (Ashmole 1968, Hulsman 1987, Page et al. 2005a).

Dietary information indicates that ASL utilise a range of benthic prey species including crustaceans; rock lobster (*Panulirus cygnus* and *Jasus* sp.), swimming crab (*Ovalipes australiensis*), cephalopods; cuttlefish (*Sepia* sp.), squid (*Sepioteuthis australis* and *Nototodarus gouldi*), octopus, fishes; King George whiting (*Sillaginodes punctata*), leather jacket (Monocanthidae), flathead (*Neoplatycephalus* sp.), swallowtail (*Centroberyx lineatus*), common bullseye (*Pempheris multiradiata*), eastern school whiting (*Sillago flindersi*), yellowtail scad (*Trachurus novaezelandiae*), Australian salmon (*Arripis truttaceus*), sharks; school shark (*Galeorhinus galeus*) and gummy shark (*Mustelus antarcticus*) and birds; little penguin (*Eudyptula minor*) (Walker and Ling 1981, Richardson and Gales 1987, Gales and Cheal 1992, Ling 1992, McIntosh et al. 2006). These studies have provided a list of the potential prey of ASL, but quantitative studies are lacking, hampering our understanding of their key prey species, habitats and interactions with fisheries. Quantitative studies have not been undertaken because traditional faecal analysis techniques have proven ineffective in ASL because most prey remains are completely digested (Gales and Cheal 1992).

The foraging behaviour of ASL is presently poorly understood relative to New Zealand and Australian fur seals (*A. pusillus doriferus*) that occur sympatrically to ASL (Arnould and Hindell 2002, Kirkwood et al. 2002, 2006, Page et al. 2005a, b, c, Baylis et al. 2005, Littnan et al. 2007). Australian sea lion (ASL) foraging behaviour has been investigated at Seal Bay, Kangaroo Is, and has determined that ASL are benthic feeders that dive almost continuously and spend more than 60 % of each dive beyond 80 % of the maximum depth (Costa and Gales 2003). Average dive depths range from 42–83 m, with maximum dives ranging from 60–105 m (Costa and Gales 2003). Fowler et al. (2006) also indicated that lactating female ASL typically forage in < 80 m, within 100 km of their colony. In contrast, juvenile ASL utilise more shallow regions (40–60 m) that are closer to their colony (within 30–40 km) (Fowler et al. 2006). Given marked differences in body sizes and life history constraints, differences in the foraging behaviour of adult females and juvenile ASL are not unexpected. Body mass in particular likely dictates the marked difference in benthic habitat accessible to male and female juvenile and adult seals. As such, satellite tracking studies are needed to identify the foraging areas utilized by different sex and age classes at different ASL populations across their range.

A Recovery Plan for ASL was recently drafted by the Department for the Environment, Water, Heritage and the Arts, based primarily on a report that identified impediments to recovery and growth of ASL populations (McKenzie et al. 2005). The report identified factor(s) that may be contributing to a decline in populations of ASL and considered the most likely to be of an anthropogenic and top-down (mortality driven) origin. Three factors fell into these categories: direct killing, pollutants and toxins, and fishery bycatch and entanglement. The report found no evidence that either direct killing or pollution and toxins were significant factors currently regulating the growth of ASL populations. There was, however, evidence that fishery bycatch and entanglement caused significant ASL mortality, at least in parts of their range. As a consequence, the report ranked fishery bycatch and entanglement as the most significant of all factors discussed, and the most likely factor contributing to limited growth in some populations of ASL.

Provisions of the Australian Government *EPBC Act* require strategic assessment of fisheries and aquaculture operations against the principles of ecological sustainable development (ESD) and include the need to monitor, assess and if necessary mitigate interactions with protected species (Fletcher et al. 2002). For the ASL the need is greatest in South Australia, where the majority of populations occur (Goldsworthy et al. 2003), where declining populations have been identified (Shaughnessy et al. in 2006), where a valuable aquaculture industry for southern bluefin tuna, yellowtail kingfish, mulloway and abalone is located and where unquantified interactions with ASL occur (Kemper and Gibbs 1997, 2001, this report).

Given the paucity of information on the foraging ecology of ASL populations in South Australia, we used satellite telemetry to investigate the foraging behaviour of: 1) adult female, 2) juvenile, 3) subadult male and 4) adult male ASL from Dangerous Reef in southern Spencer Gulf and from six populations in the Nuyts Archipelago. We compare and contrast: (1) their foraging locations, (2) their foraging behaviour, and (3) the oceanographic features associated with the regions they utilised.

In addition to providing important knowledge on the foraging behaviour of ASL to assist the species management, the study also sought to determine the distribution of foraging effort of ASL in proximity to existing finfish aquaculture in the Port Lincoln region, based on the tracking of ASL from Dangerous Reef. It also examines the distribution of foraging effort of ASL populations in the Nuyts Archipelago, a region zoned for finfish aquaculture but where none currently exists. The latter was undertaken to assess 1) the appropriateness of current finfish aquaculture buffer zones around ASL colonies of 15 km radius for large populations (> 70 pups) and 5 km for smaller populations, (MM-MPA AWG 2004); and 2) to determine whether uniform proximity guidelines for finfish aquaculture adjacent to ASL populations can be determined based upon their foraging characteristics.

Methods

Study site

The study was conducted between 17 September 2003 and 28 January 2006 at Dangerous Reef, southern Spencer Gulf, South Australia (-34.817 136.217) and the Nuyts Archipelago off Ceduna (Fig. 8.1 and 8.2). The waters around Dangerous Reef are typically 20 to 50 m deep and the continental shelf to the south of Dangerous Reef is typically 80 to 120 m deep with the nearest 100 and 200 m contours being 60 and 120 km south, respectively (Fig. 8.1). Dangerous Reef is the nearest ASL breeding colony to the offshore Port Lincoln Tuna Farming Zone (TFZ) and is the largest colony (585 pups, Table 7.3) in the region (Fig. 7.1). The waters around the Nuyts Archipelago are typically 20 to 80 m deep and the continental shelf to the south of The Nuyts is typically 80 m deep with the nearest 100 and 200 m contours being 100 and 170 km south, respectively (Fig. 8.2).

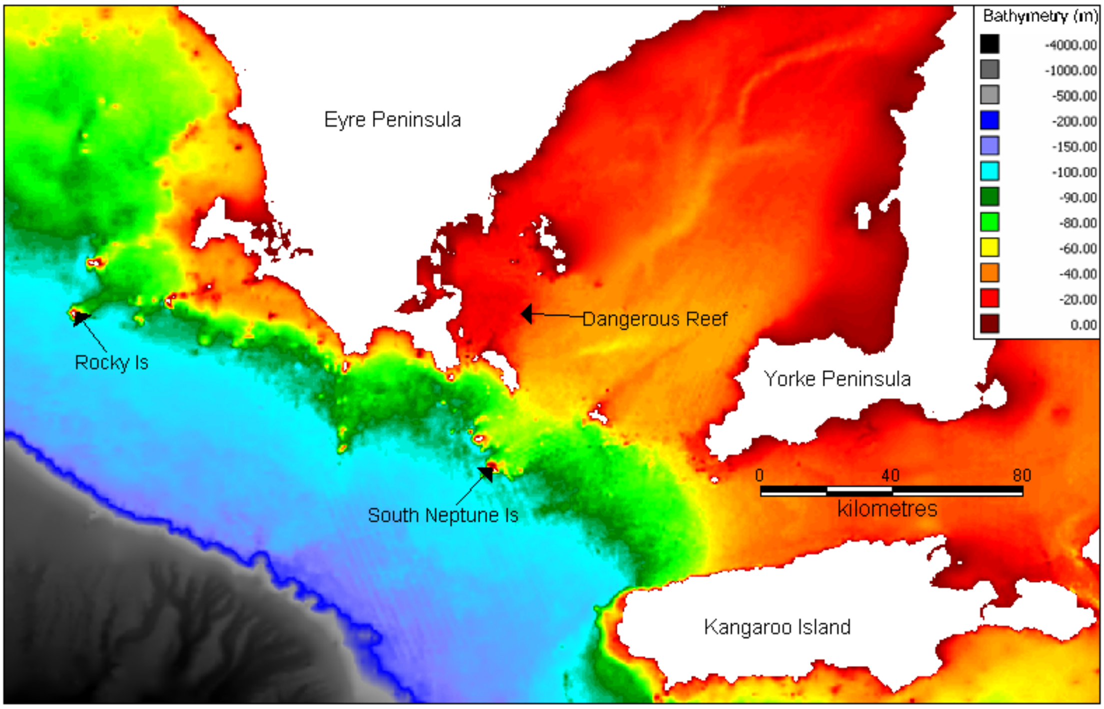


Fig. 8.1. The bathymetric depth (m) of the continental shelf and slope waters around Dangerous Reef.

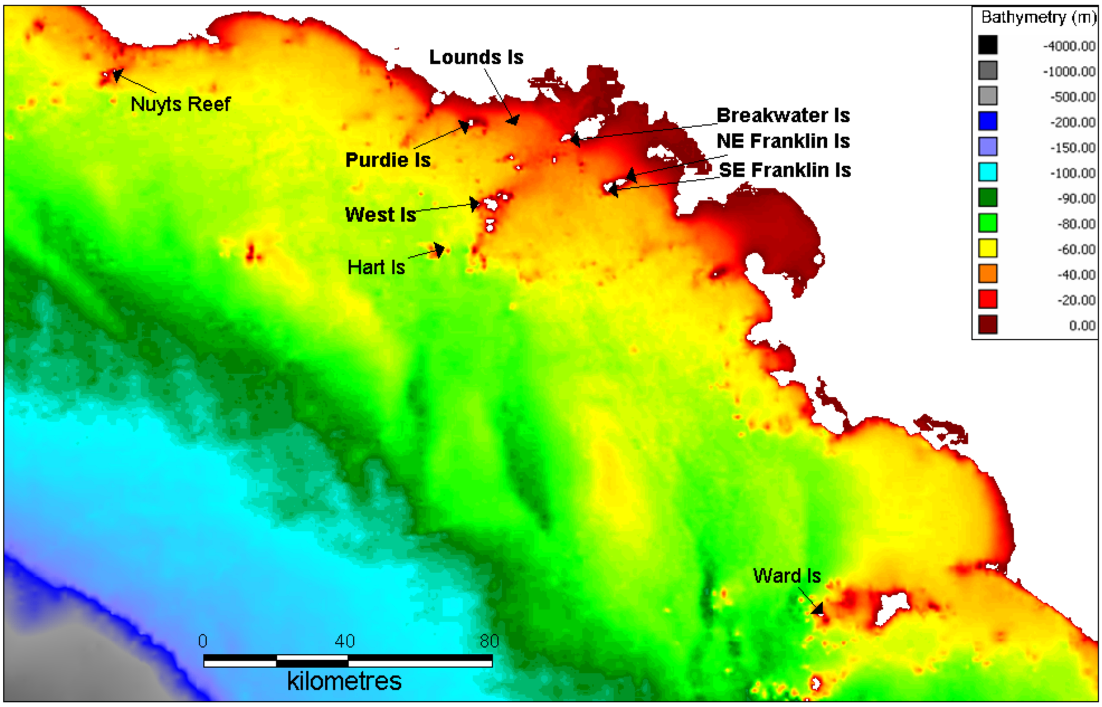


Fig. 8.2 The bathymetric depth (m) of the continental shelf and slope waters around the Nuyts Archipelago. Islands where satellite trackers were deployed are shown in bold and other islands are indicated for reference.

Capture and restraint

To deploy satellite tracking equipment, all of the juveniles and lactating females were captured using a hoop-net. Anaesthesia was induced and maintained using Isofluorane® (Veterinary Companies of Australia, Artarmon, New South Wales), administered via a purpose-built gas anaesthetic machine with a Cyprane Tec III vaporiser (Advanced Anaesthetic Specialists, Melbourne). Adult males, which had characteristic blond manes and subadult males, which are larger than adult females, but lacking blond manes, were anaesthetised using Zoletil® (Virbac, Sydney, Australia), which was administered intramuscularly using barbless darts (~1.0 to 1.5 mg per kg, 1.5 cc barbless darts: Pneu-Dart®, Pennsylvania, USA), fired from a NO_2-powered tranquilliser gun (Taipan 2000, Tranquil Arms Company, Melbourne, Australia). For all but a few deeply anaesthetised individuals, anaesthesia was maintained with Isofluorane® using the equipment and methods outlined above. The duration of anaesthetic procedures was defined as the time that the gas mask was held on the animal. Time until recovery was recorded as the duration from the removal of the gas mask until the animal raised its head off the ground. All of our research procedures were approved by the La Trobe University Animal Ethics Committee, the Primary Industries and Resources SA Animal Ethics Committee and the South Australian Department for Environment and Heritage Animal Ethics Committee.

Data collection

Anaesthetised adult female and juvenile seals were weighed with a spring balance (50 ± 0.1 kg or 200 ± 1.0kg, Salter, Melbourne, Australia) and their standard body length (nose to tail) and axillary girth were measured (± 1 cm). We used the weight and length to calculate a body condition index (kg/cm) for each seal. We measured the length and girth of adult males, but their mass exceeded the capacity of our weighing equipment. Individually-numbered plastic tags (Supertags®, Dalton, Woolgoolga, NSW, Australia) were applied to the trailing edge of each foreflipper. To investigate whether there were age-specific foraging patterns, the age of adult female ASL, a post-canine tooth was removed using a 5 mm dental elevator. To provide short-term pain relief a local anaesthetic (0.7 ml, Lignocaine®, AustraZeneca Pty Ltd, North Ryde, NSW, Australia) was injected in the gum beside the post-canine. Ages were estimated by counting growth layer groups in the cementum of decalcified and stained longitudinal sections of post canines, using methods adapted from Stewart et al. (1996). The aging technique was validated on post-canine teeth that were collected from 10 known age ASL (McIntosh 2007). Age was correctly assigned to 4 (40 %) of the known aged individuals and differed by 1 year for 4 (40 %) individuals and 2 years for 2 (20 %) individuals (McIntosh 2007).

At Dangerous Reef, satellite transmitters (KiwiSat 101, Sirtrack, Havelock North, New Zealand) were deployed on 34 adult females, 7 adult males, 1 subadult male and 7 juvenile males. Dive recorders (TDRs, Mk7, Wildlife Computers, Redmond, Washington) were concurrently deployed on 4 adult females, but not on any males nor on animals at other sites. In the Nuyts Archipelago, satellite transmitters were deployed on 30 adult females, 14 adult males, 1 subadult male, 9 juvenile males and 6 juvenile females. Transmitters were glued to the fur on the dorsal midline, using a flexible-setting epoxy (Araldite 2017, Vantico, Basel, Switzerland). To reduce power consumption, transmitters incorporated a salt water switch, which turned the transmitter off when it was underwater and after it had been on land for more than 6 h.

To recover the satellite tracking equipment some adult females and juveniles were captured using a hoop net, but most animals were given Zoletil® (females: ~1.1 to 1.2 mg per kg, males: ~1.0 to 1.5 mg per kg) prior to capture – administered via dart, using 1.0 cc barbless darts (Pneu-Dart®). Anaesthetised animals were then captured using a hoop-net and restrained by 1 to 4 people, because initial restraint stimulated a flight response in all but a few deeply anaesthetised individuals and in most cases anaesthesia had to be maintained using Isofluorane®. The animals' guard hairs were cut along the base of the satellite tracking device, to remove it from the animal.

Data analyses

Satellite location data were obtained through CLS ARGOS (Toulouse, France). The location-class *Z* positions were omitted due to the magnitude of their error (Sterling and Ream 2004), leaving location classes *B, A, 0, 1, 2, 3* for subsequent analyses. The R statistical software (version 2.3.0, R Development Core Team, R Foundation for Statistical Computing, Vienna) and the timeTrack package (version 1.1–5, M. D. Sumner, University of Tasmania, Hobart) were used to apply the filter described by McConnell et al. (1992), based on a maximum possible horizontal speed of 11.93 km/h. We initially calculated this maximum horizontal speed between consecutive satellite locations, which were either Class 0, 1, 2 and 3. We calculated the maximum possible distance that the animal could have travelled between the two locations by taking the great circle distance between two consecutive locations and adding the average error for the respective location classes (Class 0: 4.483 km, Class 1: 1.496 km, Class 2: 0.903 km, Class 3: 0.278 km, Robson et al. 2004). Visual inspection of the distribution of travel speeds indicated that travel speeds between relatively less accurate positions (Class 0 and 1) were higher than travel speeds between more accurate positions (Class 2 and 3) (Fig. 8.3). This indicated that the increased error of the lower-class satellite locations may have increased the apparent travel speeds when the lower class locations were used (Fig. 8.3). To reduce this error we only used the most accurate pairs of locations (Class 2 to 2, 2 to 3 or 3 to 3) to calculate the maximum travel speed of 11.93 km/h (Fig. 8.3).

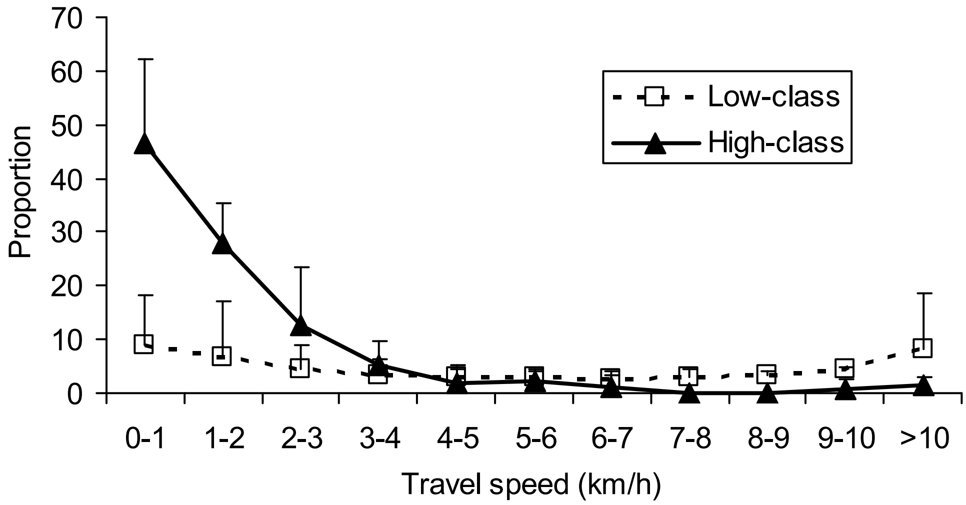


Fig. 8.3. The proportion of swim speeds recorded for all ASL. Swim speeds (+ SD) between at least 1 *low-class* satellite location (Class: 0–0, 0–1, 0–2, 0–3, 1–1, 1–2, 1–3) and between 2 *high-class* satellite locations (Class: 2–2, 2–3, 3–3) are shown separately.

A foraging trip began when a seal departed from a colony and ended when the seal hauled out on land, which was not always at the same colony. When seals hauled out, their satellite transmitter typically gave repeated high-class locations until the haulout timer switched off the transmitter. In these cases, a haulout event and the location of the colony could be determined with a high degree of confidence. However, in many cases the satellite transmitter did not give any locations after the seal had apparently hauled out on land, so in these cases we had to use the following criteria to determine if, where and when the seal hauled out: 1) no locations were received by satellites for > 8 hr, possibly indicating that the haulout timer had switched off the satellite transmitter because the seal was not in the water, 2) the distance to all nearby islands was calculated from the last satellite location to determine if there were any islands in the vicinity, 3) the direction of travel indicated that the seal was apparently travelling toward an island, 4) the direction of travel on the succeeding foraging trip indicated that the seal appeared to be heading away from the island where it had apparently hauled out.

In addition to determining the coordinates for the start and end of each foraging trip, we also needed to estimate the time of haulout and departure, so the duration of foraging trip (and overall time spent at sea) could be determined. In some cases, satellite transmitter positions may have been acquired shortly after a seal hauled out (best case), but in many cases the last position was often acquired at sea (worst case). Similarly, at the start of the next foraging trip, a satellite transmitter position may have been acquired shortly after the animal entered the water (best case) or not until the animal had been foraging for some period (worst case). Although the worst case scenarios could be determined by visually inspecting the data, we could not determine the duration between the seal exiting/entering the water using satellite transmitter location data only. Instead, we calculated the distance between the first/last location at sea and the site where the seal hauled out and interpolated the start/end times based on average travel speeds of seals when leaving or returning ashore. Average travel speeds were calculated for the start and end of each foraging trip made by four adult female seals that carried dive recorders and satellite transmitters from Dangerous Reef. From these females, we were able to confirm the start/end times for foraging trips because the dive recorders logged the precise times that the instruments became wet or dry. Using these times we calculated the average travel speed between the first/last location at sea and the start/end of each foraging trip (n = 61 trips, mean = 15.3 ± 5.2 trips/female) and calculated the grand mean for both the outward (2.63 ± 0.62 SD km/h) and inward (6.43 ± 1.29 km/h) legs of the foraging trips.

All foraging trips and haulouts prior to 10 January 2006 were classified, filtered and analysed. Very brief trips to sea (< 1 h) were excluded from further analyses for two reasons: 1) these animals were possibly in rockpools or nearshore waters and were therefore unlikely to be foraging; and 2) less than 4 satellite locations were typically received, which is the minimum number required to apply the filter described by McConnell et al. (1992) using the timeTrack package. If a satellite transmitter failed while a seal was at sea, that entire foraging trip was excluded from analyses. If a satellite transmitter failed while a seal was on shore, the duration of that haulout period could not be calculated, and was excluded. Once the satellite transmitter location record for each animal had been broken into separate foraging trips and haulouts, we determined the total number of foraging trips for each seal, their duration and the duration of each haulout period. We calculated the proportion of time at sea as the sum of all foraging trip durations divided by the deployment duration, which was the duration between the start of the first foraging trip and the end of the last haulout period.

We calculated several parameters to summarise the foraging behaviour of each seal and to describe bathymetric habitats they utilised relative to the amount of time spent in each area. Parameters were extracted at 15 min (time) intervals along each interpolated satellite track (except for parameters that described minimums, maximums or totals). Behavioural parameters included the following: (1) The maximum straight-line distance from the colony where the seal was captured to the distal point reached on each foraging trip; (2) The compass bearings from the colony where the seal was captured to each interpolated position; (3) The circular distance - *r* (calculated using Oriana, version 2.02, Kovach Computing Services, Pentraeth, Wales). The *r*-

value has a maximum of one and a minimum of zero, with relatively high *r*-values implying that a high proportion of locations concentrated around the mean compass bearing and a more uniform distribution; (4) The horizontal travel speed (the distance between consecutive locations, divided by the duration (15 min)); (5) A site fidelity index was calculated for each foraging trip to summarise whether foraging trips ended at the island where they started. The site fidelity index was calculated by assigning one to trips where the start and end point was the same and zero if they were not the same, with the index being the mean of these values. The site fidelity index has a maximum of 1 and a minimum of 0, with relatively high indices implying that a high proportion of foraging trips ended at the island they started.

Bathymetric parameters were calculated to describe the: (1) mean; (2) median and (3) maximum depth; (4) skewness and (5) excess kurtosis of the bathymetric depth; (6) mean and (7) median bathymetric gradient (change in depth in metres for each horizontal kilometre), (8) skewness and (9) excess kurtosis of the bathymetric gradient; (10) mean and (11) median directional bearing of the bathymetric gradient (degrees); (12) skewness and (13) excess kurtosis of the directional bearing of the bathymetric gradient. Bathymetric depth data were obtained from GeoScience Australia 1 x 1 km grid (Fig. 8.1 and 8.2). The bathymetric depth values for each location were interpolated as functions of their distance from the nearest nodes and assigned to each 15 min time interval of foraging trips.

Cluster analyses were conducted using PRIMER, to identify whether the foraging behaviour of seals could be categorised into ecological groups based on their foraging parameters. The Bray and Curtis association measure was used for the analyses, because it is an effective method for analysing multivariate ecological data (Beals 1984). The accuracy of assigning seals to these foraging ecotypes was tested using a discriminant function analysis (DFA, SYSTAT V10), based on the same parameters. Analysis of similarities (ANOSIM in PRIMER) were used to test for differences in the foraging behaviour of ASL.

Skewness and excess kurtosis parameters were used to describe the distribution of these values around the mean for each individual. If the bathymetric parameters were normally distributed, the value of the skewness statistic would be zero. Skewness values between -1 and 1 indicated that the distribution of bathymetric parameters was symmetrical (i.e., the seal spent relatively more time in areas where the bathymetric depth/gradient/direction were close to the mean) and moderate skewness was indicated by values less than -1 and greater than 1. Moderate skewness values that are negative indicate that the left tail of the distribution of bathymetric parameters was relatively pronounced (i.e., the seal spent more time in areas where the bathymetric depth/gradient/direction were less than the mean). Moderate skewness values that are positive indicate that the right tail of the distribution of bathymetric parameters was relatively pronounced (i.e., the seal spent more time in areas where the bathymetric depth/gradient/direction were greater than the mean). Kurtosis values indicate the extent to which bathymetric parameters clustered around the mean. If the bathymetric parameters were normally distributed, the value of the kurtosis statistics would be zero. Positive kurtosis indicates that the bathymetric parameters cluster more around the mean and have longer tails than those in the normal distribution (i.e., the seal targeted an area where the bathymetric depth was similar and travelled quickly across areas where the bathymetric depth was different). Negative kurtosis indicates that the bathymetric parameters cluster less and have shorter tails (i.e., the seal travelled in areas with different bathymetric depth and did not target a certain bathymetric depth).

To determine the number of different 1 km x 1 km (1 km^2) grid cells entered by each seal and the proportion of time that each seal spent in each cell, we assumed a constant horizontal speed between the filtered locations and interpolated a new position for each 15 minutes (of time) along the satellite track, using the R statistical software and the timeTrack package. The number of original and interpolated positions, which were located within 1 km^2 cells of a predetermined grid, were then summed and assigned to a central node. To ensure the different deployment durations recorded for different seals did not bias comparisons, the amount of time spent in each cell was converted to a proportion of the total time spent at sea for each individual, colony and/or age/sex group being compared. The proportional values of time-spent in area were plotted using the triangulation with smoothing function in VerticalMapper® (version 2.5) (MapInfo Corporation, New York) and MapInfo® (version 8.0).

Most parameters were power-transformed to equate variances for inter-sexual or spatial analyses. If the transformations did not result in the data being normally distributed for all age/sex groups, Mann-Whitney tests were used for analyses, for which Z approximations are reported. Preliminary analyses indicated that there were no significant differences in the behaviour of male and female juveniles, so the data from both sexes were pooled. Means are presented as ± standard deviation and all statistical tests are two-tailed, unless stated, with the α level of statistical significance set at 0.05. Austral seasons are referred to throughout this report: Summer (December to February), Autumn (March to May), Winter (June to August) and Spring (September to November).

Results

Animal captures

In total 109 ASL were captured and fitted with satellite transmitters. These included 64 adult females (AF), 21 adult males (AM), 2 subadult males (SAM) and 22 juveniles (Juv). In southern Spencer Gulf, 49 ASL were captured at Dangerous Reef (DR, 34 AF, 7 AM, 1 SAM, 7 Juv) (Table 8.1, 8.2). In the Nuyts Archipelago 60 ASL were captured at six sites including: 15 at West Is (WI, 5 AF, 4 AM, 1 SAM, 5 Juv); 15 at Purdie Is (PI, 5 AF, 5 AM, 5 Juv); 13 NE Franklin Is (5 AF, 3 AM, 5 Juv); 6 at SE Franklin Is (4 AF, 2 AM); 4 at Breakwater Is (BR, 4 AF) and 7 at Lounds Is (LI, 7 AF) (Table 8.3 to 8.8). SE Franklin Is and NE Franklin Is were recently named Blefuscu Island and Lilliput Is, respectively, but these names have not been adapted in this report.

Table 8.1. Summary data on the body size and anaesthesia duration for the adult females from Dangerous Reef, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth) and the estimated age of some seals. Dive recorders were concurrently deployed on the following adult females: 12011, 12111, 12311 and 12411.

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Estimated age (y)	Recapture date
Adult female - 2003								
10011	C00/C00	1:04	-	90	148	99	12.5	-
10111	C01/C01	1:22	-	96	161	101	9.5	4 Oct 03
10211	C02/C02	0:49	-	99	158	103	12.5	4 Oct 03
10411	C04/C04	0:48	-	103	159	108	10.5	16 Oct 03
10511	C05/C05	0:44	-	85	160	101	8.0	4 Oct 03
10611	C06/C06	0:50	-	66	142	87	5.5	-
10711	C07/C07	0:40	-	72	149	97	12.0	3 Nov 03
10811	C08/C08	0:46	-	93	159	96	11.5	4 Oct 03
10911	C09/C09	0:34	-	67	152	90	6.0	-
11011	C10/C10	0:58	-	104	165	104	12.0	17 Oct 03
11111	C11/C11	0:39	-	73	150	90	6.5	17 Oct 03
11211	C12/C12	1:02	-	88	161	104	9.5	-
11311	C13/C13	1:28	-	82	155	91	13.5	17 Oct 03
11411	C14/C14	1:06	-	72	152	91	7.0	17 Oct 03
11511	C15/C15	0:56	-	84	161	97	7.0	24 Oct 03
11611	C16/C16	0:57	-	93	160	103	8.5	-
11711	C17/C17	1:59	-	77	150	97	8.5	4 Nov 03
11811	C18/C18	0:42	-	73	155	91	-	17 Oct 03
11911	C19/C19	0:55	-	67	157	92	-	4 Nov 03
12011	C20/C20	1:02	-	85	167	98	-	7 Dec 03
12111	C21/C21	0:53	-	76	155	95	-	-
12211	C22/C22	1:10	-	81	169	98	9.5	21 Nov 03
12311	C23/C23	1:10	-	81	169	98	14.5	27 Nov 03
12411	C24/C24	0:54	-	85	162	98	-	27 Nov 03
Adult female - 2005								
111	C29/C29	0:47	-	70	155	90	5.0	10 May 05
311	C31/C31	0:30	-	79	161	88	12.0	-
1111	C41/C41	0:47	-	72	154	90	10.0	10 May 05
1211	C42/C42	-	-	84	161	90	-	9 May 05
1311	C43/C43	0:43	-	80	161	93	21.0	9 May 05
1411	C44/C44	0:44	-	80	161	95	5.5	9 May 05
1511	C45/C45	0:39	-	64	145	89	4.0	9 May 05
1611	C46/C46	0:36	-	68	155	85	10.0	9 May 05
1711	C47/C47	0:32	-	67	155	83	10.5	9 May 05
1811	C48/C48	0:41	-	90	158	96	-	9 May 05
2003: mean		0:58	-	83	157	97	9.7	-
2005: mean		0:39	-	75	157	90	9.8	-
Overall: mean		0:53	-	81	157	95	9.7	-

Table 8.2. Summary data on the body size and anaesthesia duration for the males from Dangerous Reef, including dates of deployment and retrieval of transmitters and morphometric measurements taken (mass, standard-length and axillary girth). Adult male masses are estimates.

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Recapture date
Adult male							
212	C30/C30	0:21	-	260	201	150	11 Apr 05
412	C32/C32	0:20	-	265	200	139	9 May 05
512	C33/C33	0:17	-	300	195	145	11 Apr 05
3012	D13/D13	0:56	0:04	250	193	118	-
3112	D14/D14	0:26	0:14	250	199	116	-
3212	D15/D15	0:15	0:17	250	192	122	-
3312	D16/D16	-	-	250	187	123	-
Juvenile male							
614	C35/C35	0:40	-	53	130	84	9 May 05
714	C36/C36	0:33	-	55	134	85	-
914	C38/C38	0:38	-	74	146	87	12 Apr 05
1914	C49/C49	0:29	-	57	139	82	9 May 05
2014	C50/C50	0:37	-	57	134	83	-
10314	C03/C03	0:27	-	88	160	100	-
12514	C25/C25	1:01	-	67	144	87	-
Subadult male							
1015	C39/C39	1:04	-	122	170	111	9 May 05
Adult male: mean		0:25	0:11	261	195	130	-
Juvenile male: mean		0:37	-	64	141	87	-
Subadult male: mean		1:04	-	122	170	111	-

Table 8.3. Summary data on the body size and anaesthesia duration for the adult females, adult males, juveniles and the subadult male from West Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth) and the estimated age of some seals.

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Estimated age (y)	Recapture date
Adult female								
121	C51/C51	0:25	0:04	79	157	83	13.5	-
321	C53/C53	0:26	0:09	92	166	91	-	-
421	C54/C54	0:20	0:12	94	160	95	12.0	-
521	C55/C55	0:28	0:13	100	162	97	10.0	-
621	C56/C56	0:37	0:02	101	165	93	8.5	-
Adult male								
1222	C62/C62	0:11	0:10	-	191	131	-	3 Jul 05
1322	C72/C73	-	-	-	198	130	-	3 Jul 05
1422	C74/C75	0:25	-	-	196	125	-	5 Jul 05
1522	C63/C63	0:23	-	-	201	128	-	3 Jul 05
Juvenile female								
723	C57/C57	0:41	0:11	36	120	70	3.0	6 Jul 05
923	C59/C59	0:25	0:08	55	137	81	4.0	-
Juvenile male								
224	C52/C52	0:14	0:12	47	131	74	-	4 Jul 05
824	C58/C58	0:32	0:05	43	116	74	-	4 Jul 05
1124	C61/C61	0:24	0:12	47	126	72	-	-
Subadult male								
1025	C60/C60	0:30	0:03	100	162	97	-	-
Adult female: mean		0:27	0:08	93	162	92	11	-
Adult male: mean		0:19	0:10	-	197	129	-	-
Juvenile male: mean		0:33	0:09	45	129	76	4	-
Juvenile female: mean		0:23	0:09	46	124	73	-	-
Subadult male: mean		0:30	0:03	100	162	97	-	-

Table 8.4. Summary data on the body size and anaesthesia duration for the adult females, adult males and juveniles from Purdie Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth).

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Recapture date
Adult female							
131	C65/C65	-	-	97	168	104	-
331	-	0:14	-	-	164	-	-
431	C66/C66	0:20	0:07	100	166	97	-
531	C67/C67	0:18	0:02	98	161	100	-
731	C69/C69	0:22	0:05	115	163	106	-
Adult male							
1132	C77/C77	0:16	0:07	-	194	127	-
1232	C80/C80	0:17	0:15	-	199	134	-
1332	C79/C79	0:15	0:08	-	211	138	-
1432	C78/C78	0:13	0:09	-	186	117	-
1532	C81/C81	0:13	0:13	-	190	118	-
Juvenile male							
234	C64/C64	0:12	0:02	67	146	86	-
634	C68/C68	0:17	0:04	51	133	75	-
834	C70/C70	0:26	0:04	50	125	78	-
934	C71/C71	0:23	0:02	65	142	84	-
1034	C76/C76	0:19	0:06	59	132	84	-
Adult female: mean		0:18	0:04	103	164	102	-
Adult male: mean		0:14	0:10	-	196	127	-
Juvenile male: mean		0:19	0:03	58	136	81	-

Table 8.5. Summary data on the body size and anaesthesia duration for the adult females, adult males and juveniles from NE Franklin Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth) and the estimated age of some seals.

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Estimated age (y)	Recapture date
Adult female								
241	C83/C83	0:18	0:02	74	147	83	-	-
341	C84/C84	0:20	0:06	79	145	93	11.5	14 Jul 05
441	C85/C85	0:19	0:05	84	156	94	-	15 Jul 05
641	C87/C87	0:20	0:08	62	143	81	-	-
941	C90/C90	0:21	0:05	75	150	87	14.0	10 Jul 05
Adult male								
142	C82/C82	0:09	0:06	-	185	111	-	9 Jul 05
742	C88/C88	0:28	0:06	-	184	113	-	-
842	C89/C89	0:20	0:06	-	181	128	-	-
Juvenile female								
543	C86/C86	0:19	0:08	54	135	80	-	-
1043	C91/C91	0:16	0:05	53	135	73	5.5	9 Jul 05
1243	C93/C93	0:13	0:03	36	115	65	1.0	10 Jul 05
1343	C94/C94	0:15	0:07	33	112	66	2.0	9 Jul 05
Juvenile male								
1144	C92/C92	0:12	0:02	74	151	87	-	-
Adult female: mean		0:19	0:05	75	148	88	12.8	-
Adult male: mean		0:19	0:06	-	183	117	-	-
Juvenile female: mean		0:15	0:05	44	124	71	2.8	-
Juvenile male: mean		0:12	0:02	74	151	87	-	-

Table 8.6. Summary data on the body size and anaesthesia duration for the adult females and adult males from SE Franklin Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth).

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Recapture date
Adult female							
251	D04/D04	0:31	0:15	93	188	93	-
351	D05/D05	0:28	0:11	101	173	89	-
451	D06/D06	0:26	0:06	108	157	96	-
651	D07/D07	0:31	0:04	105	165	96	-
Adult male							
152	C95/C95	0:07	0:25	-	201	129	10 Jul 05
252	C96/C96	0:07	0:12	-	204	128	9 Jul 05
Adult female: mean		0:29	0:09	102	171	94	-
Adult male: mean		0:07	0:18	-	203	129	-

Table 8.7. Summary data on the body size and anaesthesia duration for the adult females from Breakwater Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth).

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Recapture date
Adult female							
181	C97/C97	0:19	0:07	71	151	84	-
281	C98/C98	0:17	0:02	87	152	94	-
381	C99/C99	0:17	0:07	73	141	83	-
481	D00/D00	0:24	0:01	70	137	91	-
Overall: mean		0:19	0:04	75	145	88	-

Table 8.8. Summary data on the body size and anaesthesia duration for the adult females from Lounds Is, including details on dates of deployment and retrieval of satellite transmitters, morphometric measurements taken (mass, standard-length and axillary girth) and the estimated age of some seals.

Seal no.	Flipper tag no.	Anaesthesia duration (h:min)	Duration from anaesth. to recovery (h:min)	Body mass at deployment (kg)	Body length at deployment (cm)	Body girth at deployment (cm)	Estimated age (y)	Recapture date
Adult female								
161	D08/D08	0:25	0:04	88	173	97	18.0	22 Oct 05
261	D09/D09	0:22	0:03	89	152	90	17.0	19 Oct 05
361	D10/D10	0:18	0:04	89	156	91	12.0	20 Oct 05
461	D11/D11	0:23	0:19	85	150	88	-	-
561	D12/D12	0:18	0:06	92	160	92	23.0	20 Oct 05
661	-	0:18	0:07	75	152	80	-	-
761	-	0:16	0:04	72	145	85	11.0	20 Oct 05
Overall: mean		0:20	0:06	84	155	89	16.2	-

Summary maps of the spatial distribution of foraging effort of adult females, males and juveniles for all of the islands where seals were tracked are presented in Fig. 8.4–8.29, and for each individual seal in Appendix 1. Details on the morphology and anaesthesia of individual seals and their foraging and haulout characteristics are summarised in Table 8.1–8.16.

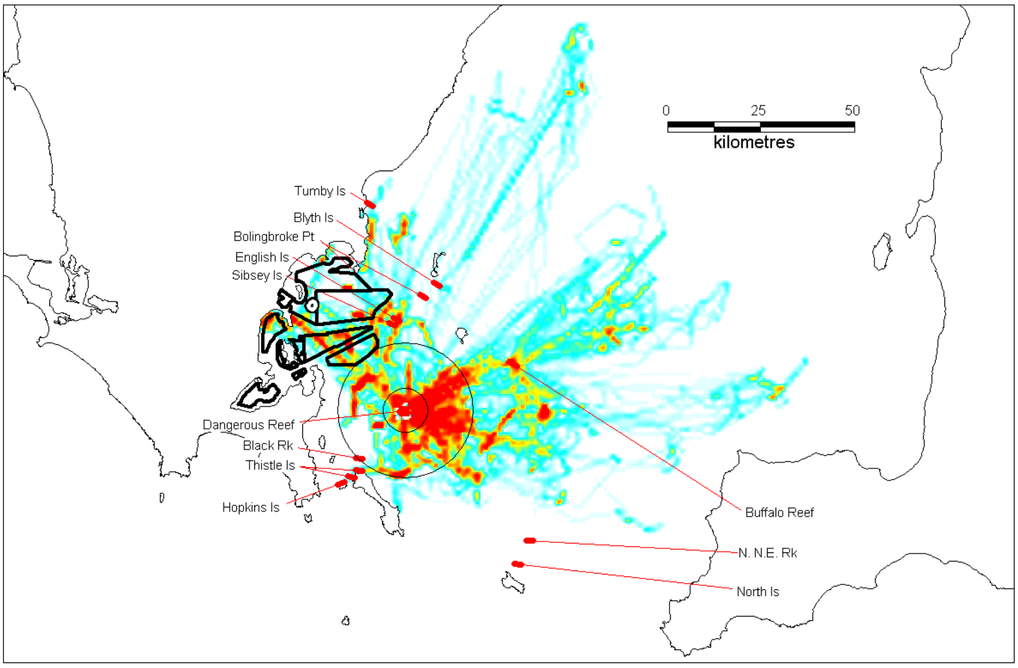


Fig. 8.4. Time spent in 1 km^2 cells by adult females (n = 24), which were satellite tracked from Dangerous Reef in 2003 and 2004. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

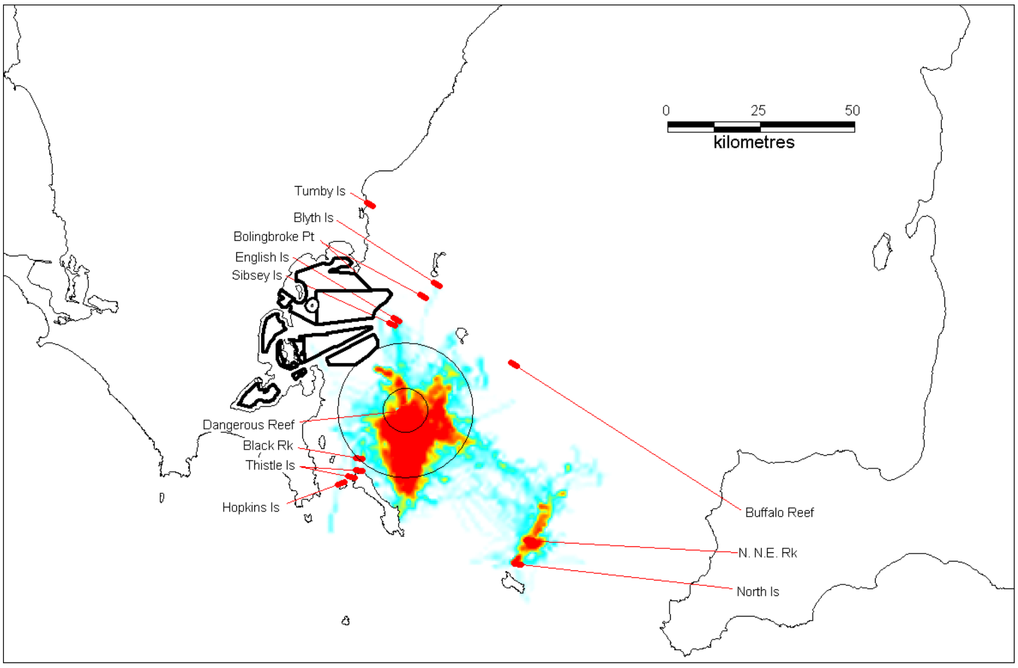


Fig. 8.5. Time spent in 1 km^2 cells by adult females (n = 10), which were satellite tracked from Dangerous Reef in 2005. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas, where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

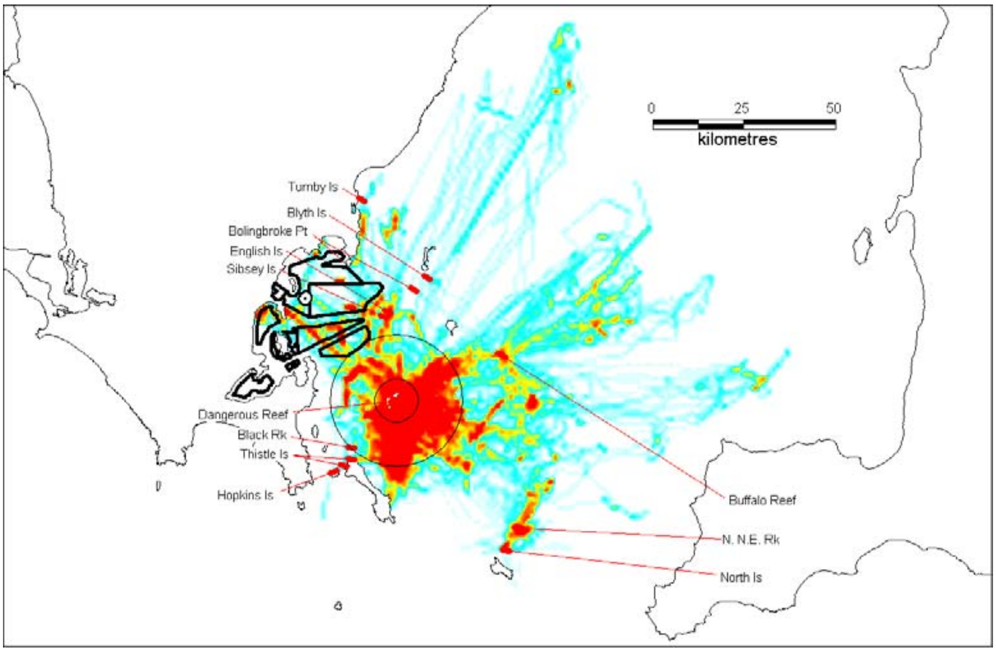


Fig. 8.6. Time spent in 1 km^2 cells by adult females (n = 34), which were satellite tracked from Dangerous Reef between 2003 and 2005. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

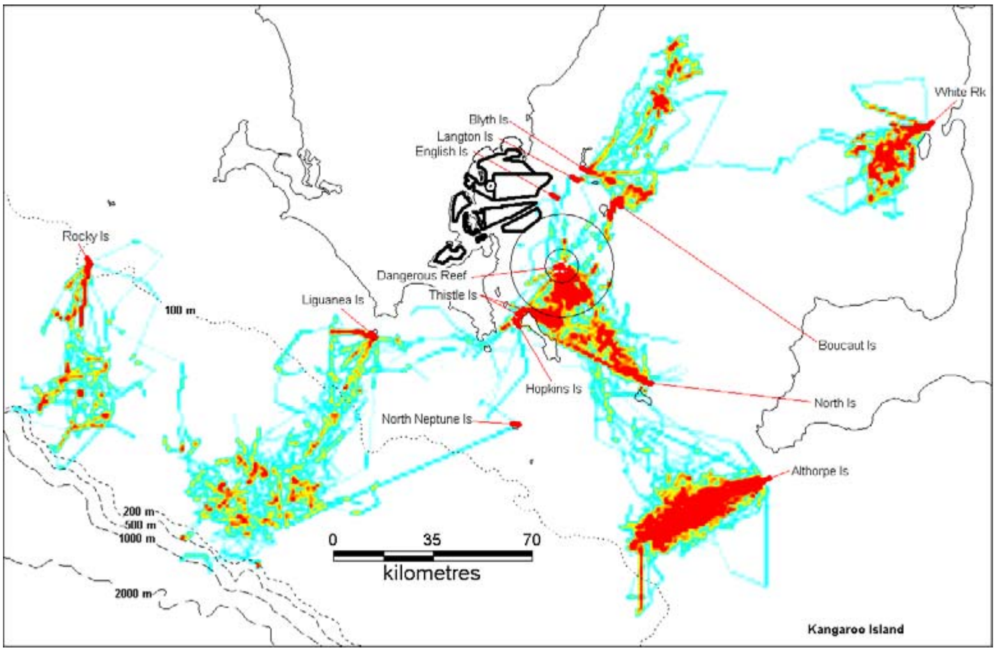


Fig. 8.7. Time spent in 1 km^2 cells by adult males (n = 7), which were satellite tracked from Dangerous Reef between 2005 and 2008. Islands used by at least 1 adult male and the 200, 500, 1000 and 2000 m contours are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas, where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

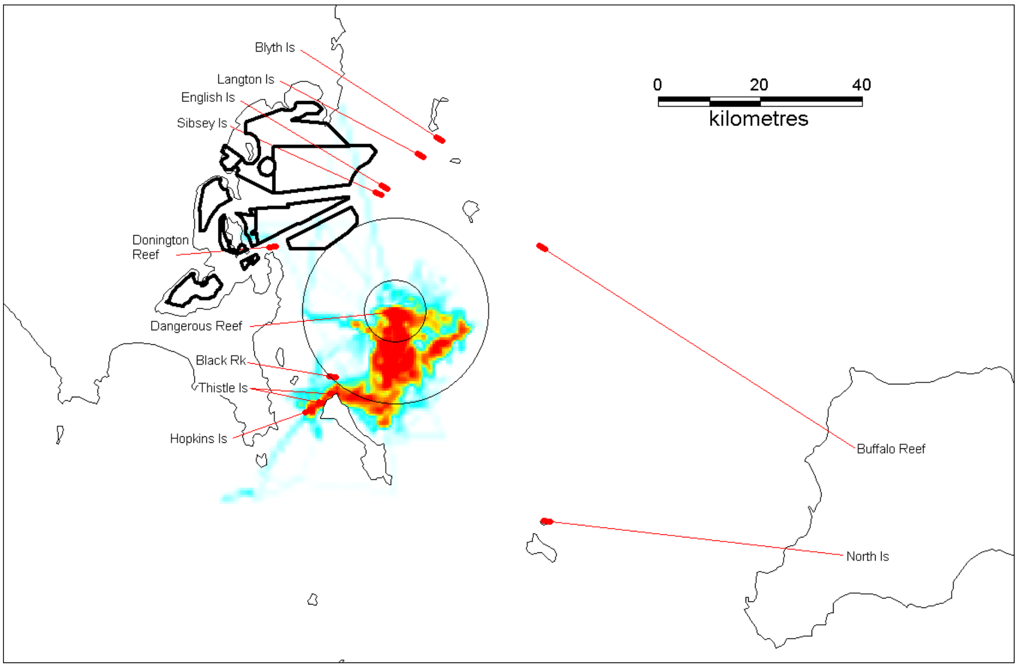


Fig. 8.8. Time spent in 1 km^2 cells by juvenile males (n = 2), which were satellite tracked from Dangerous Reef in 2003 and 2004. Islands used by at least 1 juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

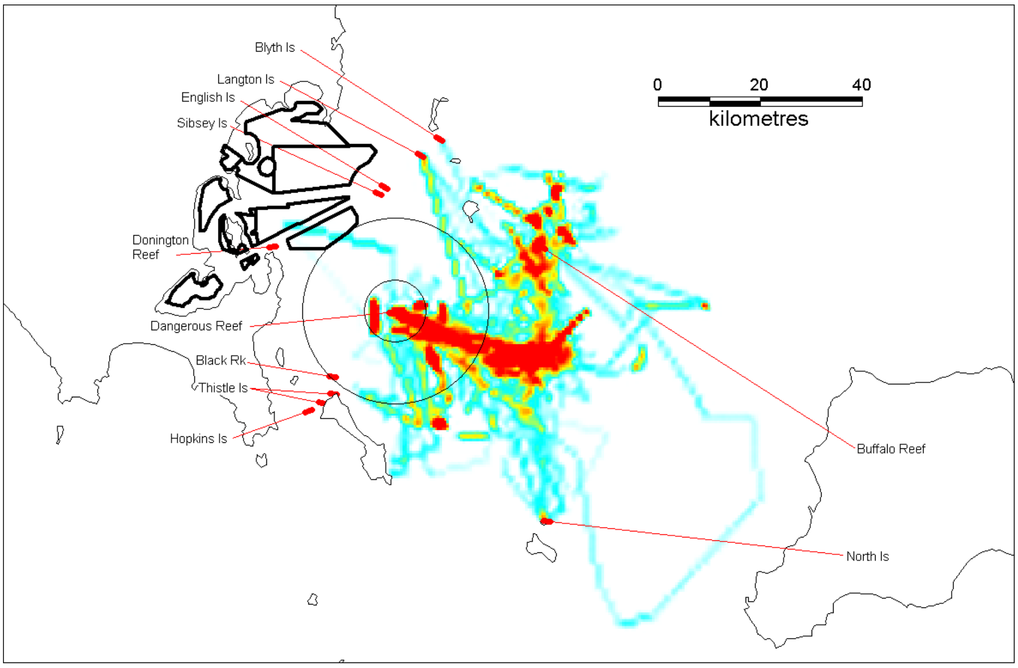


Fig. 8.9. Time spent in 1 km^2 cells by juvenile males (n = 5), which were satellite tracked from Dangerous Reef in 2005. Islands used by at least 1 juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas, where seals spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

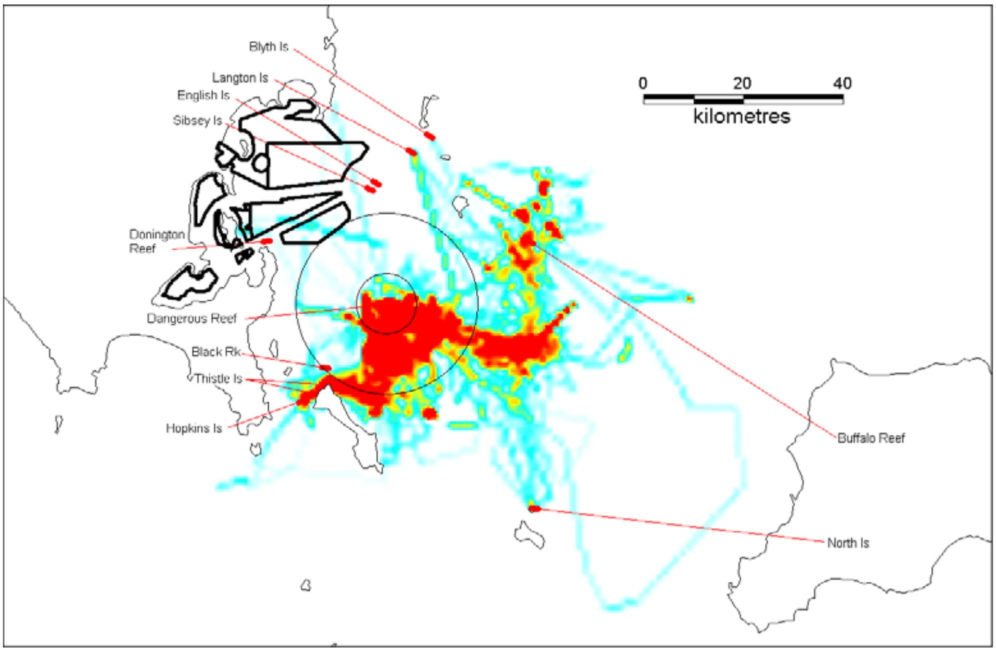


Fig. 8.10. Time spent in 1 km^2 cells by juvenile males (n = 7), which were satellite tracked from Dangerous Reef between 2003 and 2005. Islands used by at least 1 juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and blue areas where seals spent little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

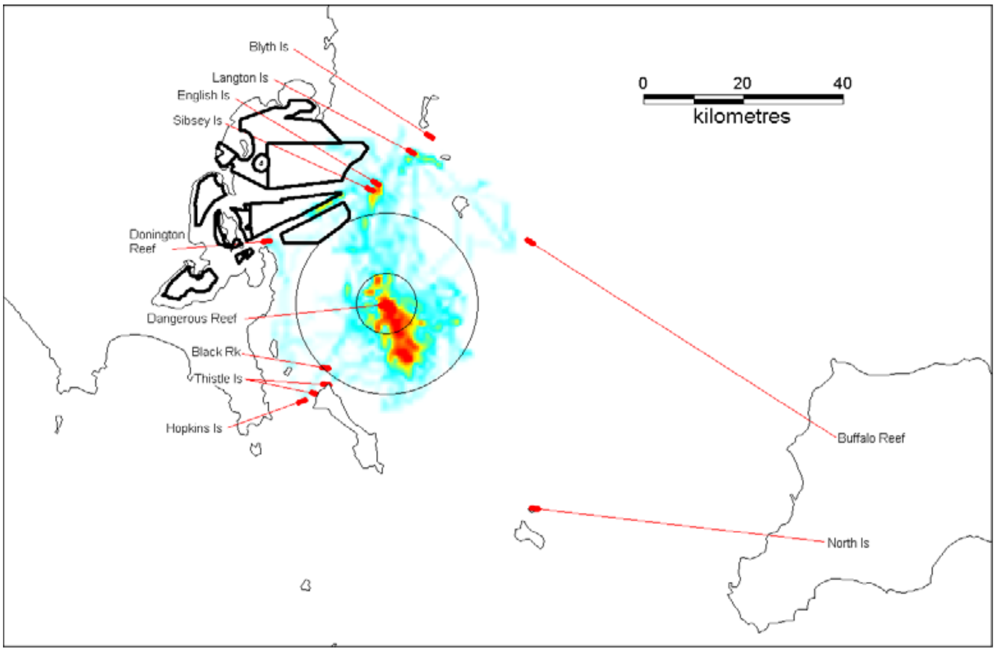


Fig. 8.11. Time spent in 1 km^2 cells by the subadult male (n = 1), which was satellite tracked from Dangerous Reef in 2005. Islands used by the subadult male and adult females are shown. Red represents regions where the seal spent more time followed by orange, yellow, green and finally blue areas where the seal spent relatively little time. The bold polygons depict the tuna farming zone boundaries and the circles around the colony indicate the 5 km and 15 km aquaculture exclusion zones.

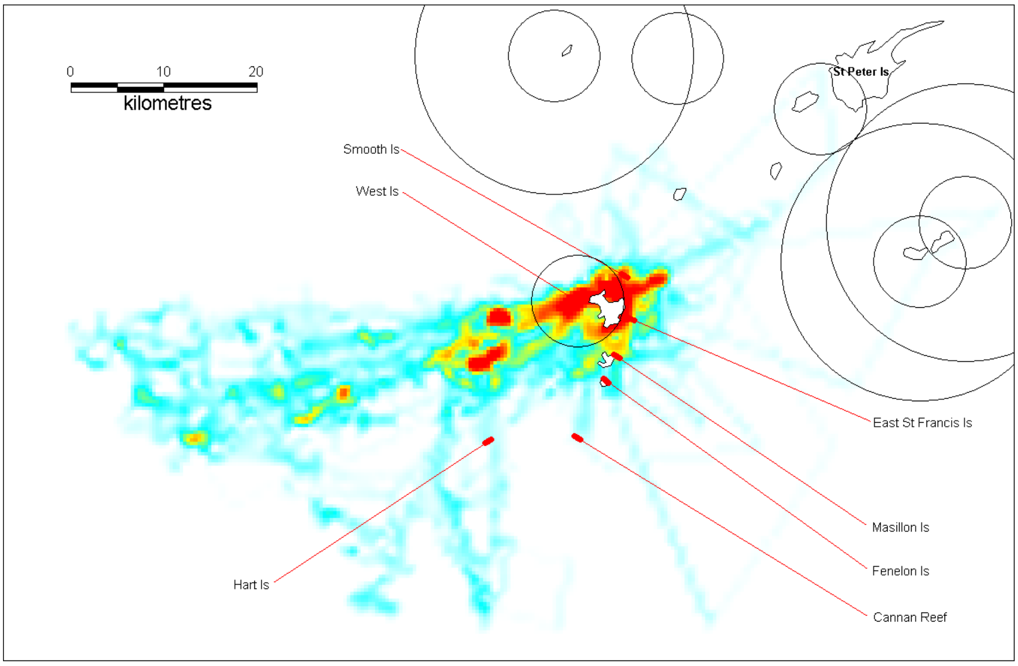


Fig. 8.12. Time spent in 1 km^2 cells by adult females (n = 5), which were satellite tracked from West Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

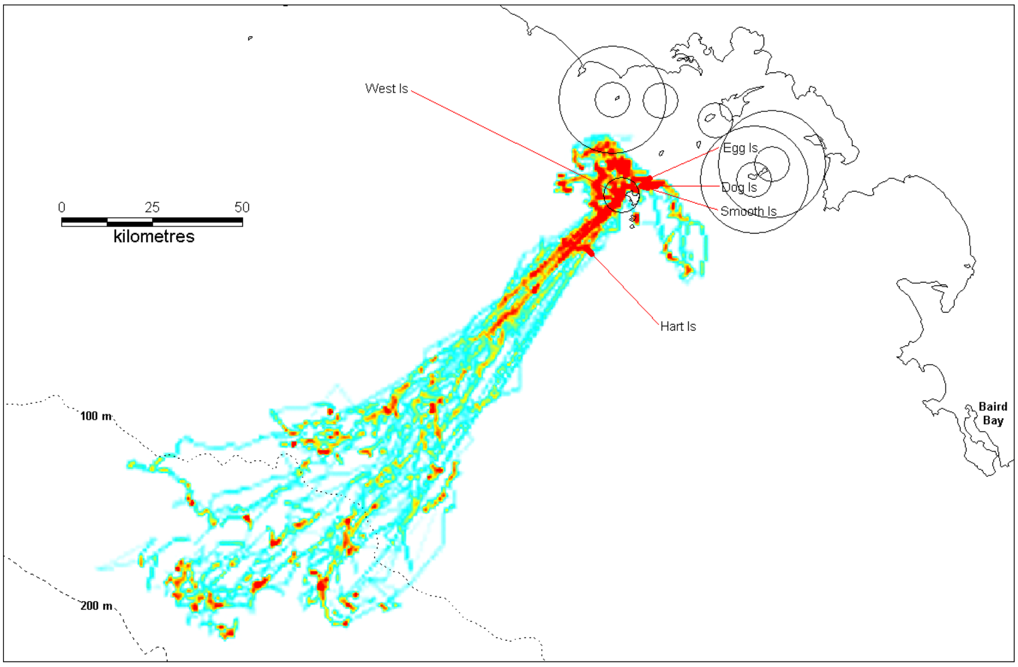


Fig. 8.13. Time spent in 1 km^2 cells by adult males (n = 4), which were satellite tracked from West Is. Islands used by at least 1 adult male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

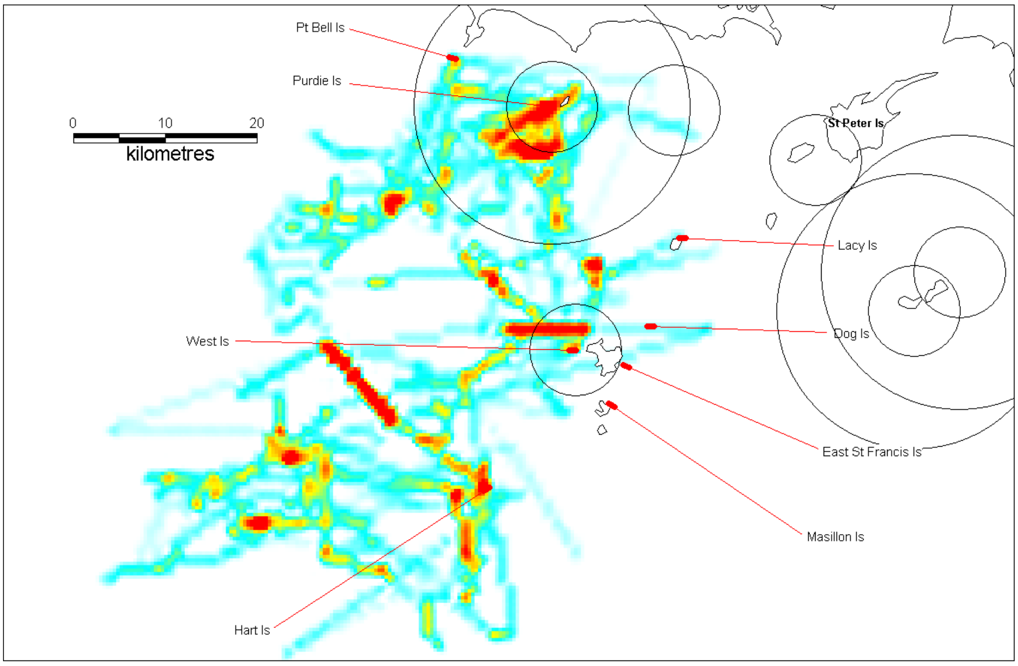


Fig. 8.14. Time spent in 1 km^2 cells by juvenile females (n = 2), which were satellite tracked from West Is. Islands used by at least 1 juvenile female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

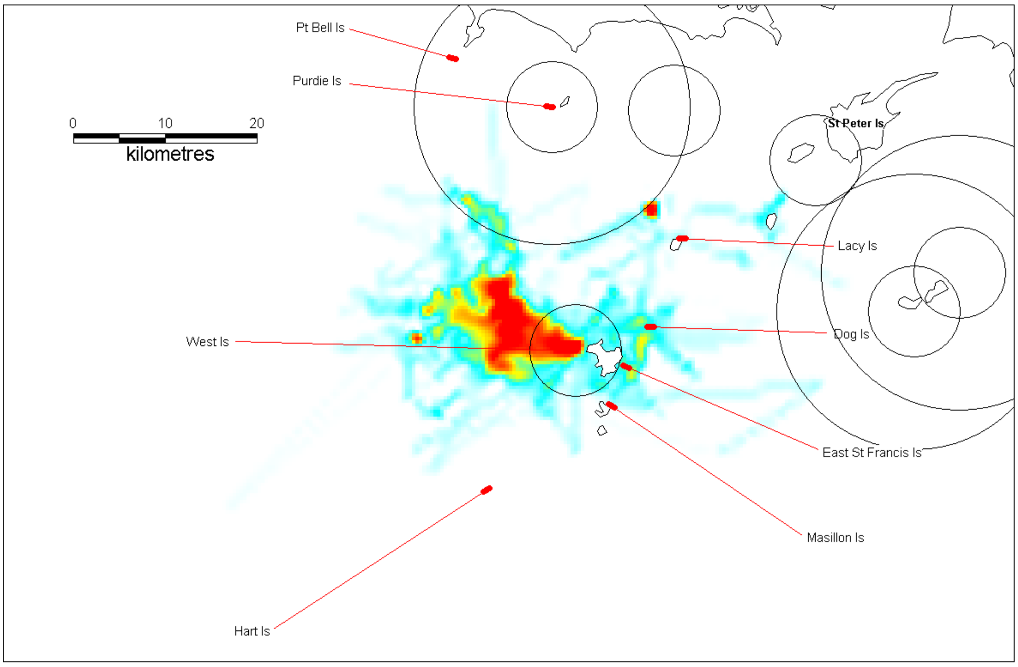


Fig. 8.15. Time spent in 1 km^2 cells by juvenile males (n = 3), which were satellite tracked from West Is. Islands used by at least 1 juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

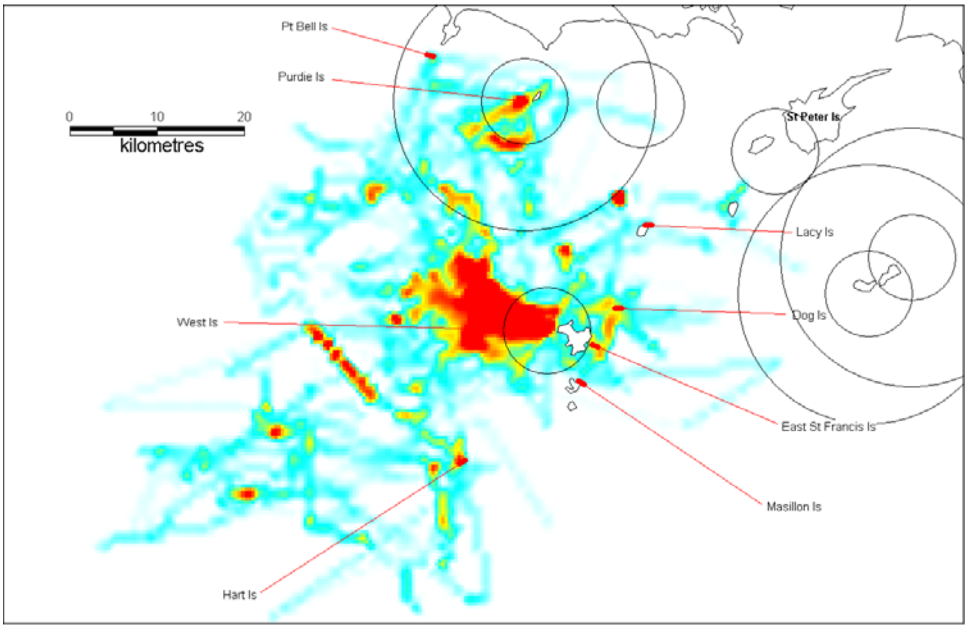


Fig. 8.16. Time spent in 1 km^2 cells by juvenile males (n = 3) and females (n = 2), which were satellite tracked from West Is. Islands used by at least 1 juvenile are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around colonies where trackers were deployed.

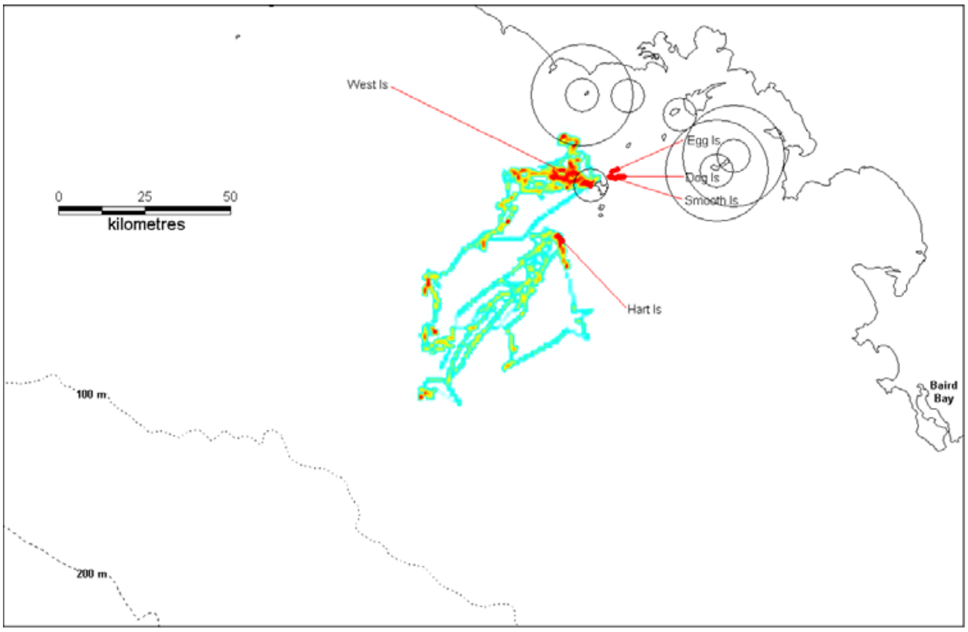


Fig. 8.17. Time spent in 1 km^2 cells by the subadult male (n = 1), which was satellite tracked from West Is. Islands used by the subadult male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

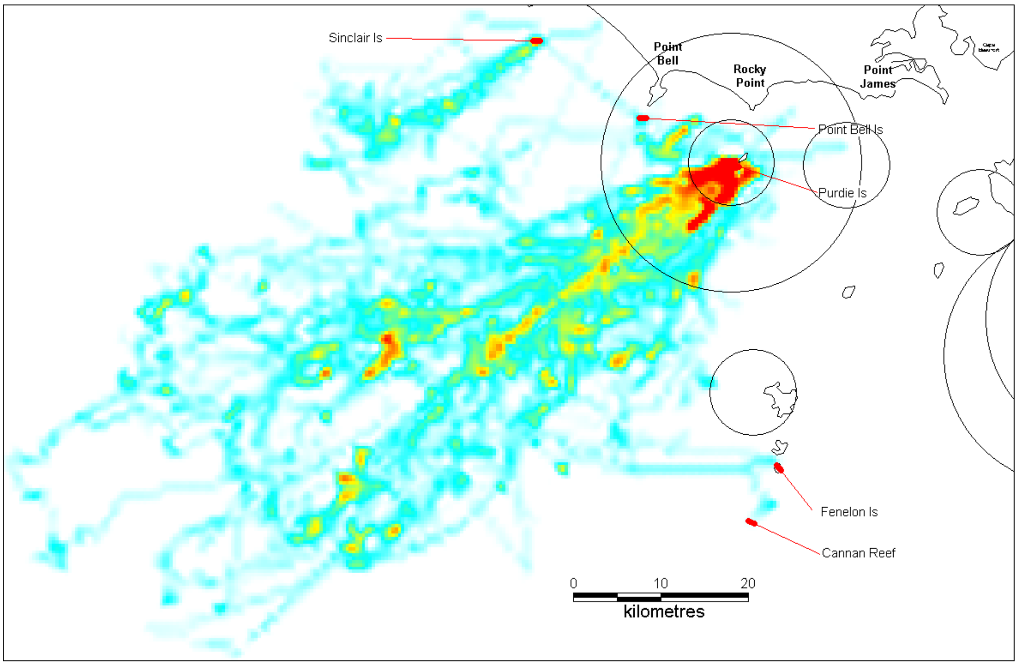


Fig. 8.18. Time spent in 1 km^2 cells by adult females (n = 5), which were satellite tracked from Purdie Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

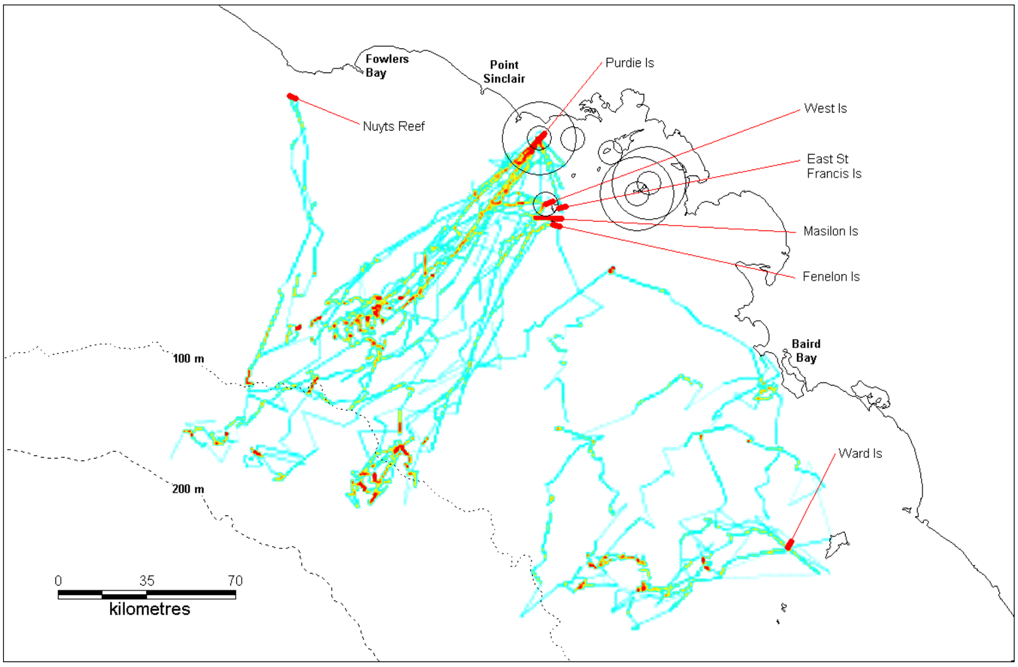


Fig. 8.19. Time spent in 1 km^2 cells by adult males (n = 5), which were satellite tracked from Purdie Is. Islands used by at least 1 adult male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

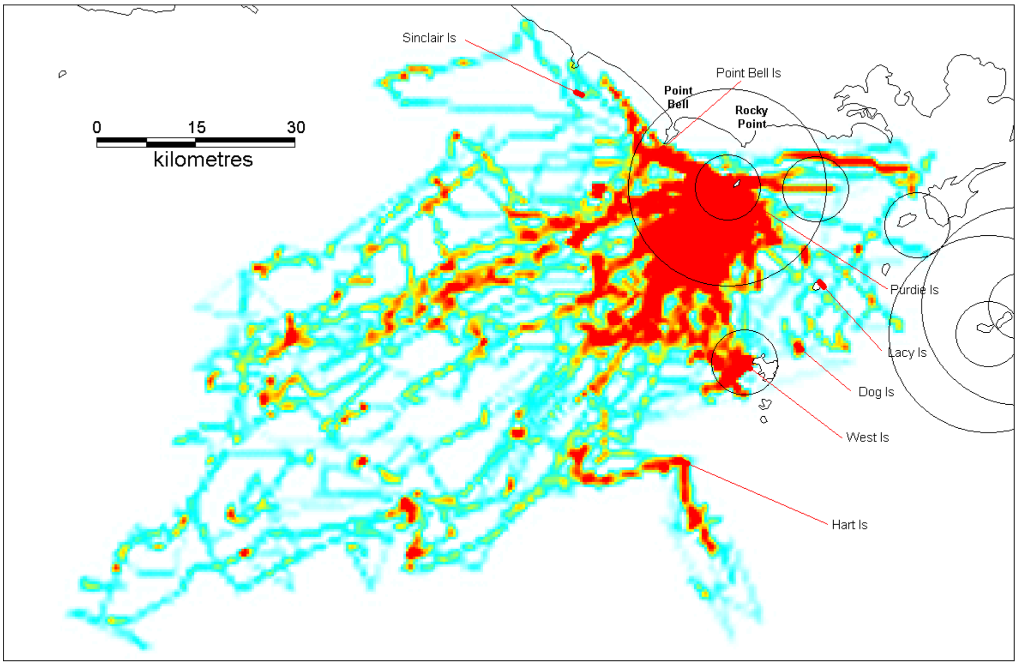


Fig. 8.20. Time spent in 1 km^2 cells by juvenile males (n = 5), which were satellite tracked from Purdie Is. Islands used by at least 1 juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

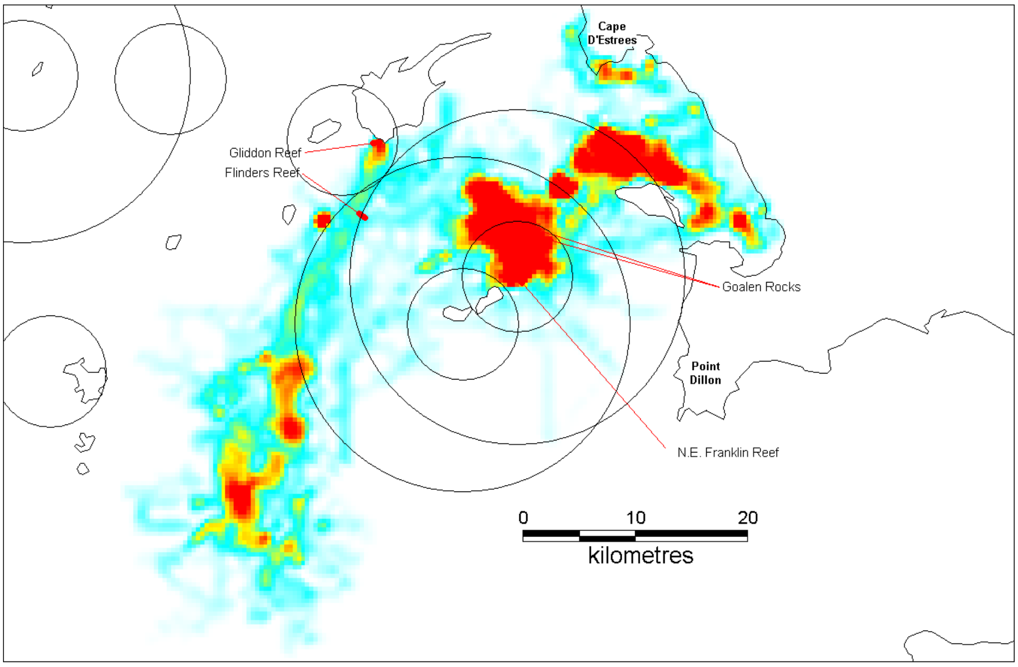


Fig. 8.21. Time spent in 1 km^2 cells by adult females (n = 5), which were satellite tracked from NE Franklin Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

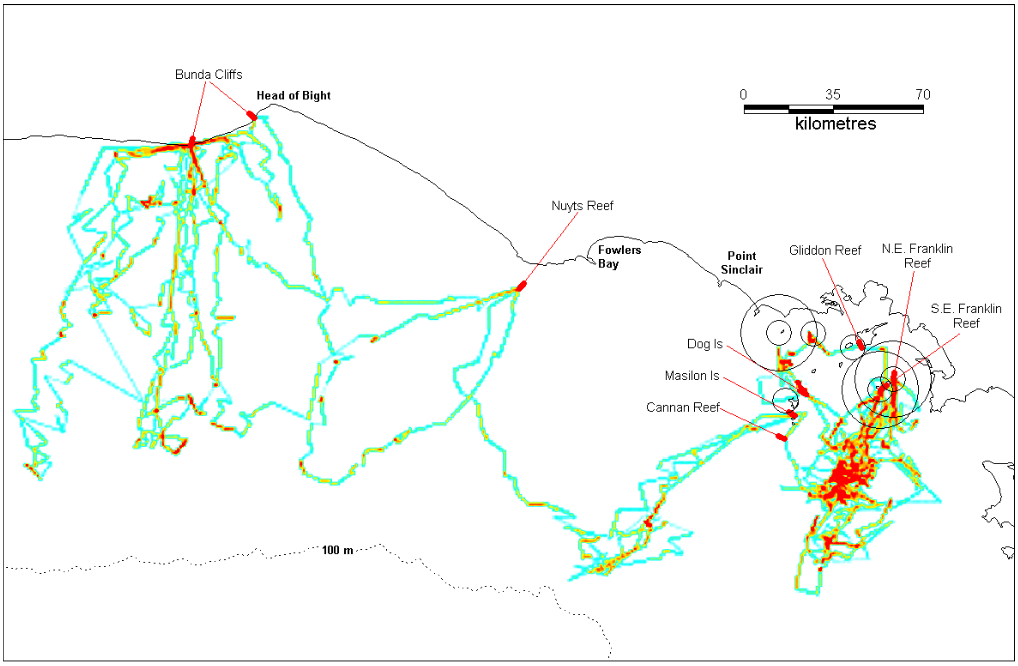


Fig. 8.22. Time spent in 1 km^2 cells by adult males (n = 3), which were satellite tracked from NE Franklin Is. Islands used by at least 1 adult male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

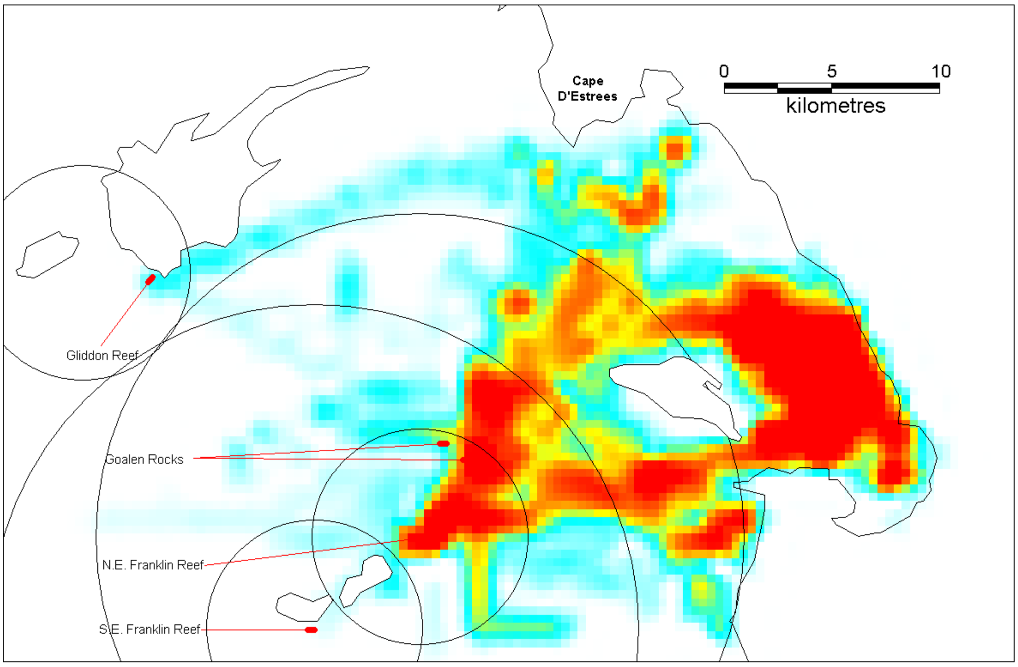


Fig. 8.23. Time spent in 1 km^2 cells by juvenile females (n = 4), which were satellite tracked from NE Franklin Is. Islands used by at least 1 juvenile female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around colonies where trackers were deployed.

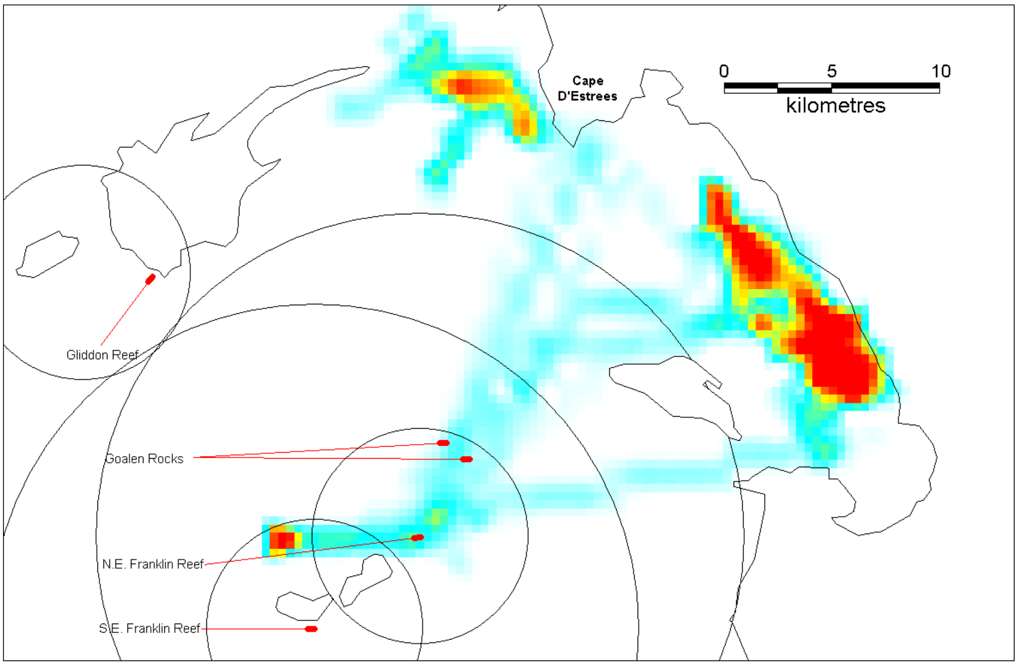


Fig. 8.24. Time spent in 1 km^2 cells by the juvenile male (n = 1), which was satellite tracked from NE Franklin Is. Islands used by the juvenile male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

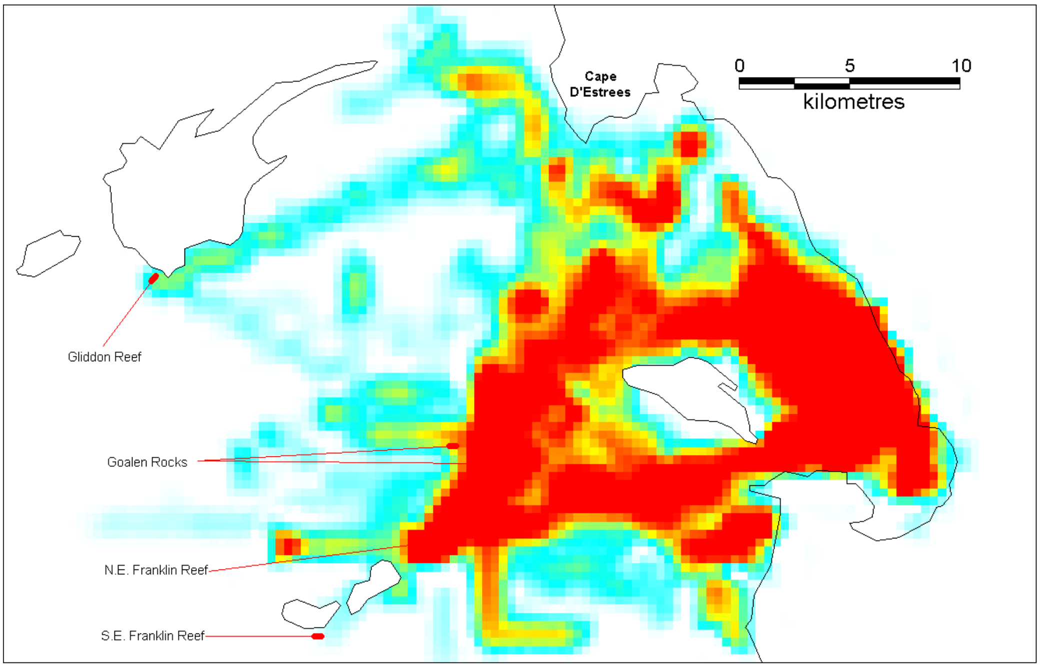


Fig. 8.25. Time spent in 1 km^2 cells by juvenile females (n = 4) and the juvenile male (n = 1), which were satellite tracked from NE Franklin Is. Islands used by the juveniles are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km and 15 km aquaculture exclusion zones around the colonies where satellite trackers were deployed.

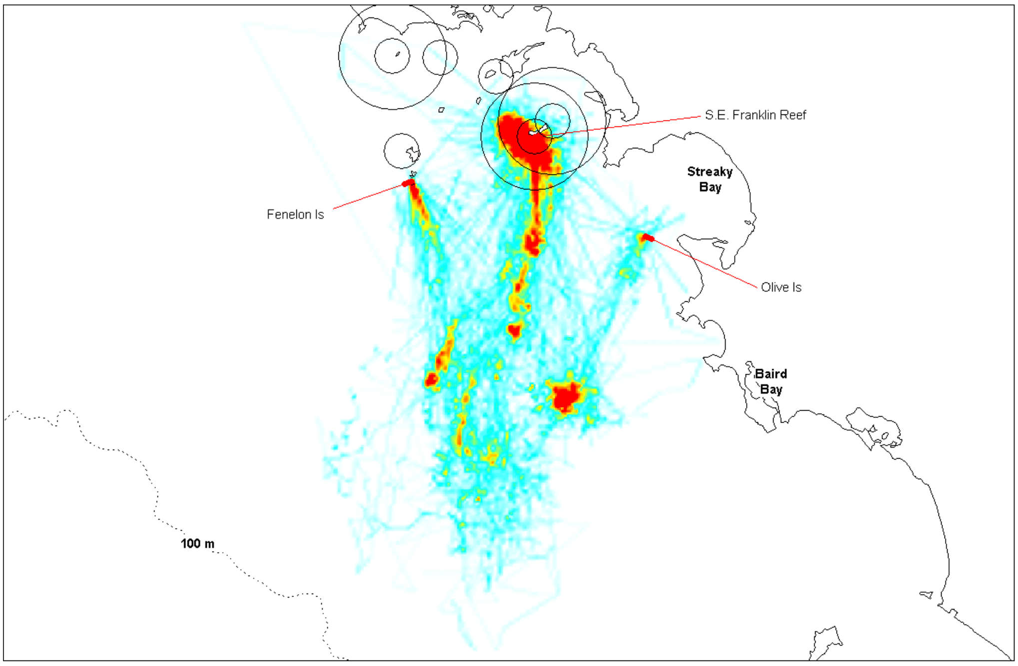


Fig. 8.26. Time spent in 1 km^2 cells by adult females (n = 4), which were satellite tracked from SE Franklin Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

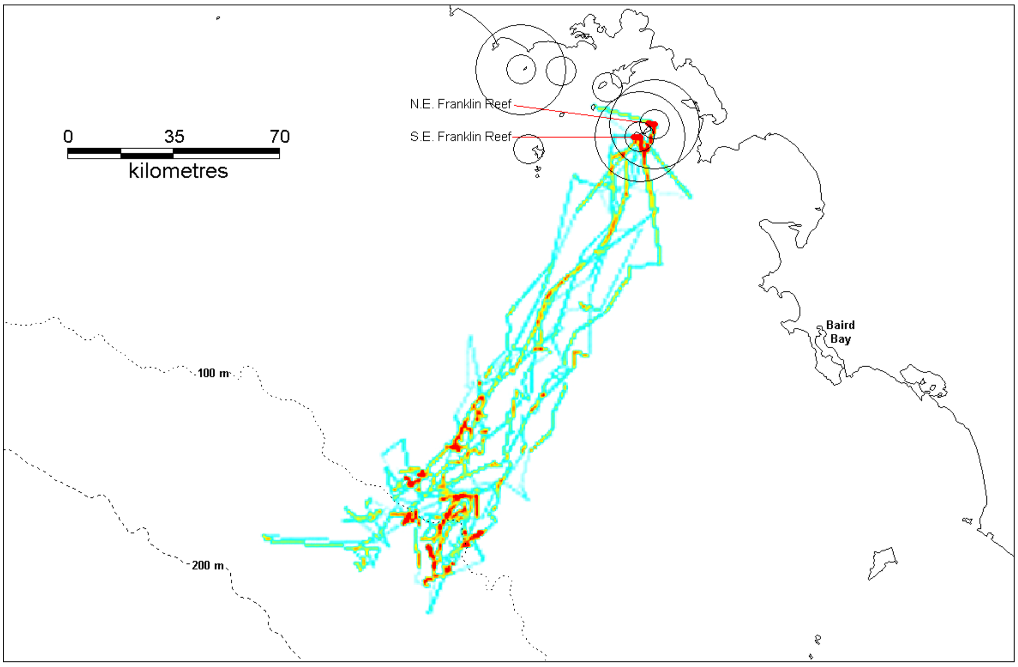


Fig. 8.27. Time spent in 1 km^2 cells by adult males (n = 2), which were satellite tracked from SE Franklin Is. Islands used by at least 1 adult male are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed.

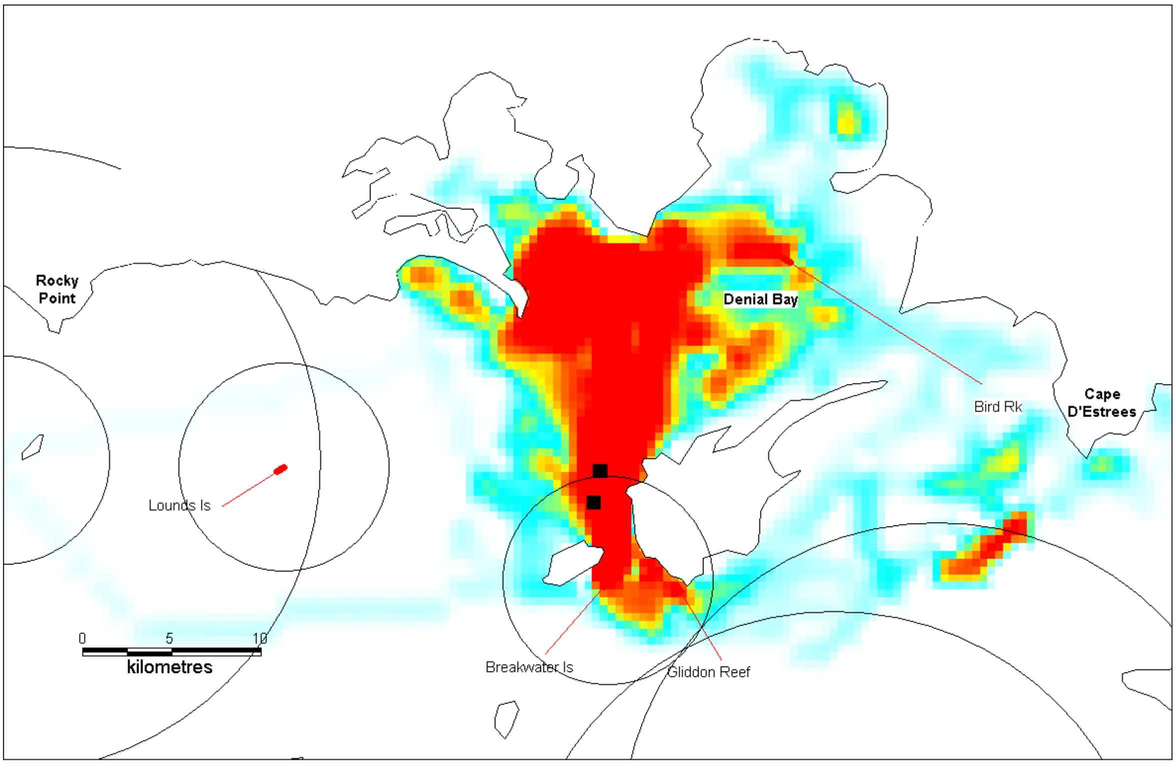


Fig. 8.28. Time spent in 1 km^2 cells by adult females (n = 4), which were satellite tracked from Breakwater Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed. Aquaculture zones FA00020 and FA00021 are indicated by black squares (3.5 km and 5.0 km north of Breakwater Is: each site measures 0.63 km x 0.63 km).

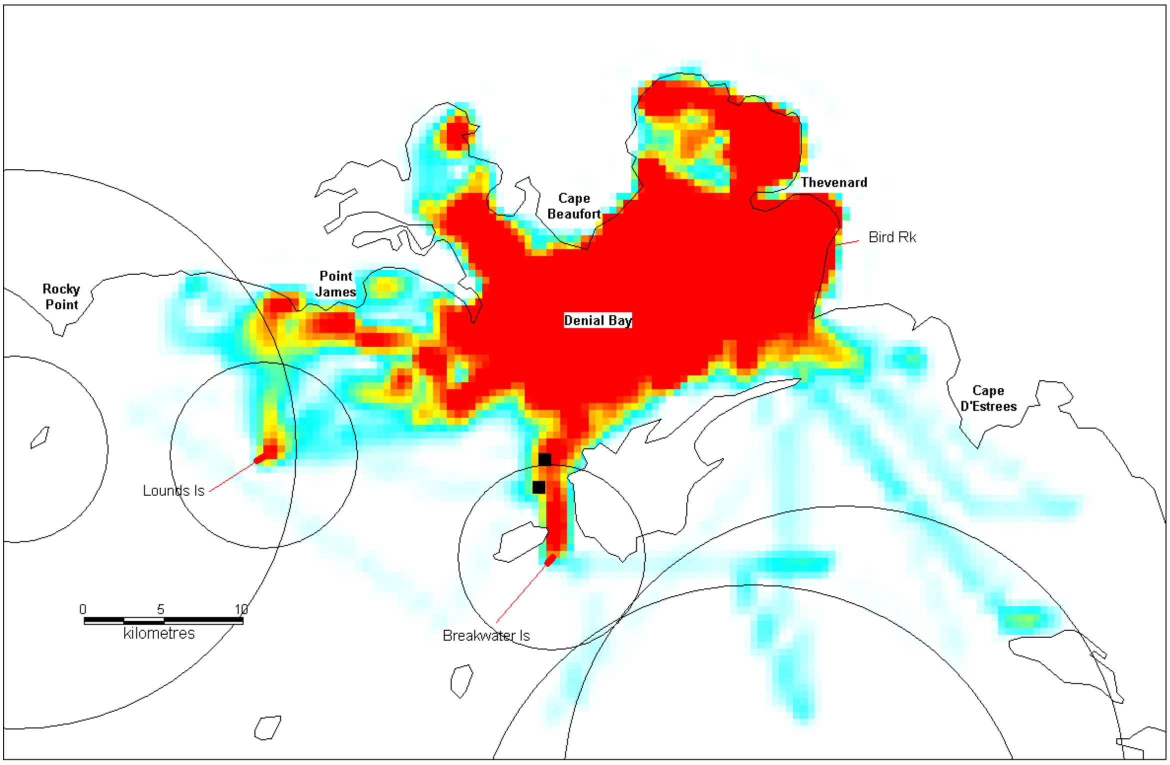


Fig. 8.29. Time spent in 1 km^2 cells by adult females (n = 7), which were satellite tracked from Lounds Is. Islands used by at least 1 adult female are shown. Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. The circles indicate the 5 km (colonies with < 100 pups) and 15 km (> 100 pups) aquaculture exclusion zones around the colonies where satellite trackers were deployed. Aquaculture zones FA00020 and FA00021 are indicated by black squares (3.5 km and 5.0 km north of Breakwater Is: each site measures 0.63 km x 0.63 km).

Table 8.9. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females from Dangerous Reef.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female - 2003																										
10011	28 Sep 03	26 Oct 03	28.3	19	0.7	0.5	0.2	2.0	11.7	4.6	0.8	0.8	47	38.7	9.6	348	275.0	142.2	0.97	2.78	3.13	0.88	37.5	19.9	0.37	0.50
10111	19 Sep 03	3 Oct 03	14.3	6	1.3	1.4	0.6	4.1	8.8	3.7	1.3	0.2	48	18.8	7.3	166	147.7	35.4	0.47	2.92	3.49	0.67	60.7	32.6	0.67	0.52
10211	20 Sep 03	2 Oct 03	11.7	6	1.2	1.3	0.3	3.9	8.3	3.6	0.9	0.7	58	23.6	4.7	107	64.9	41.1	0.51	3.92	4.16	1.03	63.5	19.5	1.00	0.00
10411	29 Sep 03	14 Oct 03	15.5	11	0.8	0.6	0.2	2.2	8.8	5.3	0.7	0.4	53	24.3	17.6	57	43.0	19.7	0.74	2.93	3.91	1.22	46.5	23.6	0.73	0.47
10511	22 Sep 03	4 Oct 03	11.3	7	0.8	0.6	0.3	2.0	10.0	3.3	0.9	0.9	46	14.2	5.9	58	47.5	22.9	0.73	2.78	3.36	0.52	43.6	24.1	1.00	0.00
10611	4 Oct 03	19 Dec 03	75.9	13	1.9	2.0	0.3	6.5	5.2	3.4	4.2	4.3	31	31.6	5.1	320	284.5	124.3	0.91	2.07	3.04	0.98	53.7	19.9	0.85	0.38
10711	19 Sep 03	2 Nov 03	44.5	20	0.8	0.7	0.2	3.5	8.8	4.3	1.5	1.3	33	15.8	6.4	139	237.2	139.5	0.71	2.78	3.61	1.11	35.3	10.6	0.65	0.49
10811	29 Sep 03	3 Oct 03	3.9	3	0.9	0.5	0.4	1.5	9.1	3.2	0.7	0.1	56	9.9	1.4	76	195.6	170.3	0.63	2.45	3.09	0.33	39.4	10.2	1.00	0.00
10911	30 Sep 03	21 Nov 03	52.3	15	1.2	1.7	0.2	7.0	9.0	5.6	2.4	2.8	34	16.3	5.0	178	177.5	69.7	0.38	2.78	3.56	1.11	35.7	13.6	0.73	0.46
11011	23 Sep 03	15 Oct 03	22.2	8	1.8	0.8	0.9	2.8	7.5	3.4	1.1	0.7	63	41.4	16.1	98	88.6	10.9	0.77	2.75	3.18	0.34	99.0	50.3	0.75	0.46
11111	29 Sep 03	17 Oct 03	18.0	7	1.4	0.5	0.5	2.0	8.3	1.4	1.3	0.4	51	34.1	6.1	304	316.5	6.2	0.93	1.66	2.29	0.70	81.9	20.9	1.00	0.00
11211	21 Sep 03	29 Nov 03	68.3	35	1.1	0.6	0.2	3.0	10.5	2.8	0.9	0.5	55	34.3	6.6	95	84.9	12.6	0.86	2.78	3.32	1.00	67.6	26.3	0.26	0.44
11311	21 Sep 03	16 Oct 03	25.1	8	2.0	0.7	0.6	2.7	9.0	2.5	1.2	0.3	62	77.4	15.6	87	78.3	7.5	0.91	3.21	3.81	0.96	171.4	48.5	0.75	0.46
11411	21 Sep 03	13 Oct 03	22.3	5	2.1	2.1	0.3	5.9	4.9	3.9	2.9	1.2	43	60.6	23.1	187	74.7	154.3	0.98	3.23	3.85	0.42	139.8	105.6	0.60	0.55
11511	20 Sep 03	23 Oct 03	33.4	9	2.4	1.8	0.3	6.2	7.0	2.8	1.5	0.4	62	66.9	33.6	25	63.1	109.8	0.96	2.73	3.20	0.62	139.9	79.3	0.11	0.33
11611	27 Sep 03	10 Nov 03	43.1	18	1.7	1.3	0.2	5.1	8.0	4.0	0.7	0.7	70	47.6	17.1	65	57.8	11.3	0.87	2.98	3.92	0.85	108.7	79.1	0.56	0.51
11711	13 Oct 03	31 Oct 03	18.5	6	1.9	1.1	0.6	3.0	5.8	2.9	1.4	0.8	59	14.5	2.3	296	313.4	12.4	0.88	1.06	2.03	0.38	40.4	10.3	1.00	0.00
11811	5 Oct 03	16 Oct 03	11.0	3	0.6	0.4	0.2	1.0	10.4	7.4	4.7	1.5	11	4.8	3.3	57	242.1	171.0	0.73	1.26	2.71	0.16	13.0	11.6	1.00	0.00
11911	5 Oct 03	3 Nov 03	29.2	16	1.1	1.1	0.3	3.5	10.9	3.2	0.8	0.4	59	14.5	4.7	92	79.0	25.8	0.72	2.25	2.95	0.82	47.3	29.3	1.00	0.00
12011	16 Oct 03	6 Dec 03	51.2	23	1.1	0.8	0.2	2.4	9.9	4.5	1.2	1.2	49	30.0	23.2	55	57.9	53.7	0.83	2.78	3.28	1.08	69.0	53.3	1.00	0.00
12111	2 Nov 03	20 Nov 03	18.0	5	1.6	1.1	0.7	3.5	4.4	1.4	2.5	1.2	39	24.1	1.2	319	336.4	8.1	0.95	1.46	2.78	0.94	44.2	13.3	0.40	0.55
12211	24 Oct 03	20 Nov 03	26.5	13	0.9	0.2	0.6	1.4	7.0	1.4	1.2	0.6	44	23.1	2.4	132	114.5	30.0	0.51	2.50	3.02	0.66	53.3	10.7	0.85	0.38
12311	30 Oct 03	26 Nov 03	27.6	13	0.8	0.6	0.2	1.6	11.0	5.1	1.4	1.0	37	22.8	16.1	142	177.6	153.9	0.85	1.97	2.71	0.40	43.8	28.5	0.69	0.48
12411	4 Nov 03	6 Dec 03	32.0	12	1.0	0.5	0.3	1.6	7.7	4.0	1.9	1.4	34	45.6	20.1	55	55.3	26.3	0.89	2.78	3.30	0.63	67.5	32.3	0.42	0.51
Adult female - 2005																										
111	26 Jan 05	8 May 05	101.9	68	0.8	0.5	0.2	1.9	16.1	4.7	0.8	0.6	50	28.9	15.0	125	115.3	29.9	0.78	2.78	3.54	0.88	47.8	26.8	0.69	0.47
311	27 Jan 05	25 Jun 05	149.0	91	0.8	0.5	0.2	3.2	16.5	4.1	0.8	0.6	49	14.5	5.6	173	176.1	61.1	0.57	2.78	3.56	0.87	54.6	32.9	0.89	0.31
1111	11 Apr 05	10 May 05	28.6	23	0.7	0.4	0.4	1.8	16.9	3.7	0.6	0.3	52	15.4	5.0	180	172.4	69.6	0.59	2.78	3.67	0.86	45.2	16.2	0.78	0.42
1211	13 Apr 05	8 May 05	24.9	12	0.7	0.5	0.3	2.2	11.0	4.3	1.5	1.6	31	10.1	4.3	223	309.3	97.8	0.78	2.61	3.54	1.43	34.9	22.4	1.00	0.00
1311	16 Apr 05	8 May 05	22.1	14	0.9	0.9	0.4	3.7	17.7	4.5	0.8	0.6	53	13.3	1.8	168	162.4	21.1	0.57	2.78	3.69	1.14	47.4	18.8	1.00	0.00
1411	14 Apr 05	8 May 05	24.4	20	0.4	0.2	0.2	0.9	15.0	3.4	0.9	0.5	32	12.2	3.5	159	193.9	75.1	0.29	2.88	4.04	1.20	31.4	9.6	1.00	0.00
1511	13 Apr 05	8 May 05	25.7	18	0.7	0.7	0.3	3.2	12.7	3.6	0.8	0.6	45	12.0	3.9	152	149.0	56.3	0.35	2.67	3.57	1.49	35.2	19.6	1.00	0.00
1611	17 Apr 05	8 May 05	21.4	18	0.4	0.2	0.3	1.3	15.1	4.9	0.8	0.6	36	12.4	3.9	157	169.8	81.7	0.40	2.81	3.56	0.87	29.2	11.1	1.00	0.00
1711	13 Apr 05	8 May 05	25.5	18	0.7	0.2	0.4	1.4	16.1	3.7	0.8	0.5	48	14.7	3.7	151	117.7	60.7	0.67	2.65	3.37	0.84	44.6	12.3	1.00	0.00
1811	12 Apr 05	8 May 05	26.2	19	0.3	0.1	0.2	0.5	21.3	3.6	1.1	0.5	20	14.7	5.4	153	183.5	155.8	0.83	2.85	4.01	1.09	25.0	9.8	0.47	0.51
2003: mean, median, SD			29.3	12	1.3	0.5	0.4	3.3	8.4	2.0	1.6	1.1	48	30.6	18.4	102	150.5	100.1	0.78	2.78	3.24	0.52	66.8	38.8	0.72	0.26
2005: mean, median, SD			45.0	30	0.6	0.2	0.3	2.0	15.8	2.8	0.9	0.3	42	14.8	5.2	158	174.9	53.9	0.58	2.78	3.65	0.21	39.5	9.7	0.88	0.18
Overall: mean, median, SD			33.9	17	1.1	0.5	0.3	2.9	10.6	4.1	1.4	1.0	46	26.0	17.3	146	157.7	88.9	0.72	2.78	3.36	0.49	58.8	35.1	0.77	0.25

Table 8.10. Summary data on the parameters that describe the foraging and haulout characteristics of the adult males, juveniles and subadult male from Dangerous Reef.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult male																										
212	29 Jan 05	9 Apr 05	69.5	46	1.3	0.9	0.3	4.6	15.1	6.0	0.3	0.5	83	32.7	17.9	163	165.6	28.3	0.67	4.61	5.56	1.68	179.1	149.6	0.07	0.25
412	2 Feb 05	31 May 05	117.6	44	1.6	0.7	0.5	3.2	14.0	3.9	1.1	0.8	60	88.2	4.8	152	150.6	3.9	0.97	4.31	5.07	1.02	153.0	71.1	0.82	0.39
512	29 Jan 05	2 Feb 05	4.3	2	0.6	0.3	0.4	0.8	17.0	0.8	3.1		16	28.4	6.8	185	186.2	221.5	0.95	3.52	3.81	0.05	44.5	20.9	0.00	0.00
3012	30 Jan 06	14 Mar 06	43.1	11	2.7	1.3	0.5	4.5	16.4	3.4	1.3	0.7	68	112.0	25.5	235	235.8	4.2	0.98	5.49	5.93	0.75	349.7	171.6	0.91	0.30
3112	31 Jan 06	16 Mar 06	44.2	21	1.0	0.8	0.2	2.3	16.6	4.6	1.2	0.9	46	44.1	17.6	33	35.4	11.3	0.98	2.91	4.11	0.94	70.0	58.9	0.71	0.46
3212	30 Jan 06	14 Mar 06	42.7	17	1.4	0.6	0.2	2.2	12.8	5.5	1.2	0.8	53	102.0	31.9	71	65.6	16.4	0.97	2.99	3.69	0.83	87.4	49.5	0.88	0.33
3312	29 Jan 06	11 Mar 06	41.5	11	2.3	1.7	0.4	4.5	13.1	3.5	1.6	1.7	59	93.6	69.4	233	220.6	44.0	0.74	4.59	5.06	1.23	206.4	160.1	0.73	0.47
Juvenile male																										
614	27 Jan 05	10 Feb 05	14.0	11	0.6	0.2	0.4	1.0	13.1	4.9	0.7	0.5	44	21.9	6.4	203	204.5	18.6	0.85	2.96	3.67	0.74	32.2	7.5	0.36	0.50
714	28 Jan 05	19 Feb 05	22.0	17	0.5	0.2	0.1	1.0	13.5	5.1	0.9	0.5	36	19.0	6.0	211	183.7	45.4	0.75	2.78	3.33	1.05	26.2	12.7	0.59	0.51
914	29 Jan 05	10 Mar 05	40.3	12	1.4	1.4	0.2	4.5	9.2	5.8	2.1	1.8	40	11.0	3.9	110	104.6	49.5	0.49	1.99	2.64	0.44	40.9	34.1	1.00	0.00
1914	14 Apr 05	8 May 05	24.5	19	0.4	0.1	0.2	0.8	15.8	4.3	0.9	0.6	34	9.9	2.9	171	182.7	30.9	0.32	2.78	3.16	0.50	26.3	10.1	1.00	0.00
2014	12 Apr 05	3 Jun 05	51.2	34	0.7	0.3	0.2	1.4	14.8	3.3	0.8	0.6	46	18.0	5.9	182	182.6	53.0	0.53	3.28	4.02	0.91	56.9	27.1	0.71	0.46
10314	17 Sep 03	10 Dec 03	83.5	38	1.0	0.4	0.5	1.9	8.8	2.5	1.2	0.8	44	30.1	8.6	112	107.0	41.7	0.68	2.78	3.31	0.89	60.8	17.8	0.68	0.47
12514	8 Nov 03	15 Feb 04	99.6	40	1.3	1.1	0.3	5.1	7.9	3.7	1.2	0.9	51	29.5	10.3	83	97.1	50.6	0.77	2.78	3.30	1.08	56.6	33.7	0.85	0.36
Subadult male																										
1015	29 Jan 05	7 May 05	97.5	78	0.5	0.3	0.2	1.9	16.5	5.2	0.8	0.8	40	15.4	6.5	148	174.6	115.3	0.59	3.52	4.26	1.20	38.8	21.3	0.64	0.48
Adult male: mean, median, SD			51.8	22	1.6	0.7	0.3	3.2	15.0	1.7	1.4	0.9	55	71.6	35.2	163	151.4	75.4	0.90	4.31	4.74	0.88	155.7	104.2	0.59	0.39
Juvenile male: mean, median, SD			47.9	24	0.8	0.4	0.3	2.2	11.9	3.2	1.1	0.5	42	19.9	8.0	171	151.7	46.4	0.63	2.78	3.35	0.43	42.8	15.2	0.74	0.23
Subadult male: mean, median, SD			97.5	78	0.5	-	0.2	1.9	16.5	-	0.8	-	40	15.4	-	148	174.6	-	0.59	3.52	4.26	-	38.8	-	0.64	-

Table 8.11. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females, adult males, juveniles and subadult male from West Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
121	27 May 05	13 Jun 05	16.5	15	0.6	0.4	0.1	1.4	17.3	7.4	0.5	0.4	55	10.6	7.6	78	66.9	13.2	0.79	2.49	3.44	1.29	31.5	18.9	0.13	0.35
321	28 May 05	12 Jun 05	15.5	11	0.8	0.6	0.1	1.9	16.5	10.4	0.7	0.5	53	17.0	12.4	99	99.4	67.0	0.61	4.12	4.57	1.33	61.8	47.9	0.45	0.52
421	28 May 05	20 Jun 05	22.5	12	1.1	0.7	0.3	2.4	17.6	6.2	0.8	0.4	59	24.7	10.5	223	230.3	15.1	0.75	3.16	4.28	0.97	80.8	46.3	0.50	0.52
521	28 May 05	15 Jun 05	18.7	16	0.5	0.3	0.1	1.2	19.4	8.7	0.7	0.5	43	13.3	8.2	142	131.6	35.8	0.76	3.03	4.36	1.56	42.2	30.3	0.19	0.40
621	29 May 05	1 Jul 05	32.7	12	1.9	1.1	0.7	5.0	14.6	2.5	0.9	0.6	68	39.4	13.7	252	257.9	6.4	0.82	3.49	4.13	0.86	147.1	72.4	1.00	0.00
Adult male																										
1222	1 Jun 05	29 Jun 05	28.4	4	4.8	0.5	4.0	5.2	15.7	1.1	3.1	0.2	61	167.6	6.4	224	225.1	0.2	0.95	4.94	5.35	0.56	529.3	66.6	1.00	0.00
1322	31 May 05	1 Jul 05	31.5	5	4.4	0.9	3.3	5.4	15.0	2.5	2.4	0.8	64	127.2	21.8	229	228.9	4.8	0.94	3.94	4.30	0.39	372.9	65.1	1.00	0.00
1422	30 May 05	4 Jul 05	35.1	9	2.5	1.7	0.2	4.3	16.4	7.0	1.5	1.0	62	97.0	61.7	215	232.1	37.5	0.78	4.34	5.22	1.12	252.8	160.5	0.78	0.44
1522	29 May 05	1 Jul 05	32.4	18	1.0	0.5	0.4	1.8	14.9	4.6	0.9	0.7	53	15.8	6.6	226	201.0	141.6	0.81	2.45	3.63	1.22	59.6	29.3	0.50	0.51
Juvenile female																										
723	28 May 05	5 Jul 05	38.7	14	1.8	1.0	0.4	3.9	11.2	4.6	1.1	0.8	62	36.3	13.4	243	217.3	89.1	0.90	2.74	3.48	0.81	103.3	54.6	0.43	0.51
923	28 May 05	2 Jul 05	35.0	20	0.6	0.4	0.2	1.6	13.6	4.0	1.2	0.8	35	30.6	4.1	343	339.8	15.0	0.97	2.74	3.53	1.17	43.5	25.3	0.65	0.49
Juvenile male																										
224	29 May 05	3 Jul 05	35.8	29	0.6	0.3	0.1	1.4	17.5	5.2	0.7	0.4	48	14.7	7.7	283	281.2	84.0	0.79	2.78	3.83	1.13	46.5	28.8	0.90	0.31
824	29 May 05	3 Jul 05	35.3	17	1.2	0.4	0.6	1.7	16.6	3.9	0.9	0.5	56	19.2	6.5	279	292.6	19.2	0.86	2.31	3.26	0.67	74.2	30.5	1.00	0.00
1124	28 May 05	19 Jun 05	21.8	11	0.6	0.6	0.1	1.7	23.9	20.3	1.5	0.9	29	12.8	6.6	95	94.9	34.3	0.83	3.19	4.11	0.84	37.4	33.1	0.45	0.52
Subadult male																										
1025	28 May 05	25 Jun 05	27.2	12	1.3	0.6	0.4	2.5	17.4	3.5	1.0	0.4	56	36.5	25.0	254	266.3	50.0	0.89	2.91	3.73	0.68	98.8	62.3	0.92	0.29
Adult female: mean, median, SD			21.2	13	1.0	0.6	0.3	2.4	17.1	1.8	0.7	0.1	56	21.0	11.6	142	157.2	83.1	0.74	3.16	4.16	0.43	72.7	45.7	0.46	0.34
Adult male: mean, median, SD			31.8	9	3.2	1.7	2.0	4.1	15.5	0.7	2.0	1.0	60	101.9	64.3	225	221.8	14.2	0.87	4.14	4.63	0.81	303.6	198.2	0.82	0.24
Juvenile female: mean, median, SD			36.9	17	1.2	0.8	0.3	2.7	12.4	1.7	1.1	0.1	49	33.5	4.0	293	278.5	86.6	0.94	2.74	3.50	0.04	73.4	42.3	0.54	0.16
Juvenile male: mean, median, SD			31.0	19	0.8	0.3	0.2	1.6	19.3	4.0	1.0	0.4	44	15.6	3.3	279	222.9	111.0	0.82	2.78	3.73	0.43	52.7	19.2	0.78	0.29
Subadult male: mean, median, SD			27.2	12	1.3	-	0.4	2.5	17.4	-	1.0	-	56	36.5	-	254	266.3	-	0.89	2.91	3.73	-	98.8	-	0.92	-

Table 8.12. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females, adult males and juveniles from Purdie Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
131	31 May 05	11 Jun 05	10.4	8	0.7	0.3	0.3	1.3	17.2	3.6	0.6	0.4	53	43.2	7.8	279	286.7	8.5	0.97	3.13	4.43	0.91	73.4	31.3	0.88	0.35
331	4 Jun 05	3 Sep 05	91.3	25	2.0	0.9	0.4	4.5	20.9	4.0	1.8	0.7	53	55.7	21.3	229	232.9	19.7	0.87	3.90	4.76	0.54	190.0	75.7	0.92	0.28
431	31 May 05	17 Jun 05	17.1	9	1.2	0.9	0.2	2.8	16.3	5.7	0.7	0.3	63	45.3	29.7	225	202.7	68.8	0.71	3.45	3.94	0.93	118.0	108.8	0.67	0.50
531	2 Jun 05	16 Jun 05	13.8	5	2.0	0.6	1.4	2.7	13.1	3.2	1.0	0.3	66	55.1	6.4	241	243.8	6.5	0.85	3.94	4.59	1.43	182.9	51.5	1.00	0.00
731	2 Jun 05	4 Jun 05	2.3	2	0.9	0.8	0.3	1.5	18.2	11.2	0.6		61	18.2	12.4	277	295.1	4.8	0.78	3.36	4.43	0.20	63.4	54.7	0.50	0.71
Adult male																										
1132	5 Jun 05	17 Jul 05	41.7	9	3.3	1.9	0.6	6.7	14.6	3.4	1.5	0.9	68	147.1	71.8	177	186.8	29.7	0.94	3.88	4.76	0.59	345.0	224.2	0.44	0.53
1232	4 Jun 05	23 Jun 05	18.7	4	3.3	1.8	0.6	4.8	11.1	0.8	1.8	0.5	64	128.3	62.6	205	202.4	3.5	0.90	4.22	5.24	0.91	318.0	160.7	0.25	0.50
1332	4 Jun 05	22 Jun 05	18.0	4	2.7	1.4	0.7	3.6	11.5	1.0	2.4	0.1	53	94.6	42.3	220	220.5	4.0	0.77	3.53	4.86	1.38	283.2	154.1	1.00	0.00
1432	4 Jun 05	24 Jun 05	20.5	4	3.6	2.2	0.5	5.4	12.2	0.5	2.0	1.4	65	131.3	77.6	219	226.4	9.9	0.80	4.69	5.44	0.40	387.7	240.8	1.00	0.00
1532	2 Jun 05	4 Jun 05	1.5	2	0.3	0.4	0.0	0.6	55.3	64.5	0.8		29	32.4	4.6	169	173.3	5.0	0.82	8.21	7.13	1.03	47.8	53.3	0.00	0.00
Juvenile male																										
234	31 May 05	2 Aug 05	63.1	21	1.8	1.1	0.4	3.7	13.1	3.9	1.2	1.0	60	61.0	30.4	216	202.0	52.5	0.82	3.76	4.82	1.08	167.0	108.4	0.57	0.51
634	1 Jun 05	18 Jul 05	47.0	21	1.0	0.6	0.4	2.5	12.9	3.3	1.3	0.5	45	27.4	18.9	220	244.5	41.0	0.60	3.17	3.84	0.87	76.4	50.2	1.00	0.00
834	4 Jun 05	23 Jun 05	18.5	11	0.9	0.4	0.3	1.6	9.5	4.3	0.9	0.7	49	19.4	9.1	157	238.8	129.8	0.65	2.78	3.90	1.13	43.9	20.1	0.64	0.50
934	1 Jun 05	21 Aug 05	81.4	38	1.0	0.7	0.2	2.9	15.4	5.5	1.1	0.9	48	23.6	14.8	202	201.3	68.4	0.64	3.16	3.97	1.23	73.6	47.7	0.89	0.31
1034	1 Jun 05	22 Jun 05	21.3	10	0.8	0.5	0.4	1.8	10.8	2.5	1.4	1.2	37	31.6	11.2	179	188.8	35.5	0.58	2.78	3.53	0.82	53.8	44.9	0.40	0.52
Adult female: mean, median, SD			27.0	10	1.4	0.6	0.5	2.6	17.1	2.8	0.9	0.5	59	43.5	15.2	241	252.2	38.5	0.84	3.45	4.43	0.31	125.5	59.3	0.79	0.20
Adult male: mean, median, SD			20.1	5	2.7	1.3	0.5	4.2	20.9	19.3	1.7	0.6	56	106.8	45.7	205	201.9	22.3	0.85	4.22	5.49	0.96	276.3	133.4	0.54	0.45
Juvenile male: mean, median, SD			46.3	20	1.1	0.4	0.3	2.5	12.3	2.3	1.2	0.2	48	32.6	16.5	202	215.1	24.9	0.66	3.16	4.01	0.48	82.9	48.9	0.70	0.24

Table 8.13. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females, adult males and juveniles from NE Franklin Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
241	3 Jun 05	9 Jun 05	6.0	5	0.6	0.3	0.1	1.0	15.7	10.5	0.8	0.5	41	8.1	5.2	43	142.4	163.7	0.66	2.78	3.98	2.05	21.5	15.6	0.00	0.00
341	2 Jun 05	13 Jul 05	41.0	33	0.6	0.3	0.1	1.8	20.8	6.9	0.7	0.5	47	9.8	3.6	275	226.1	160.0	0.81	2.89	3.77	1.16	39.2	20.4	0.55	0.51
441	2 Jun 05	14 Jul 05	42.2	16	1.6	0.8	0.2	2.5	19.0	5.1	1.1	0.6	60	33.3	9.3	236	258.6	32.7	0.92	2.84	4.07	0.78	132.3	68.5	0.44	0.51
641	3 Jun 05	9 Jun 05	6.3	3	1.1	0.2	1.0	1.3	14.5	0.2	1.4	0.4	44	22.5	1.5	31	24.3	4.8	0.89	1.76	2.49	0.69	69.6	7.1	1.00	0.00
941	3 Jun 05	9 Jul 05	35.9	14	1.8	0.9	0.2	3.9	14.7	4.5	0.8	0.5	70	19.4	3.2	43	65.1	85.8	0.89	2.23	3.44	1.30	89.5	33.7	1.00	0.00
Adult male																										
142	3 Jun 05	7 Jul 05	34.4	8	2.6	0.5	1.9	3.2	14.2	1.6	1.9	0.5	58	65.0	13.4	206	202.7	7.0	0.91	3.99	5.01	0.77	273.0	56.1	0.25	0.46
742	3 Jun 05	10 Jun 05	7.7	4	1.7	0.9	0.4	2.6	12.2	7.1	0.4	0.2	81	44.3	19.3	277	275.3	46.3	0.88	3.74	4.20	0.86	97.9	83.2	0.50	0.58
842	4 Jun 05	1 Aug 05	57.8	15	2.3	1.3	0.2	4.2	18.7	8.2	1.7	0.9	58	263.0	78.3	275	271.6	20.4	0.98	4.71	5.48	0.79	257.0	150.9	0.53	0.52
Juvenile female																										
543	4 Jun 05	22 Jun 05	18.1	10	1.0	0.5	0.5	1.7	15.1	5.4	0.9	1.0	52	18.4	2.8	33	91.9	138.7	0.92	2.51	3.46	1.20	56.2	20.4	0.20	0.42
1043	3 Jun 05	9 Jul 05	36.0	15	1.4	0.6	0.3	2.7	15.1	3.0	1.0	0.3	58	21.5	2.8	64	57.4	4.7	0.89	2.57	3.37	0.69	89.4	31.7	0.93	0.26
1243	3 Jun 05	10 Jul 05	36.4	17	0.9	0.6	0.1	1.9	14.9	13.7	1.3	0.6	40	12.1	3.4	33	62.5	77.5	0.82	2.63	3.26	1.54	34.3	15.4	0.29	0.47
1343	3 Jun 05	8 Jul 05	35.5	12	1.9	0.4	1.3	2.6	17.6	2.5	1.1	0.3	62	22.5	1.1	71	64.1	5.9	0.94	1.85	2.49	0.46	92.2	18.4	1.00	0.00
Juvenile male																										
1144	5 Jun 05	18 Jun 05	13.2	4	2.3	0.6	1.8	3.2	11.8	2.3	1.4	0.5	62	22.9	0.6	53	43.2	22.1	0.91	2.34	2.75	0.68	107.7	14.2	1.00	0.00
Adult female: mean, median, SD			26.3	14	1.2	0.6	0.3	2.1	17.0	2.8	1.0	0.3	53	18.6	10.2	43	143.3	100.5	0.83	2.78	3.55	0.64	70.4	43.5	0.60	0.42
Adult male: mean, median, SD			33.3	9	2.2	0.5	0.8	3.3	15.0	3.3	1.3	0.8	66	124.1	120.8	275	249.9	40.9	0.93	3.99	4.90	0.65	209.3	96.8	0.43	0.15
Juvenile female: mean, median, SI			31.5	14	1.3	0.5	0.6	2.2	15.7	1.3	1.1	0.2	53	18.6	4.7	48	69.0	15.5	0.89	2.54	3.14	0.44	68.0	27.8	0.61	0.42
Juvenile male: mean, median, SD			13.2	4	2.3	-	1.8	3.2	11.8	-	1.4	-	62	22.9	-	53	43.2	-	0.91	2.34	2.75	-	107.7	-	1.00	-

Table 8.14. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females and adult males from SE Franklin Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
251	16 Oct 05	15 Mar 06	149.3	67	1.5	1.2	0.1	4.0	14.8	6.3	0.8	0.7	65	48.5	30.2	156	151.9	36.9	0.71	3.79	4.89	1.19	145.0	128.8	0.76	0.43
351	16 Oct 05	16 Mar 06	150.4	38	2.5	1.1	0.4	3.9	11.9	3.2	1.5	0.8	61	97.3	32.8	192	206.0	16.0	0.91	5.51	5.90	0.96	298.8	143.7	0.66	0.48
451	16 Oct 05	15 Mar 06	150.1	37	2.7	1.2	0.2	4.8	19.7	2.8	1.4	0.7	65	65.5	29.7	186	186.9	34.1	0.86	3.64	4.56	0.92	234.6	114.2	1.00	0.00
651	16 Oct 05	9 Mar 06	144.6	132	0.6	0.3	0.2	1.8	17.4	5.1	0.5	0.3	53	13.3	7.4	259	284.7	37.6	0.62	3.59	4.68	1.27	51.0	26.5	0.99	0.09
Adult male																										
152	5 Jun 05	12 Jun 05	6.8	2	2.9	3.3	0.5	5.2	9.6	3.3	1.1		72	93.3	122.8	130	131.2	107.0	0.73	4.11	4.55	1.64	326.5	437.2	0.50	0.71
252	7 Jun 05	8 Jul 05	31.2	4	5.4	0.9	4.5	6.4	13.5	2.7	3.1	1.3	63	158.4	10.7	208	207.6	3.2	0.93	3.76	4.79	0.45	560.9	124.7	1.00	0.00
Adult female: mean, median, SD			148.6	69	1.8	1.0	0.2	3.6	15.9	3.4	1.1	0.5	61	56.2	35.0	189	207.4	56.2	0.78	3.71	5.01	0.61	182.3	107.9	0.85	0.17
Adult male: mean, median, SD			19.0	3	4.2	1.8	2.5	5.8	11.5	2.7	2.1	1.4	68	125.8	46.0	169	169.4	54.0	0.83	3.93	4.67	0.17	443.7	165.7	0.75	0.35

Table 8.15. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females from Breakwater Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
181	4 Jun 05	2 Aug 05	58.9	35	1.0	0.4	0.4	1.8	15.9	3.1	0.7	0.4	57	14.5	4.3	31	167.9	174.0	0.92	2.33	3.09	0.80	54.1	22.7	0.69	0.47
281	4 Jun 05	29 Jun 05	25.0	22	0.6	0.3	0.1	1.7	17.7	10.1	0.6	0.4	51	18.7	4.3	27	65.8	117.8	0.92	2.61	3.56	1.04	33.2	16.2	0.41	0.50
381	5 Jun 05	22 Jun 05	16.8	9	1.1	0.5	0.4	1.7	14.2	2.6	0.9	0.6	54	22.4	5.0	31	38.0	17.9	0.91	2.70	3.28	0.68	64.7	28.1	0.00	0.00
481	5 Jun 05	12 Jul 05	36.8	17	1.3	0.7	0.3	3.0	11.0	4.6	1.0	0.5	57	14.7	4.7	344	270.5	135.8	0.83	1.89	2.71	0.76	49.0	25.9	0.76	0.44
Overall: mean, median, SD			34.4	21	1.0	0.3	0.3	2.0	14.7	2.9	0.8	0.2	55	17.6	3.8	31	135.6	105.9	0.90	2.47	3.16	0.36	50.2	13.1	0.46	0.35

Table 8.16. Summary data on the parameters that describe the foraging and haulout characteristics of the adult females from Lounds Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Deployment duration (d)	No. of foraging trips	Mean trip duration (d)	SD	Min. trip duration (d)	Max. trip duration (d)	No. hits per day (at sea)	SD	Mean haulout duration (d)	SD	Time at sea (%)	Mean max. distance (km)	SD	Median bearing (deg)	Mean bearing (deg)	SD	Circular distance (r-value)	Median speed (km/h)	Mean speed (km/h)	SD	Mean total distance travelled (km)	SD	Mean site fidelity index	SD
Adult female																										
161	16 Oct 05	21 Oct 05	4.4	2	1.1	0.3	0.9	1.4	10.7	1.0	2.1		36	13.4	3.1	58	36.6	3.2	0.86	1.76	2.49	1.31	44.3	0.9	1.00	0.00
261	17 Oct 05	19 Oct 05	1.3	1	1.3		1.3	1.3	25.6					18.2		39	39.1		0.89	2.23	3.29		85.0		1.00	
361	16 Oct 05	20 Oct 05	3.4	2	1.4	0.5	1.0	1.7	24.6	0.7	0.6		68	20.2	1.1	39	29.9	1.6	0.92	2.52	3.47	0.40	94.1	20.9	1.00	0.00
461	16 Oct 05	16 Mar 06	150.4	114	0.7	0.4	0.2	2.3	17.6	6.3	0.7	0.5	51	27.9	3.1	67	66.8	4.3	0.99	2.78	3.92	1.21	42.0	22.6	0.99	0.09
561	18 Oct 05	19 Oct 05	1.0	2	0.5	0.2	0.3	0.6	25.7	5.7	0.1		90	13.7	3.4	69	44.9	21.7	0.83	4.24	4.65	1.78	42.9	5.2	1.00	0.00
661	18 Oct 05	22 Nov 05	35.7	18	1.3	0.7	0.3	2.9	23.6	4.7	0.7	0.5	66	32.0	3.9	63	65.6	6.7	0.98	2.55	3.47	0.88	78.4	36.2	0.44	0.51
761	18 Oct 05	20 Oct 05	2.0	1	2.0		2.0	2.0	18.1					30.1		47	46.7		0.97	2.33	3.65		149.4		1.00	
Overall: mean, median, SD			28.3	20	1.2	0.5	0.8	1.7	20.9	5.6	0.8	0.7	62	22.2	7.8	58	47.1	14.2	0.92	2.52	3.56	0.65	76.6	38.9	0.92	0.21

The mean time that ASL were maintained under gas anaesthesia reduced significantly throughout the study ($F_{4,97}$ = 44.815, $P < 0.0001$, 5 time periods). During the first capture session at Dangerous Reef, the average gas anaesthesia time was 56.9 ± 18.5 min (n = 26), but decreased to an average of 36.6 ± 11.2 min (n = 18) by the second capture session (Table 8.1 and 8.2). This decreased further to an average of 19.6 ± 6.9 min (n = 58) for seals captured in the Nuyts Archipelago (Table 8.3–8.8). All seals recovered well from anaesthesia, and females that had been with a pup typically re-commenced nursing shortly after they recovered.

Adult females (females that had pups) were significantly shorter and lighter than males, and juveniles were significantly shorter and lighter than adult females and males ($P < 0.01$ in all cases) (Table 8.1 and 8.2). The body condition index (kg/cm) did not vary significantly between adult females, adult males and juveniles ($P > 0.05$ in all cases). Age estimates ranged from 4 to 21 y for adult females with a mean age of 9.7 ± 3.6 y (Table 8.1 and 8.2). Juvenile females (too small to have had a pup) ranged in age from 1 to 5 yr with a mean age of 3.1 ± 1.7 y (Table 8.3 and 8.5). No age estimates were available for adult or juvenile males.

Deployment durations

The average period of satellite transmission per deployment was 49.2 ± 52.6 d (n = 109), but ranged between 3 and 268 d. Half (n = 55) of the transmitters were recovered before transmission ceased, and hence for this group, transmission duration was less (31.5 ± 19.3 d, range: 3–104 d) compared to those not recovered (67.2 ± 67.8 d, range: 5–268d, n = 54). Transmitter malfunction (due to battery failure) may have played a part in reducing transmission time for some transmitters. Some of the transmitters that were recovered were broken (e.g., broken aerial, worn epoxy that exposed electronics). There was a significant effect of moult-stage (1– just started; 2 – mid moult; 3 - almost completed; 4 – completed) of the animal on transmission duration ($F_{3,21}$ = 8.905, P = 0.0005). The lowest transmission duration was recorded for seals in mid-moult (19.1 ± 15.8 d, n = 7), and the greatest for those that had completed moult (164.6 ± 84.7 d, n = 7) (Fig. 8.30). The age/sex group of the seals did not affect the duration of transmission ($F_{2,51}$ = 1.070, P = 0.3504).

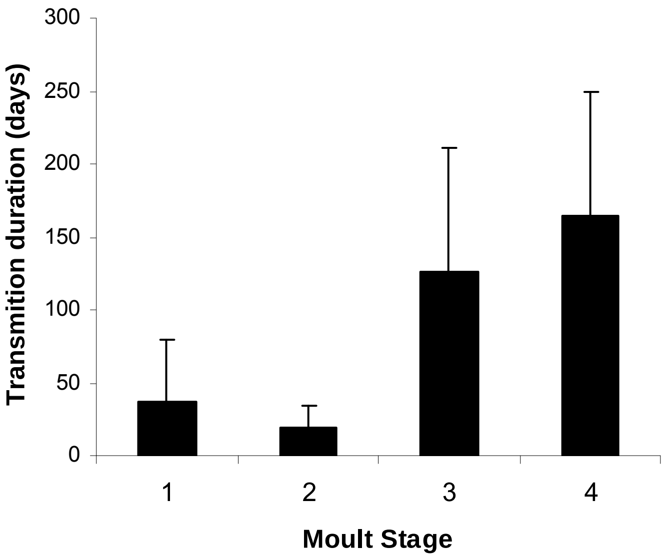


Fig. 8.30. Effect of moult stage on transmission duration of satellite transmitters deployed on ASL. Error bars denote standard deviation.

Satellite-derived locations

Dangerous Reef

In total, 10,627 unfiltered locations were obtained (classes *B*, *A*, *0*, *1*, *2*, *3*) from all of the foraging trips made by satellite-tracked ASL at Dangerous Reef: adult females (5,434 locations), adult males (3,241), juvenile males (1,359) and the subadult male (593). The maximum travel speed between high-class satellite locations (11.93 km/h) indicated a relatively high proportion of speeds below 4 km/h, compared with speeds between low-class locations (Fig. 8.3), which most reflected differences in the accuracy of the locations rather than differences in swimming speeds. The maximum travel-speed-filter removed 269 locations (based on the maximum travel speed of (11.93 km/h) and as a result, 10,358 locations were used to determine the foraging behaviour of the ASL from Dangerous Reef. After filtering, the average numbers of locations (satellite hits) per day at sea were: 10.6 ± 4.1 for adult females (Table 8.9), 15.0 ± 1.7 for adult males, 11.9 ± 3.2 for juvenile males and 16.5 for the single subadult male (Table 8.10).

Nuyts Archipelago

In total, 21,081 unfiltered locations (classes *B*, *A*, *0*, *1*, *2*, *3*) were obtained from all of the foraging trips made by satellite-tracked ASL in the Nuyts Archipelago: adult females (13,577 locations), adult males (3,513), juvenile males (2,304), juvenile females (1,410) and the subadult male (277). The maximum travel-speed-filter removed 1,722 locations and as a result 19,359 locations were used to determine the foraging behaviour of the ASL from the Nuyts Archipelago. After filtering, the average numbers of locations (satellite hits) per day at sea are shown in Table 8.11–8.16.

Time at sea and onshore

In total, 983 foraging trips were recorded from ASL at Dangerous Reef (adult females 582 trips, adult males 152, juvenile males 171 and the subadult male 78, Tables 8.9 and 8.10). In total, 1,037 foraging trips were recorded from ASL in the Nuyts Archipelago (adult females 683 trips, adult males 92, juvenile males 162, juvenile females 88 and the subadult male 12, Tables 8.11–8.16). The number of foraging trips recorded for each individual and the average number of foraging trips recorded are shown in Tables 8.9–8.16.

The proportions of time that ASL spent at sea and on-shore were close to parity (1:1) (adult females 0.51 ± 0.13 d, adult males 0.58 ± 0.15 d, juveniles 0.47 ± 0.10 d, subadult males 0.48 ± 0.11 d). Adult males spent a significantly greater proportion of time at sea than both adult females and juveniles (adult male v adult female $P = 0.016$, adult male v juvenile $P = 0.003$) (Tables 8.9–8.16).

The mean foraging trip durations for each age/sex group were: adult females (1.16 ± 0.57 d, n = 64), adult males (2.46 ± 1.36 d, n = 21), juveniles (1.08 ± 0.51d, n = 22) and subadult males (0.90 ± 0.57 d, n = 2) (Tables 8.9–8.16). The mean foraging trip durations of adult females, juveniles and subadult males did not differ significantly ($P > 0.05$ in all cases), but those of adult males were significantly longer than those of adult females, juveniles and subadult males ($P < 0.05$ in all cases) (Tables 8.9–8.16). Shore bout durations of adult females (1.16 ± 0.79 d), adult males (1.64 ± 0.82), juveniles (mean 1.13 ± 0.31 d) and subadult males (0.90 ± 0.14 d) differed significantly ($F_{3,103} = 2.717$, $P = 0.049$), because adult males spent significantly longer ashore than adult females and juveniles ($P < 0.05$ in both cases) (Tables 8.9–8.16).

Adult females at SE Franklin Is made significantly longer foraging trips than those at Dangerous Reef, West Is and Breakwater Is ($P < 0.05$ in all cases), but there were no other inter-site differences in foraging trip duration (Tables 8.9–8.16). Adult females at Dangerous Reef spent a significantly lower proportion of time at sea compared to those at Purdie, SE Franklin and Lounds Is ($P < 0.05$ in all cases), but there were no other inter-site differences (Table 8.9–8.16).

Among adult males, there were no significant inter-site differences in the mean shore bout duration ($F_{4,16} = 0.529$, $P = 0.716$), nor in the proportion of time spent at sea ($F_{4,16} = 0.452$, $P = 0.770$) (Tables 8.10–8.14). Foraging trip durations of adult males at Dangerous Reef (1.56 ± 0.73

d) were significantly shorter in duration than those at SE Franklin Is (mean 4.15 ± 1.77 d) and West Is (mean 3.18 ± 1.76 d) ($P < 0.05$ in both cases) (Tables 8.10–8.14).

For juveniles at Dangerous Reef the duration of foraging trips was significantly shorter and the proportion of time spent at sea was significantly less than for juveniles at NE Franklin Is ($P < 0.050$ in both cases) (Tables 8.10–8.13). There were no other significant inter-site differences in the mean duration of juveniles' foraging trips ($F_{3,18} = 1.951$, $P = 0.158$), nor shore bout durations ($F_{3,18} = 0.080$, $P = 0.970$), nor proportions of time spent at sea ($F_{3,18} = 1831$, $P = 0.178$) (Tables 8.10–8.13).

Site fidelity – use of additional sites

There were no significant differences in the site fidelity index between the age/sex groups, both when the data for all colonies were combined and when the age/sex from each island was analysed ($P > 0.05$ in all cases). Overall, 68 % of seals used at least one additional haulout site, with the grand mean of site fidelity indices of 71 % (i.e. on average, 71 % of foraging trips ended at the place of origin, range 0–100 %, Tables 8.9–8.18, Fig. 8.4–8.11).

The 10 females tracked from Dangerous Reef in 2005 used 6 haulouts, compared to the 9 by the 24 females in 2003 (Table 8.18). In 2003, English Is was most commonly used (20 % of females), as was Blyth Is (20 % of females) (Table 8.18). Because of the limited foraging in a NE direction in 2005, no females hauled out at Buffalo Reef, compared to 29 % in 2003 (Table 8.18), which was close to an important foraging site (Fig. 8.4–8.5). Overall, females from Dangerous Reef used a total of 12 additional haulouts, the most common being English Is (a breeding colony), which was used by 26 % of females (Table 8.17, Fig. 8.6). Other haulouts included Hopkins Is, Black Rock, Thistle Is (two locations), North Islet (a breeding colony), Sibsey Is, North NE Rocks, Bolingbroke Point and Tumby Is (Table 8.17, Fig. 8.6). The 7 adult males from Dangerous Reef had a lower average site fidelity index than the females (59 vs. 77 %) and the males used 21 additional haulout sites (Table 8.17), many of which were ASL breeding colonies (Fig. 8.4–8.11). Adult males used haulouts that were farther afield than those used by the adult females and juvenile males, including Rocky Is, Four Hummocks Is, Liguanea Is, Althorpe Is and North Neptune Is (Table 8.17, Fig. 8.7). The 7 juvenile males from Dangerous Reef had an average site fidelity index of 74 % and they used 8 haulout sites, most of which were used by the adult females, but juvenile males also used Langton Is (Table 8.17, Fig. 8.8–8.10). The subadult male had a site fidelity index of 64 % and it used 6 additional haulout sites, including Sibsey Is and Donington Reef, which is close to the tuna farming zone (Table 8.17, Fig. 8.11).

In the Nuyts Archipelago, additional haulout sites were recorded for each colony from which seals were tracked. The average site fidelity index for each age/sex group in the Nuyts Archipelago ranged from: 46–92 % for females, 43–82 % for adult males, 54–100 % for juveniles and 92 % for the subadult male (Table 8.11–8.16). Seals tracked from West Is, Purdie Is and NE Franklin Reef utilised the most additional haulouts (range 11–13) and those at SE Franklin Reef, Breakwater and Lounds Is typically used 3 additional sites (Tables 8.19–8.24).

Table 8.17. Proportion of individuals of each sex class from Dangerous Reef, that hauled out at an island other than Dangerous Reef (n = 34, 7, 7, 1 respectively).

Island	Adult female	Adult male	Juvenile male	Subadult male
English	26	14		100
Buffalo Reef	21		14	
Hopkins Is	6	14	43	100
Black Rock	6	14	14	100
Langton Is		43	14	100
Thistle Is 1	6	14	29	
Blyth Is	6	14	14	
Thistle Is 2	3	14	29	
Liguanea Is		43		
North Islet	3	14	14	
Sibsey Is	6			100
Four Hummocks Is		14		
N NE Rocks	3	14		
Rocky Is		14		
Althorpe Is		14		
Bolingbroke Pt	3			
Boucaut Is		14		
Curta Rocks		14		
Donington Reef				100
Lewis Is		14		
N Neptune Is		14		
Peaked Rock		14		
Smith Is		14		
Tumby Is	3			
White Rocks		14		
Williams Is		14		

Table 8.18. Proportion of adult females in 2003/04 and 2005 that hauled out at an island other than Dangerous Reef (n = 24 and 10 respectively).

Island	2003/04	2005
English Is	29	20
Buffalo Reef	29	
Black Rock		20
Blyth Is	4	10
Sibsey Is	4	10
N NE Rocks		10
North Islet		10
Hopkins Is	8	
Thistle Is 1	8	
Bolingbroke Pt	4	
Thistle Is 2	4	
Tumby Is	4	
Langton Is		

Table 8.19. Proportion of individuals of each sex class from West Is that hauled out at an island other than West Is (n = 5, 4, 2, 3 and 1 respectively).

Island	Adult female	Adult male	Juvenile female	Juvenile male	Subadult male
Hart Is	20	25	50		100
St Francis (East of)	60			33	
Dog Is		25		67	
Lacy Is			50	33	
Masilon Is	20			33	
Smooth Is	20	25			
Cannan Reef	20				
Egg Is		25			
Fenelon Is	20				
Island near Pt Bell			50		
Purdie Is			50		

Table 8.20. Proportion of individuals of each sex class from Purdie Is that hauled out at an island other than Purdie Is (n = 5, 5 and 5 respectively).

Island	Adult female	Adult male	Juvenile male
West Is		60	40
Island near Pt Bell	40		20
Fenelon Is	20	20	
Masilon Is		40	
Sinclair Is	20		20
Cannan Reef	20		
Dog Is			20
Hart Is			20
Lacy Is			20
Nuyts Reef		20	
St Francis (East of)		20	
Ward Is		20	

Table 8.21. Proportion of individuals of each sex class from NE Franklin Is that hauled out at an island other than NE Franklin Is (n = 5, 3, 4 and 1 respectively).

Island	Adult female	Adult male	Juvenile female	Juvenile male
Goalen Rocks 2	40		75	
Gliddon Is	20	33	25	
Goalen Rocks 1	40		25	
SE Franklin Is		33	25	
Cannan Reef		33		
Dog Is		33		
Evans Is			25	
Flinders Reef	20			
GAB cliffs 1		33		
GAB cliffs 2		33		
Lacy Is			25	
Masilon Is		33		
Nuyts Reef		33		

Table 8.22. Proportion of individuals of each sex class from SE Franklin Is that hauled out at an island other than SE Franklin Is (n = 4 and 2 respectively).

Island	Adult female	Adult male
NE Franklin Is		50
Fenelon Is	25	
Olive Is	25	

Table 8.23. Proportion of females from Breakwater Is that hauled out at an island other than Breakwater Is (n = 4).

Island	Adult female
Gliddon Is	100
Bird Rock	50
Evans Is	25

Table 8.24. Proportion of females from Lounds Is that hauled out at an island other than Lounds Is (n = 7).

Island	Adult female
Bird Rock	29
Breakwater Is	14
Purdie Is	14

Travel Speed

Both the mean and median travel speeds of ASL undertaking foraging trips differed significantly among the different age/sex groups (mean: $F_{3,105} = 20.841$, $P < 0.0001$; median: $F_{3,105} = 19.069$, $P < 0.0001$) (Table 8.9–8.16). Pair-wise comparisons indicate that most of this difference was due to the greater travel speeds of adult males, which were significantly greater than those of adult females and juveniles ($P < 0.05$ in both cases) (Table 8.9–8.16).

Among adult females, both the mean and median travel speeds varied significantly among sites ($F_{6,57}$ = 10.154, P < 0.0001; $F_{6,57}$ = 6.470, P < 0.0001, respectively) (Table 8.9–8.16). The mean and median travel speeds of adult females at SE Franklin Is, West and Purdie Is were significantly greater than those at Dangerous Reef, NE Franklin Is, Breakwater Is and Lounds Is (P < 0.05 in all cases) (Table 8.9–8.16). The mean and median travel speeds of juveniles varied significantly among sites ($F_{3,18}$ = 4.744, P = 0.013; $F_{3,18}$ = 3.614, P = 0.033, respectively), with juveniles at Purdie Is travelling significantly faster than juveniles at Dangerous Reef and NE Franklin Is (P < 0.05 in both cases) (Table 8.9–8.16). The travel speeds of juveniles at West Is were also greater than those from NE Franklin Is (P < 0.05 in both cases) (Table 8.9–8.16). In contrast, there were no significant differences between the mean and median travel speeds of adult males among sites ($F_{4,16}$ = 0.817, P = 0.533; $F_{4,16}$ = 0.517, P = 0.725, respectively) (Table 8.9–8.16).

Diving behaviour

The four lactating female ASL from Dangerous Reef that were fitted with time depth recorders (TDR) provided fine scale data on diving behaviour, departure and arrival times, and the duration of foraging trips. Each ASL showed the same general diving behaviour. When they left the colony they travelled near the surface for a short distance before commencing dives to the seabed (Fig. 8.31). Most dives occurred in 30–45 m, with seals minimising the time spent during the descent and ascent phases of each dive, to maximise foraging time on the seabed (Fig. 8.32). A total of 82 foraging trips were recorded from the 4 seals, averaging 0.89 d (21.4 hrs) in duration, the longest lasting 2.4 d (Table 8.25). In total, 72 shore attendance bouts were recorded for the four seals, which averaged 0.94 d (22.6 h) in duration, the longest being 4.5 d (Table 8.25). On average, the 4 seals spent 49 % of their time foraging at sea and 51 % of their time ashore (Table 8.25). Most foraging occurred at night, with departures from land occurring most frequently between 6–8 pm local time and returns to land occurring between 5–7 am (Fig. 8.33).

Table 8.25. Summary of the mean, minimum and maximum durations of foraging trips and shore attendance bouts undertaken by lactating female ASL that were fitted with dive loggers (TDRs) at Dangerous Reef.

Animal ID	Foraging trip durations (days)					Attendance bouts (days)					Sea	Shore
(days tracked)	mean	SD	min	max	n	mean	SD	min	max	n		
12011 (52 d)	0.91	0.65	0.31	2.36	29	0.86	0.83	0.03	4.46	28	51 %	49 %
12211 (27 d)	1.01	0.27	0.62	1.38	13	1.13	0.47	0.20	1.87	12	47 %	53 %
12311 (33 d)	0.77	0.50	0.40	1.82	20	0.95	0.62	0.24	2.41	13	46 %	54 %
12411 (33 d)	0.87	0.60	0.20	1.80	20	0.79	0.62	0.07	1.79	19	52 %	48 %
Mean	0.89	0.51				0.94	0.64				49 %	51 %

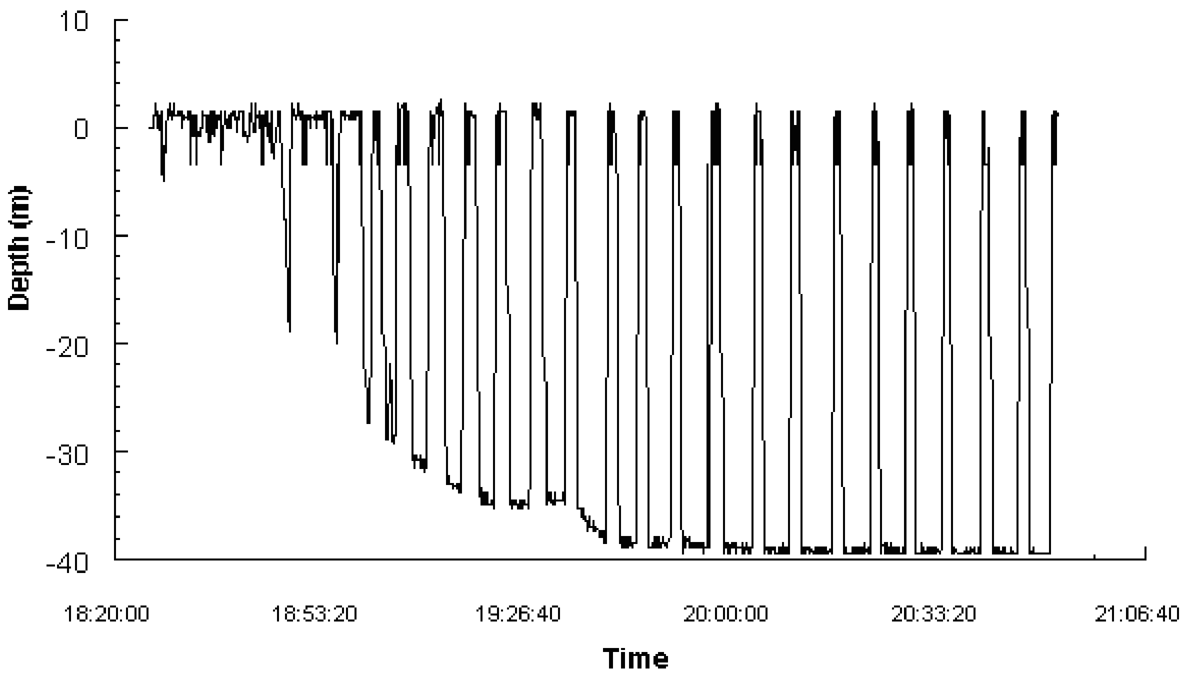


Fig. 8.31. Example of a TDR record of an adult female ASL from Dangerous Reef, at the commencement of a foraging trip, illustrating the initial shallow dives as it departed the colony, with the commencement of benthic dives that progressively followed the seafloor as water depth increased.

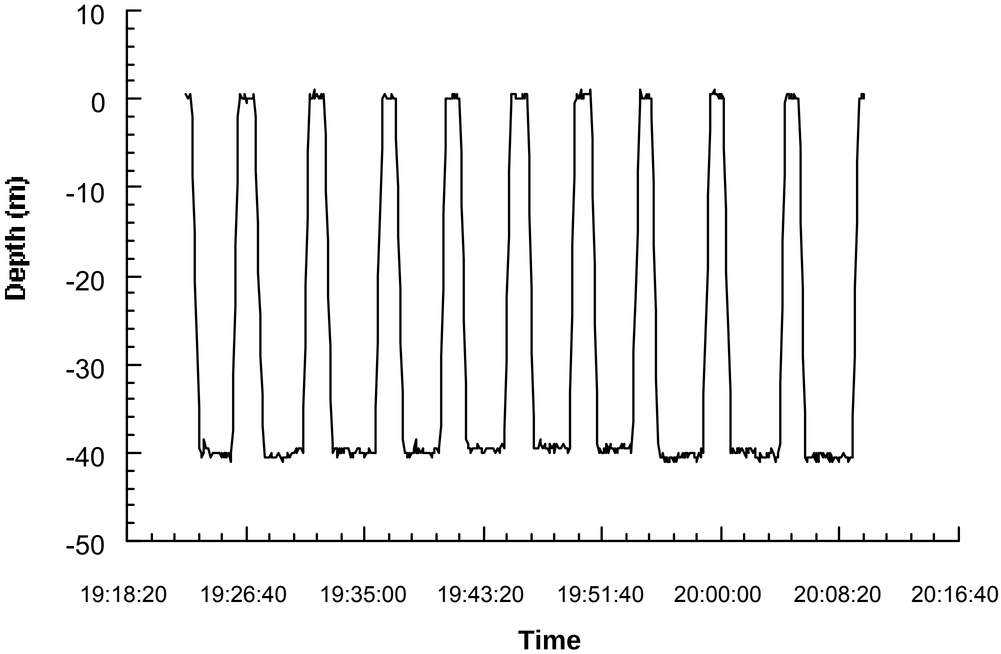


Fig. 8.32. An example of ten consecutive dives from the middle of a foraging bout of an adult female ASL from Dangerous Reef. This plot illustrates the rapid descent and ascent phases of dives, which maximises the time spent foraging on the seafloor.

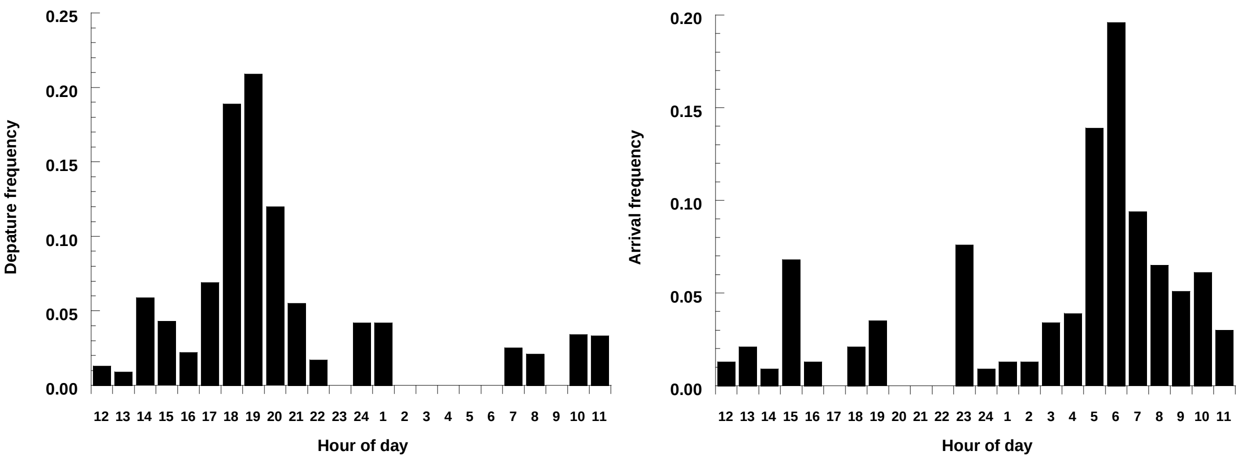


Fig. 8.33. Frequency distribution of departure times (left) and arrival times (right) of an adult female ASL from Dangerous Reef, based on the data from the TDR.

All seals dived continuously during foraging trips (ie, there was no evidence of rest periods at sea) and almost every dive went to the seafloor, where ASL are thought to feed (Gales and Cheal 1992, Costa and Gales 2003, McIntosh et al. 2006). To test whether ASL dived to the seafloor, we compared the depths covered by the foraging effort maps (refer Appendix 1) with the maximum dive depths recorded by dive loggers. We examined this for three ASL, by determining the exact position and maximum depth of each dive and by comparing that depth to data extracted from bathymetric depth maps using GIS for a total of 13,968 dives (mean 4656 ± 1023 dives per seal, Fig. 8.34–8.39). Histograms of the distribution of dive effort based on the TDR data and depths derived from satellite positions indicated close agreement (Fig. 8.34, 8.36, 8.38) and linear regressions of dive logger versus GIS-derived depths showed significant, positive relationships ($P < 0.001$ in all cases, Fig. 8.35, 8.37, 8.39). Comparisons of mean foraging depths based on dive loggers and those derived from satellite locations and bathymetric depth data were in close agreement (36.7 v. 36.4 m; 27.5 v. 24.1 m and 44.6 v. 41.5 m). This indicates that our method of estimating dive depths, based on the bathymetric depth where the animal was located is appropriate for describing the depth ranges over which individuals (without dive recorders) focus their foraging effort. A notable exception was that in the shallow waters near colonies (< 15 m), the depths extracted from satellite positions underestimated the depths recorded by dive loggers (Fig. 8.34–8.39).

Based on these highly significant relationships (Fig. 8.35, 8.37, 8.39), we compared the mean and median depths where all satellite tracked ASL foraged, based on data from their satellite trackers (Table 8.26–8.33). There were significant differences between the mean and median depths used by the different age/sex groups ($F_{3,105} = 17.141$, $P < 0.0001$; $F_{3,105} = 14.349$, $P < 0.0001$, respectively) (Table 8.26–8.33). Differences were due to the greater mean and median depths used by adult males (64.1 and 64.7 m, respectively) compared to adult females (29.1 and 29.8 m, respectively) and juveniles (33.9 and 35.0 m, respectively) ($P < 0.05$ in all cases), but there were no significant differences between the mean and median depths used by adult females and juveniles ($P > 0.05$ in all cases) (Table 8.26–8.33). The mean and median depths used by the two subadult males were 44.5 and 44.0 m, respectively (Table 8.26–8.33).

Among adult females, both the mean and median foraging depths varied significantly between sites ($F_{6,57} = 18.049$, $P < 0.0001$; $F_{6,57} = 16.475$, $P < 0.0001$, respectively) (Table 8.26–8.33). The mean and median depths varied from 8.3 and 7.5 m, respectively, at Breakwater Is, to 54.0 and 56.4 m, respectively, at SE Franklin Reef (Table 8.26–8.33). The mean and median foraging depths for adult females did not differ significantly among females from West Is, Purdie Is, and SE Franklin Reef, from which were seals foraged in deeper waters (Table 8.26–8.33). Similarly, the mean and median foraging depths did not differ significantly in the waters used by adult females from NE Franklin Reef, Breakwater Is and Lounds Is, from which seals foraged in shallower waters (Table 8.26–8.33). The seals from NE Franklin Reef, Breakwater Is and Lounds Is used significantly shallower mean and median depths than the seals from West Is, Purdie Is, and SE Franklin Reef ($P < 0.05$ in all cases) (Table 8.26–8.33). Adult females from Dangerous Reef had intermediate mean and median foraging depths, which differed significantly from the island groups where ASL used either deep or shallow waters ($P < 0.05$ in all cases) (Table 8.26–8.33).

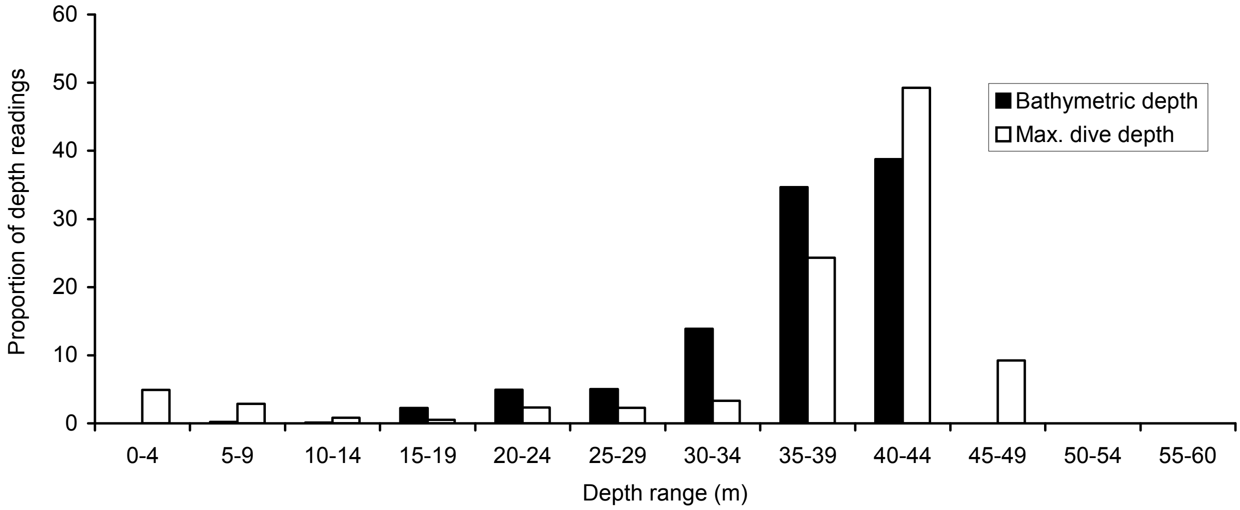


Fig. 8.34. Proportion of depth readings in 5 m depth ranges from the TDR (maximum dive depth) and the bathymetric depth in the location where ASL 12011 was diving.

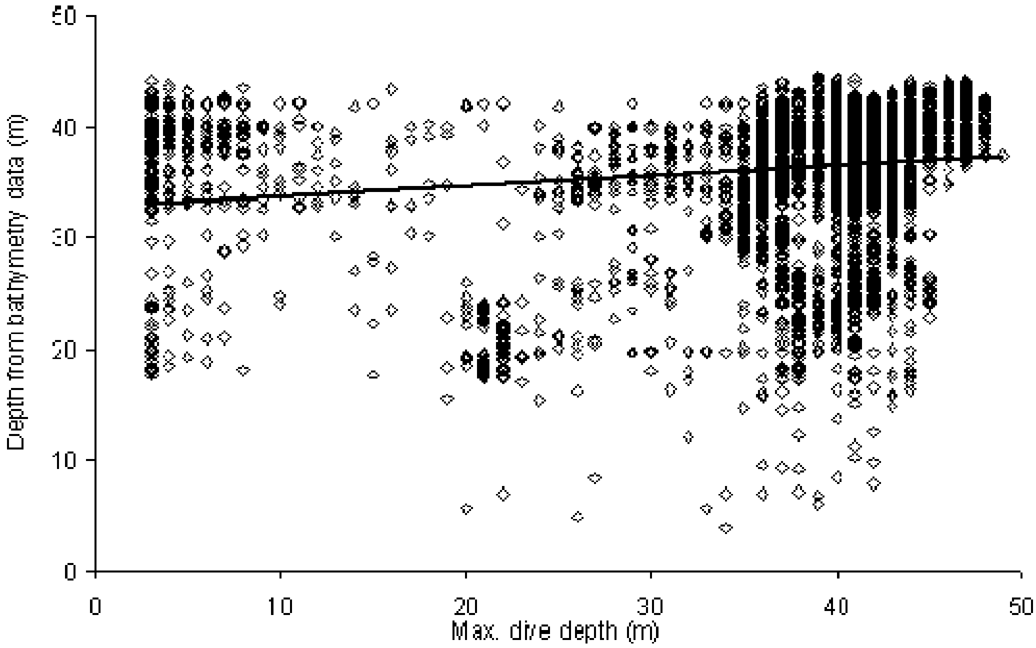


Fig. 8.35. The relationship between maximum dive depth (m) and the bathymetric depth in the location where the seal was diving for seal 12011 ($r = 0.31$, $P < 0.001$). Mean maximum dive depth 36.7 ± 11.0 m and mean bathymetric depth derived from satellite location data was 36.4 ± 6.1 m.

Similarly, the mean and median foraging depths of juveniles varied significantly among sites ($F_{3,18} = 27.847$, $P < 0.0001$; $F_{3,18} = 27.783$, $P < 0.0001$, respectively), because juveniles from

Purdie Is and West Is used significantly greater depths than juveniles from Dangerous Reef and NE Franklin Is ($P < 0.05$ in all cases), but juveniles at NE Franklin Is used significantly shallower waters than juveniles at all other sites ($P < 0.05$ in all cases) (Table 8.26–8.33). In contrast, there were no significant differences between the mean and median foraging depths of adult males among sites ($F_{4,16} = 0.389$, $P = 0.813$, $F_{4,16} = 0.325$, $P = 0.857$, respectively) (Table 8.26–8.33).

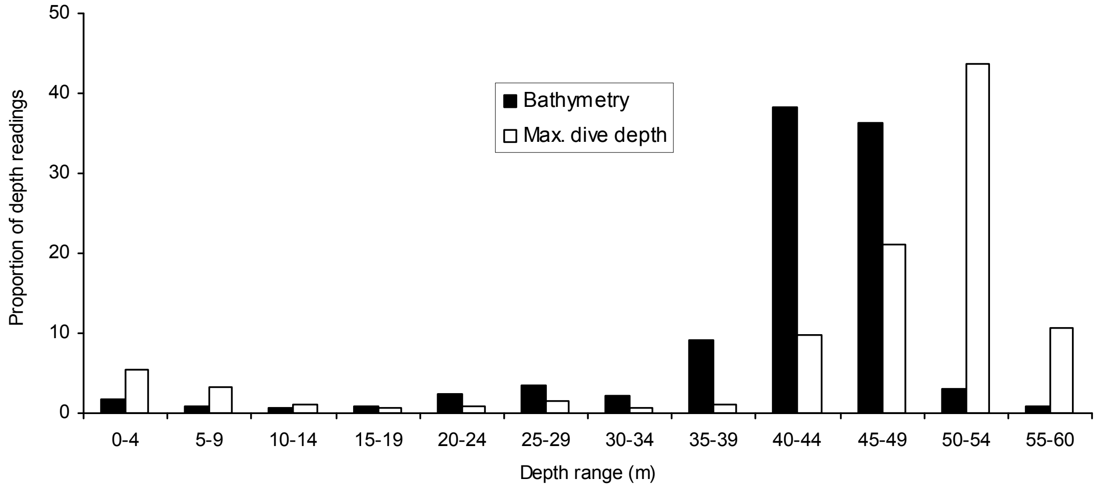


Fig. 8.36. Proportion of depth readings in 5 m depth ranges from the TDR (maximum dive depth) and the bathymetric depth in the location where ASL 12211 was diving.

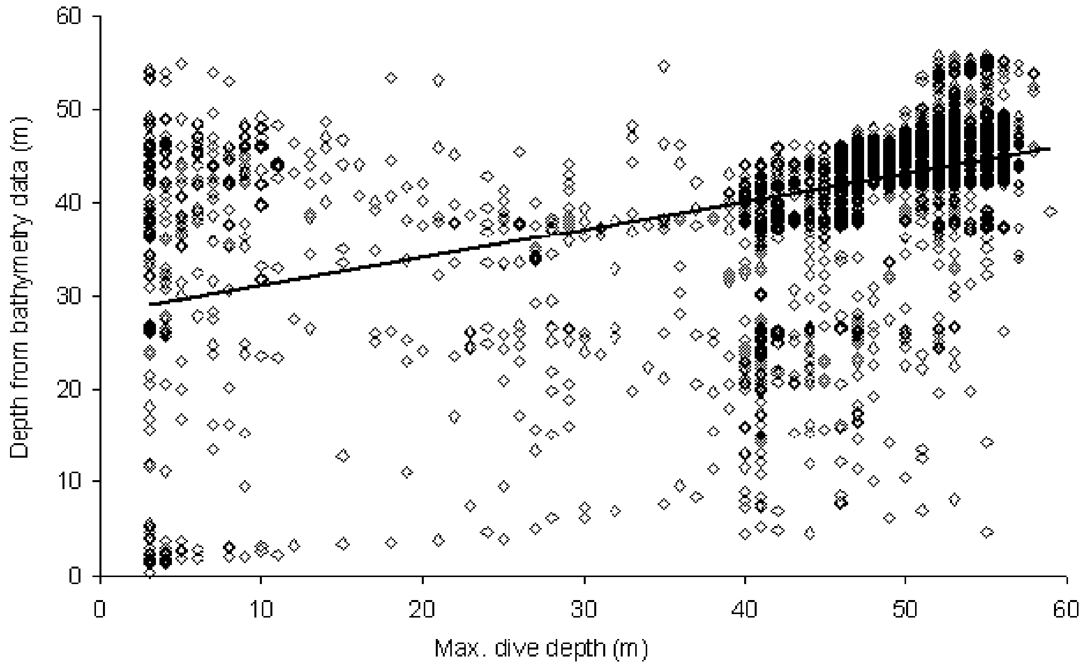


Fig. 8.37. The relationship between maximum dive depth (m) and the bathymetric depth in the location where the seal was diving for seal 12211 ($r = 0.52$, $P < 0.001$). Mean maximum dive depth 44.6 ± 14.3 m and mean bathymetric depth derived from satellite location data was 41.5 ± 9.1 m.

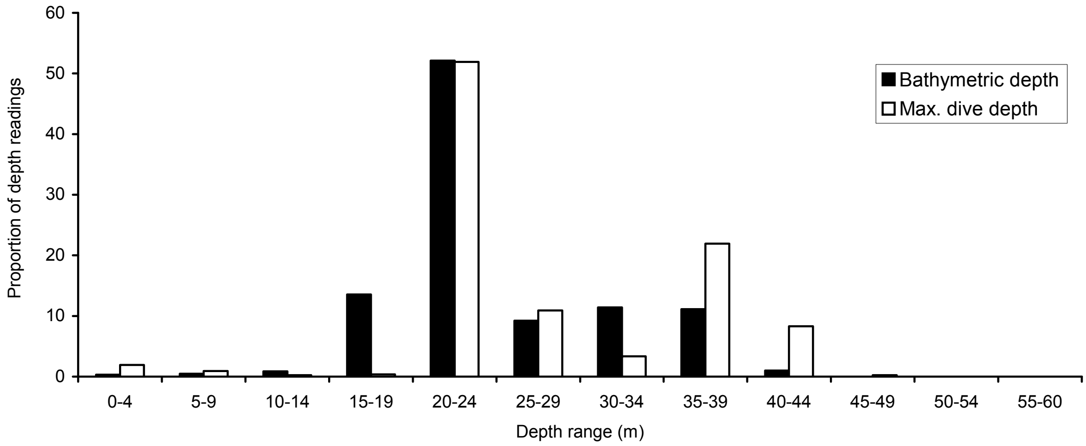


Fig. 8.38. Proportion of depth readings in 5 m depth ranges from the TDR (maximum dive depth) and the bathymetric depth in the location where ASL 12311 was diving.

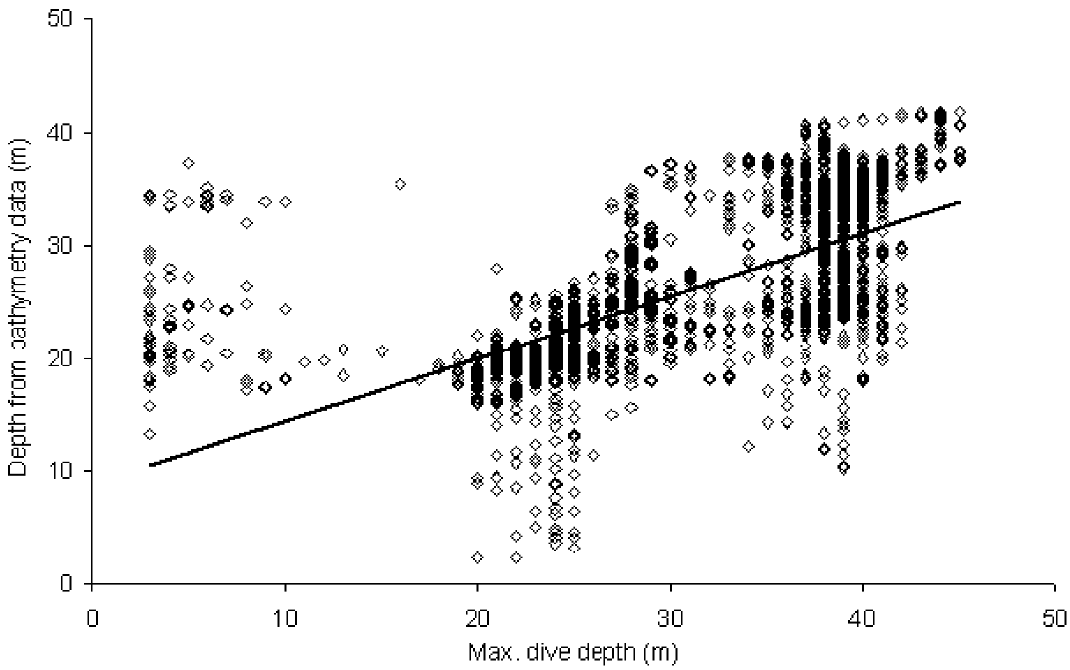


Fig. 8.39. The relationship between maximum dive depth (m) and the bathymetric depth in the location where the seal was diving for seal 12311 (r = 0.68, P < 0.001). Mean maximum dive depth 27.5 ± 8.5 m and mean bathymetric depth derived from satellite location data was 24.1 ± 6.6 m.

Table 8.26. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females from Dangerous Reef.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female - 2003																		
10011	28 Sep 03	26 Oct 03	16	8	20	41	0.5	-0.5	0.19	0.21	0.11	2.0	5.4	160	76	155	0.4	-0.2
10111	19 Sep 03	3 Oct 03	37	7	40	55	1.5	2.4	0.13	0.14	0.09	4.7	29.1	170	64	168	0.3	0.1
10211	20 Sep 03	2 Oct 03	34	12	38	59	0.3	-1.3	0.13	0.20	0.07	3.7	15.2	181	74	185	0.3	0.4
10411	29 Sep 03	14 Oct 03	32	8	35	43	0.9	0.6	0.18	0.22	0.10	2.7	8.7	172	77	157	0.4	-0.4
10511	22 Sep 03	4 Oct 03	33	8	34	46	0.6	0.1	0.14	0.18	0.10	3.9	18.4	152	77	142	0.7	0.2
10611	4 Oct 03	19 Dec 03	19	9	21	43	-0.1	0.3	0.14	0.19	0.09	3.7	15.8	143	81	127	0.5	-0.3
10711	19 Sep 03	2 Nov 03	23	6	22	45	-1.0	0.7	0.14	0.17	0.10	4.0	19.4	157	89	142	0.5	-0.6
10811	29 Sep 03	3 Oct 03	22	6	21	37	-0.9	0.4	0.11	0.15	0.07	5.0	30.8	155	79	138	1.0	0.4
10911	30 Sep 03	21 Nov 03	25	8	22	45	-0.4	-0.5	0.23	0.36	0.22	7.4	59.9	195	87	175	-0.1	-1.3
11011	23 Sep 03	15 Oct 03	40	12	45	59	1.4	1.1	0.11	0.17	0.07	4.1	19.5	183	83	178	-0.1	-0.6
11111	29 Sep 03	17 Oct 03	11	8	12	25	0.0	-1.8	0.12	0.08	0.10	1.2	1.8	162	78	162	0.1	-0.4
11211	21 Sep 03	29 Nov 03	43	7	44	59	1.7	5.0	0.11	0.17	0.07	4.3	20.9	189	86	185	-0.1	-0.6
11311	21 Sep 03	16 Oct 03	40	7	42	50	1.6	3.4	0.10	0.13	0.07	5.5	36.6	217	90	219	-0.3	-1.0
11411	21 Sep 03	13 Oct 03	21	6	23	29	1.7	3.1	0.15	0.23	0.07	3.2	11.5	161	89	154	0.3	-0.8
11511	20 Sep 03	23 Oct 03	25	6	26	42	1.1	3.9	0.08	0.12	0.06	6.1	47.0	161	83	155	0.3	-0.5
11611	27 Sep 03	10 Nov 03	38	5	39	56	2.0	7.0	0.10	0.12	0.07	5.6	41.5	184	94	166	0.2	-1.0
11711	13 Oct 03	31 Oct 03	18	1	17	23	-1.3	2.2	0.06	0.04	0.05	1.6	3.7	156	99	147	0.1	-1.2
11811	5 Oct 03	16 Oct 03	22	5	21	33	0.1	1.1	0.17	0.25	0.09	3.3	9.6	171	82	147	0.8	-0.1
11911	5 Oct 03	3 Nov 03	37	6	38	48	2.5	7.8	0.12	0.18	0.08	4.5	22.1	162	75	155	0.6	0.6
12011	16 Oct 03	6 Dec 03	35	7	38	45	1.3	1.3	0.11	0.16	0.07	5.1	29.0	170	80	156	0.4	-0.3
12111	2 Nov 03	20 Nov 03	20	1	20	25	-0.5	26.9	0.18	0.09	0.22	-0.4	4.8	252	79	284	-2.1	3.0
12211	24 Oct 03	20 Nov 03	41	9	44	56	1.9	3.4	0.14	0.22	0.09	3.6	14.0	162	80	162	0.4	0.2
12311	30 Oct 03	26 Nov 03	24	7	20	42	-0.7	-0.1	0.11	0.19	0.06	4.7	26.5	167	85	153	0.3	-0.7
12411	4 Nov 03	6 Dec 03	38	6	39	47	1.6	3.7	0.11	0.12	0.08	5.9	44.5	152	57	151	1.1	3.0
Adult female - 2005																		
111	26 Jan 05	8 May 05	38	9	39	59	1.1	1.4	0.21	0.38	0.10	5.1	31.7	173	94	165	0.3	-0.7
311	27 Jan 05	25 Jun 05	31	9	33	85	0.0	0.8	0.17	0.27	0.12	7.8	79.3	152	65	143	0.8	0.9
1111	11 Apr 05	10 May 05	29	7	28	44	0.2	-0.6	0.16	0.13	0.13	4.2	27.7	145	62	137	1.1	1.8
1211	13 Apr 05	8 May 05	20	3	19	37	-2.3	9.8	0.08	0.09	0.07	7.7	89.0	162	97	147	0.3	-1.0
1311	16 Apr 05	8 May 05	32	7	33	43	0.8	0.5	0.22	0.21	0.15	2.7	9.5	150	67	148	0.4	1.2
1411	14 Apr 05	8 May 05	30	7	30	46	0.2	-0.6	0.18	0.19	0.13	4.0	18.1	158	65	146	0.8	0.8
1511	13 Apr 05	8 May 05	29	8	27	47	-0.2	-0.5	0.18	0.20	0.12	4.1	18.5	155	71	149	0.4	0.1
1611	17 Apr 05	8 May 05	29	7	30	45	0.2	-0.9	0.19	0.19	0.14	4.1	19.5	154	67	142	0.7	0.3
1711	13 Apr 05	8 May 05	33	8	34	46	1.0	0.6	0.16	0.20	0.11	4.0	18.1	156	69	148	0.7	0.4
1811	12 Apr 05	8 May 05	26	7	25	41	-0.1	-0.5	0.18	0.22	0.11	3.4	12.0	154	81	137	0.7	-0.2
2003: mean, median, SD			29	9	30	44	0.7	2.9	0.13	0.04	0.08	4.0	22.3	172	23	155	0.2	-0.1
2005: mean, median, SD			30	5	30	49	0.1	1.0	0.17	0.04	0.12	4.7	32.3	156	7	146	0.6	0.4
Overall: mean, median, SD			29	8	30	46	0.5	2.4	0.14	0.04	0.09	4.2	25.3	167	21	154	0.4	0.0

Table 8.27. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult males, juveniles and subadult male from Dangerous Reef.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult male																		
212	29 Jan 05	9 Apr 05	36	18	36	106	-1.1	2.0	0.24	0.39	0.15	5.6	45.6	189	85	185	-0.1	-1.0
412	2 Feb 05	31 May 05	75	15	79	109	1.1	1.2	0.15	0.29	0.08	5.8	45.3	206	79	221	-0.7	-0.1
512	29 Jan 05	2 Feb 05	17	12	20	39	-0.1	-1.0	0.15	0.14	0.12	3.2	13.3	150	80	145	0.4	-0.6
3012	30 Jan 06	14 Mar 06	116	39	125	1144	-11.4	244.8	0.23	0.59	0.10	7.6	78.2	199	82	215	-0.5	-0.6
3112	31 Jan 06	16 Mar 06	23	9	26	42	0.9	0.2	0.11	0.13	0.07	2.7	7.6	142	79	138	0.6	0.0
3212	30 Jan 06	14 Mar 06	20	9	20	44	0.3	-0.3	0.09	0.06	0.08	8.9	132.7	259	67	284	-1.9	3.5
3312	29 Jan 06	11 Mar 06	118	69	120	1045	-5.7	52.5	0.37	1.08	0.10	5.2	29.5	192	81	201	-0.3	-0.4
Juvenile male																		
614	27 Jan 05	10 Feb 05	29	18	27	92	-1.8	4.2	0.30	0.38	0.20	3.0	10.5	146	80	127	0.6	-0.5
714	28 Jan 05	19 Feb 05	26	14	28	86	-0.3	0.9	0.34	0.41	0.21	2.8	10.2	129	73	111	1.1	1.0
914	29 Jan 05	10 Mar 05	32	8	36	42	0.8	-0.6	0.14	0.18	0.09	4.2	20.4	160	64	149	0.9	1.6
1914	14 Apr 05	8 May 05	30	6	30	42	0.2	-0.5	0.18	0.16	0.14	4.4	24.7	147	54	142	0.7	1.9
2014	12 Apr 05	3 Jun 05	28	9	28	58	0.4	0.1	0.23	0.27	0.15	3.7	18.6	151	75	140	0.8	0.5
10314	17 Sep 03	10 Dec 03	41	9	45	59	1.7	2.5	0.12	0.25	0.06	6.9	67.2	181	88	171	0.0	-0.8
12514	8 Nov 03	15 Feb 04	39	10	42	69	1.5	2.2	0.11	0.16	0.07	4.7	31.5	173	76	160	0.2	-0.3
Subadult male																		
1015	29 Jan 05	7 May 05	27	10	25	46	0.1	-0.7	0.18	0.25	0.11	3.0	9.3	163	79	156	0.4	-0.2
Adult male: mean, median, SD			58	45	36	361	-2.3	42.8	0.19	0.10	0.10	5.6	50.3	191	39	201	-0.4	0.1
Juvenile male: mean, median, SD			32	6	30	64	0.3	1.3	0.20	0.09	0.14	4.2	26.2	155	18	142	0.6	0.5
Subadult male: mean, median, SD			27	-	25	46	0.1	-0.7	0.18	-	0.11	3.0	9.3	163	-	156	0.4	-0.2

Table 8.28. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females, adult males, juveniles and subadult male from West Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
121	27 May 05	13 Jun 05	21	15	14	59	-0.8	-0.7	1.29	0.92	1.06	0.6	-0.4	145	102	142	0.6	-0.8
321	28 May 05	12 Jun 05	31	20	27	68	-0.3	-1.3	0.78	0.73	0.52	1.1	0.7	171	88	165	0.0	-0.8
421	28 May 05	20 Jun 05	62	12	64	74	3.3	12.3	0.21	0.44	0.07	3.6	13.5	207	98	237	-0.6	-0.8
521	28 May 05	15 Jun 05	33	17	33	68	-0.1	-1.1	0.89	0.76	0.62	1.0	0.4	190	92	198	-0.3	-0.9
621	29 May 05	1 Jul 05	61	13	65	71	3.4	11.4	0.19	0.46	0.05	3.6	12.5	180	94	191	-0.2	-1.0
Adult male																		
1222	1 Jun 05	29 Jun 05	98	26	103	139	0.5	-0.3	0.11	0.26	0.06	6.7	49.3	202	79	219	-0.8	0.1
1322	31 May 05	1 Jul 05	84	17	90	115	0.6	0.3	0.08	0.21	0.05	9.2	93.4	196	90	212	-0.5	-0.5
1422	30 May 05	4 Jul 05	75	24	69	119	0.2	-0.1	0.24	0.48	0.06	3.0	8.5	204	94	223	-0.6	-0.6
1522	29 May 05	1 Jul 05	50	14	55	68	1.9	2.8	0.31	0.49	0.08	2.5	7.1	196	93	205	-0.3	-0.8
Juvenile female																		
723	28 May 05	5 Jul 05	62	9	65	75	2.2	7.5	0.16	0.34	0.06	4.1	17.9	189	91	198	-0.2	-0.8
923	28 May 05	2 Jul 05	44	13	48	64	1.5	1.6	0.26	0.32	0.13	2.0	4.1	208	66	206	-0.3	0.7
Juvenile male																		
224	29 May 05	3 Jul 05	54	14	59	68	2.1	3.6	0.27	0.55	0.05	2.9	7.9	222	80	239	-1.1	0.6
824	29 May 05	3 Jul 05	59	8	60	68	4.0	19.1	0.18	0.43	0.06	4.1	16.1	213	78	227	-0.9	0.6
1124	28 May 05	19 Jun 05	33	16	32	67	-0.1	-0.8	0.64	0.57	0.40	1.0	0.2	176	88	149	0.3	-0.8
Subadult male																		
1025	28 May 05	25 Jun 05	62	10	63	88	1.9	8.1	0.19	0.42	0.05	3.7	13.7	198	85	216	-0.6	-0.4
Adult female: mean, median, SD			41	19	33	68	1.1	4.2	0.67	0.47	0.52	2.0	5.3	179	23	191	-0.1	-0.9
Adult male: mean, median, SD			77	20	80	110	0.8	0.7	0.19	0.11	0.06	5.4	39.6	199	4	215	-0.6	-0.5
Juvenile male: mean, median, SD			53	12	57	69	1.8	4.5	0.21	0.07	0.09	3.1	11.0	198	13	202	-0.3	-0.1
Juvenile female: mean, median, SD			49	14	59	68	2.0	7.3	0.36	0.24	0.06	2.7	8.1	204	24	227	-0.6	0.1
Subadult male: mean, median, SD			62	-	63	88	1.9	8.1	0.19	-	0.05	3.7	13.7	198	-	216	-0.6	-0.4

Table 8.29. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females, adult males and juveniles from Purdie Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
131	31 May 05	11 Jun 05	50	13	55	63	1.6	1.8	0.19	0.34	0.05	3.3	11.2	229	84	246	-1.0	0.4
331	4 Jun 05	3 Sep 05	57	11	61	80	2.2	6.5	0.13	0.21	0.06	3.4	11.7	187	82	196	-0.3	-0.4
431	31 May 05	17 Jun 05	52	14	56	75	1.3	1.3	0.26	0.36	0.09	2.3	6.1	185	82	195	-0.3	-0.5
531	2 Jun 05	16 Jun 05	58	11	62	68	2.3	5.8	0.11	0.18	0.06	3.8	16.1	185	93	195	-0.3	-0.8
731	2 Jun 05	4 Jun 05	35	11	40	54	1.1	0.1	0.27	0.24	0.17	2.2	4.7	201	51	200	-1.0	2.8
Adult male																		
1132	5 Jun 05	17 Jul 05	73	16	74	106	1.0	2.0	0.16	0.39	0.06	5.5	33.4	197	86	209	-0.4	-0.8
1232	4 Jun 05	23 Jun 05	82	23	85	117	0.4	-0.5	0.12	0.27	0.06	6.0	44.0	203	84	220	-0.6	-0.4
1332	4 Jun 05	22 Jun 05	68	16	65	98	0.4	1.0	0.10	0.17	0.05	4.7	24.1	193	83	204	-0.4	-0.4
1432	4 Jun 05	24 Jun 05	75	26	66	144	-0.1	-0.7	0.12	0.20	0.05	3.6	13.1	198	74	206	-0.5	0.2
1532	2 Jun 05	4 Jun 05	33	18	30	68	0.0	-1.2	0.79	0.86	0.43	1.1	0.1	203	76	191	-0.5	0.0
Juvenile male																		
234	31 May 05	2 Aug 05	57	15	61	91	1.4	2.2	0.21	0.39	0.06	3.0	9.2	187	84	197	-0.3	-0.5
634	1 Jun 05	18 Jul 05	49	12	52	67	1.8	3.5	0.18	0.25	0.08	2.5	6.0	201	73	205	-0.5	0.3
834	4 Jun 05	23 Jun 05	30	14	32	59	0.1	-0.8	0.36	0.32	0.30	2.7	14.7	215	66	220	-1.0	1.5
934	1 Jun 05	21 Aug 05	45	15	49	68	1.3	1.0	0.27	0.35	0.11	2.3	6.5	203	72	206	-0.6	0.4
1034	1 Jun 05	22 Jun 05	52	13	55	70	2.0	4.3	0.28	0.51	0.08	3.0	9.5	191	85	197	-0.4	-0.3
Adult female: mean, median, SD			51	9	56	68	1.7	3.1	0.19	0.07	0.06	3.0	10.0	197	19	196	-0.6	0.3
Adult male: mean, median, SD			66	19	66	107	0.3	0.1	0.26	0.30	0.06	4.2	22.9	199	4	206	-0.5	-0.3
Juvenile male: mean, median, SD			47	10	52	71	1.3	2.0	0.26	0.07	0.08	2.7	9.2	199	11	205	-0.6	0.3

Table 8.30. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females, adult males and juveniles from NE Franklin Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
241	3 Jun 05	9 Jun 05	16	8	19	33	0.6	-0.9	0.33	0.30	0.18	1.5	1.4	155	91	179	-0.5	-1.2
341	2 Jun 05	13 Jul 05	24	8	25	51	0.3	1.6	0.22	0.20	0.15	2.4	5.7	222	84	244	-1.3	1.3
441	2 Jun 05	14 Jul 05	43	13	48	63	1.2	0.8	0.12	0.14	0.08	3.6	18.2	189	72	197	-0.5	0.3
641	3 Jun 05	9 Jun 05	5	6	3	35	-2.4	5.1	0.15	0.19	0.08	3.2	11.7	188	79	194	-0.8	0.0
941	3 Jun 05	9 Jul 05	7	10	2	41	-1.6	1.4	0.13	0.16	0.06	2.7	8.7	166	117	209	0.0	-1.6
Adult male																		
142	3 Jun 05	7 Jul 05	59	11	61	83	2.2	9.3	0.10	0.18	0.06	5.2	30.5	193	83	203	-0.4	-0.5
742	3 Jun 05	10 Jun 05	39	18	40	75	0.4	-1.0	0.26	0.37	0.11	2.7	11.1	186	95	205	-0.4	-0.8
842	4 Jun 05	1 Aug 05	60	14	58	97	0.0	0.9	0.17	0.36	0.05	3.3	11.2	178	84	189	-0.1	-0.6
Juvenile female																		
543	4 Jun 05	22 Jun 05	7	7	4	48	-1.9	4.2	0.13	0.14	0.08	2.8	10.5	181	105	209	-0.4	-1.2
1043	3 Jun 05	9 Jul 05	6	9	2	42	-1.8	1.9	0.10	0.14	0.05	2.8	9.9	168	94	193	-0.1	-1.3
1243	3 Jun 05	10 Jul 05	14	10	13	48	-1.2	1.4	0.18	0.12	0.16	3.6	17.5	232	54	236	-2.3	7.1
1343	3 Jun 05	8 Jul 05	3	7	1	39	-3.0	8.3	0.07	0.11	0.04	3.6	15.0	164	111	136	0.1	-1.5
Juvenile male																		
1144	5 Jun 05	18 Jun 05	5	6	2	32	-3.0	8.3	0.08	0.16	0.04	4.2	19.1	195	94	217	-0.4	-1.0
Adult female: mean, median, SD			19	15	19	44	-0.4	1.6	0.19	0.09	0.08	2.7	9.1	184	25	197	-0.6	-0.2
Adult male: mean, median, SD			53	12	58	85	0.9	3.1	0.18	0.08	0.06	3.7	17.6	186	8	203	-0.3	-0.6
Juvenile female: mean, median, SD			8	5	3	44	-1.9	3.9	0.12	0.05	0.06	3.2	13.2	186	31	201	-0.7	0.8
Juvenile male: mean, median, SD			5	-	2	32	-3.0	8.3	0.08	-	0.04	4.2	19.1	195	-	217	-0.4	-1.0

Table 8.31. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females and adult males from SE Franklin Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
251	16 Oct 05	15 Mar 06	50	16	52	80	1.6	2.3	0.20	0.33	0.06	2.3	4.4	193	85	205	-0.4	-0.6
351	16 Oct 05	16 Mar 06	65	13	66	92	1.0	1.9	0.15	0.29	0.07	5.0	27.3	211	81	229	-0.7	-0.3
451	16 Oct 05	15 Mar 06	60	14	61	89	1.1	3.2	0.14	0.24	0.06	3.7	14.2	200	83	208	-0.4	-0.5
651	16 Oct 05	9 Mar 06	42	13	47	67	2.0	3.0	0.29	0.37	0.12	1.8	2.2	202	71	211	-0.5	-0.1
Adult male																		
152	5 Jun 05	12 Jun 05	63	32	51	127	-0.2	-0.7	0.24	0.37	0.06	1.7	1.3	184	71	183	-0.3	0.3
252	7 Jun 05	8 Jul 05	83	18	85	115	0.8	0.3	0.07	0.12	0.05	7.3	63.3	205	82	212	-0.6	-0.2
Adult female: mean, median, SD			54	10	56	82	1.4	2.6	0.19	0.07	0.07	3.2	12.0	202	7	209	-0.5	-0.4
Adult male: mean, median, SD			73	14	68	121	0.3	-0.2	0.16	0.12	0.05	4.5	32.3	195	14	198	-0.4	0.0

Table 8.32. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females from Breakwater Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
181	4 Jun 05	2 Aug 05	10	4	10	30	-0.5	1.5	0.22	0.22	0.14	2.0	3.9	235	73	231	-0.3	-0.2
281	4 Jun 05	29 Jun 05	7	7	5	50	-3.2	12.9	0.16	0.20	0.11	3.2	13.2	210	88	216	-0.6	-0.2
381	5 Jun 05	22 Jun 05	5	4	4	26	-1.7	3.2	0.15	0.20	0.07	2.7	7.2	224	93	242	-0.7	-0.3
481	5 Jun 05	12 Jul 05	11	6	11	33	-1.1	1.1	0.22	0.22	0.13	2.3	6.5	217	61	215	-0.2	0.8
Overall: mean, median, SD			8	3	7	35	-1.6	4.7	0.19	0.04	0.12	2.5	7.7	222	11	223	-0.5	0.0

Table 8.33. Summary data on the parameters that describe the bathymetric depth in the regions used by the adult females from Lounds Is.

Seal no.	First foraging trip commenced	Last foraging trip ended	Mean depth (m)	SD	Median depth (m)	Maximum depth (m)	Depth skewness	Depth kurtosis	Mean slope (m)	SD	Median slope (m)	Slope skewness	Slope kurtosis	Mean aspect (m)	SD	Median aspect (m)	Aspect skewness	Aspect kurtosis
Adult female																		
161	16 Oct 05	21 Oct 05	16	6	15	37	-1.7	2.3	0.19	0.09	0.19	0.3	-0.6	215	32	214	-0.6	1.1
261	17 Oct 05	19 Oct 05	8	9	5	40	-1.6	2.0	0.14	0.12	0.10	1.0	0.1	187	50	207	-1.5	2.6
361	16 Oct 05	20 Oct 05	9	8	9	33	-1.2	1.3	0.21	0.19	0.15	1.9	3.2	202	66	205	-0.5	1.2
461	16 Oct 05	16 Mar 06	6	4	4	40	-2.2	10.2	0.12	0.10	0.10	2.9	15.9	208	94	220	-0.4	-0.8
561	18 Oct 05	19 Oct 05	21	7	20	34	-0.6	-1.0	0.19	0.11	0.19	0.2	-1.0	210	41	211	-0.5	0.4
661	18 Oct 05	22 Nov 05	3	6	1	34	-3.6	13.0	0.09	0.12	0.06	5.4	35.1	209	84	200	-0.6	0.1
761	18 Oct 05	20 Oct 05	6	8	3	34	-2.3	4.6	0.12	0.11	0.11	4.1	21.3	192	55	204	-0.6	1.6
Overall: mean, median, SD			10	6	5	36	-1.9	4.6	0.15	0.04	0.11	2.2	10.6	203	11	207	-0.7	0.9

Distance and direction of travel

Data on the maximum distance travelled from colonies by ASL and the total distance travelled on foraging trips are summarised for each animal in Tables 8.9–8.16. The distance data differed significantly among the age/sex groups ($F_{3,105}$ = 33.326, P < 0.0001, $F_{3,105}$ = 27.505, P < 0.0001), due to significantly longer distances travelled by adult males (max. dist = 98.4 ± 58.5 km; total dist. = 247.7 ± 151.2 km, n = 21), compared to adult females (max. dist = 27.3 ± 18.5 km; total dist. = 75.1 ± 54.2 km, n = 64), juveniles (max. dist = 23.3 ± 11.0 km; total dist. = 63.6 ± 33.3 km, n = 22), and subadult males (max. dist = 26.0 ± 14.9 km; total dist. = 68.8 ± 42.4 km, n = 2) (P < 0.05 in all cases) (Table 8.9–8.16). There were no significant differences between the maximum distances travelled nor the mean total distance travelled on foraging trips by adult females, juveniles or subadult males (P > 0.05 in all cases) (Table 8.9–8.16).

Among adult females, both the mean maximum (straight line) and total distance travelled on foraging trips varied significantly between sites ($F_{6,57}$ = 3.511, P = 0.005; $F_{6,57}$ = 5.810, P < 0.0001, respectively) (Table 8.9–8.16). The grand mean of the maximum distances travelled by each animal ranged from 17.6 ± 3.8 km for Breakwater Is to 56.2 ± 35.0 km for SE Franklin Reef. Similarly, the total distance travelled per foraging trip was lower for Breakwater Is (50.2 ± 13.1 km) and highest for SE Franklin Reef (182.3 ± 107.9 km) (Table 8.9–8.16). Inter-site differences in maximum and total distances travelled were due to the greater distances travelled by Purdie Is and SE Franklin Reef females, relative to females from other sites (P > 0.05 in all cases) (Table 8.9–8.16).

In contrast to adult females, the mean maximum distance and total distance travelled by adult males and juveniles on foraging trips did not vary significantly between sites (adult males: $F_{4,16}$ = 0.600, P = 0.668; $F_{4,16}$ = 2.092, P = 0.129, respectively; juveniles:, $F_{3,18}$ = 1.783, P = 1.863; $F_{3,18}$ = 1.942, P = 1.590, respectively) (Table 8.9–8.16).

The circular distance *r* of the direction of travel varied significantly among the age/sex groups ($F_{3,105}$ = 3.324, P = 0.0026); it was significantly greater in adult males (i.e., they had a greater tendency for at-sea locations to be focused around the mean heading) than adult females and juveniles (P < 0.05 in both cases) (Table 8.9–8.16). Circular distance varied among sites in adult females ($F_{6,57}$ = 2.562, P = 0.029), and juveniles ($F_{3,18}$ = 8.549, P = 0.001), but not in adult males ($F_{4,16}$ = 0.618, P = 0.656) (Table 8.9–8.16). In adult females, circular distance was lowest (i.e., least focused foraging heading) among Dangerous Reef and Purdie Is females, and greatest (i.e., most focused foraging heading) among Lounds Is and Breakwater Is females (Table 8.9–8.16).

Comparison of foraging behaviour among age/sex groups and sites

Dangerous Reef

Deployments of satellite transmitters on ASL at Dangerous Reef occurred over three main periods, between September to November 2003 (24 adult females, 2 juveniles), January to May 2005 (10 adult females, 3 adult males, 1 subadult male, 5 juveniles) and January 2006 (4 adult males) (Table 8.9–8.10). The foraging patterns of the 34 adult female ASL tracked between 2003 and 2005 were variable in both the location and distance from Dangerous Reef where individual seals focused their foraging effort (Fig. 8.4). There was inter-individual overlap in areas used (especially waters near Dangerous Reef) and most regions in southern Spencer Gulf region were utilised, with the exception of regions immediately to the south-west of Dangerous Reef, which were bounded by Thistle Is and the Eyre Peninsula (Fig. 8.4). Where land did not limit foraging distance, to the north and north-east of Dangerous Reef, animals travelled to maximum distances of ~95 km (Fig. 8.4). The mean maximum distances that seals travelled from Dangerous Reef were 30.6 ± 18.4 and the range was 9.9–66.9 km (Table 8.9). The mean total distance travelled on foraging trips was 13–171 km (Table 8.9).

There was considerable inter-individual variation in the foraging locations of adult female ASL from Dangerous Reef (Table 8.9, Fig. 8.4, Appendix 1). For example, two females (C00 and C11) foraged inshore, along the coasts of north Boston Bay, to Point Boston, Louth Bay and Point Bolingbroke to Tumby Is (Appendix 1). Most other seals concentrated their foraging effort in open water, but as indicated, the distance and direction that seals foraged from Dangerous Reef varied (Table 8.9). The parameters used in the cluster analyses were the: 1) mean maximum distance travelled from Dangerous Reef; 2) mean total travelled distance per foraging trip; 3) mean heading (direction) of travel; 4) circular distance; 5) mean speed; 6) mean depth used; 7) mean maximum depth attained (based on bathymetric depth data – see diving behaviour section, above); and 8) site fidelity index. Cluster analyses identified 4 main foraging ecotypes, which were apparent at 75 % similarity (Fig. 8.40). The most accurate Discriminant Function Analysis (DFA) indicated that there were significant differences between the 4 foraging ecotypes (Wilks' Lambda = 0.0107, $F_{12, 71}$ = 27.011, $P < 0.0001$). This DFA assigned all but one seal (97 %) to the correct foraging ecotype (Jack-knifed classification matrix, Ecotype 1: 13 of 14 seals (93 %), Ecotype 2–4: 100 %) based on 4 of the behavioural parameters (mean heading, circular distance, mean maximum distance and mean foraging depth) (Table 8.34).

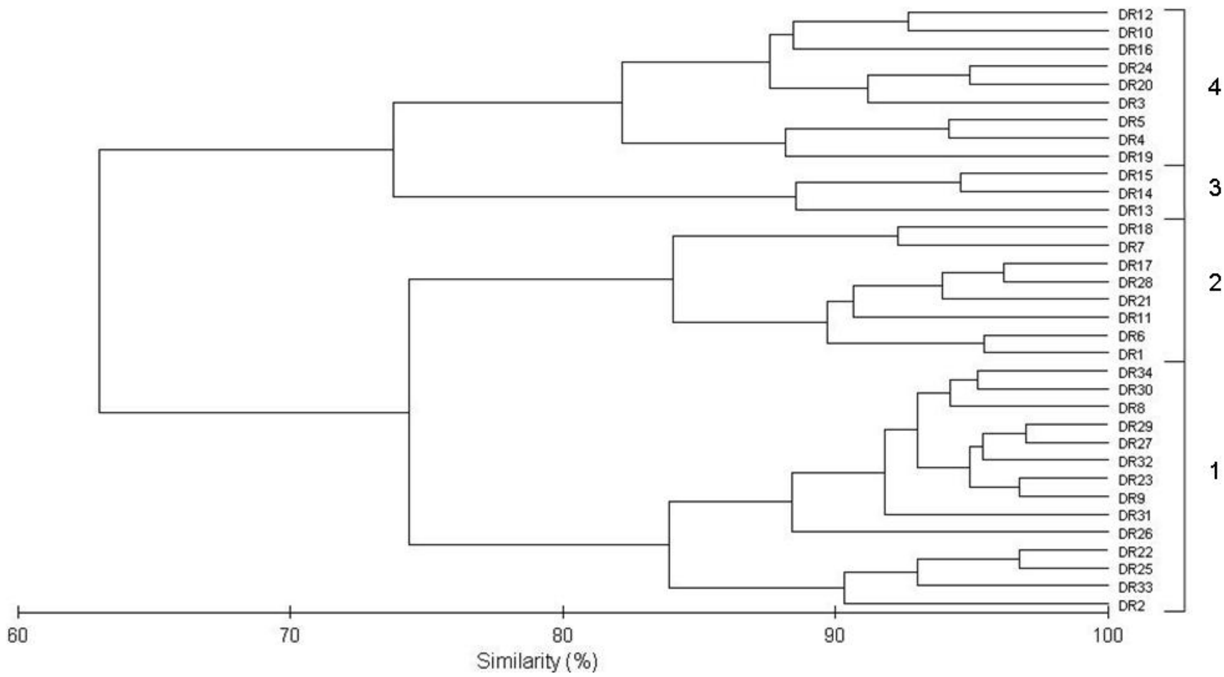


Fig. 8.40. Bray-Curtis similarity dendrogram based on the foraging parameters of 34 adult female ASL from Dangerous Reef, with the 4 foraging behavioural ecotypes indicated on the right.

Table 8.34. Mean mass, heading, circular distance, total foraging trip distance and depth of the foraging ecotypes, which were identified by cluster analyses, based on the 34 adult female ASL from Dangerous Reef.

Foraging ecotype	Mass (kg)	Mean Heading (degrees)	Circular distance (*r*)	Mean maximum distance (km)	Mean depth (m)
Ecotype 1 (n = 14)	77.6	160.9	0.56	42.4	30.4
Ecotype 2 (n = 8)	76.1	289.3	0.86	42.6	18.6
Ecotype 3 (n = 3)	78.8	72.0	0.95	150.4	28.7
Ecotype 4 (n = 9)	89.6	64.3	0.77	68.1	36.6

Circular histograms of the mean direction of travel for each individual within each foraging ecotype are presented in Fig. 8.41 (Table 8.9). Examples of the distributions of foraging effort for each foraging ecotype are presented in Fig. 8.42. Differences in the mean directions of foraging locations among the 4 ecotypes were tested using the Oriana circular statistics software package. Each ecotype differed significantly from the other 3 ecotypes (Watson-Williams F-test, $P < 0.0001$ in all cases), except for ecotypes 3 and 4 (Watson-Williams F-test, $F_{1,10} = 0.617$, $P = 0.450$).

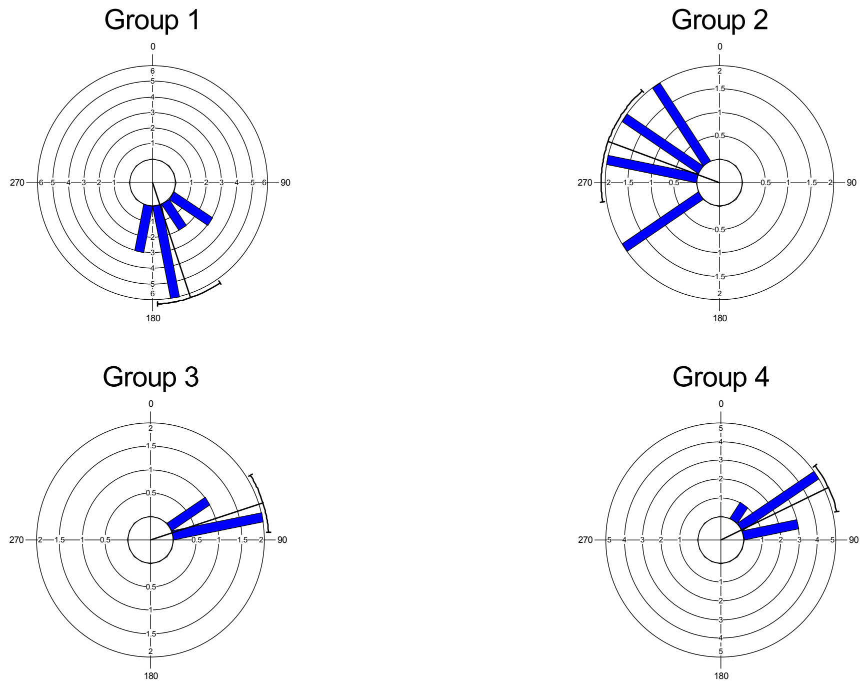
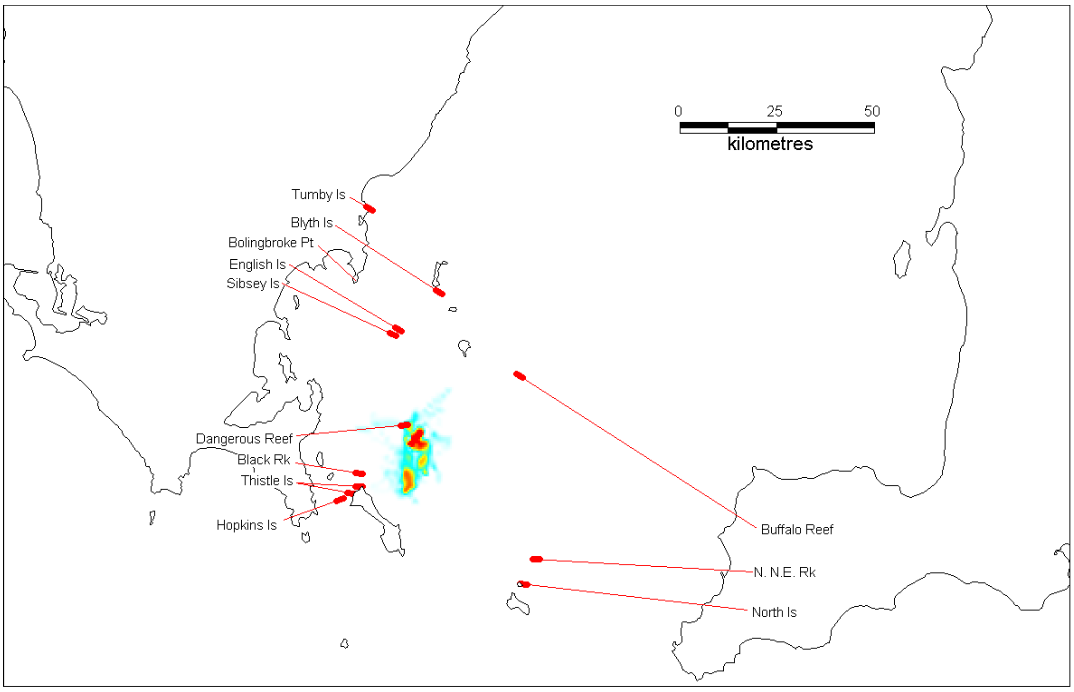
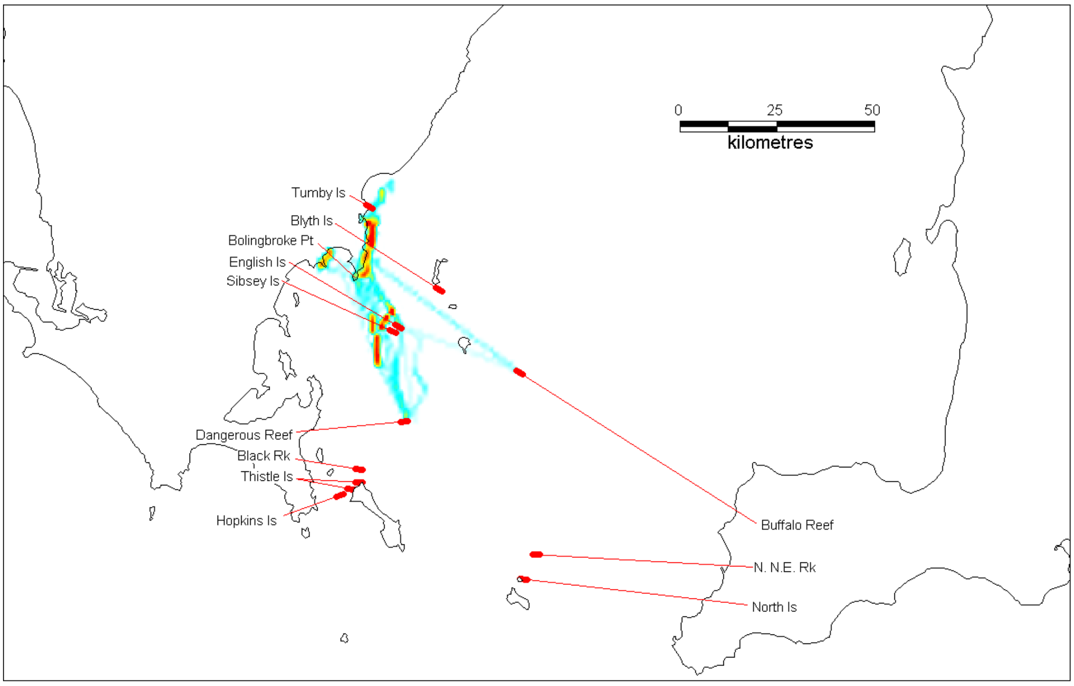


Fig. 8.41. Circular histograms of the mean direction of travel on foraging trips for the 4 foraging ecotypes (groups), which were identified by cluster analyses, based on the foraging parameters of 34 adult female ASL that were satellite tracked from Dangerous Reef between 2003–2005.

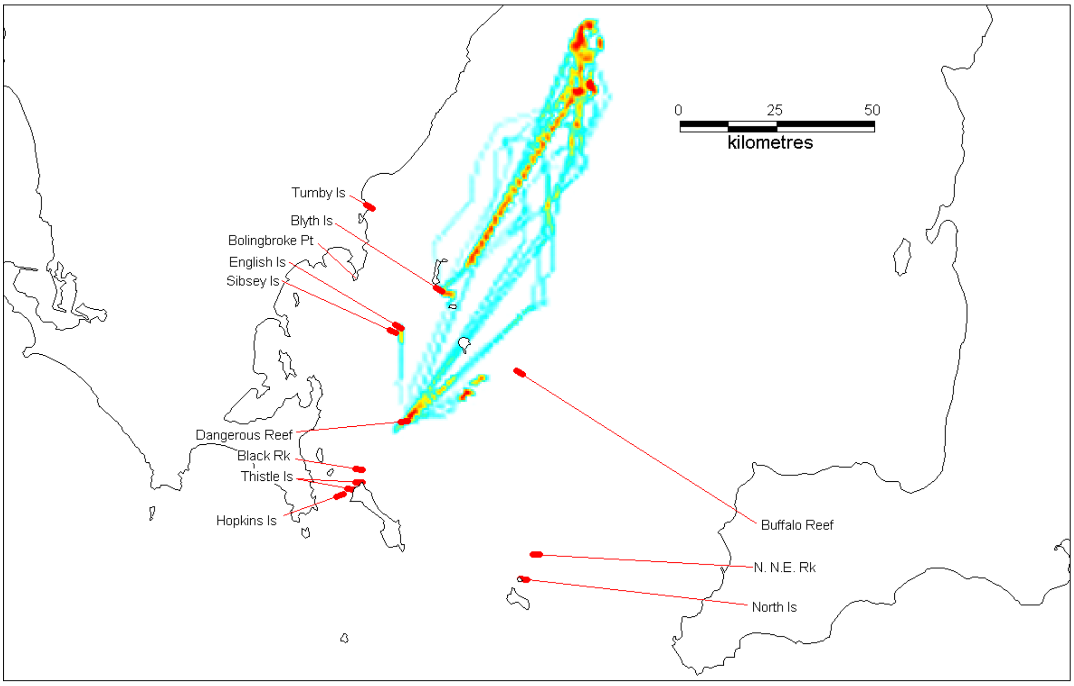


Ecotype 1 (AF 1311)

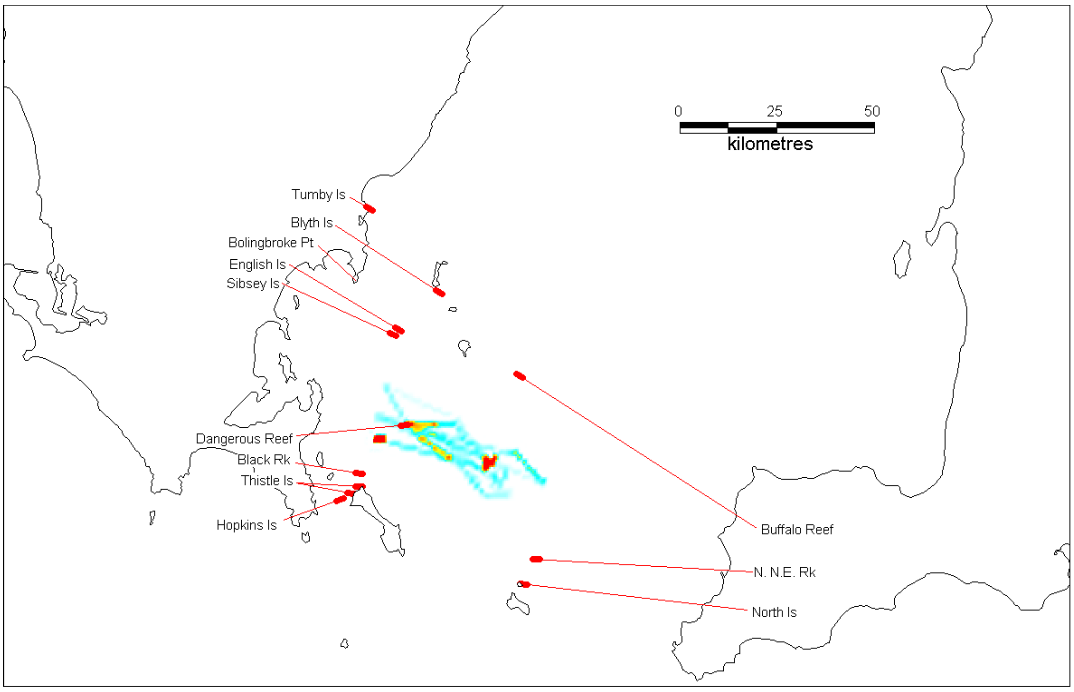


Ecotype 2 (AF 10011)

Fig. 8.42. Foraging areas of representative adult female ASL from the 4 foraging behaviour ecotypes, which were identified by cluster analyses, based on the foraging parameters of 34 adult female ASL that were satellite tracked from Dangerous Reef between 2003–2005. Fig. 8.42. continued on next page.



Ecotype 3 (AF 11511)



Ecotype 4 (AF 10211)

Fig. 8.42. (cont.) Foraging areas of representative adult female ASL from the 4 foraging behaviour ecotypes, which were identified by cluster analyses, based on the foraging parameters of 34 adult female ASL that were satellite tracked from Dangerous Reef between 2003–2005.

The tracking of 10 adult females from Dangerous Reef between January-May 2005 showed a different pattern to those from 2003, because the females in 2005 typically foraged closer to Dangerous Reef and mostly between the colony and Thistle Is (Fig. 8.5). Nine of these 10 females were assigned to foraging ecotype 1 (Fig. 8.40) and the other adult female was in foraging behaviour ecotype 2 (DR28, Fig. 8.40). The mean maximum distance travelled from Dangerous Reef by the females in 2005 (14.8 ± 5.2 km) was significantly less than the distance travelled by females in 2003 (30.6 ± 18.4 km) ($F_{1,32}$ = 6.990, P = 0.013) and the mean total foraging trip distance was also significantly less for females in 2005 (39.5 ± 9.7 km and 66.8 ± 38.8 km, respectively, $F_{1,32}$ = 4.736, P = 0.037, Table 8.9). The site fidelity index for females in 2005 was higher than in 2003 and the difference approached significance ($F_{1,32}$ = 3.073, P = 0.089) indicating that in 2003 a greater number of foraging trips ended at a site other than Dangerous Reef (Table 8.9). The mean direction of foraging trips by females differed significantly between 2003 (71.7 ± 91.2°) and 2005 (164.8 ± 45.8°) (Watson-Williams F-test, $F_{1,32}$ = 9.900, P = 0.004) (Fig. 8.43).

Fig. 8.43. Circular histograms of the mean direction of travel on foraging trips for adult female ASL satellite tracked at Dangerous Reef in 2003 (n = 24) and 2005 (n = 10).

Seven juvenile ASL were satellite tracked between 2003 and 2005. Their distributions of foraging effort are detailed in Fig. 8.8–8.10. Individual tracks and time in area plots are presented in Appendix 1. All of the juvenile ASL tracked from Dangerous Reef were males and typically foraged between Reevesby Is, Hopkins and Thistle Is, and Wedge Is (Fig. 8.8–8.10). Most foraging activity occurred south and east of Dangerous Reef (Fig. 8.8–8.10). In general, the foraging space of juvenile formed a subset of that used by adult females (Fig. 8.6 and 8.10). Analysis of similarities of the foraging parameters (maximum and total distances, bearing, circular distance and travel speed) did not indicate any significant differences (R = -0.175, P = 0.984) (Table 8.9 and 8.10) between the adult females and juveniles at Dangerous Reef, but significant differences were apparent between adult females and juveniles based on the depths used (mean, median and maximum) ($R = 0.11$, $P = 0.015$) (Table 8.26–8.27).

Seven adult males and one subadult male were satellite tracked from Dangerous Reef. Their distributions of foraging effort are detailed in Fig. 8.7 and 8.11. Individual tracks and time in area plots are presented in Appendix 1. Males were typically wider ranging and foraged in a broader range of habitats than adult females and juveniles. Adult males used both southern Spencer Gulf, Investigator Strait and continental shelf waters to the south of Eyre Peninsula (Fig. 8.7 and 8.11). Most foraging by adult males took place away from Dangerous Reef, with most males dispersing to alternate haulouts and foraging from those sites (Fig. 8.7 and 8.11). These sites included Rocky Is, Liguanea Is, Hopkins Is, Althorpe Is, Blythe and Boucaut Is (near Reevesby Is) and White Rock (near Wardang Is) (Fig. 8.7 and Appendix 1). The single subadult male foraged in a region (Fig. 8.11) that was similar to region used by the juvenile males (Fig. 8.10).

Nuyts Archipelago

A total of 60 ASL were satellite tracked from 6 sites in the Nuyts Archipelago in 2005. Deployments were undertaken at Purdie and West Is, NE Franklin and Breakwater Is in May/June 2005, and at Lounds Is and SE Franklin Is in October 2005. Summary maps of the spatial distributions of foraging effort of adult females, males and juveniles for each island where seals were tracked are presented in Fig. 8.12–8.29 and for each individual seal in Appendix 1. Details on the morphology and anaesthesia of individual seals and their foraging and haulout characteristics are summarised in Tables 8.3–8.8 and 8.11–8.16.

The tracking data from 30 adult female ASL across 6 different breeding colonies in the Nuyts Archipelago allowed us to examine the foraging patterns exhibited by adult females from different sites. In the Nuyts Archipelago, adult females typically demonstrated one of two different foraging ecotypes. Females that foraged *inshore*, in shallow waters, were typically of smaller body mass compared to females that foraged *offshore*, in deeper waters. This was supported by a Bray-Curtis dendrogram (Fig. 8.44), which was based on 2 parameters: body mass (Table 8.3–8.6) and mean depth (Table 8.11–8.16). The accuracy of assigning seals to these foraging ecotypes was tested using a discriminant function analysis, based on the main morphometric and foraging parameters. The most significant discriminant function that separated these ecotypes used two parameters: body mass and mean depth (Wilks' Lambda = 0.1456, $F_{2,27} = 79.239$, $P < 0.0001$). The canonical discriminant equation (100 % of females assigned to the correct ecotype, Jack-knifed classification) was:

$$\textit{Inshore}(\text{-ve}) \text{ or } \textit{Offshore}(\text{+ve}) = -7.297 + 0.052_{\text{mass}} + 0.094_{\text{mean depth}}$$

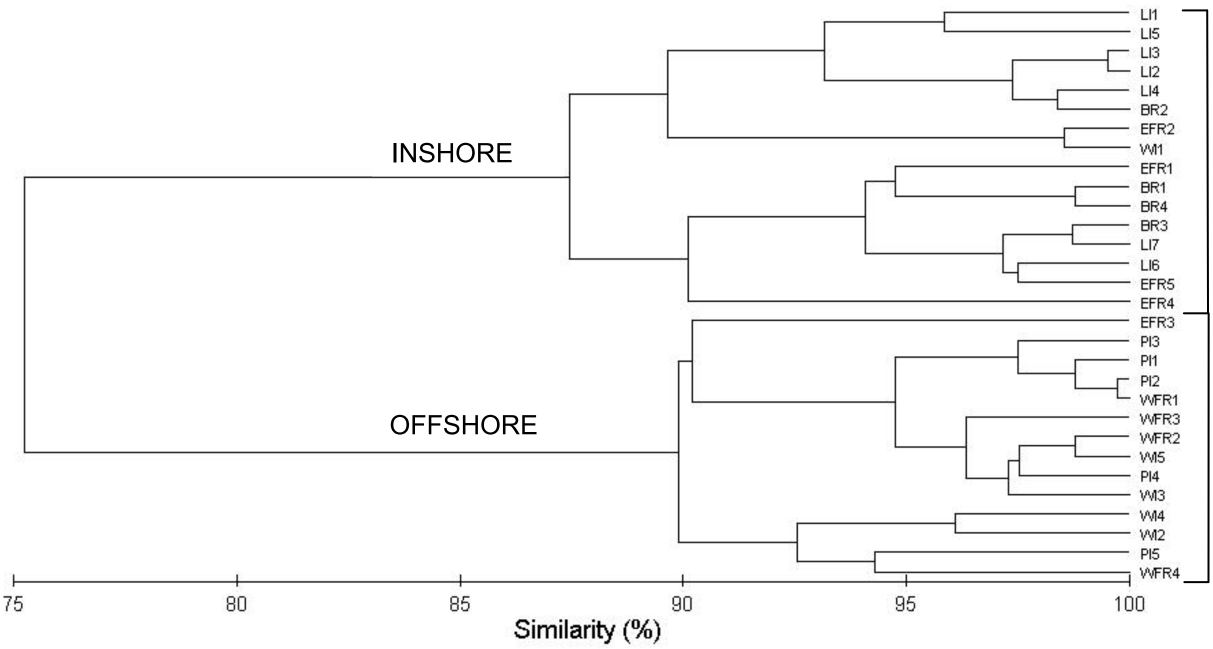


Fig. 8.44. Bray-Curtis similarity dendrogram based on the body mass and mean depth used by the 30 adult female ASL from the Nuyts Archipelago. The 2 foraging ecotypes are indicated.

There was a significant difference in the body size of females in the *inshore* and *offshore* foraging ecotypes (Table 8.35). Females in the *inshore* foraging ecotype were about 20 kg (25 %) lighter, 15 cm (10 %) shorter and 9 cm (10 %) less in girth compared to *offshore* feeding females (Table 8.35). In addition, the mean body condition (kg/cm) of *offshore* females was about 15 % greater than that of the inshore foraging ecotype (Table 8.35). Age-estimates were available for 3 females from the *offshore* ecotype and 7 from the *inshore* ecotype (excluding 1 outlier), which enabled size at age relationships to be compared with the same data from Dangerous Reef (n = 26 aged females, excluding 1 outlier). Analysis of covariance (ANCOVA) was used to determine whether the relationship between age and length differed between Dangerous Reef females and the *inshore* ecotype of females from the Nuyts Archipelago. The slopes were homogenous (age x ecotype: $F_{1,29}$ = 2.152, P = 0.153), but there was a significant age ($F_{1,29}$ = 10.725, P = 0.0027) and ecotype effect on body length ($F_{1,29}$ = 3.999, P = 0.0550) (Fig. 8.45). The *inshore* females were shorter for any given age, compared to Dangerous Reef females (Fig. 8.45). The analysis of body mass versus age detected no differences in mass between Dangerous Reef and the *inshore* females from the Nuyts Archipelago (ANCOVA, age: $F_{1,29}$ = 5.069, P = 0.0321; ecotype: $F_{1,29}$ = 0.004, P = 0.9504; age x ecotype: $F_{1,29}$ = 0.097, P = 0.7578) (Fig. 8.45). Only three *offshore* females were aged, but their age-length relationship indicated that they were similar to the adult females from Dangerous Reef (Fig. 8.45).

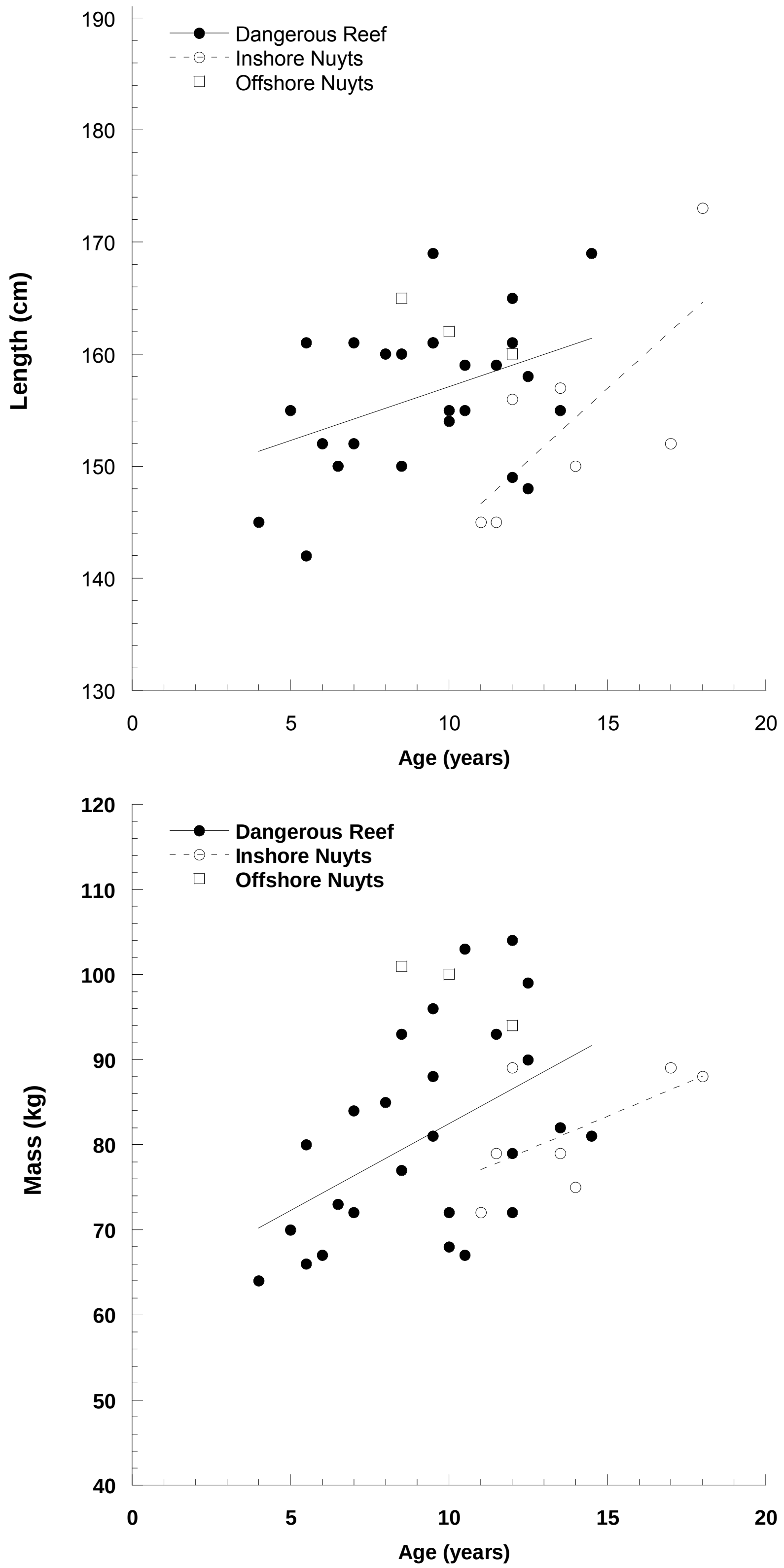


Fig. 8.45. Relationships between the estimated age and length, and age and mass of adult female ASL from Dangerous Reef and from the *inshore* and *offshore* foraging ecotypes from the Nuyts Archipelago. Linear regressions are given for the Dangerous Reef and *inshore* Nuyts ecotypes (excluding two outlier females with estimated ages of 21 and 23).

Table 8.35. The foraging parameters of the *inshore* and *offshore* foraging ecotypes of adult females from the Nuyts Archipelago. Probability values are indicated by: ** < 0.01, * < 0.05 and ns: not significantly different. [a] Watson-William F test. Body mass and the mean depth used are shown in bold because these parameters resulted in the most significant discriminant function.

	Inshore n = 16		*Offshore* n = 14		*t statistic*	P
	Mean	sd	Mean	sd		
Mass (kg)	**78.8**	**8.7**	**98.7**	**7.6**	**6.664**	**
Length (cm)	150.7	8.5	165.3	7.9	4.868	**
Girth (cm)	87.6	5.1	96.2	4.8	4.626	**
Proportion of time at sea	0.54	0.10	0.59	0.07	1.483	ns
Max. distance	18.5	7.1	40.7	23.6	3.590	**
Mean heading (°)	56.9	59.3	226.7	59.1	44.526[a]	**[a]
Circular distance	0.88	0.08	0.80	0.11	2.276	*
Mean speed (km/hr)	3.4	0.6	4.5	0.5	5.900	**
Total foraging distance (km)	61.8	32.2	130.1	76.0	3.280	**
Site fidelity index	0.69	0.38	0.71	0.26	0.212	ns
Mean depth used (m)	**11.0**	**6.6**	**50.0**	**11.4**	**11.640**	**
Max depth (m)	38.0	8.6	72.3	10.3	9.877	**
Body condition (kg/cm)	0.52	0.04	0.60	0.06	4.266	**

Based on the satellite tracking data, we compared the start and end times of each foraging trip for adult females in the *onshore* and *offshore* foraging ecotypes. On average, adult females in the *onshore* foraging ecotype started their foraging trips later in the day, than those in the *offshore* foraging ecotype ($F = 6.019$, $P = 0.018$). On average, adult females in the *onshore* foraging ecotype ended their foraging trips earlier in the day, compared with adult females in the *offshore* foraging ecotype ($F = 12.579$, $P = 0.001$).

For the diving depth data, the skewness and kurtosis values indicated that all females passed over a broad range of water depths, but females from the *inshore*/*offshore* foraging ecotypes moved quickly through deep/shallow habitats to target shallow/deep waters, respectively. The skewness values for the *offshore* foraging ecotype were significantly greater than for the *inshore* foraging ecotype for the depths used ($t = 34.22$, $P < 0.001$), but not for the aspect nor slope ($P > 0.05$ in both cases) (Table 6.19–6.23). The depths used by adult females from the *inshore* foraging ecotype were moderately, negatively skewed, which indicates that females in this ecotype spent relatively more time where the depth was less than the mean depth that they passed over during each foraging trip (Table 6.19–6.23). The depths used by adult females from the *offshore* foraging ecotype were moderately, positively skewed, which indicates that females in this ecotype spent relatively more time where the depth was greater than the mean depth that they passed over during each foraging trip (Table 6.19–6.23). The kurtosis values of the depths used by the females in both the *inshore* and the *offshore* foraging ecotypes were positive, which indicated that females in each ecotype used a narrow band of depths, which were similar to the mean depth that they used (Table 6.19–6.23).

Nearly all adult female ASL from each of the six sites in the Nuyts Archipelago were allocated to either *inshore* or *offshore* foraging ecotypes. This dichotomy between *inshore* and *offshore* foraging ecotypes essentially held for each location. Purdie Is, West Is and SE Franklin Is were typified by *offshore* females (Fig. 8.12, 8.18, 8.27). NE Franklin Is, Breakwater Is and Lounds Is were typified by *inshore* females (Fig. 8.21, 8.28, 8.29). There were two exceptions to this pattern, with one female from NE Franklin Is in the *offshore* foraging ecotype (female no. 441, Fig. 8.21, Appendix 1) and one female from West Is allocated to the *inshore* foraging ecotype (female no. 121, Fig. 8.12, Appendix 1).

Females in the *offshore* foraging ecotype typically travelled from their colonies in an arc between south and west, in the direction of the continental shelf break, but none of these females used waters deeper than 90 m. The 4 adult females from West Is that were in the *offshore* foraging ecotype conducted trips of 1.1 ± 0.6 d and foraged in an arc between southeast and southwest (mean bearing 179.8 ± 76.2 deg) of the colony in areas that averaged 47 ± 17 m depth (Tables 8.11, 8.28). Adult females from West Is travelled an average maximum distance of 23.6 ± 11.6 km from the colony and an average total distance of 83.0 ± 45.6 km on foraging trips (Table 8.11, Fig. 8.12). These 4 adult females from West Is used additional haulout sites at Smooth Is, East St Francis Is, Masillon Is, Fenelon Is, Canna Reef and Hart Is, from which their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.12, Appendix 1). Adult females from Purdie Is made *offshore* foraging trips of 1.2 ± 0.6 d and foraged southwest (252.2 ± 38.5 deg) of the colony in areas that averaged 51 ± 9 m depth (Table 8.12, 8.29). Adult females from Purdie Is travelled an average maximum distance of 43.5 ± 15.2 km from the colony and an average total distance of 125.5 ± 59.3 km on foraging trips (Table 8.12). Adult females from Purdie Is used additional haulout sites at Sinclair Is, Fenelon Is, Cannan Reef and the islands off Point Bell (Fig. 8.18, Appendix 1). When adult females departed from different haulout sites, their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.18, Appendix 1). Adult females from SE Franklin Is conducted *offshore* foraging trips of 1.8 ± 1.0 d and foraged in an arc between southwest and southeast (207.4 ± 56.2 deg) of the colony in areas that averaged 54 ± 10 m depth (Tables 8.14, 8.31). Adult females from SE Franklin Is travelled an average maximum distance of 56.2 ± 35.0 km from the colony and an average total distance of 182.3 ± 107.9 km on foraging trips (Table 8.14). Adult females from SE Franklin Is used additional haulout sites at Fenelon Is and Olive Is, from which their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.26, Appendix 1).

Female ASL in the *inshore* foraging ecotype typically travelled in an arc between north and east of their colonies, toward nearby bays and shallow seagrass beds. None of the *inshore* females used waters deeper than 51 m. The 4 *inshore* females from NE Franklin Is conducted foraging trips that lasted an average of 1.0 ± 0.6 d and foraged in an arc between southeast and southwest (114.5 ± 89.1 deg) of the colony in areas that averaged 13 ± 9 m depth (Table 8.11, 8.28). Adult females from NE Franklin travelled an average maximum distance of 14.9 ± 7.1 km from the colony and an average total distance of 55.0 ± 30.4 km on foraging trips (Table 8.11, Fig. 8.21). The 4 adult females from NE Franklin Is used additional haulout sites at Flinders Reef, Gliddon Reef and Goalen Rocks, from which their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.21, Appendix 1). Adult females from Breakwater Is made *inshore* foraging trips of 1.0 ± 0.3 d and typically foraged north of the colony in areas that averaged 8 ± 3 m depth (Tables 8.15, 8.32). Adult females travelled an average maximum distance of 17.6 ± 3.8 km from the colony and an average total distance of 50.2 ± 13.1 km on foraging trips (Table 8.15). Adult females from Breakwater Is used additional haulout sites at Purdie Is, Gliddon Reef and Bird Rock (Fig. 8.28, Appendix 1). When adult females from Breakwater Is departed from different haulout sites, their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.28, Appendix 1). Adult females from Lounds Is conducted *inshore* foraging trips of 1.2 ± 0.5 d and foraged in an arc between north and east (47.1 ± 14.2 deg) of the colony in areas that averaged 10 ± 6 m depth (Tables 8.16, 8.33, Fig. 8.29). Adult females travelled an average maximum distance of 22.2 ± 7.8 km from the colony and an average total distance of 76.6 ± 38.9 km on foraging trips (Table 8.16). Adult females from Lounds Is used additional haulout sites at Breakwater Is and Bird Rock, from which their foraging trips showed similar patterns in the average distances and directions travelled (Fig. 8.29, Appendix 1).

In the Nuyts Archipelago, juvenile seals were satellite tracked from Purdie Is (n = 5), West Is (n = 5) and NE Franklin Is (n = 5). Distributions of their foraging effort are presented in Fig. 8.14, 8.15, 8.16, 8.20, 8.23 and 8.24 and in Appendix 1. The distributions of foraging effort of juveniles were similar to those of adult females at their respective sites, both in terms of areas of foraging activity and the directions and depths used (Tables 8.11–8.16, 8.28–8.33, Fig. 8.14, 8.15, 8.16, 8.20, 8.23 and 8.24). ANOSIM indicated that there were no significant differences in the foraging parameters (total and maximum distances, median and mean bearings, circular distance and median and mean speeds), or depths (mean, median and maximum depths, mean and median slopes) used by the juveniles (sexes combined) and adult females from any of these 3 sites in the Nuyts Archipelago ($P > 0.05$ in all cases).

In the Nuyts Archipelago, adult males were satellite tracked at West Is (n = 4), Purdie Is (n = 5), NE Franklin Is (n = 3) and SE Franklin Is (n = 2). The distributions of their foraging effort are presented in Fig. 8.13, 8.19, 8.22 and 8.27 and in Appendix 1. Adult males typically foraged to the southwest of their colonies, unless they moved to an alternate haulout site, from where they also headed southwest (Fig. 8.13, 8.19, 8.22 and 8.27, Table 8.11–8.14). Adult male foraging effort was typically concentrated around the 100 m depth contour, but some foraging occurred in shallower and deeper waters (maximum depth range: 68 - 144 m, Table 8.11–8.14). ANOSIM indicated that there were significant differences in the foraging parameters (total and maximum distances, median and mean bearings, circular distance and median and mean speeds), and depths (mean, median and maximum depths, mean and median slopes) used by the adult males compared to both juveniles (sexes combined) and adult females from each of the sites ($P < 0.05$ in all cases). The distributions of foraging effort of adult males differed to those of adult females and juveniles at their respective sites, both in terms of distances travelled and the directions and depths used (Tables 8.11–8.16, 8.28–8.33, Fig. 8.13, 8.19, 8.22 and 8.27).

The single subadult male that was satellite tracked from West Is (Fig. 8.17) displayed a similar pattern of foraging behaviour to the adult males from the Nuyts Archipelago (Fig. 8.13, 8.19, 8.22 and 8.27), the subadult male spent relatively more time in nearshore waters, to the west of West Is, an area utilised by juveniles (Fig. 8.14–8.16). The subadult male typically foraged to the southwest of West Is, in waters that averaged 62 ± 10 m (with a maximum of 88 m).

Importance of body mass

Among the 64 adult females, body size was a significant factor in shaping many foraging attributes. Body mass of females was significantly positively correlated with the proportion of time spent at sea ($F_{1,57} = 12.845$, $P = 0.0007$, $r^2 = 0.187$), mean travel speed ($F_{1,62} = 30.569$, $P < 0.0001$, $r^2 = 0.334$), mean total distance travelled ($F_{1,62} = 9.716$, $P = 0.028$, $r^2 = 0.137$), mean depth ($F_{1,62} = 27.295$, $P < 0.0001$, $r^2 = 0.309$) and maximum foraging depth ($F_{1,62} = 29.724$, $P < 0.0001$, $r^2 = 0.328$) (Fig. 8.46). Body length was positively correlated to mean travel speed ($F_{1,63} = 14.062$, $P = 0.004$, $r^2 = 0.185$), mean total distance travelled ($F_{1,63} = 5.777$, $P = 0.0192$, $r^2 = 0.085$), mean depth ($F_{1,63} = 41.724$, $P < 0.0001$, $r^2 = 0.393$) and maximum foraging depth ($F_{1,63} = 30.849$, $P < 0.0001$, $r^2 = 0.332$). Girth was positively related to the mean ($F_{1,62} = 18.057$, $P < 0.0001$, $r^2 = 0.228$) and maximum foraging depths ($F_{1,62} = 4.842$, $P = 0.0316$, $r^2 = 0.074$). Interestingly, none of these relationships were significant for juveniles nor for adult and subadult males (length and girth only, because weights were estimated).

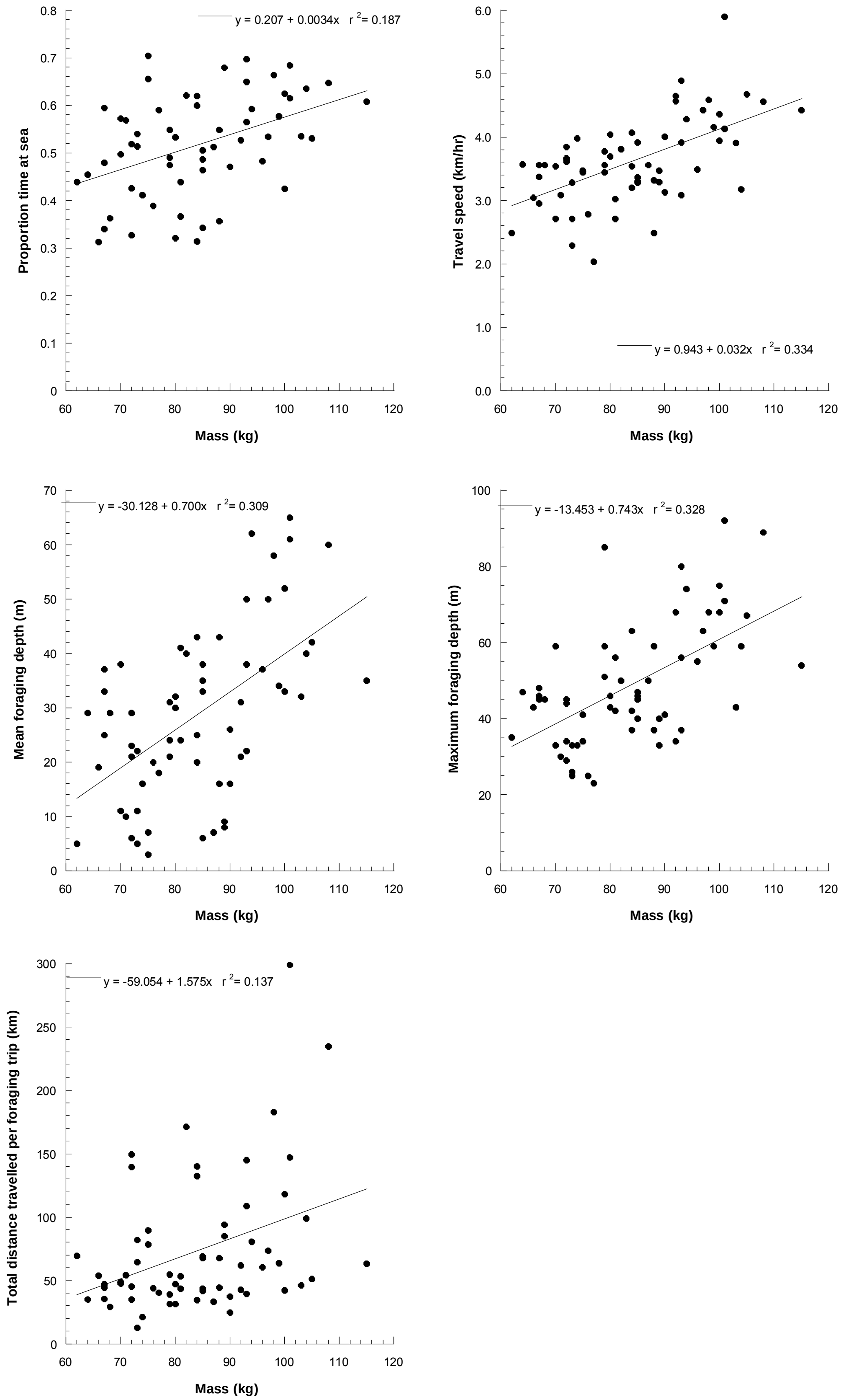


Fig. 8.46. Correlations between the mass of adult female ASL and the: 1) proportion of time at sea, 2) travel speed, 3) mean foraging depth, 4) maximum foraging depth and 5) mean total distance travelled. All correlations are significant at P < 0.05 (n = 64 females).

Distribution of ASL foraging effort in proximity to finfish aquaculture in Spencer Gulf

Adult female ASL were tracked over two time periods at Dangerous Reef; between September 2003 and January 2004, when tuna pens in the Port Lincoln Tuna Farming Zone (TFZ) were not stocked, and between January and May 2005, when the tuna pens were stocked (Fig 8.4-8.6). During the period when tuna pens were not stocked, 24 adult females were tracked from Dangerous Reef (Fig. 8.4). Of these, four (16.7 %) spent some time foraging within the TFZ (females 10611–C06, 10711–C07, 11111–C11 and 12111–C21, see Appendix 1). Based on tracking results, most of this time appeared to have been in-transit between haulout and foraging grounds, but at least two of the seals appeared to have spent some time foraging within the TFZ.

Female 10611–C06 spent most of her time foraging in northern Boston and Louth Bays, and commuting to and from English Is (Appendix 1). This travel between haulout and foraging grounds meant that 10611–C06 regularly travelled through the TFZ. Numerous tracking locations occurred well within the TFZ, suggesting that some of the female's foraging was being undertaken within the zone. However, from the quality of the tracking position data, it is impossible to determine specifically whether the seal interacted directly with farms, but this female was seen alongside a tuna pen in Louth Bay on 21 October 2003 (Chris Brookes of the Stehr Group, see below).

Female 10711–C07 spent much of her time foraging north-west of Dangerous Reef, bringing her into close proximity to the TFZ (Appendix 1). Several good quality positions where obtained adjacent to leases in the TFZ, although as in the case of female 10611–C06, it is unclear whether the seal interacted directly with any farms.

Female 11111–C11 appeared to focus her foraging effort inshore in the northern part of Boston Bay and between Point Boston and Louth Is (Appendix 1). The most direct travel route between these favoured foraging grounds and Dangerous Reef is through the TFZ. The lack of satellite positions obtained for this animal within the TFZ, suggests that this animal spent little time feeding in the area, and what time was spent there was in transit.

Adult female 12111–C21 made several trips into the Port Lincoln TFZ, on trips originating from both Dangerous Reef and English Is (Appendix 1). There were a number of good quality locations obtained adjacent to several of the leases and it is likely that this seal foraged in waters adjacent to them, but as with all these females, data were obtained at a time when the tuna pens were not stocked.

During the second period of tracking at Dangerous Reef (January and May 2005) when the tuna pens were stocked, the foraging behaviour of adult female ASL based on 10 satellite tracked animals (Fig. 8.5) was different to the general pattern observed between September 2003 and January 2004. None of the adult females tracked foraged near the TFZ, with most foraging effort being focused between Dangerous Reef and Thistle Is, and females generally ranged over smaller areas (Fig. 8.5, Appendix 1). Foraging trips were significantly shorter in 2005 (mean 0.6 days) compared to 2003/04 (mean 1.3 days) ($t = 4.17$, $P < 0.001$), as were shore attendance bouts (0.9 days and 1.6 days, respectively) ($t = 2.05$, $P < 0.05$), but proportion of time spent at sea and on shore did not differ significantly between years ($t = 1.29$, $P > 0.05$ (Table 8.9). Both the mean maximum distance and the total distance travelled by adult females on foraging trips were significantly shorter during 2005 than in 2003/04 ($t = 2.64$, $P < 0.05$ and $t = 2.17$, $P < 0.05$, respectively), but there was no difference in the mean or maximum depths at which females foraged ($t = 1.23$, $P > 0.05$ and $t = 1.23$, $P > 0.05$, respectively) (Table 8.9).

Because both tracking periods (2003/04, 2005) were undertaken when adult females were at similar stages of lactation (early to mid breeding season), differences in the foraging behaviour of females across these periods is likely due to seasonal difference in prey distribution and abundance. The fact that no females foraged within the TFZ when tuna pens were stocked, suggests that finfish farming activity in the TFZ, despite its close proximity to ASL breeding sites, appears to have little influence on the foraging behaviour of female ASL.

Similarly, tracking of juveniles (n=7), subadult (n=1) and adult males (n=7) indicated that foraging effort by these seals was typically directed away from the TFZ (Fig. 8.7–8.11, Appendix 1).

Distribution of ASL foraging effort in proximity to aquaculture zones in the Nuyts Archipelago

We satellite tracked adult females (n=33) from 6 of the 8 known breeding locations in the Nuyts Archipelago. From 3 of these we also tracked adult males (n=15) and juveniles (n=15). With respect to the aquaculture zones north of Goat Is (FA00020 and FA00021), adult females from Gliddon Reef, and Breakwater and Lounds Is regularly used the waters in close proximity to these aquaculture zones (Fig. 8.47).

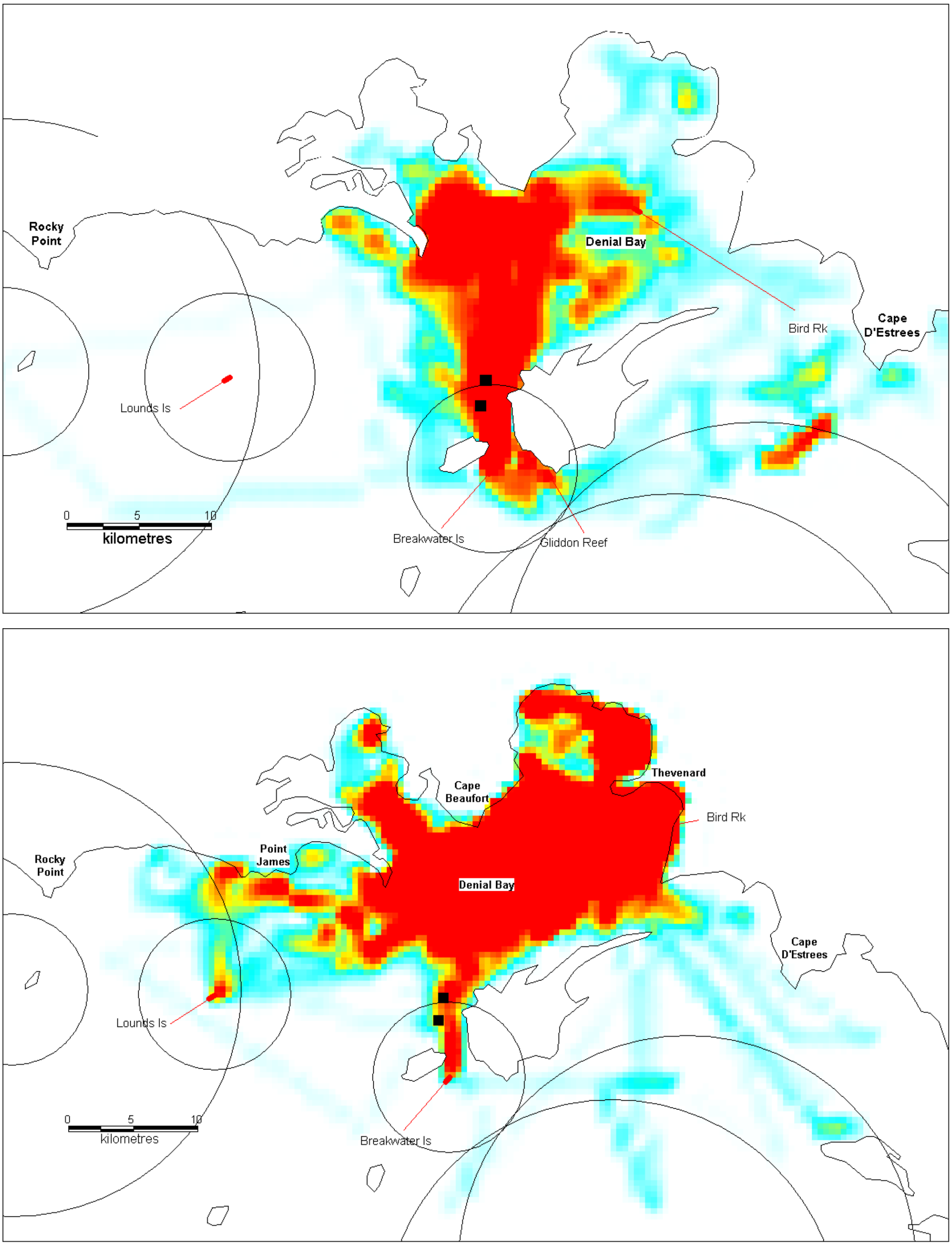


Fig. 8.47. Time spent in 1 km^2 cells by adult females, which were satellite tracked from Breakwater Is (top plot, n = 4) and Lounds Is (bottom plot, n = 7). Red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas, where seals spent relatively little time. The circles around the colonies indicate the respective 5 km aquaculture exclusion zones. Aquaculture zones FA00020 and FA00021 are indicated by black squares (3.5 km and 5.0 km north of Breakwater Is: each site measures 0.63 km x 0.63 km).

Tracking results from other colonies in the Nuyts Archipelago (West, Purdie, NE Franklin and SE Franklin Is), indicate that seals from these colonies are unlikely to forage in proximity to these aquaculture zones. Based on the tracking results from seals at West Is, which all foraged *offshore*, it is unlikely that seals from the Fenelon Is colony (southern-most in the St Francis Group) forage near the aquaculture zone. The adult female ASL tracked from Breakwater Is, foraged predominately in the Denial Bay region, and frequently used the passage between Goat and St Peter Is, travelling in close proximity to the aquaculture zone.

Distribution of ASL foraging effort relative to buffer zones around ASL colonies

Aquaculture exclusion zones are in place around all ASL breeding colonies in South Australia to reduce the potential for interactions with ASL. The buffer zones are 15 km around *large* ASL colonies (≥ 70 pups per breeding cycle) and 5 km around *small* colonies (< 70 pups) (Fig. 8.4–8.29) (Marine Mammal Protected Areas Aquaculture Working Group 2004). Changes in pup production over a three year period may result in changes to the *large* or *small* classification of colonies (Marine Mammal Protected Areas Aquaculture Working Group 2004). In the present study, satellite trackers were attached to ASL at the following large colonies: Dangerous Reef, SE Franklin Is, NE Franklin Is and Purdie Is, and small colonies: Breakwater Is, Lounds Is and West Is (Table 8.36, Fig. 8.4–8.29).

Table 8.36 shows the mean proportion of time spent in aquaculture buffer zones at the colonies where individual ASL were captured. The mean proportion of time spent within 5 km of colonies ranged from: 6.8 ± 6.1 % - 29.2 ± 18.7 % for adult females, 1.4 ± 1.1 % - 6.4 ± 5.4 % for adult males, 7.2 % - 19.0 ± 3.8 % for juvenile males, 3.7 ± 4.4 % - 11.3 ± 4.6 % for juvenile females and 7.3 % - 29.2 % for subadult males. The mean proportion of time spent within the 15 km of colonies ranged from: 33.0 ± 3 % - 72.9 ± 27.1 % for adult females, 6.0 ± 6.0 % - 28.0 ± 33.6 % for adult males, 19.2 % - 81.4 ± 6.4 % for juvenile males, 15.0 ± 15.7 % - 50.1 ± 35.3 % for juvenile females and 32.4 % - 78.4 % for subadult males. As expected, ASL from each age/sex group spent a significantly greater proportion of their time within 15 km than within 5 km of their colonies ($P < 0.01$ in all cases) (Table 8.36). Overall, adult males spent significantly less time within 5 km and 15 km of their colonies compared to adult females ($P < 0.01$ in both cases) and adult males spent significantly less time within 15 km of their colonies compared to juveniles ($P < 0.01$), but there were no other differences among age/sex groups ($P > 0.05$ in all cases) (Table 8.36). When the amount of time spent within 5 km or 15 km was compared between age/sex groups at each site, there were no significant differences for any of the age/sex groups ($P > 0.05$ in all cases) (Table 8.36).

Table. 8.36. Mean proportion of time spent in the aquaculture buffer zones around the respective colonies where satellite trackers were fitted to ASL. Aquaculture exclusion zones are 15 km at large colonies (Dangerous Reef, SE Franklin and Purdie Is: bold) and 5 km at other colonies (bold), but time spent data are given for 5 km and 15 km for all sites.

	Time spent within 5km (%)		Time spent within 15km (%)	
	Mean	SD	Mean	SD
Dangerous Reef				
Adult female	22.4	19.1	**63.0**	**33.7**
Adult male	5.2	8.5	**14.9**	**20.6**
Juvenile male	16.7	8.2	**62.0**	**29.6**
Subadult male	29.2	-	**78.4**	**-**
SE Franklin Is				
Adult female	13.0	15.7	**33.6**	**39.6**
Adult male	4.9	3.7	**13.0**	**8.2**
Purdie Is				
Adult female	9.7	7.2	**33.0**	**35.0**
Adult male	4.3	4.4	**12.6**	**13.8**
Juvenile male	15.6	7.2	**44.9**	**19.9**
NE Franklin Is				
Adult female	25.5	27.0	**58.0**	**40.0**
Adult male	1.4	1.1	**6.0**	**6.0**
Juvenile female	11.3	4.6	**50.1**	**35.3**
Juvenile male	7.2	-	**19.2**	**-**
Breakwater Is				
Adult female	**14.1**	**6.7**	65.7	26.1
Lounds Is				
Adult female	**6.8**	**6.1**	47.6	41.4
NE Franklin Is				
Adult female	**25.5**	**27.0**	58.0	40.0
Adult male	**1.4**	**1.1**	6.0	6.0
Juvenile female	**11.3**	**4.6**	50.1	35.3
Juvenile male	**7.2**	**-**	19.2	-
West Is				
Adult female	**29.2**	**18.7**	72.9	27.1
Adult male	**6.4**	**5.4**	28.0	33.6
Juvenile female	**3.7**	**4.4**	15.0	15.7
Juvenile male	**19.0**	**3.8**	81.4	6.4
Subadult male	**7.3**	**-**	32.4	-

Discussion

The only other published information on the foraging behaviour of ASL is from studies undertaken at Seal Bay on Kangaroo Is, on juvenile and adult females (Costa and Gales 2003, Fowler et al. 2006). Seal Bay is located on the south coast of Kangaroo Is where ASL forage over a deep, cold and exposed continental shelf (Fowler 2005, Fowler et al. 2006). In contrast, Dangerous Reef is located in the relatively shallow, warm and sheltered waters of southern Spencer Gulf, and the Nuyts Archipelago is also located in a relatively shallow and sheltered region on the west coast of the Eyre Peninsula. Fowler et al. (2006) demonstrated that adult female and juvenile ASL from Seal Bay did not use the same foraging habitats, because juveniles do not have the capacity to dive as deep as adult females (Fowler et al. 2006). Juveniles at Seal Bay used an inshore subset of the habitat used by females and as a result, juvenile ASL were regarded as particularly vulnerable to environmental alterations caused by fisheries and/or climate change (Fowler et al. 2006). The current study presents information on the foraging locations of ASL from several colonies and different age/sex groups. We present the first foraging behaviour data from adult male ASL and highlight inter-colony differences in the foraging behaviour of adult female ASL.

Anaesthesia of ASL

We report results on ASL anaesthesia and deployment durations to inform future studies of ASL. Not surprisingly, satellite transmitters that were attached to ASL that had not moulted their fur did not remain attached for as long as those attached to animals that had moulted. We applied glue sparingly, when attaching tracking equipment and we did not record any adverse effects that resulted from the lengthy tracker deployments in this study. The use of Isoflurane produced stable, reliable and consistent patterns of anaesthesia, as has been reported previously (Gales and Mattlin 1998). This study was the first to use Zoletil® (tiletamine-zolazepam) and remote injection to anaesthetise ASL. We routinely used Zoletil® on adult male ASL and frequently used it to aid in the recovery of tracking equipment from adult females and juveniles. In all cases the combination of Zoletil® and Isoflurane provided a relatively deep (compared to Isoflurane alone), but stable, reliable and consistent pattern of anaesthesia. Similar results were reported by McKenzie (2006), who used a combination of Zoletil® and Isoflurane on NZFS. Zoletil has not been used extensively on NZFS or ASL, because some researchers have experienced a high mortality rate from its use (Boyd et al. 1990, Heath et al. 1996). Recent studies on NZFS (McKenzie 2006), Australian fur seals (Arnould pers. comm.) and this study on ASL, demonstrate that Zoletil® can be used safely and effectively on seals.

Foraging depths of ASL

In comparing the foraging behaviour and habitats used by different individuals and age/sex groups, we assumed that all ASL foraged close to or on the seafloor. If some ASL routinely use prey in mid-water or near the surface, we may have incorrectly demonstrated that body size is correlated to diving behaviour. The dive records of adult females from Dangerous Reef indicated that ASL almost exclusively forage on or near the seafloor (Fig 8.31, 8.32). This is consistent with other studies that have demonstrated a predominance of benthic diving (adult females: Costa and Gales 2003, adult females, juveniles and pups: Fowler et al. 2006, adult males: Goldsworthy and Page unpublished data) and the consumption of benthic prey (Gales and Cheal 1992, McIntosh et al. 2006, Peters et al. unpublished data). Given the uniformity of these results, our use of regional bathymetric depth and the location of foraging areas to interpolate the dive depths of ASL, is unlikely to have resulted in a misleading relationship between body size and foraging depth.

Foraging behaviour of adult females

Adult female ASL demonstrated marked variability in foraging behaviour both within and among populations. Adult females within some populations shared similar foraging characteristics (eg, females at sites in the Nuyts Archipelago), while females at Dangerous Reef exhibited highly individual foraging patterns. Spatial differences in the foraging behaviour of Antarctic fur seals *Arctocephalus gazella* have been reported from different islands in the Southern Ocean. At South Georgia, Antarctic fur seals typically make brief, shallow dives to target Antarctic krill *Euphasia superba*, whereas at Heard Is and Iles Kerguelen, Antarctic fur seals forage on fish, in both benthic and pelagic habitats, both of which require relatively deep dives (Boyd et al. 1991, 1998 Green 1997, Lea et al. 2002). Intraspecific differences in predator foraging ecology is an important characteristic that underscores the need to account for variation in models of habitat use and in managing interactions with human activities.

Adult female ASL provide sole care of their pups and alternate between trips to sea and periods nursing their pups on shore, during relatively long periods of lactation (Costa 1991). The percentage of time ashore summarises the amount of time that females allocate to energy acquisition versus energy delivery to their pups. In regions (or times) where prey can be procured relatively rapidly, females would be expected to conduct briefer trips and increase the amount of time they spend on shore, nursing their pups. The mean foraging trip durations of the adult females in this study (1.16 ± 0.57 d) were relatively brief, but the mean shore bout durations (1.16 ± 0.79 d) were within the range reported from Seal Bay (trip: 1.92 ± 0.43 d, shore: 1.63 ± 0.20 d) and Dangerous Reef (1.82 ± 0.34 d, 0.93 ± 0.39 d) (Higgins 1990, Kretzmann et al. 1991, Higgins and Gass 1993, Lowther 2007, Goldsworthy et al. 2007b). The percentage of time that adult females spent ashore in this study (51.3 ± 13.4 %) was greater than shown in previous studies at Seal Bay (47.6 ± 6.1 %) and Dangerous Reef in 2006 (32.1 ± 10.9 %) (Lowther 2007), suggesting that foraging conditions in the regions used by adult females from Dangerous Reef in 2006 (Lowther 2007) were relatively poor compared with the foraging conditions at Seal Bay (Higgins 1990, Kretzmann et al. 1991, Higgins and Gass 1993) and from the other sites used in this study. Interestingly, conditions for foraging appeared to be better at Dangerous Reef in 2003 and 2005 (this study) compared with 2006 (Lowther 2007). Poorer foraging conditions at Dangerous Reef in 2006 were also indicated by lower growth rates of ASL pups, compared with Seal Bay (summarised in Goldsworthy et al. 2007b). Annual and spatial variation in the proportion of time adult females spend ashore, suggests that this parameter may be a useful indicator of trends or variability in prey availability, which may assist in monitoring ecosystem health.

Nocturnal foraging is a common strategy among fur seals (eg, Page et al. 2006), but it was not apparent among the adult female ASL at Seal Bay (Costa and Gales 2003). In contrast, our study showed that although some females foraged during the day and night, TDR records and satellite tracking data indicated that females from Dangerous Reef and the Nuyts Archipelago (both *onshore* and *offshore* foraging ecotypes), timed their departures and arrivals to increase the proportion of time spent foraging at night (eg, Fig. 8.33). Data from four individuals fitted with TDRs at Dangerous Reef indicated that ASL females foraged mainly at night, leaving the colony in the early evening and returning in the early morning. In order to maximise foraging time at night, most trips lasted just under one day. As a consequence, seals spent approximately equal proportions of time at sea and on land. Given the propensity for night-time foraging, seals feeding in distant locations more than one days' travel from Dangerous Reef, may use additional haulout sites in order to minimise the period of day-time spent foraging. Additional haulout sites may also be used by ASL to access regions that are further from their colony and therefore used by fewer adult females. The nocturnal dive activity displayed by seals in this study most likely reflects the availability of their cryptic prey, which may emerge to feed at night, but move into cracks and crevices to hide when day approaches. Because ASL conduct a high proportion of foraging at night, it is possible that they also interact with aquaculture operations more frequently at night.

Differences in the travel speeds and distances travelled by *inshore* and *offshore* adult female ASL in the Nuyts Archipelago were consistent with *offshore* foragers commuting rapidly across regions that were near colonies. Rapid traversing of nearshore waters is also evident among chick-rearing seabirds and fur seals (Gremillet et al. 2004, Page et al. 2006), which implies that these colonial breeding animals cannot rely on nearshore resources, in accordance with the theory of localised depletion (Ashmole 1963, Hamilton et al. 1967, Birt et al. 1987). The theory of localised depletion suggests that large aggregations of colonial breeding animals may deplete local food resources

(Ashmole 1963, Birt et al. 1987), which increases the separation of breeding and feeding habitats and increases the cost of commuting to provision dependent young, which remain at the central place (Orians and Pearson 1979). In contrast, *inshore* foragers travelled relatively slowly, indicating that they commenced active foraging as soon as they left the colony. *Inshore* foragers used habitats that were relatively shallow and typically covered in seagrass.

The diving behaviour of adult females from Dangerous Reef was similar to the behaviour reported previously for ASL from Seal Bay (Costa and Gales 2003, Fowler et al. 2006). Females in the present study foraged in shallow, continental shelf, gulf and inshore waters by undertaking brief foraging trips. These findings support the idea that adult female ASL are benthic predators, whose diet is influenced by both the benthic prey available in their limited foraging range and the metabolic demands of gestation and lactation (Costa and Gales 2003).

The benthic dive patterns that characterised the foraging behaviour of ASL correspond with predator avoidance behaviour, which is also apparent in northern elephant seal, Australian fur seal and NZFS dive records (Le Boeuf et al. 1988, Arnould and Hindell 2001, Page et al. 2005b). The main predators of ASL are most likely great white (*Carcharodon carcharias*) and bronze whaler sharks (*Carcharhinus brachurus*), which are near-surface predators that use visual cues to hunt (e.g. Riedman 1990), occur around ASL colonies (authors pers. obs) and prey upon ASL (Shaughnessy et al. 2007). By flanking the seafloor and thereby reducing the time spent near the surface, ASL may reduce the risk of detection by predators.

Within the Nuyts Archipelago, females from each colony displayed one of two distinct foraging behaviours, which could be broadly categorised into *inshore* and *offshore* foraging ecotypes. *Inshore* foraging ecotypes were displayed by females from Lounds, Breakwater and NE Franklin Is, while offshore foraging ecotypes were typical of females from Purdie, West and SE Franklin Is. The dichotomy between *inshore* and *offshore* ecotypes held for each breeding site studied, with the exception of two females: one from West Is and one from NE Franklin Is. Females from the *offshore* ecotype were on average 25 % heavier than *inshore* females and 10 % longer and larger in girth. The average heading of *offshore* females was SW, while for *inshore* females it was NE. *Offshore* females travelled 30 % faster than *inshore* females and travelled twice as far on foraging tips. Mean foraging depth of *offshore* females was almost five-times that of *inshore* females, and almost twice the maximum depths were obtained by *offshore* females. Because body size is related to oxygen stores and diving capability in marine mammals (Kooyman 1989, Mori 2002), results are consistent in demonstrating adaptive response in body-size, with *offshore* deep-diving females being larger than *inshore* shallow-diving females. Body size (especially mass) was correlated significantly with many parameters of foraging, including travel speed, distance from colony and the mean depth.

If differences in body size are due to phylogenetic constraints, it suggests that individuals that exhibit either *inshore* or *offshore* foraging ecotypes form genetically distinct populations. If this is the case then it may be similar to the pattern found for bottlenose and common dolphins – where there are large genetically diverse offshore populations and smaller regional coastal populations that are genetically differentiated from each other (eg Hoelzel et al. 1998). Campbell et al. (2007) detected high-levels of population subdivision based upon mtDNA lineages at both macro and micro-scales and extreme levels of natal phylopatry, which are far greater than has been determined for other seal species. The relationships between population subdivision and foraging ecotypes could not be determined in our study, but our results suggest that genetic subdivision may not be responsible for determining the foraging ecotypes of populations. Evidence comes from two main factors. First, there appears to be marked variability in the differentiation of foraging ecotypes within and among populations. For example although females within populations tended to express the same foraging ecotypes, we found two females in the Nuyts Archipelago that showed the alternate pattern. Similarly, at Dangerous Reef we have detected multiple foraging ecotypes within the one population. Second, differentiation of foraging ecotypes appears to be restricted to females. Tracking of 15 adult males in the Nuyts Archipelago indicated that all foraged in deeper outer-shelf waters, irrespective of the predominant foraging ecotypes of females within their population. In addition, genetic studies have indicated that although there are high levels of female philopatry as detected by mtDNA population subdivision, microsatellite DNA markers indicate much greater levels of male dispersal, effectively making groups of colonies panmictic (Campbell 2005). This has been supported by our tracking studies of males at both Dangerous Reef and the Nuyts Archipelago. These findings suggest that phylogenetic constraints are not responsible for differentiating foraging ecotypes.

It is worth speculating about what factors might explain the observed patterns, if differentiation of foraging ecotypes is not driven by phylogenetic constraints. It is possible that body size may be plastic to the physiological requirements of the different foraging ecotypes. Large body size to optimise oxygen storage in *offshore* deep foragers, and reduced body size for *inshore* shallow foragers. Such facultative adjustment in body size implies that social or cultural factors may be important in determining the foraging ecotypes that individual ASL females utilise. Factors that support the cultural transmission of maternal foraging ecotypes include the extended lactation period in ASL (lasting at least 17 months), which provides extended nutritional support to pups. Pup diving capacity has been shown to develop over this period (Fowler et al. 2006), and pups are competent foragers when they wean. In addition, pups are highly mobile at a very young age.

We have detected tagged pups moving up to 20 km to adjacent colonies or haulouts at four months of age, and nursing with their mothers at these sites. It is likely that pups follow their mothers, thus providing a mechanism by which they may observe the habitats their mother feeds, and the techniques used in hunting for particular prey species. This at sea association over at least a 12 month period, may provide an opportunity for pups to learn how to exploit maternal habitats and prey species.

The ‘Family Farm hypothesis’ (Goldsworthy unpublished data), predicts cultural inheritance of foraging space and prey preference from mother to daughter. Foraging specialisation and cultural transmission of foraging habit, may explain the unusual breeding biology in the species. Where resources are scarce, or if they require significant skill to utilise them, individuals that change their feeding habitats and strategies may suffer reduced fitness. Cultural transmission of foraging habit could provide strong selection for philopatry and extended maternal care of offspring, as well as explaining asynchronous breeding in the species. Cultural inheritance of diet has been proposed in some other marine mammal species, including bottlenose dolphins and sea otters (eg Sargeant et al. 2005, Tinker et al. 2007)

Foraging behaviour of adult and subadult males

Based on the larger body size and greater energy requirements of adult male ASL, we expected they would either utilise different prey in the same regions as lactating females or that males and females would utilise spatially separated habitats. In the present study we showed that males and females used spatially separated habitats, with males foraging over the shelf break. We expect that males exploit waters over the shelf break because they provide more optimal foraging conditions than waters over the continental shelf. Little is known about the main prey of ASL, so it is difficult to determine whether inter-sexual differences in foraging locations are a result of their prey preferences or abilities to exploit prey in each habitat. The lack of inshore foraging by adult males suggests that inshore habitats may not support sufficient densities of the prey used by adult males or they may not be able to efficiently use the prey of females and juveniles use. The large body size of adult male ASL facilitates the use of prey in deeper habitats, but this specialisation possibly makes them less efficient users of smaller, more manoeuvrable cephalopods and smaller fishes. Gales and Cheal (1992) indicated that fur seals are likely to be more adept at capturing small pelagic prey than ASL, so ASL may specialise on larger, less-manoeuvrable and/or cryptic prey, which are typically benthic. Such predator/prey size relationships have been found among sympatric tern species and different demographic groups of fur seals (Ashmole 1968, Hulsman 1987, Page et al. 2005a).

There are no comparative data on the identity, energy content or biology of ASL prey from continental shelf waters versus shelf break waters, so we cannot confirm that adult male ASL travel to shelf break waters because prey there are more energy rich or easier to access. The intra-sexual competition hypothesis may explain why male ASL have evolved to utilise different habitats and prey than those used by adult females and juveniles. Male otariids fight vigorously with one another to acquire and defend breeding territories, where most matings occur (Bartholomew 1970, Troy 1997). Selection then favours large males because they have greater fasting capacities and therefore increased mating opportunities compared with smaller rivals (Bartholomew 1970, Troy 1997). Achieving prime condition requires that male otariids undertake longer duration foraging trips and travel further than lactating females. Once at foraging grounds, males' large body size and their capacity to dive deeper and spend longer underwater per dive than smaller seals may enable them to utilise the larger or more energy-rich prey, which males require to attain and maintain their large mass.

Given that intra-sexual competition favours larger body size in male ASL, their central place foraging tendency seems unusual. Page et al. (2005c) discussed 3 possible reasons for this counter-intuitive behaviour, which they describe for adult male NZFS: (1) the benefits of displaying to females and rivals outside the breeding season (Troy 1997), (2) delaying fat accumulation until immediately prior to the breeding season (Beck et al. 2003), and (3) predator avoidance. Unconstrained (male and non-lactating female) harbour seals (*Phoca vitulina*) and southern elephant seals (*Mirounga leonina*) exhibit relationships between trip duration and (1) body size and (2) age, respectively (Thompson et al. 1998, Field et al. 2005), but this has not been demonstrated for male otariids (Sterling and Ream 2004, Page et al. 2005c). Although we found that the distances travelled by males were positively related to trip duration, this relationship offers little insight into factors that affect male ASL foraging trip duration.

In contrast to the inter-site differences recorded among adult females and juveniles, the foraging behaviour of adult males was broadly similar across sites. Inter-site differences were apparent in the foraging trip durations of adult males, but this did not influence the typical distributions of foraging effort. Adult males travelled relatively quickly to and from colonies, which was across the foraging grounds used by the adult females in the *offshore* behavioural ecotype. The distribution of foraging effort of adult males was characterised by a relatively small region of intense foraging, which was reached after a period of rapid travel. Adult males are most likely compensated for the time and energy that they expend commuting to and diving in distant and deep foraging grounds, if these regions provide more optimal foraging conditions than the shallower habitats of the continental shelf. Furthermore, adult males ranged widely with some males from the Nuyts Archipelago travelling as far west as some of the colonies along the Bunda Cliffs, and as far south as Ward Is. Adult males tracked from Dangerous Reef foraged in both shallow gulf waters and deeper waters to the south of Spencer Gulf. Some males based themselves at a particular colony or haulout, and spend weeks or months foraging from that point, before moving to an alternate haulout or colony (Fig. 8.7). Males regularly visited other breeding colonies, some as far as 290 km from the population where they were tagged. This is consistent with the findings of Campbell (2005), who examined microsatellite DNA among ASL colonies and determined that most gene flow among ASL populations was attributable to the dispersal of males.

Subadult male ASL displayed foraging behaviour that was intermediate between those of the juveniles and adult males (Fig 8.11, 8.17). The transition to adult male behaviour most likely occurs during or after puberty, when metabolic demands and growth rates increase dramatically. The rapid increase in energy requirements may require a relatively rapid change in the foraging behaviour of pubescent males. Because subadult males do not forage in the deeper regions used by adult males, this indicates that smaller subadult males cannot efficiently capture and handle the prey used by adult males or dive as deep. There are no published studies on the foraging behaviour of subadult male otariid seals, but the diving behaviour of juvenile male and lactating female northern fur seals offers insights into niche partitioning among juvenile males and lactating females (Sterling and Ream 2004, Sterling and Ream unpublished data). The relatively high density of dives in the regions utilised by juvenile male northern fur seals indicates that their more distant foraging habitats were of better quality (i.e. prey were more aggregated) compared to the habitats utilised by lactating females (Sterling and Ream unpublished data). Similarly, subadult male ASL would not be expected to forage in the same regions used by adult females, because prey may be more depleted in these areas, compared with distant or deeper habitats. In order to maximise their growth and fitness, subadult males would be expected to conduct longer duration foraging trips and search out more profitable foraging grounds, which lactating females could not utilise. Further studies of the foraging behaviour of subadult male ASL may highlight additional size-related influences on ASL foraging habitats, behaviours and diet.

Foraging behaviour of juveniles

The depth of benthic habitats on the continental slope can only be effectively accessed by adult males, whereas females and juveniles utilise shallower benthic habitats on the continental shelf. Juvenile ASL appear to forage in a shallow subset of the region used by adult females from the same colony, suggesting that colony differences in foraging ecotype are reinforced at an early age. The *inshore* versus *offshore* dichotomy of foraging observed in adult females was apparent among juveniles in the Nuyts Archipelago, but juveniles foraged closer to their colonies, so overall the pattern was less pronounced than among females. Fowler et al. (2006) also found that most juvenile ASL from Seal Bay foraged in *offshore* regions and utilised a shallow subset of the regions used by adult females. Given that adult female body size was related to the inter-site differences, we expected that juvenile ASL would all forage in *inshore* regions, because of their size, which determines how deep they can dive to access prey (Kooyman 1989, Mori 2002). Juvenile ASL are unlikely to be deep divers and were expected to be restricted to hunting in shallow regions (Fowler et al. 2006). The *offshore* foraging ecotype exhibited by juveniles at *offshore* islands indicates that factors other than body size may also affect the foraging behaviour of juvenile ASL.

The inter-site differences in the foraging locations of ASL do not appear to be related to the depths of available habitats in the regions around each site, because *inshore* habitats were within the foraging range of all *offshore* juveniles (and adult females). The *offshore* and *inshore* foraging patterns of juveniles in the Nuyts Archipelago suggest that juveniles may follow their mothers on some foraging trips. Fowler et al. (2007) discussed how the unique breeding cycle and relatively long lactation duration of ASL may provide opportunities for foraging lessons, as has been suggested for seals (Bowen et al. 1999), other marine mammals (Sargent et al. 2005, Tinker et al. 2007) and many terrestrial animals (eg Lee 1986). It is clear that young ASL do not exclusively forage side by side with their mothers (Fowler et al. 2007), but broad similarities in the foraging locations of juveniles and adult females (Fowler et al. 2007, this study) indicate that social factors may account for some of this behavioural diversity. Unfortunately, we do not know whether any of the adult females and juveniles that were satellite tracked were related, so we cannot compare the foraging locations of mothers and their offspring. Nonetheless, the dichotomy in the *offshore* versus *inshore* foraging ecotypes (among adult females and juveniles) indicates that females may start some foraging trips with their offspring. During relatively brief periods of instruction juvenile ASL may learn the direction of their mothers' foraging grounds and possibly some of their foraging techniques.

We hypothesised that the inter-site variation of adult female ASL foraging locations was based on differences in their body size and that juveniles may learn how to use prey in these regions. Proximity to *inshore* foraging grounds did not appear to influence the behaviour of individuals from *offshore* colonies. For example, Lounds/Purdie and NE Franklin/SE Franklin Is, which are characterised by *inshore/offshore* foragers, are separated by 13 km and 6 km, respectively. Australian sea lions from these sites have the potential to overlap considerably, but there is little exchange/movement of females and juveniles among sites (philopatry). Such a pattern may reinforce colony-specific foraging patterns among maternal lineages. Colony-specific foraging patterns are supported by results from DNA studies into ASL population structure (Campbell

2003, Campbell et al. 2007) and asynchrony in breeding schedules (eg. Olive to Franklins, Franklins to western Nuyts colonies, Goldsworthy et al. 2007b).

Combined satellite tracking and DNA-based studies are required to determine the mechanism that underlies the development of these colony-specific foraging patterns. In the absence of such data, it is worthwhile speculating as to the mechanisms that could promote such variation. It is possible that females are either: 1) phylogenetically constrained in body size and therefore adapted to foraging in particular depth ranges, or 2) body size is facultative (i.e. becomes optimised) to suit the *inshore* or *offshore* foraging mode. Either mechanism could result in the observed differences in ASL: 1) population structure (Campbell 2003), 2) timing of breeding and 3) foraging patterns. It remains possible that reinforcement of maternal foraging patterns could have lead to the development of maternal lineages among ASL at different colonies, but the question remains as to what selective factors shaped the development of foraging ecotypes in the first place?

Distribution of ASL foraging effort in proximity to TFZ at Port Lincoln

Tracking results indicate that the TFZ is not a major region where ASL from Dangerous Reef forage. This indicates that at the population level, the distance between the TFZ and finfish aquaculture operations has not altered the foraging behaviour of this ASL. This was most directly demonstrated by results that indicated even less foraging activity by Dangerous Reef ASL in proximity to the TFZ when tuna finfish pens were stocked, compared to when they were empty. These results indicate that stocking and feeding at finfish pens does not appear to change the foraging patterns of ASL at Dangerous Reef.

However, despite these results, it is clear that some ASL do interact with the finfish aquaculture industry. Based on an industry questionnaire, ASL are the species responsible for most attacks on tuna (chapter 6). Although NZFS are more commonly seen in and around tuna cages, they were not considered a threat to tuna because the fish are too large for NZFS to handle. New Zealand fur seals were more likely feeding on bait fish fed to tuna, or on other prey species attracted to cages. All seals observed during night surveys at tuna cages were ASL, and few ASL were seen during daylight hours (chapter 6). This may lend support to the industry view that most attacks occur at night (chapter 6).

The fact that tracking data demonstrate that from a broad population perspective the foraging behaviour of the Dangerous Reef ASL population does not appear to be modified by its proximity to the TFZ, but that industry questionnaire and surveys undertaken at finfish cages demonstrate that some individual ASL do attack tuna in finfish cages, suggests that a small subset of the ASL population (not tracked in our study) interact with finfish farms. The prevalence of this behaviour among the ASL population is unknown, although it is suspected to be principally undertaken by subadult and adult males. Operational interactions between seals and finfish aquaculture and with commercial fisheries typically result from a subset of a population becoming habituated to interactions as a consequence of reinforced behaviour that results from repeated successful (i.e. rewarded) feeding interactions (Shaughnessy et al. 2003, Kemper et al. 2003, Tilzey et al. 2006). Recent tracking of Australian and NZFS caught at salmonid finfish farms in Tasmania has demonstrated the extent to which parts of the seal population have adapted to foraging in and around finfish cages, with many seals spending long periods feeding in association with salmonid farms throughout winter months (Robinson et al. 2008). Traps could be applied to capture and track seals that interact with finfish farms in South Australia. The new generation of satellite linked GPS tags now available provide much greater precision and more locations per day, enabling accurate quantification of time spent at individual finfish cages to be quantified. Greater information about the behaviour and extent of interactions by the subset of the population that interacts with finfish farms would provide important information to assist managing seal interactions into the future.

Distribution of ASL foraging effort near the Goat Is aquaculture zone

Because aquaculture structures provide shelter and food, they are attractive habitats for wild fish and invertebrates, which would otherwise scatter across broad areas (Dempster et al. 2004, reviewed in Dempster et al. 2006). Our results indicate that ASL from Dangerous Reef do not routinely use prey that are associated with the aquaculture structures in southern Spencer Gulf. In contrast, adult females from Breakwater Is, Gliddon Reef and Lounds Is regularly use the proposed aquaculture zone north of Goat Is (Fig. 8.47, Table 8.36). Because the aquaculture zone is close to an important corridor between these ASL colonies and their foraging grounds in Denial Bay, it is likely that these ASL will interact with aquaculture zones more frequently than at Dangerous Reef. Since the commencement of this study, the Goat Is aquaculture zone has been zoned for shellfish only. Australian sea lions are not likely to prey on abalone, but ASL may be attracted by other species that may aggregate in and around the aquaculture structures. If individual ASL utilise fish and invertebrate species that gather around the structures, it is possible that ASL from colonies near the aquaculture zone may benefit as a result of the new, reliable foraging ground.

Aggregations of wild and caged fish (or invertebrates) attract large predators, which sometimes damage aquaculture structures and/or become entangled in them and drown (Kemper and Gibbs 1997, Dempster et al. 2004, 2006, Kemper et al. 2003, Boyra et al. 2004, Robinson et al. 2008). It is likely that ASL will investigate these aquaculture structures for prey or as sites to haul-out, so the structures should be engineered to minimise their potential to entangle and drown ASL. A recent assessment of the risk posed by fisheries related bycatch mortality to subpopulations of ASL in South Australia (Goldsworthy and Page 2007) indicated that as few as 1–3 bycatch mortalities per year would be enough to bring about a quasi-extinction (< 10 females) of the subpopulations at Breakwater Is, Lounds Is and Gliddon Reef. Because these subpopulations are highly vulnerable to becoming quasi-extinct from low-levels of bycatch mortality, it is imperative that interactions between ASL and aquaculture structures proposed for the zones north of Goat Is are closely monitored. Once the aquaculture structures are established, studies of the interactions should include both satellite tracking of adult female and juvenile ASL, and observations of their behaviour around the aquaculture structures.

Spatial management implications

Satellite tracking results demonstrated marked difference in the foraging behaviour of ASL both within and between populations. For adult females (the largest age/sex group of ASL that were studied), varying levels of within and between population differences in foraging behaviour were demonstrated. At Dangerous Reef, there was marked individual variability in the distance and direction to foraging grounds, with at least 4 distinct foraging behaviour ecotypes being identified. In contrast, results from the Nuyts Archipelago identified only 2 main foraging behaviours among the 6 populations investigated, with most individuals within each population specialising either in the *inshore* (NE Franklin, Lounds and Breakwater Is), or *offshore* (Purdie, West and SE Franklin Is) foraging ecotypes. Results indicate that universal foraging distances to guide management of human activities in proximity to ASL colonies are likely to be inappropriate. Given the extreme variability in foraging behaviour both within and between populations, we recommend that population specific data be used to set management guidelines.

Based on the findings of this study, the current aquaculture buffer zones around ASL colonies (15 km for large and 5 km for small colonies) represent a variable fraction of the time spent at-sea, by different age and sex groups within populations (eg 5 km and 15 km buffers represent 7–29 % and 34–73 % for adult females, respectively, and 1–6 % and 6–28 % for adult males, respectively). As such, the level of protection that the zones afford is likely to vary markedly between colonies, and may be of limited value in both reducing the potential prevalence of aquaculture interactions and in protecting critical foraging habitats of ASL populations.

If buffer zones are meant to afford protection from potential negative interactions with aquaculture, then we recommend that appropriate colony-specific buffers zones be developed on a case-by case basis as part of the recommended risk assessment process for minor colonies (Marine Mammal – Marine Protected Areas Aquaculture Working Group 2004). This would require satellite tracking studies of ASL populations adjacent to proposed or existing finfish or shellfish aquaculture. For other colonies, the default buffer zones could remain (but see below).

We recommend the distinction in the scale of the buffer zones required for small (5 km) and large (15 km) populations of ASL be reconsidered. Buffer zones were implemented to reduce both the potential economic impact of seal interactions at finfish farms and the conservation consequences of ASL deaths resulting from finfish farm interactions. Recent population viability analyses (PVAs) of ASL populations have indicated that the conservation impacts of anthropogenic ASL mortalities are most significant for small populations (Goldsworthy et al. 2007a, Goldsworthy and Page 2007). The 60% of ASL populations in South Australia that produce fewer than 30 pups per breeding cycle are highly vulnerable and at greatest risk of extinction. Only 1–2 additional female mortalities are required each year (beyond natural mortality for stable populations) to place small populations in a negative trajectory with quasi-extinction times within 30 years (Goldsworthy et al. 2007a, Goldsworthy and Page 2007). These findings are contrary to the assumption of the current buffer zones that smaller colonies are of least risk. As such, smaller populations should receive the same or greater protection as recommended for larger populations (i.e. minimum of 15 km).

Recommendations

Based on our current level of understanding of the foraging behaviour of ASL and the nature and extent of seal interactions with finfish aquaculture, our main recommendations for the placement of aquaculture zones in the vicinity of ASL haulouts and colonies are:

- The current MM-MPA-AWG (2004) 5 and 15km aquaculture buffer zones have no biological basis in terms of managing the risk to ASL proximity to fin-fish aquaculture and should be reviewed in light of the findings of this report.
- We recommend assessment of the risk of ASL-finfish farm interaction on a site-by-site basis. Such assessments would be based on satellite tracking of a representative number of ASL from colonies adjacent to the proposed aquaculture zone. Given the high vulnerability (risk of extinction) of small ASL colonies, the recommended buffer of 5 km for small ASL colonies (less than 30 pups) should be reviewed and we recommend that, as a starting point, a minimum 15 km buffer zone be adopted for all ASL colonies.
- The distance between important ASL haulouts and finfish farms should also be considered based on tracking studies.
- Consider adopting buffer zone guidelines for other sea-cage aquaculture (shellfish) and/or researching interactions between seals and shellfish farms.

- To reduce the potential for interactions between NZFS and finfish farms (mulloway, kingfish, Atlantic salmon) distance restrictions to haulouts should also be considered, as should buffer zones for other sea-cage aquaculture (shellfish).
- Conduct appropriate spatial analysis of tracking data in order to provide spatial maps of the distribution of foraging effort of seal populations in South Australia and assess the extent of spatial overlap with current and planned finfish and other aquaculture zones.
- To assist in determining if the presence of aquaculture operations affects the behaviour of seals, data on the habitat use of seals in the vicinity of proposed operations prior to and at various stages after operations have been established would be valuable. This study has collected data on the foraging behaviour of ASL within the proposed aquaculture zone in western Eyre Peninsula, providing baseline data to which future studies can be compared.
- Data presented in this report have largely focused on the behavior of ASL. Although available data suggests that NZFS are not the major species causing tuna stock mortality, they have the potential to create significant problems for the aquaculture of smaller finfish species. Further abundance and at-sea distribution data may be required in future in order to mitigate these interactions. Data on foraging habitat use by NZFS in the vicinity of Port Lincoln and the Eyre Peninsula is currently limited.
- Develop a trapping and tracking program of seals that directly interact with finfish aquaculture in the Port Lincoln region. Recent tracking of Australian fur seals and NZFS caught at salmonid finfish farms in Tasmania has demonstrated the extent to which parts of the seal population have adapted to foraging in and around finfish cages, with many seals spending long periods feeding in association with salmonid farms throughout winter months (Robinson et al. 2008). Trapping technology used to capture interacting ASL and NZFS could be adapted and applied to capture and track individuals that interact with finfish farms in South Australia. The new generation of satellite linked GPS tags now available provide much greater precision and increased number of locations at sea, enabling accurate quantification of the time spent at individual finfish cages. Greater information about the behaviour and extent of interaction by the subset of the population that interacts with finfish farms would provide important information to assist managing that part of the seal population into the future. In addition, the deployment of critter-camera technology would provide invaluable footage to demonstrate how seals enter finfish farms and kill farmed fish. Such data would underpin attempts to categorising the nature and extent of injury and probable cause of death of farmed finfish.

9 ASSESSMENT OF DIFFERENT HOME RANGE ESTIMATES AND SPATIAL SCALES TO DESCRIBE THE DISTRIBUTION OF AUSTRALIAN SEA LION FORAGING EFFORT

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Introduction

Food resources are patchily and widely distributed in the marine environment and the foraging success of marine animals is determined by their ability to find and exploit these patches. Marine animals exploiting patchy environments typically move slowly in areas where resources are plentiful and quickly where resources are scarce, because searching for plentiful patches is likely to be more beneficial than remaining in sparse ones. Although marine animals have been shown to respond to these patchy habitats at different spatial scales, most studies consider their behaviour at a single scale. Investigations into the behaviour of individual marine animals and their interactions with their conspecifics, their habitats and their food may therefore benefit from an understanding of their scale-dependent behaviour, which is most likely related to their movement patterns.

Ultimately, the available scale of habitat or other variables being investigated determines the finest relevant scale to investigate the behaviour of marine animals, but several techniques have been used to assess the scales at which animals behave in dynamic habitats. Recently the scale at which individual yellow-nosed albatross respond to different environmental parameters was calculated using first-passage time analysis (Pinaud and Weimerskirch 2005). Individual albatross increased their search effort at different spatial scales in relation to environmental parameters, possibly basing their behaviour on past foraging experiences (Pinaud and Weimerskirch 2005). In some studies, the biological relevance of the spatial scale is not considered, because the scales are set by environmental planning needs or expert perceptions of pertinent scales of importance (Nams et al. 2006). Some studies that have incorporated biologically-relevant scales have either based them on the relative sizes of available habitat types or the home range size of individual animals. However, it can be difficult to measure biologically relevant scales for individuals, because, for example, some animals interact with their environment at multiple scales and the cumulative home range sizes of many animals do not reach an asymptote over time.

Marine animals that display central-place foraging tendencies, such as seabirds and otariid seals, are well suited to an investigation of foraging behaviour at different spatial scales. These marine predators use the marine environment to feed, but return to land to breed and provision their dependent young, which limits their ability to use distant food resources. This separation and the associated energetic cost of commuting are novel factors that affect the fitness of animals that exhibit central place tendencies (Hunt et al. 1986, Forero et al. 2002, reviewed in Gremillet et al. 2004).

The constraint of having to return to land means that cumulative size of a central place forager's home range would be expected to asymptote with time. A home range implies non-random visits to previously used habitats, which indicates that there are associated fitness benefits compared to random dispersal behaviour. For such site fidelity to exist among marine animals, which are searching for prey in a dynamic environment, they must return to previously visited sites more often than expected by chance alone. Home ranges can be measured in many different ways and much research has been conducted to determine the calculation of their extents and structure. A challenge in using home range estimates to infer population processes is the need to calculate the number of location fixes required to assess each individual's cumulative home range. One means of determining whether sufficient locations have been collected is to assess whether the addition of subsequent locations significantly expands the home range area. This approach has been used to assess the accuracy of home range estimates for individual animals (reviewed in White and Garrott 1990).

Similarly, the cumulative home range size of several central place foragers from the same population would be expected to exhibit an asymptotic relationship if they used overlapping foraging grounds. The asymptotic home range has been used to infer the number of individuals required to adequately represent an entire population's home range (Hindell et al. 2003). Hindell et al. (2003) mapped the distribution of elephant seal foraging effort in 350 x 350 km grid cells and found that the cumulative area visited did not significantly increase after 25 seals had been satellite tracked. Such an approach aids in the interpretation of telemetry studies, because in most cases only a small fraction of the total population is studied and these individuals are monitored for a small fraction of their lives. Such investigations may be useful to aid in the interpretation of tracking studies, particularly when either economic and logistic constraints, the species' natural history and/or its conservation status limit the number of individuals that can be studied.

Australian sea lions (ASL) are endemic to Australia and they were recently listed as *Threatened* (*Vulnerable* Category) under *Australian Government EPBC Act 1999*, because they have a relatively small population (11,000 seals, Goldsworthy et al. 2003), which does not appear to have recovered since the sealing era (~1800–1830). Australian sea lion juveniles, adult females and adult males typically forage for 1–3 days and after each trip they typically rest on land for similar durations (Higgins and Gass 1993, Fowler et al. 2006, chapter 8). These regular haul-out periods mean that most ASL exhibit a central place foraging tendency, which increases the potential for overlapping foraging ranges both within and among individuals over time. Diving behaviour and energetic studies indicate that ASL are benthic foragers that dive almost continuously (Costa and Gales 2003). Average dive depths of adult females range from 42–83 m, with maximum dive depths ranging from 60–105 m (Costa and Gales 2003). The diet of ASL is poorly understood, because few diagnostic prey remains can be recovered from their scats (Gales and Cheal 1992), which may be due to the presence of rocks in their stomach (Needham 1997). It is thought that ASL feed on a wide variety of prey including cephalopods, rock lobsters, sharks and other fish species (Gales and Cheal 1992, Ling 1992, McIntosh et al. 2006).

This study was based on the foraging behaviour of juvenile, adult female and adult male ASL from several colonies in South Australia. The objectives of this study were to assess the level of intra-individual and inter-individual variation in ASL foraging locations. Knowledge of this variation underpins models of the distribution of foraging effort of seal populations in proximity to existing finfish aquaculture farms off the southern Eyre Peninsula and in regions currently zoned for finfish farms, but where none currently exist, off the west coast of the Eyre Peninsula. The development of such GIS tools will assist in planning finfish aquaculture sites to minimise the costs of interactions to industry, and risks to seal populations. The first aim of this study was to determine the cumulative number of foraging trips required to represent a significant extent of a single ASL's foraging space. This study also aimed to determine the number of individuals required to cover a significant portion of a population's foraging space, based on the movement patterns of 34 adult female ASL from a single colony. To investigate both of these questions, we analysed the distribution of foraging effort at several spatial scales to determine how this altered the number of individual foraging trips required to represent the foraging space used by an individual and the population.

Methods

Study sites

The seals used in this study were satellite tracked between September 2003 and January 2006 from Dangerous Reef, southern Spencer Gulf, South Australia (34° 49' 58"S 136° 12' 37"E) and from several colonies (Breakwater Is, Lounds Is, NE Franklin Is, SE Franklin Is, Purdie Is and

West Is) in the Nuyts Archipelago, off Ceduna, South Australia (Fig. 9.1 and 9.2). SE Franklin Is and NE Franklin Is were recently named Blefuscu Is and Lilliput Is, respectively, but these names have not been adapted in this report.

Capture and restraint

To deploy satellite tracking equipment, all of the juveniles and lactating females were captured using a hoop-net. Anaesthesia was induced and maintained using Isoflurane® (Veterinary Companies of Australia, Artarmon, New South Wales), administered via a purpose-built gas anaesthetic machine with a Cyprane Tec III vaporiser (Advanced Anaesthetic Specialists, Melbourne). Adult males, which had characteristic blonde manes, were anaesthetised using Zoletil® (Virbac, Sydney, Australia), which was administered intramuscularly using barbless darts (~1.0 to 1.5 mg per kg, 1.5 cc barbless darts: Pneu-Dart®, Pennsylvania, USA), fired from a NO_2-powered tranquilliser gun (Taipan 2000, Tranquil Arms Company, Melbourne, Australia). For all but a few deeply anaesthetised individuals anaesthesia was maintained with Isoflurane® using the equipment and methods outlined above. All of our research procedures were approved by the La Trobe University Animal Ethics Committee, the Primary Industries and Resources SA Animal Ethics Committee and the South Australian Department for Environment and Heritage Animal Ethics Committee.

Data collection

At Dangerous Reef, satellite transmitters (KiwiSat 101, Sirtrack, Havelock North, New Zealand) were deployed on 34 adult females, 7 adult males, 1 subadult male and 7 juvenile males. Dive recorders (TDRs, Mk7, Wildlife Computers, Redmond, Washington) were concurrently deployed on 4 adult females, but not on any males nor animals at other sites. In the Nuyts Archipelago, satellite transmitters were deployed on 30 adult females, 14 adult males, 1 subadult male, 9 juvenile males and 6 juvenile females. Transmitters were glued to the fur on the dorsal midline, using a flexible-setting epoxy (Araldite 2017, Vantico, Basel, Switzerland). To reduce power consumption, transmitters incorporated a salt water switch, which turned the transmitter off when it was underwater and after it had been on land for greater than 6 h.

To recover the satellite tracking equipment some adult females and juveniles were captured using a hoop net, but most animals were given Zoletil® (females: ~1.1 to 1.2 mg per kg, males: as above) prior to capture – administered via dart, using 1.0 cc barbless darts (Pneu-Dart®). Anaesthetised animals were then captured using a hoop-net and restrained by 1 to 4 people, because initial restraint stimulated a flight response in all but a few deeply anaesthetised individuals and in most cases anaesthesia had to be maintained using Isoflurane®. To remove the satellite tracking equipment the animals' guard hairs were cut along the base of the device.

Data analyses

Satellite location data were obtained through Service Argos Inc. The location-class *Z* positions were omitted due to the magnitude of their error (Sterling and Ream 2004). The R statistical software (version 2.3.0, R Development Core Team, R Foundation for Statistical Computing, Vienna) and the timeTrack package (version 1.1–5, M. D. Sumner, University of Tasmania, Hobart) were used to apply the filter described by McConnell et al. (1992), based on the maximum possible horizontal speed of 11.93 km/h (refer to chapter 8 of this report).

For the analysis of the number of seals required to represent the foraging range of the adult female population from Dangerous Reef, we used data from all 34 adult females that had been satellite tracked, regardless of how many foraging trips were recorded. For the analysis of the number of foraging trips required to represent the foraging range of each individual ASL, we used data from individuals for which 20 or more foraging trips were recorded. A foraging trip began when a seal departed from a colony and ended when the seal hauled out on land, which was not always at the same colony. We included all of the completed foraging trips in the analyses of each seals' foraging range.

Once the satellite record for each animal had been broken into separate foraging trips and haulouts, we calculated the total number of foraging trips for each seal and the duration of each foraging trip and each haulout. We calculated the proportion of time at sea as the sum of all foraging trip durations divided by the deployment duration, which was the duration between the start of the first foraging trip and the end of the last haulout. We calculated several parameters to summarise the foraging behaviour of each seal. To classify foraging behaviour as parameters and to weight the parameters by the amount of time spent in each area, the parameters were extracted at 15 min (time) intervals along each interpolated satellite track (except for parameters that described maximums and totals). Behavioural parameters were calculated to describe: (1) The maximum straight-line distance from the colony where the seal was captured to the distal point reached on each foraging trip. (2) The total distance covered on each foraging trip. (3) A site fidelity index was calculated for each foraging trip to summarise whether foraging trips ended at the island where they started. The site fidelity index was calculated by assigning a 1 to trips where the start and end point was the same and a 0 if they were different, with the index being the mean of these values. The site fidelity index has a maximum of 1 and a minimum of 0, with relatively high indices implying that a high proportion of foraging trips ended where they started. (4) Finally, the length of the mean compass bearing (*r*) was calculated using Oriana (version 2.02, Kovach Computing Services, Pentraeth, Wales). The *r*-value has a maximum of 1 and a minimum of 0, with relatively high *r*-values implying that a high proportion of locations were concentrated around the mean compass bearing and are therefore unlikely to be uniformly distributed.

We assumed a constant horizontal speed between the filtered locations and interpolated a new position for each minute (of time) along the satellite track for each foraging trip conducted by each individual, using the R statistical software and the timeTrack package. The number of original and interpolated positions, which were located within each grid cell of predetermined grids, were then summed and assigned to a central node (centre of each rectangular grid square). To examine the effect of different spatial scales on the number of grid cells visited by each individual, the grid cells visited were extracted at resolutions of 1 x 1 km, 2 x 2 km, 5 x 5 km and 10 x 10 km. We then summarised the number of grid cells entered by: 1) each seal on each foraging trip, and 2) each adult female from Dangerous Reef on all of their foraging trips.

Following the approach of Hindell et al. (2003), we calculated the total spatial extent occupied by: 1) each individual seal, and 2) all of the adult females from Dangerous Reef. We initially selected, at random, one of the trips/seals and calculated the total number of grid cells entered on the trip/overall. Next we selected a second seal, at random, from the other trips/seals and calculated the number of unique grid cells entered on the trip/overall. We repeated this procedure until all trips/seals were included in the calculation of the cumulative number of grid cells entered. We then used a Monte Carlo bootstrap technique to estimate the mean use and the associated variance (Manly 1997, Chernick 1999). We repeated the above process 10,000 times for each trip/seal, calculating the cumulative number of grid cells entered for *j* trips/seals, plus the associated standard deviation ($\hat{\sigma}_{boot}$):

$$\hat{\sigma}_{boot} = \sqrt{\frac{n-1}{n}} \left(\sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - x_j)^2} \right),$$

where *n* is the number of iterations, *x* is the mean number of grid cells entered for the j^{th} trip/seal at iteration *i* (Chernick 1999). Using this method different trips/seals were chosen, at random, for each of the 10,000 iterations.

The resulting data (mean number of grid cells visited for each trip/seal) were plotted using Curve Expert (v1.37) and a Gompertz function was used to calculate the asymptotic number of grid cells entered for each trip/seal, which was interpreted as the maximum number of grid cells entered for *j* trips/seals. We then calculated 95 % of the maximum number of grid cells entered for *j* trips/seals and interpreted this as representing a significant extent of the foraging range for each trip/seal. Based on the Gompertz function, we then calculated the number of trips/seals required to achieve 95 % coverage of the total foraging range.

We compared a different means of expressing ASL foraging ranges by calculating kernel home ranges for the 34 females from Dangerous Reef, using the Animal Movement extension (Hooge and Eichenlaub 1997) within ArcView GIS 3.2a. Kernel home ranges can be useful measures of home range because they present the probability of finding an animal at any location at any time. Home ranges were not calculated separately for each trip, so the number of trips required to represent the kernel home range of an individual was not determined. To ensure that the different deployment durations recorded for different seals did not bias comparisons, we randomly sampled 500 of the 1 min interval locations for each seal and used these 500 points to calculate the kernel home ranges. These kernel home ranges were first calculated for cells of 1 x 1 km (smoothing factor, H = 0.02 for all individuals) and are presented as the 50 % and 95 % probability kernels for each individual. The kernel ranges were then plotted using VerticalMapper® (version 2.5, MapInfo Corporation, New York) and MapInfo® (version 8.0) and predetermined grids were overlayed to determine the number of grids cells entered by each kernel. If any part of a seal's kernel home range entered a grid cell it was regarded as entered by that individual. To examine the effect of different spatial scales on the number of grid cells visited by each individual, the grid cells visited were extracted at resolutions of 1 x 1 km, 5 x 5 km and 10 x 10 km.

Results

Assessing the foraging space used by individual ASL

Of the 49 ASL tracked at Dangerous Reef, sufficient foraging trips (n ≥ 20) were recorded by 7 adult females, 3 adult males and 3 juvenile males to assess the number of foraging trips required to cover a significant extent of each individual's foraging space (Table 9.1). In the Nuyts Archipelago, sufficient numbers of foraging trips were recorded by 9 adult females (2 from Breakwater Is, 1 from Lounds Is, 1 from NE Franklin Is, 1 from Purdie Is and 4 from SE Franklin Is) and 4 juvenile males (3 from West Is and 1 from Purdie Is), giving totals of 16 adult females, 3 adult males and 7 juveniles for these analyses (Table 9.1).

The average number of foraging trips used to describe the behaviour of individuals was: 49 ± 35 SD (adult female), 37 ± 14 (adult male) and 32 ± 8 (juvenile male). The mean trip durations and proportions of time spent at sea for these ASL were similar for the age/sex groups: 1.1 ± 0.7 d, 51 ± 9 % (adult female), 1.3 ± 0.3 d, 63 ± 18 % (adult male) and 1.1 ± 0.4 d, 49 ± 5 % (juvenile male) (Table 9.1). Adult males travelled further to forage than adult females and juveniles, which travelled similar distances. The mean maximum distances and mean total distances travelled by each age/sex group were: 31.4 ± 24.2 km, 89.9 ± 82.0 km (adult female), 55.0 ± 29.3 km, 134.0 ± 57.0 km (adult male) and 29.2 ± 15.2, 76.8 ± 41.1 km (juvenile male) (Table 9.1). The mean site fidelity index for each age/sex group indicated that 76 ± 23 % and 80 ± 41 % of the trips made by adult females and juvenile males ended at the same colony as they started and 53 ± 41 % of the trips made by males ended at the same colony (Table 9.1). The grand means of the circular distances (adult females: 0.77 ± 0.20, adult males: 0.87, juvenile males: 0.67) imply that each individual typically foraged along a similar bearing on successive foraging trips. However, the circular distance ranged from 0.29 to 0.99, indicating considerable variation in the bearings that individuals travelled on different trips (Table 9.1).

Successive foraging trips conducted by each ASL typically went to similar areas, even if they used other haulouts (eg Fig. 9.1). The shape of the curves, which depicted the number of grid cells visited on each foraging trip relative to the number of trips conducted, were typically different among individuals (Table 9.1), but similar within individuals for the four spatial scales investigated (Table 9.1, Fig. 9.2). The data demonstrated the typical shape of a sigmoidal curve, which exhibits an asymptote, and the Gompertz function fitted the data well in all cases, with the lowest r^2 value of 0.991. As expected, at broader spatial scales the cumulative number of grid cells visited typically asymptote at a lower number of foraging trips, because the larger scale encompassed relatively more cells, particularly those that were close to the colony and in foraging hotspots (Table 9.1, Fig. 9.1). At finer spatial scales, the asymptote values were relatively high, because even individuals that repeatedly used a similar area to forage still deviated enough to visit new cells (Table 9.1, Fig. 9.1).

In most cases the asymptotic number of foraging trips recorded was similar to the number of foraging trips recorded for each individual, because individuals typically visited new cells on most foraging trips. For each of the spatial scales investigated, the mean number of foraging trips required to visit 95 % of the asymptotic number of grid cells was significantly, positively correlated to the number of foraging trips recorded, for the age/sex groups combined ($r^2 > 0.920$, $P < 0.001$, n = 26 in all cases), for adult females ($r^2 > 0.924$, $P < 0.001$ n = 16 in all cases) and juvenile males ($r^2 > 0.821$, $P < 0.024$, n = 7 in all cases), but not for adult males ($r^2 < 0.991$, $P < 0.310$, n = 3 in all cases). However, the mean number of foraging trips required to visit 95 % of the asymptotic number of grid cells was not significantly correlated to any of the other foraging trip parameters for any of the age/sex groups or for the age/sex groups combined ($r^2 > 0.050$ in all cases).

Table 9.1. The foraging trip parameters for each individual ASL and the number of foraging trips required for each ASL to visit a significant extent (95 % of the asymptote) of their total foraging range, at different spatial scales.

												No. trips required to visit 95% of all cells used			
Seal no.	Island	No. of foraging trips	Mean trip duration (d)	SD	Time at sea (%)	Mean max. distance (km)	Mean total distance travelled (km)	SD	Mean site fidelity index	SD	Circular distance (*r*-value)	1 x 1 km cells	2 x 2 km cells	5 x 5 km cells	10 x 10 km cells
Adult female															
181	Breakwater	35	1.0	0.4	57	14.5	54.1	22.7	0.69	0.47	0.92	33	34	31	30
281	Breakwater	22	0.6	0.3	51	18.7	33.2	16.2	0.41	0.50	0.92	25	25	26	27
461	Lounds	114	0.7	0.4	51	27.9	42.0	22.6	0.99	0.09	0.99	126	142	130	95
341	NE Franklin	33	0.6	0.3	47	9.8	39.2	20.4	0.55	0.51	0.81	38	37	39	44
331	Purdie	25	2.0	0.9	53	55.7	190.0	75.7	0.92	0.28	0.87	49	21	16	18
251	SE Franklin	67	1.5	1.2	65	48.5	145.0	128.8	0.76	0.43	0.71	67	56	50	46
351	SE Franklin	38	2.5	1.1	61	97.3	298.8	143.7	0.66	0.48	0.91	38	34	33	34
451	SE Franklin	37	2.7	1.2	65	65.5	234.6	114.2	1.00	0.00	0.86	35	32	36	37
651	SE Franklin	132	0.6	0.3	53	13.3	51.0	26.5	0.99	0.09	0.62	134	127	120	122
111	Dangerous	68	0.8	0.5	50	28.9	47.8	26.8	0.69	0.47	0.78	69	62	56	46
311	Dangerous	91	0.8	0.5	49	14.5	54.6	32.9	0.89	0.31	0.57	76	72	64	50
1111	Dangerous	23	0.7	0.4	52	15.4	45.2	16.2	0.78	0.42	0.59	30	27	19	17
1411	Dangerous	20	0.4	0.2	32	12.2	31.4	9.6	1.00	0.00	0.29	23	22	17	8
10711	Dangerous	20	0.8	0.7	33	15.8	35.3	10.6	0.65	0.49	0.71	24	19	14	17
11211	Dangerous	35	1.1	0.6	55	34.3	67.6	26.3	0.26	0.44	0.86	34	29	27	39
12011	Dangerous	23	1.1	0.8	49	30.0	69.0	53.3	1.00	0.00	0.83	30	25	19	19
1211	Dangerous	12	0.7	0.5	31	10.1	34.9	22.4	1.00	0.00	0.78	-	-	-	-
1311	Dangerous	14	0.9	0.9	53	13.3	47.4	18.8	1.00	0.00	0.57	-	-	-	-
1511	Dangerous	18	0.7	0.7	45	12.0	35.2	19.6	1.00	0.00	0.35	-	-	-	-
1611	Dangerous	18	0.4	0.2	36	12.4	29.2	11.1	1.00	0.00	0.40	-	-	-	-
1711	Dangerous	18	0.7	0.2	48	14.7	44.6	12.3	1.00	0.00	0.67	-	-	-	-
1811	Dangerous	19	0.3	0.1	20	14.7	25.0	9.8	0.47	0.51	0.83	-	-	-	-
10011	Dangerous	19	0.7	0.5	47	38.7	37.5	19.9	0.37	0.50	0.97	-	-	-	-
10111	Dangerous	6	1.3	1.4	48	18.8	60.7	32.6	0.67	0.52	0.47	-	-	-	-
10211	Dangerous	6	1.2	1.3	58	23.6	63.5	19.5	1.00	0.00	0.51	-	-	-	-
10411	Dangerous	11	0.8	0.6	53	24.3	46.5	23.6	0.73	0.47	0.74	-	-	-	-
10511	Dangerous	7	0.8	0.6	46	14.2	43.6	24.1	1.00	0.00	0.73	-	-	-	-
10611	Dangerous	13	1.9	2.0	31	31.6	53.7	19.9	0.85	0.38	0.91	-	-	-	-
10811	Dangerous	3	0.9	0.5	56	9.9	39.4	10.2	1.00	0.00	0.63	-	-	-	-
10911	Dangerous	15	1.2	1.7	34	16.3	35.7	13.6	0.73	0.46	0.38	-	-	-	-
11011	Dangerous	8	1.8	0.8	63	41.4	99.0	50.3	0.75	0.46	0.77	-	-	-	-
11111	Dangerous	7	1.4	0.5	51	34.1	81.9	20.9	1.00	0.00	0.93	-	-	-	-
11311	Dangerous	8	2.0	0.7	62	77.4	171.4	48.5	0.75	0.46	0.91	-	-	-	-
11411	Dangerous	5	2.1	2.1	43	60.6	139.8	105.6	0.60	0.55	0.98	-	-	-	-
11511	Dangerous	9	2.4	1.8	62	66.9	139.9	79.3	0.11	0.33	0.96	-	-	-	-
11611	Dangerous	18	1.7	1.3	70	47.6	108.7	79.1	0.56	0.51	0.87	-	-	-	-
11711	Dangerous	6	1.9	1.1	59	14.5	40.4	10.3	1.00	0.00	0.88	-	-	-	-
11811	Dangerous	3	0.6	0.4	11	4.8	13.0	11.6	1.00	0.00	0.73	-	-	-	-
11911	Dangerous	16	1.1	1.1	59	14.5	47.3	29.3	1.00	0.00	0.72	-	-	-	-
12111	Dangerous	5	1.6	1.1	39	24.1	44.2	13.3	0.40	0.55	0.95	-	-	-	-
12211	Dangerous	13	0.9	0.2	44	23.1	53.3	10.7	0.85	0.38	0.51	-	-	-	-
12311	Dangerous	13	0.8	0.6	37	22.8	43.8	28.5	0.69	0.48	0.85	-	-	-	-
12411	Dangerous	12	1.0	0.5	34	45.6	67.5	32.3	0.42	0.51	0.89	-	-	-	-
Adult male															
212	Dangerous	46	1.3	0.9	83	32.7	179.1	149.6	0.07	0.25	0.67	51	49	45	42
412	Dangerous	44	1.6	0.7	60	88.2	153.0	71.1	0.82	0.39	0.97	46	41	32	30
3112	Dangerous	21	1.0	0.8	46	44.1	70.0	58.9	0.71	0.46	0.98	27	23	19	20
Juvenile male															
2014	Dangerous	34	0.7	0.3	46	18.0	56.9	27.1	0.71	0.46	0.53	35	36	33	39
10314	Dangerous	38	1.0	0.4	44	30.1	60.8	17.8	0.68	0.47	0.68	40	39	39	42
12514	Dangerous	40	1.3	1.1	51	29.5	56.6	33.7	0.85	0.36	0.77	47	40	35	30
234	Purdie	21	1.8	1.1	60	61.0	167.0	108.4	0.57	0.51	0.82	29	25	18	16
634	Purdie	21	1.0	0.6	45	27.4	76.4	50.2	1.00	0.00	0.60	31	30	26	21
934	Purdie	38	1.0	0.7	48	23.6	73.6	47.7	0.89	0.31	0.64	50	49	46	38
224	West	29	0.6	0.3	48	14.7	46.5	28.8	0.90	0.31	0.79	37	37	37	33
Dang Reef ad. fem: mean, SD		17	1.1	0.5	46	26.0	58.8	35.1	0.77	0.25	-	-	-	-	-
Individuals with more than 20 foraging trips															
Adult female: mean, SD		49	1.1	0.7	51	31.4	89.9	82.0	0.76	0.23	0.77	52	48	44	41
Adult male: mean, SD		37	1.3	0.3	63	55.0	134.0	57.0	0.53	0.41	0.87	41	38	32	30
Juv. male: mean, SD		32	1.1	0.4	49	29.2	76.8	41.1	0.80	0.15	0.69	38	37	33	31

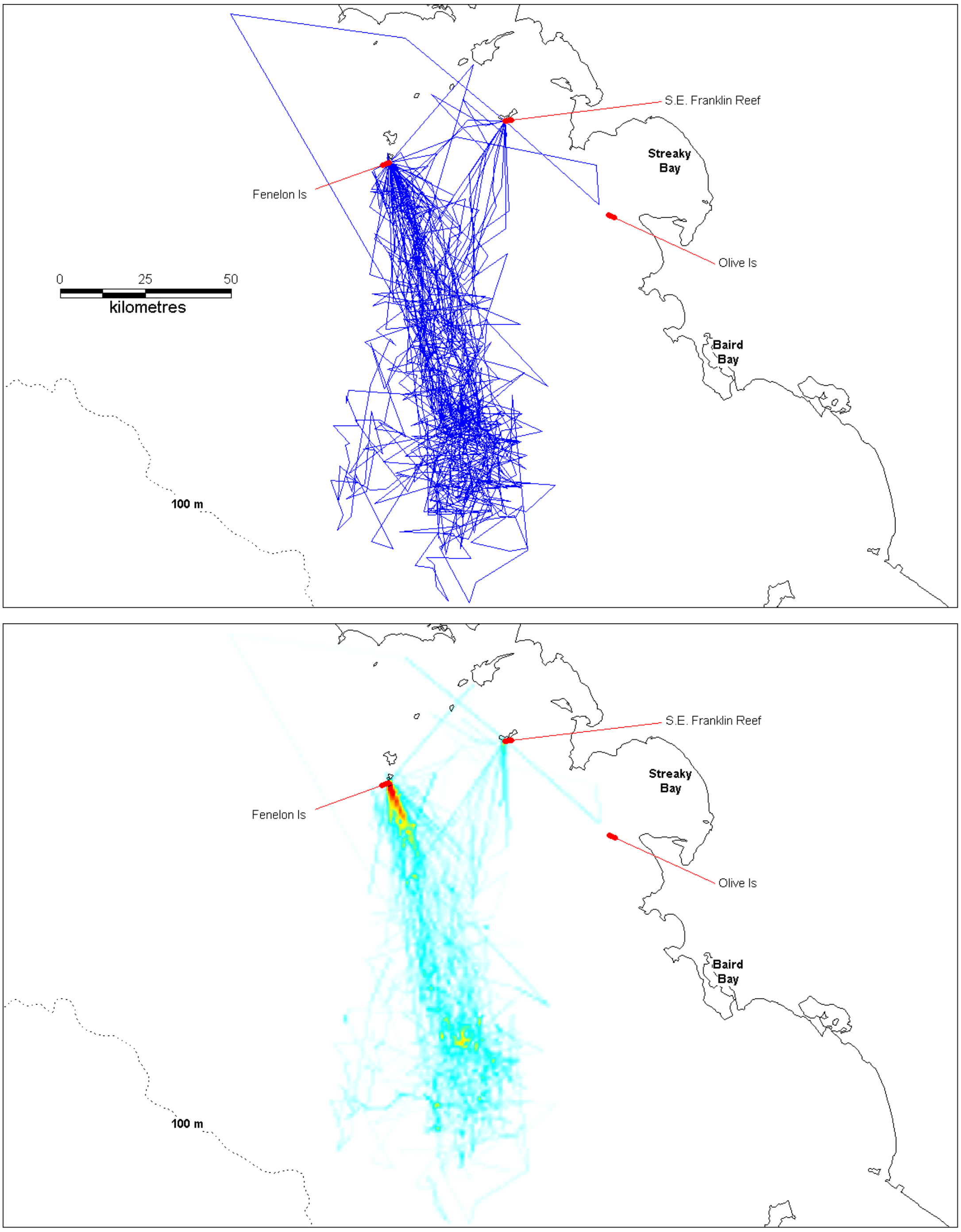

Fig. 9.1. An example of the tracks based on 132 foraging trips (top panel) and the time spent in 1 x 1 km grid cells (bottom panel) by an adult female ASL (seal 651) from SE Franklin Is. On the time spent in area map, red represents regions where the seal spent more time followed by orange, yellow, green and finally blue areas, where the seal spent relatively little time. Other islands in the region and the 100 m depth contour are shown.

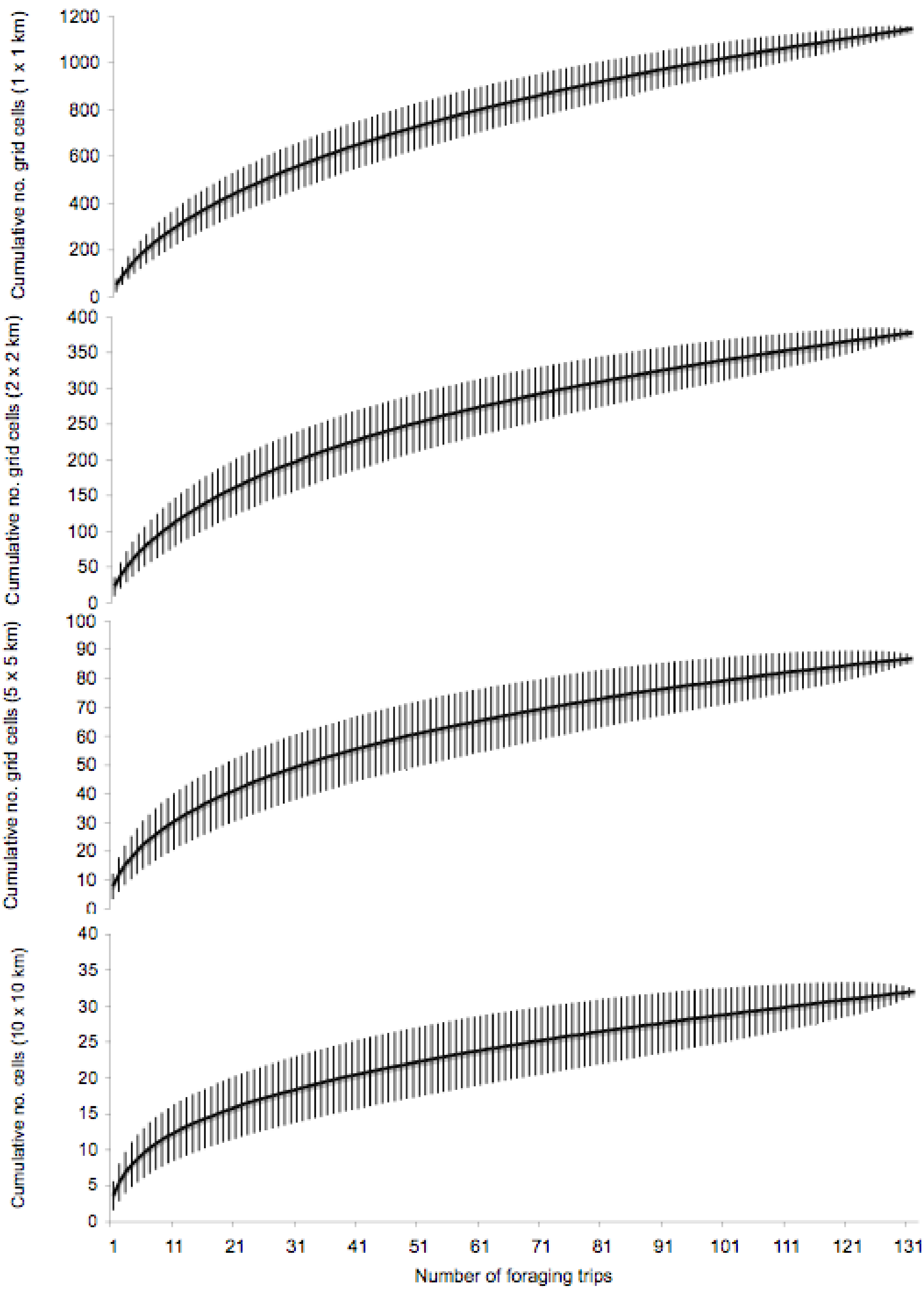

Fig. 9.2. An example of the mean and standard deviation of the number of foraging trips conducted relative to the cumulative number of grid cells visited by adult female ASL (seal 651) from SE Franklin Is. For each spatial scale, the respective number of foraging trips required to reach both the asymptotic number of foraging trips and 95 % of the asymptote were: 1 x 1 km: 141 and 134, 2 x 2 km: 134 and 127, 5 x 5 km: 126 and 120, 10 x 10 km: 128 and 122 (Table 9.1). These data demonstrate the asymptotic nature of the curves and the general similarities between the four spatial scales.

Assessing the foraging space used by adult female ASL from Dangerous Reef

The average number of trips used to describe the foraging behaviour of the adult female population at Dangerous Reef was 17 ± 18 SD (Table 9.1). The mean trip durations and proportions of time spent at sea for these ASL were: 1.1 ± 0.5 d and 46 ± 13 % (Table 9.1). The mean maximum distances and mean total distances travelled by adult females at Dangerous Reef were: 26.0 ± 17.3 km and 58.8 ± 35.1 km (Table 9.1). The mean site fidelity index indicated that 77 ± 25 % of the trips made by adult females from Dangerous Reef ended at the same colony as they started (Table 9.1).

Adult female ASL from Dangerous Reef dispersed widely to forage and many of them used other haulouts whilst foraging in distant waters (Fig. 9.3). The shapes of the curves, which depicted the number of grid cells visited relative to the number of individuals tracked, were similar for the three different means of assessing the size of the foraging space and for the three spatial scales investigated (Table 9.2, Fig. 9.4–9.6). The data demonstrated the typical shape of a sigmoidal curve, which exhibits an asymptote, and the Gompertz function fitted the data well in all cases, with the lowest r^2 value of 0.990.

For each of the spatial scales investigated, the mean number of individuals required to visit 95 % of the asymptotic number of grid cells was similar to, or greater than, the number of individuals that had been satellite tracked, because most individuals visited some unique cells. For each of the methods investigated, the mean number of individuals ranged from: 1) actual cells visited: 35–41, 2) 50 % kernel: 45–52, 3) 95 % kernel: 38–48 (Table 9.2, Fig. 9.4–9.6).

Based on the actual number of cells visited (Fig. 9.4), the asymptote was reached after fewer individuals when the analyses were run at broader spatial scales, because the larger scale encompassed relatively more cells, particularly those that were close to the colony and in foraging hotspots (Table 9.1, Fig. 9.3). At finer spatial scales, the asymptote values were relatively high, because even individuals that used similar areas deviated enough to visit unique cells (Table 9.1, Fig. 9.4–9.6). Conversely, the 50 % and 95 % kernel density functions did not always asymptote slowly at fine spatial scales and quickly at broader spatial scales, because of the impact of outlying kernels in distant waters (Fig. 9.3, 9.5–9.6). The mean number of individuals that were required to describe the foraging space, based on the broad scale kernel density functions, was relatively high, because the kernel estimates did not include the regions alongside the colony for individuals that commuted quickly in this region. For these individuals, which typically foraged at greater distances from Dangerous Reef, there were proportionally more unique cells visited per individual and at broad spatial scales, these effectively increased the asymptotic number of individuals (Fig. 9.3).

To describe the bearings travelled by adult females from Dangerous Reef, the circular distance was calculated. The grand mean circular distance for all adult females (r = 0.72 ± 0.20), and 2) using 500 randomly selected locations from each female, but treating all adult females as a single factor (r = 0.25). The relatively high grand mean indicates that intra-individual variation in circular distance was lower than inter-individual variation. This implies that each adult female foraged along a similar bearing on successive trips, but that different adult females used disjunct foraging areas, which were more spread out around Dangerous Reef (Fig. 9.3).

Table 9.2. The number of cells visited based on the tracking of the 34 adult female ASL from Dangerous Reef, showing the results of the three means of estimating their home range: 1) the actual cells visited, 2) the 50 % probability kernel and 3) the 95 % probability kernel. The number of cells visited was calculated at 3 spatial scales: 1 x 1 km, 2 x 2 km and 5 x 5 km.

	Asymptote (a)	Asymptote x 95% (a x 0.95)	No. of seals to visit a x 0.95
Cells visited			
1 x 1 km	5795	5505	41
2 x 2 km	1703	1618	38
5 x 5 km	330	313	35
50% kernel			
1 x 1 km	1345	1278	52
2 x 2 km	327	311	45
5 x 5 km	62	59	47
95% kernel			
1 x 1 km	7040	6688	38
2 x 2 km	1755	1667	38
5 x 5 km	141	134	48

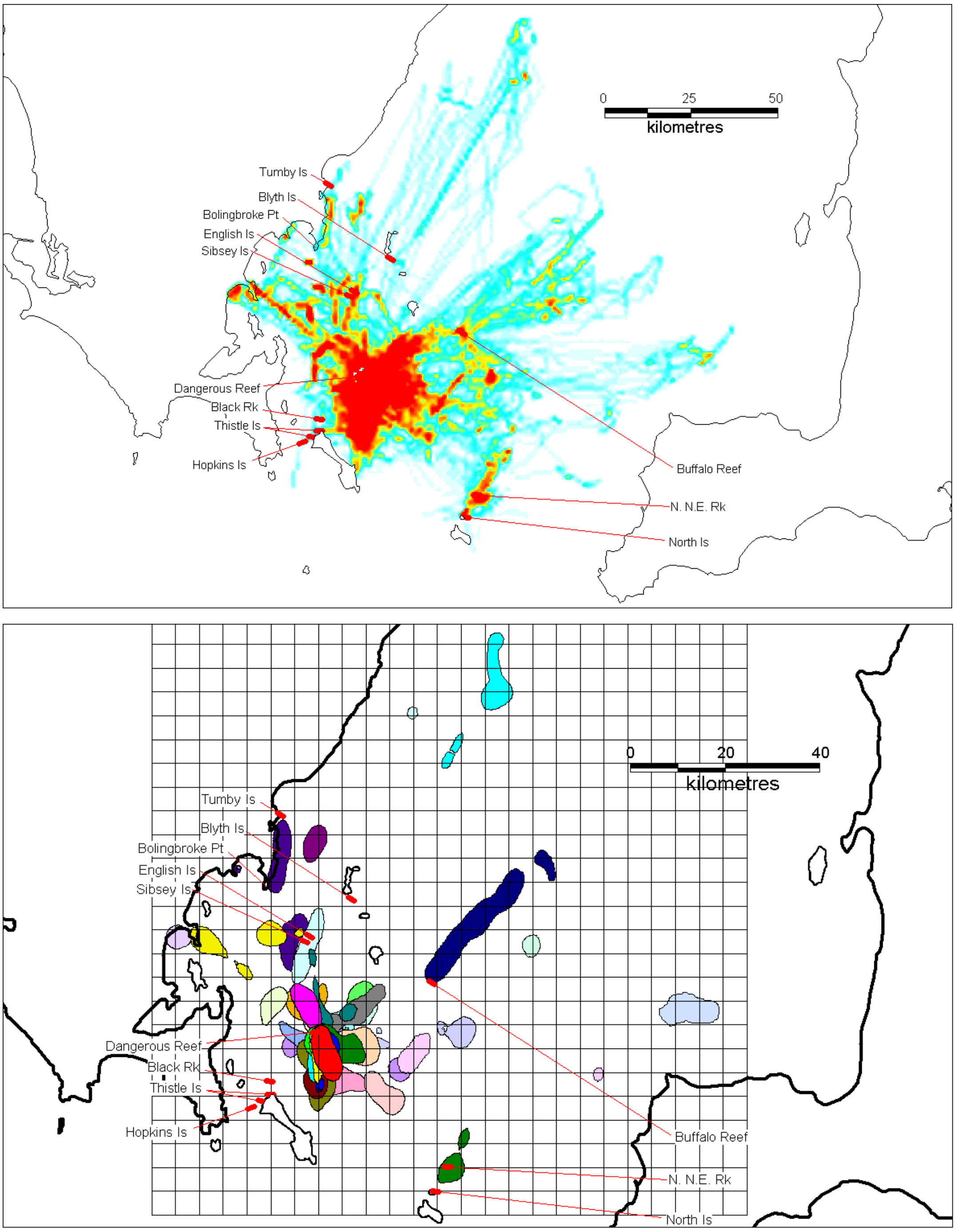

Fig. 9.3. The foraging areas used by 34 adult females from Dangerous Reef, expressed as time spent in area (top plot) and 50 % kernel probability plots (bottom plot). Islands used by at least 1 adult female are shown. Top plot: time spent in 1 km^2 cells by adult females, where red represents regions where seals spent more time followed by orange, yellow, green and finally blue areas where seals spent relatively little time. Bottom plot: kernel home ranges of the 34 adult female ASL satellite tracked from Dangerous Reef. Kernel home ranges are presented in different colours for each individual. The grid is 5 x 5 km, which was used to determine which cells each ASL visited.

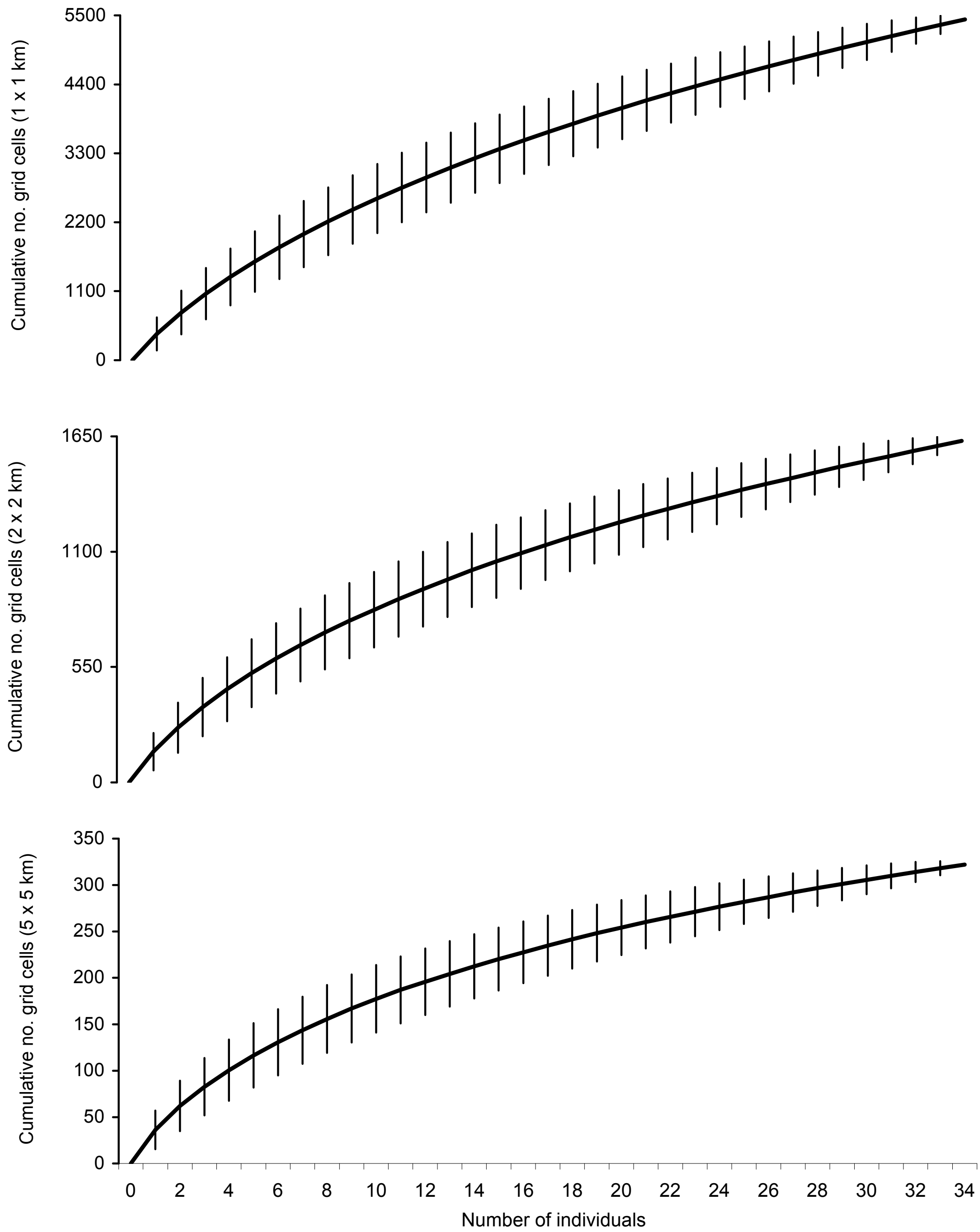

Fig. 9.4. Based on the actual number of cells visited, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of individuals required to reach 95 % of the asymptotic number of grid cells visited were: 1 x 1 km: 41, 2 x 2 km: 38, 5 x 5 km: 35 (Table 9.1). These data demonstrate the asymptotic nature of the curves and the general similarities between the three spatial scales.

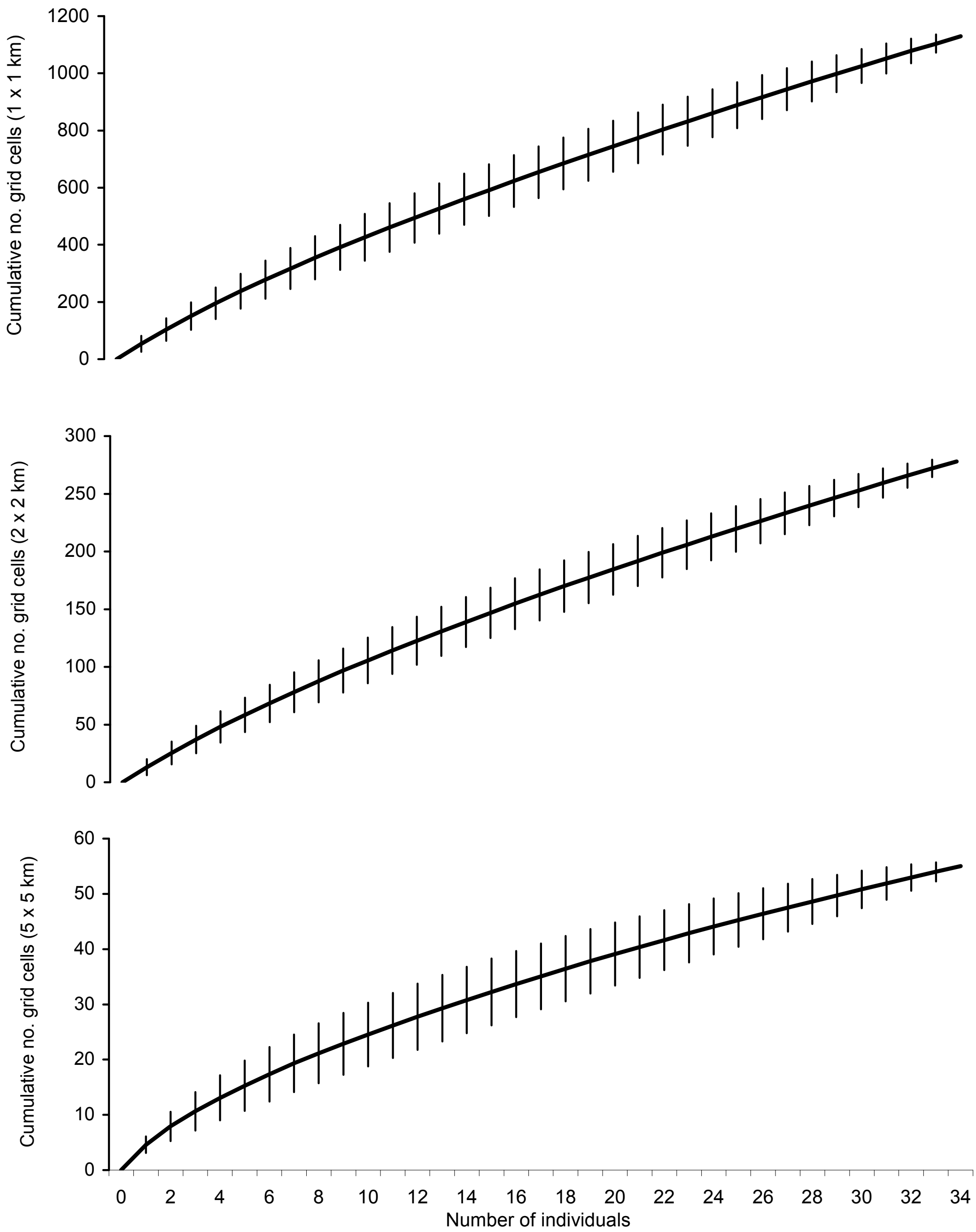

Fig. 9.5. Based on the 50 % kernel density function, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of individuals required to reach 95 % of the asymptotic number of grid cells visited were: 1 x 1 km: 52, 2 x 2 km: 45, 5 x 5 km: 47 (Table 9.1). These data demonstrate the asymptotic nature of the curves and the general similarities between the three spatial scales.

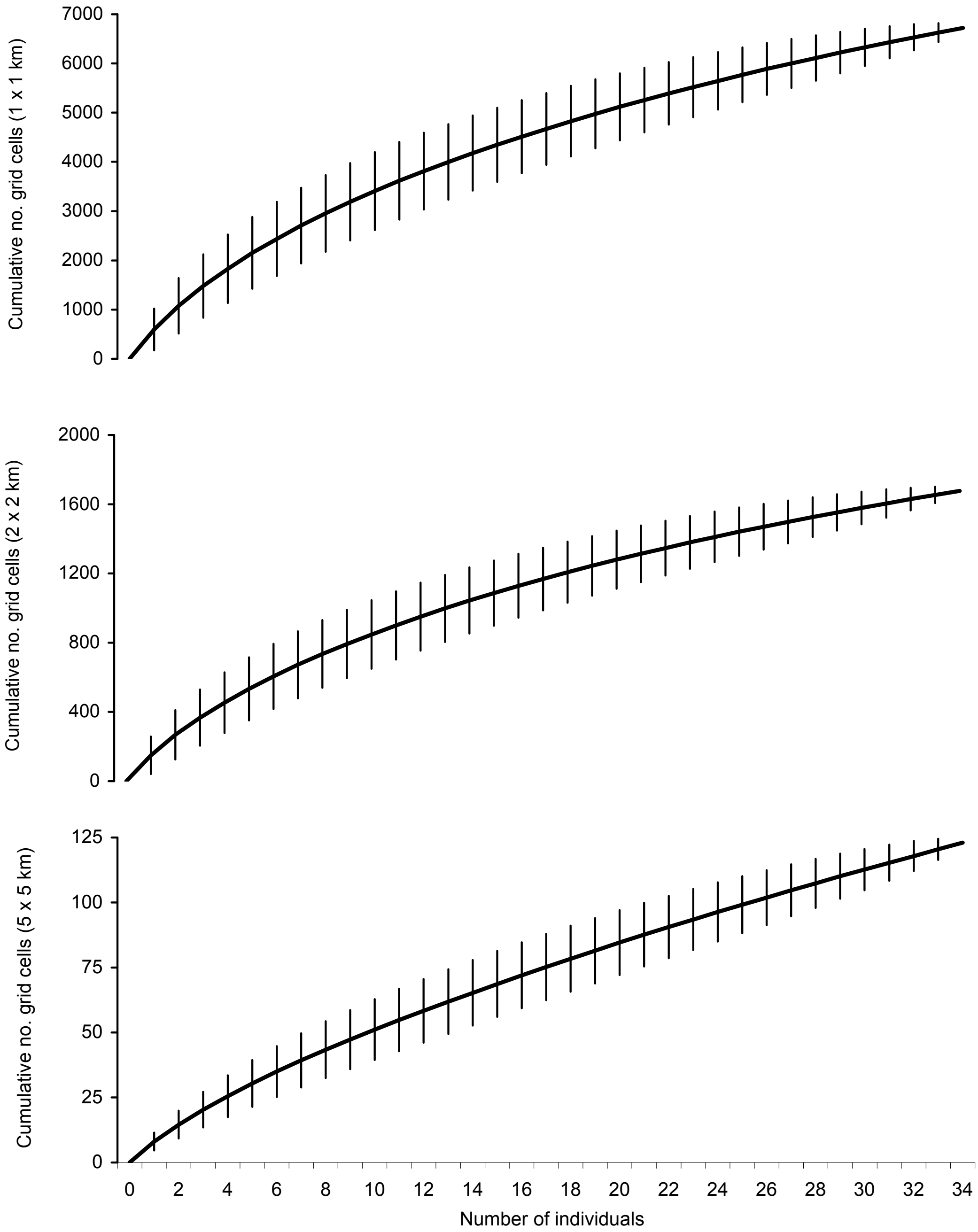

Fig. 9.6. Based on the 95 % kernel density function, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of individuals required to reach 95 % of the asymptotic number of grid cells visited were: 1 x 1 km: 38, 2 x 2 km: 38, 5 x 5 km: 48 (Table 9.1). These data demonstrate the asymptotic nature of the curves and the general similarities between the three spatial scales.

Discussion

We examined the potential suitability of using two different measures (the grid cells visited and kernel home ranges) of the foraging space used by ASL. For each of these different measures of home range, we assessed a range of spatial scales that could potentially be employed to refine our understanding of: 1) ASL foraging behaviour, 2) ASL foraging habitats and 3) potential interactions between ASL and fishing/aquaculture operations. These means of describing the foraging space of ASL are discussed below, with respect to their potential to improve the analysis of satellite tracking data and the management of protected species.

A previous study that described the behaviour of a large ocean predator, using the methods that we followed, found that at least 25 adult female southern elephant seals were required to estimate the foraging distribution of the entire population (Hindell et al. 2003). The grid cells used by Hindell et al. (2003) (350 x 350 km) were much larger than the ones that we used because the elephant seal foraging locations were determined using geolocation data loggers, which are accurate to ± 100 km, and also because each elephant seal's foraging grounds extends over thousands of kilometres of the Southern Ocean (Hindell et al. 2003). Geolocation devices and such large grid cells could not be used to describe the foraging locations of ASL, which typically forage within 100 km of their colonies (Table 9.1). The smaller grid cells assessed in our study resulted in a high number of grid cells being visited, relative to the distances travelled. As a result of the small foraging ranges of the adult female ASL from Dangerous Reef, the numbers of ASL required to cover 95 % of the total foraging space was greater than the number of elephant seals. Not surprisingly, an increased grid cell size reduced the number of ASL required to represent the population response, based on the numbers of grid cells visited. If even larger grid cells (> 15 x 15 km) were used to assess the foraging space used by adult females from Dangerous Reef, then the foraging ranges of many individuals would be encompassed by a single grid cell. Although the data could be analysed in this way, we used finer scale grids to assess the foraging ranges in as much detail as possible. For example, if larger grid cells were used, the grid cells used by ASL that foraged close to the colony would not have any impact on the foraging space used by the population, because all seals commuted through the nearshore cells.

Although we removed the satellite locations where individuals exceeded their swim speed capacity, it is likely that the inaccuracy of some remaining locations exaggerated the estimate of the number of trips/individuals were required to cover 95 % of the foraging space. The accuracy of satellite locations obtained in this study ranged from ± 0.15 to ± 10 km, which varies in relation to the number of uplinks used to determine the location (Sterling and Ream 2004). Inaccurate locations, which are outside the normal foraging range, increase the number of grid cells visited and as a result the cumulative number of cells visited on that trip and/or by that individual would be artificially high. This problem is apparent in figure 9.1, in which the hits to the northwest and to the southeast of SE Franklin Is may be inaccurate locations that passed the swim speed filter. Although it is not possible to determine whether these locations were anomalous, future studies may benefit by assessing the impact of filtering the data with a lower swim speed threshold. In the present study, many of the brief foraging trips were characterised by < 5 satellite locations and these foraging trips may be entirely filtered if the swim speed threshold is greatly reduced. Furthermore, when more accurate tracking devices are available, such as GPS logging trackers, the data will be more suited to assessing the foraging behaviour at fine scales (eg < 1 km).

The adult females from Dangerous Reef were able to forage in all directions around the colony (Fig. 9.3). Some ASL colonies are located close to mainland Australia or on large islands, which reduces the potential directions of travel (and therefore the available foraging space) by almost half (eg Fowler et al. 2006). Although some colonies are not near the mainland, different individuals still travel along similar bearings and forage in similar locations (chapter 8). By not foraging at all points of the compass, ASL from such colonies do not disperse as widely as the adult females at Dangerous Reef. The individuals at Dangerous Reef may use twice the number of grid cells that ASL from some colonies potentially visited. As a result, the number of trips/individuals required to determine the total number of cells used at some ASL colonies may be less than the minimum numbers estimated for Dangerous Reef.

The kernel home ranges summarised the most import 50 and 95 % of each individual’s foraging range and as a result, areas where individuals travelled relatively quickly were not included in the kernel densities. Individuals that commuted rapidly in nearshore waters typically foraged further from the colony and their foraging ranges overlapped very little with those of other individuals (Fig. 9.3). Because they travelled further, these individuals contributed relatively more unique cells to the cumulative number of cells visited by the adult females from Dangerous Reef (Table 9.1). Future studies that assess the foraging space used by individuals from a population may benefit by classifying individuals based on characteristics of their foraging behaviour (eg mean maximum distance from colony; see chapter 8 for an example of this classification) and then assessing the foraging space of subsets of individuals at different spatial scales. It is likely that the foraging behaviour of individuals that forage in close proximity to their colonies could be described at finer spatial scales, because fewer individuals would be required to reach the asymptotic number of cells visited. Conversely, the foraging behaviour of individuals that forage in distant waters may be best assessed at very broad spatial scales, particularly if these animals forage in disjunct regions.

We did not find any relationships between the foraging trip parameters and the numbers of foraging trips required to achieve 95 % coverage of the total number of cells visited. We expected that fewer trips would be required to cover the foraging space of individuals that foraged closer to their colony, compared with animals that travelled further from the colony, because these latter individuals had the potential to visit more new cells on each trip. The inaccuracy of satellite locations may have artificially increased the number of cells visited on each trip, but we expected this would have a similar effect on all individuals. This lack of a relationship between the foraging trip parameters and the numbers of foraging trips required could occur if individuals foraging in nearshore waters did not always forage in the same area on successive trips, thereby visiting new cells despite the short distance they travel. Conversely, individuals that utilised distant waters appear to have shown strong site fidelity in their foraging locations on successive trips, thereby visiting relatively few new cells despite the long distances they travel.

Central-place foragers, such as sea lions and fur seals are thought to expend more energy when they swim to distant foraging grounds in search of prey, than when utilising nearshore foraging grounds (Arnould et al. 1996). Adult female ASL that forage close to the colony would most likely expend less energy than those that travel to distant waters, but these females may show increased site fidelity if the distant regions are more fruitful compared to nearshore habitats. Some fur seal foraging behaviour studies support this idea, because individuals that invest more time travelling to pelagic waters often exploit prey in shallower depths, compared with females on shorter trips (e.g. Boyd et al. 1991, Arnould et al. 1996, Page et al. 2005b). Similarly, individuals undertaking longer trips may be compensated for the additional energy they expend if the prey they use contains more energy than those found locally or if prey are more abundant and easier to catch in distant waters. If it is true that prey are more difficult to procure in the waters adjacent to Dangerous Reef, then adult female ASL would be expected to forage over broader areas on successive trips to avoid repeatedly using the small areas that they had previously exploited.

To assess the foraging behaviour of the adult female ASL from Dangerous Reef, we analysed the time that ASL spent foraging in different areas (grid cells) and also in different kernel density functions (Fig. 9.3). The time spent in area maps summarise the raw data and highlight the foraging hotspots used by individual ASL and by the adult female population from Dangerous Reef. The kernel densities present the different probabilities of finding each ASL within a certain region while at sea. As a result, kernel densities provide fisheries and wildlife managers with a robust means of assessing probabilities of interactions between commercial fishing/aquaculture operations and individual ASL. For example, aquaculture leases are prohibited within 15 km of Dangerous Reef, to reduce the potential for interactions with ASL. This area encompasses 60.1 % and 39.4 % of the 50 % and 95 % kernel density functions, respectively, and encloses a region where adult female ASL spent 54.5 % of their time at sea. These tools could be employed to model the potential impacts that different commercial fishing and/or aquaculture operations or exclusion zones, might have on ASL at other sites in South Australia.

We determined the number of foraging trips and individual ASL that need to be monitored using satellite telemetry to determine the foraging space used by an individual ASL and by a population of adult female ASL. It took between 30–52 foraging trips and 35–52 individual ASL to cover 95 % by the foraging space used by each individual and the adult female ASL population at Dangerous Reef, respectively. Studies investigating the foraging behaviour of ASL could use these figures to estimate the minimum sample size required to estimate the foraging distribution of the entire population. Such an approach allows inferences to be made about foraging behaviour at the population level, rather than documenting the behaviour of fewer individuals and making assumptions about the population response. About 60 % of the breeding sites of ASL produce < 30 pups per breeding cycle (i.e. < 30 adult females per site) and median pup production in South Australia is about 25 pups per breeding cycle. In the case of *threatened species*, such as the ASL, where population sizes (or logistics or economics) do not permit sufficient sample sizes, then similar analyses could be conducted at broader spatial scales, to determine what scales are supported by the data and conservative approaches to population management should be employed.

Recommendations

Conduct appropriate spatial analysis of all tracking data, to provide quantitative spatial data that determines the appropriate duration of individual deployments and the sample size required for each demographic group.

10 BENEFITS AND ADOPTION

Industry/community sectors benefiting from research

The broad goals of this project were to a) provide information on the foraging zones and the location of seal breeding colonies in South Australia, b) to assist in the zoning and appropriate placement of finfish aquaculture developments, and c) to evaluate the nature and extent of seal-finfish farm interactions through observation and satellite tracking to provide a baseline against which future changes can be assessed. Based on this information the need for the development of future management and research needs could be assessed.

The study provided a comprehensive appraisal of the status of ASL populations in southern Spencer Gulf and the Nuyts Archipelago, and identified several new breeding and haul-out sites that had previously been unknown. It has also provided the most comprehensive data on the foraging behaviour of ASL based on the satellite tracking of over 100 individuals. These have provided unparalleled detail of the spatial distribution of foraging effort of some ASL populations. Results from research presented in this study will benefit ASL management, managers of natural resources and protected species, and the general public.

Information on the nature and extent of seal-finfish farm interactions and the most effective mitigation methods used were surveyed by a questionnaire (to finfish farmers) and measured by an observer program. These provide a baseline against which changes in the abundance and activity of seals around finfish cages can be assessed in the future. Some finfish farmers also provided mortality records of stock recovered by divers and in some cases were able to determine if the cause of death was due to seal attack.

Summary of project extension to beneficiaries

Throughout the project, regular information, updates on project progress and advice was given to PIRSA Aquaculture Policy Group, industry groups including the Tuna Boat Owners Association, and state and national agencies responsible for the conservation of marine mammals— South Australian Department for Environment and Heritage (SA DEH), the Department of the Environment, Water, Heritage and the Arts (DEWHA).

A workshop was held at Port Lincoln Marine Science Centre on 17 November 2004. The goal was to inform finfish farm managers about the purpose of the PIRSA/FRDC project, and to seek their cooperation in assessing the nature and extent of seal aquaculture interactions in the region.

In November 2004, letters were sent to Mr David Ellis (Research Manager – Tuna Boat Owners Association) and Mr Ross Gordon (finfish aquaculture farm representative), summarising the main outcomes of the workshop, and the cooperation sought from industry with the next phase of the work program, as well as a time frame over which industry questionnaires, fish mortality data and mitigation/seal interaction appraisal at all farms would be undertaken.

Mr Martin Cawthorn (a prominent researcher in the field of interactions between marine mammal and fisheries based in New Zealand) was contacted with respect to the project, and briefed on the project scope, aims, and preliminary results. Mr Cawthorn (contacted 19 October 2004) commented that he considered the project excellent, and highlighted that the approach to satellite tracking a representative number of seals was the only practical way to acquire data to adequately assess seal - finfish aquaculture issues from a planning perspective.

Mr Ian Cresswell (Assistant Secretary Wildlife Trade & Sustainable Fisheries Branch Department of the Environment and Heritage) is the key person responsible for seals at that level within the Department for Environment and Heritage in 2004. Discussions were held with Mr Cresswell about the nature and scope of the project, and he commented that his section strongly supported the research and would be very interested in the project outcomes. He was very keen to receive copies this and subsequent reports, and requested that these be passed onto their Marine and Migratory Section, that has direct input to the National Seal Strategy Group.

Presentations were given in June 2005 at the launch of the suite of Innovative Solutions for Aquaculture Planning and Management projects (SARDI Aquatic Sciences), and at the Southern Bluefin Tuna Aquaculture Subprogram Industry Workshop (Port Lincoln, 22–23 November 2005). There has been ongoing contact with finfish farm managers in the Port Lincoln region, as part of industry surveys, and farm assessments as part of this project. A presentation was given to West Coast Eyre Peninsula stakeholder groups and PIRSA (SARDI, November 2005). A radio interview (Mr Ian Nightingale & Mr Derek Hamer) was given in September 2005 and a media release to the West Coast Sentinel resulted in a newspaper article 1 December 2005.

The primary communications approach of the project outcomes will be the dissemination of this report to key stakeholders and other interested parties.

How benefits and beneficiaries compare to those identified in the original application

The sectors of the industry and/or community that will benefit from research undertaken by this project are finfish aquaculture farmers (SA, interstate and overseas), the Australian Southern Bluefin Tuna Association (formerly the Tuna Boat Owners Association), PIRSA Aquaculture and AFMA, State and Commonwealth agencies responsible for the conservation and management of seals and marine ecosystems including the SA DEH, DEWHA, Department of Agriculture, Fisheries and Forestry (DAFF), the National Seal Strategy Group, and environmental advocacy groups such as the Conservation Council SA, Humane Society International, and the Wilderness Society.

The Australian community will also benefit from the social, economic and ecological advantages that will result from improved management of marine finfish aquaculture. Some of these improvements will include a reduction in the costs of seal interactions that will result from better placement of finfish farms, and mitigation strategies introduced to reduce the economic costs of seal-finfish-farm interactions. The benefits and beneficiaries do not differ to those identified in the original application

Adoption of the research by identified beneficiaries

Most of the adoption of research from this study will occur following its publication; however, there have been a number of cases across multiple stakeholders where this research has already been of benefit to management. These include the following.

PIRSA Aquaculture/aquaculture Industry – results from research on tracking ASL have been used to assist decisions regarding the appropriate placement of abalone sea cage aquaculture both in Denial Bay (Goat Island) and Anxious Bay (Waldegrave Island) (west coast Eyre Peninsula). In both these cases, results from this project were used to assist the Development Assessment Commission (South Australia) reach their decision. Future adoption of research outputs from this project are detailed in Section 11.

FRDC/AFMA/DEWHA – results from ASL tracking from this study were used to assist the development of models to describe the spatial distribution of foraging effort of different age and sex groups. These were used to undertake a desk-top risk assessment of the implications of interactions between seals and the southern rock lobster fishery and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) (FRDC project number 2005/077, Goldsworthy et al. 2007a, Goldsworthy and Page 2007), and to assist development of spatial models of ASL foraging effort in the follow-up FRDC-DEWHA funded project (2007/04). For the gillnet SESSF, spatial modelling of ASL tracking results are being used to assist the development of recommendations for spatial closures in the fishery to enable recovery of threatened ASL populations.

This report addresses key objectives of the National Strategy to Address Interactions between Humans and Seals: Fisheries, Aquaculture and Tourism (2006), including:

- Obtain data on the nature and extent of interactions between seals and aquaculture
- Minimise and mitigate adverse interactions between seals and aquaculture
- Develop arrangements to report interactions between seals and aquaculture operations
- Encourage aquaculture industries to embrace stewardship of the marine ecosystem

11 FURTHER DEVELOPMENT

A number of further developments have been recommended following this research project.

Seal-finfish farm interactions

Physical protection of farmed fish from predation by seals and continuous vigilance is the most effective mitigation measure to reduce seal-finfish farm interactions. By using appropriate net materials and construction design, effective seal-fences, regular gear maintenance, and appropriate site placement, the negative effects of seals on finfish farms can be minimised. The reduction of excess feed and frequent removal of dead fish are also likely to reduce the attractiveness of pens to seals. All of these measures and others have been recommended in various reports and studies over the years (Pemberton and Shaughnessy 1993, Pemberton 1996, Schotte and Pemberton 2002, Kemper et al. 2003, NSSG and Stewardson 2007) and have been adopted to various degrees by the industry, resulting in a significant reduction in predation by seals at many farms. However, the effectiveness of such mitigation measures will be greatly reduced if they are not adopted industry-wide. Efforts of individual operators to exclude seals from farms, and in-turn reduce the attraction of seals to the area, will be undermined if nearby operators use suboptimal or ineffective mitigation measures.

To ensure effective mitigation measures are adopted across the industry it may be necessary to outline minimum mitigation requirements under legislation. This could be achieved through the existing legislation. A regulation under the current *Aquaculture Act 2001* requires licensees to submit a Seabird and Large Marine Vertebrate Interaction Strategy at the commencement of operations, which satisfies the Minister. The strategy details what procedures the licensee will implement to minimise the risk of interactions and to manage incidents of entanglement or entrapment of seabirds and large marine vertebrates. This Regulation could be used to ensure that best practice mitigation measures (such as seal-fences and net maintenance regimes) become standard across the industry. Amendment of the Regulations to allow for annual review of documented strategies for all existing operations would allow any new or altered mitigation actions to be incorporated across the industry. Minimum mitigation strategies should be established and regularly reviewed in consultation with industry, government and research agencies. Under the existing regulation, operational practices detailed in the strategy can be audited, with failure to comply resulting in fines or in suspended or cancelled licences.

To ensure mitigation measures remain effective and incorporate new developments in technology, changes to stock management, adaptation of seals to mitigation measures and changes in the status of seal populations, an active monitoring and management regime is required. Such a regime needs to respond to such changes quickly and appropriately based on sound data. This will require the development of standard methods of recording and reporting seal interactions and causes of fish mortality. Mortality assessment is likely to be the most cost-effective performance measure to monitor changes in the level and costs of seal interactions in the future.

The use and construction of seal-fences should be standardised across the industry and the standards should incorporate height requirements, design and advances in material construction if different designs are shown to be effective. Based on available information, seal-fences must be a minimum height of 2 m to be an effective barrier, although the most effective height requires further trial. Seal-fences should be constructed so that they form a continuous barrier with the extension of the pen netting, thereby preventing access by seals via gaps between the pen netting and the seal-fence. Although electric fences were widely adopted in the 1990s they have since been largely abandoned due to high maintenance costs and unreliability. New methods of constructing and operating electric fences that are cost effective and reliable should be investigated.

The distance between finfish operations and seal colonies has been the primary regulation used to minimise the risk of interaction. Appropriate site placement is in its infancy and requires further understanding of the nature and extent of ASL and NZFS interactions with finfish operations (see below). Given the variation in the foraging behaviour of ASL from different colonies and age/sex categories, it is difficult to develop a universal proximity model of risk in relation to distance of farm sites from ASL colonies or haulouts. Until further information is gathered, the best approach is to assess the risk of interaction on a site-by-site basis, based on tracking a representative number of animals in proposed aquaculture zones.

Recommendations

Recommendations for further research and development with respect to finfish farm management and impacts on seal populations are outlined below. The main procedures for minimising finfish mortality caused by seals that should be in the management plans of tuna farms are:

- Incorporation of seal-fences on the pontoons with a minimum fence height of 2 m.
- Regular and frequent net maintenance, including repair of holes.
- Regular and frequent removal of tuna carcasses, because they are likely to attract seals.
- Promote and if necessary require the implementation industry-wide of measures that are demonstrated to effectively mitigate adverse interactions.
- Incorporate management measures into regulations with regular auditing requirements.

Zoning and location of aquaculture in proximity to seal colonies and haulouts

Background to existing zones in South Australia

South Australian Cabinet requested the establishment of the ‘Marine Mammal – Marine Protected Areas Aquaculture Working Group’ (MM-MPA AWG), which was asked to ‘develop appropriate and consistent policies for use in relation to the proximity of aquaculture to core areas of proposed Marine Protected Areas (MPAs) and significant wildlife habitats such as seal colonies and whale breeding areas’ (MM-MPA AWG, 2004). The working group was a sub-committee of the Aquaculture Advisory Committee, the role of which, under the *Aquaculture Act 2001* is to advise the South Australian Minister for Agriculture, Food and Fisheries on administration and policy aspects of the Act.

In October 2004, the MM-MPA AWG produced a report detailing recommendations to address the proximity of finfish aquaculture to significant seal and sea lion colonies in South Australia. The report concluded that the only aquaculture activity to pose a risk to NZFS and ASL colonies is finfish aquaculture and the only colonies at risk from finfish aquaculture are breeding colonies of ASL (MM-MPA AWG, 2004). The following management recommendations were made by the MM-MPA AWG.

- There will be no specific restrictions in relation to the location of finfish aquaculture and New Zealand fur seal colonies.
- There will be no restrictions in relation to the location of finfish aquaculture greater than 15km from Australian sea lion colonies.
- Finfish aquaculture proposed to be located between 5-15km of minor Australian sea lions breeding colonies will be assessed on a risk assessment basis.
- Finfish aquaculture will not be approved within 15km of the eight major Australian sea lion breeding colonies at The Pages, Dangerous Reef, Seal Bay, West Waldegrave Island, Olive Island and Nicolas Baudin Island.
- Finfish aquaculture proposed to be located within 5km of any Australian sea lion breeding sites will not be approved.

These recommendations were intended to guide future aquaculture and environmental management decisions and policies until further research could better define spatial issues associated with finfish aquaculture and ASL conservation management in South Australia (MM-MPA AWG, 2004). ASL colonies that were estimated to produce more than 70 pup per breeding season were designated as ‘major’ colonies, while all the remaining colonies (<70 pups) were designated as ‘minor’ colonies (MM-MPA AWG, 2004).

Relevance of research to zoning issues

The 15km and 5km aquaculture ‘buffer zones’ around major and minor ASL colonies were recommended by the MM-MPA AWG to reduce both the potential economic impact of seal interactions at finfish farms and the conservation consequences of ASL deaths resulting from finfish farm interactions (MM-MPA AWG, 2004). The rationale for different sized buffer zones for major and minor colonies was as follows. The MM-MPA AWG judged that the consequences to ASL conservation of ‘repeated interactions could range from moderate to severe depending on colony pup production with potentially severe consequences from colonies that provided the most pups per breeding season (i.e. major colonies) and moderate consequences for breeding colonies classified as minor’ (MM-MPA AWG, 2004). The scientific basis for this rationale is contrary to the results of recent research. Firstly, molecular genetic analysis of ASL population structure has identified strong-sex-biased dispersal in the species, typified by extreme female natal site-fidelity, unparalleled among other seals (Campbell et al. 2008). Population subdivision is evident at both large and small geographic scales with some fixed genetic differences identified between some colonies separated by as little as 20km (Campbell et al. 2008). Secondly, population viability analyses (PVAs) indicate that the small colonies that make up the majority of the ASL population are most vulnerable to extinction and anthropogenic impacts (Goldsworthy and Page 2007). The key findings of these studies are that ASL colonies need to be managed as individual subpopulations, and that small colonies are most vulnerable to extinction. As such the assumptions of the MM-MPA-AWG that repeated aquaculture interactions are likely to be more severe for major as opposed to minor colonies are not supported, and neither is the rationale for smaller buffer zones for minor colonies. Based on the findings of Campbell et al. (2008) and Goldsworthy et al. (2007), minor colonies require larger buffer zones than major colonies, contrary to the recommendations of the MM-MPA-AWG (2004).

This study examined the extent of protection afforded by the MM-MPA-AWG (2004) buffer zones, by satellite tracking ASL in southern Spencer Gulf and the Nuyts Archipelago and examining the time spent at sea within and outside the buffer zone areas. Our findings indicate that the buffer zones represent a variable fraction of the time spent at sea by different age and sex groups within ASL populations. Five kilometre buffers represented between 7–29 % and 15 km buffers represented between 34–73 % of the time at sea of adult females, while for adult males the values were 1–6 % and 6–28 %, respectively. Given the marked inter-individual and inter-site variability in the foraging behaviour of different ASL identified in this study, the extent of protection that current buffer zones may afford colonies is likely to vary markedly between colonies. Because of the variable extent of protection afforded using the current MM-MPA-AWG (2004) aquaculture buffers zones, we recommend for all colonies in proximity to areas to be zoned for aquaculture, that appropriate buffer zones be developed on a case-by-case basis in order to adopt a biological basis for buffer design. Increasing the size of buffers may not be possible for some small colonies, which are in close proximity to existing fish farms (e.g. English Is, Appendix 4), but should be adopted for all future aquaculture developments.

Recent developments in modelling the spatial distribution of foraging effort of ASL colonies being developed through FRDC Project 2007/041 (Goldsworthy unpublished data) will be useful in informing the likelihood of interactions between ASL and new aquaculture proposals. However, given the marked variability in the distribution of foraging effort within and among colonies and that fact that current models of foraging effort are based on tracking data from a limited number of sites, satellite tracking provides the only means of providing confidence to an assessment of the likelihood of interactions in addition to providing detailed information on the critical habitats used by ASL from each site. Recent developments in new archival GPS tags have significantly reduced the cost of satellite tracking studies. They also provide higher precision locations and more data than the satellite transmitter tags used in this study.

Currently there are no specific distance restrictions recommended in relation to NZFS. Given that NZFS populations are increasing, the potential for interactions with finfish farms is also likely to increase (NSSG and Stewardson 2007), especially with smaller finfish species (mulloway and kingfish). Although NZFS populations are currently thought to be at low risk from the proximity of finfish farms, the siting of proposed finfish farms in proximity to NZFS haulouts should receive careful consideration. The present distribution of most kingfish and mulloway farms in northern Spencer Gulf (from Arno Bay north) is likely to minimise interactions with NZFS, which rarely venture this far into gulf waters. However, kingfish and mulloway farms in the southern part of Spencer Gulf may be increasingly vulnerable to predation by NZFS, given that nearby haulouts (eg Donington Reef and Rabbit Island) and breeding colonies are increasing in size. Changes in the rates of interactions between NZFS and finfish aquaculture (especially kingfish and mulloway) in southern Spencer Gulf should be closely monitored, and careful consideration should be given to expansion of small-finfish aquaculture in the region. The current policy of ‘no-specific distance restrictions’ with finfish aquaculture and NZFS colonies and haulouts may require review.

New finfish aquaculture operations near seal haulouts are currently considered by the MM-MPA AWG to pose a low risk to ASL populations. The satellite tracking conducted in the present study indicates that all age classes utilise a number of additional haulouts, many of which are close to important foraging areas. The use of additional haulouts by adult females is higher than previously thought and this finding emphasises the need to assess the application for new aquaculture zones on a site-by-site basis. For management purposes, assessments would need to consider proximity to both haulouts and breeding colonies, as well as proximity to important foraging areas.

During the present study we made significant advances in developing methods to calculate ASL core/critical foraging regions. However, issues of whether these are representative of the entire population or the potential for these analyses to overlook seasonal differences in foraging locations have yet to be resolved. Recent improvements to spatial modelling of ASL foraging effort based on extant tracking data, in addition to recent developments in satellite tracking technology, provide scope for a more cost effective means of predicting the risk of aquaculture locations.

The report and recommendations of the MM-MPA AWG (2004) were restricted to finfish aquaculture activities. Subsequent to the report, the potential threats to ASL posed by new sea-cage technology for shellfish (eg: abalone) aquaculture both in proximity to the West Waldegrave Is ASL colony off Elliston, and at Goat Is (Denial Bay) have raised concerns. These concerns stem from the potential of sea-cage aquaculture to act as an attractant to seals, as well as providing a risk of entanglement. Given this, it may be prudent to revisit aquaculture buffer zone policy for all forms of sea-cage aquaculture (finfish and shellfish).

Recommendations

Based on our current level of understanding of the foraging behaviour of ASL and NZFS and the nature and extent of seal interactions with finfish aquaculture, our main recommendations for the siting of aquaculture zones in the vicinity of seal haulouts and colonies are as follows:

- The current MM-MPA-AWG (2004) 5 and 15km aquaculture buffer zones have no biological basis in terms of managing the risk to ASL and this should be reviewed in light of the findings of this report.
- Because ASL foraging behaviour varies between individuals and among colonies, we recommend that aquaculture buffer zones be developed on a site-by-site basis, taking into account important biological attributes relating to the distribution of foraging effort, population size and vulnerability to extinction.
- The distance between important ASL haulouts and important foraging areas and finfish aquaculture should also be considered.
- To reduce potential interactions between NZFS and finfish farms (mulloway, kingfish, Atlantic salmon) distance restrictions to haulouts should be considered.
- Consideration should be given to adopting buffer zone guidelines for other sea-cage aquaculture (eg abalone) using a risk-based approach, including further research into seal interactions in this aquaculture sector.

Performance measures

Three options for cost-effective performance measures are proposed to: 1) determine changes in the interaction rates of seals with aquaculture and the resultant costs to industry, 2) assess industry compliance to recommendations to minimise seal interactions; and 3) assess whether aquaculture practices are having deleterious impacts on adjacent populations of seals.

1. *Standardised and mandatory reporting of fish mortality* - Efforts should be made to improve procedures for recording the causes of death of farmed finfish. This could be done through a training scheme for divers so that attacks by seals are properly identified and recorded consistently across industry. In addition, animal husbandry standards at finfish farms should be improved to reduce fish mortality. The process of reporting back to industry by PIRSA Aquaculture should include an indication of how companies are progressing with regard to managing mortalities attributable to seal attacks. Mortality assessment is probably the most cost-effective performance measure to monitor changes in the level of seal attacks, the effectiveness of mitigation procedures in management plans and the costs associated with seal interactions. Mortality assessment would provide a means to monitor variations in the rates on seal interactions between years and seasons, among regions, lease-sites and companies.

2. *Annual farm assessments* – Compliance checks to ensure that farm seal-mitigation practices meet minimum requirements; including appropriate seal deterrents (fences), records of net maintenance, diver logbooks and fish mortality records.

3. *Population monitoring of selected seal colonies* - Given the *threatened* species status of ASL, there is great sensitivity around developments or activities, such as sea-cage technology (finfish or shellfish aquaculture), in proximity to their breeding colonies or critical foraging areas/movement corridors. The only clear and quantitative measure that such activities pose little or no ongoing threat to the sustainability of populations is through ongoing assessment of pup production to determine changes in the status and trends in their abundance. There are large numbers of breeding populations of ASL in South Australia, very few of these are subject to regular surveys (Goldsworthy et al. 2007a). It may be prudent where sea-cage aquaculture is being developed in close proximity to ASL populations to build in some ongoing support for population surveys as a key performance measure, which would demonstrate that aquaculture activities are not posing a threat to these populations.

Recommendations for further research and development

- Develop and establish standard methods of recording and evaluating interactions and impacts of seals on finfish farms including categorising the nature and extent of injury and probable cause of death of farmed finfish. This could be implemented through a training course for divers and farm workers covering aspects such as identification of types of injuries, identifying course of mortality, seal species identification and standard recording and reporting procedures. This would assist in improving industry reporting and assessment of seal-finfish aquaculture interactions and allow development of robust performance indicators to assess the ongoing effectiveness of mitigation measures.

- Further research focused on reducing non-seal related causes of mortality and injury of farmed finfish (such as disease) through improved husbandry practices would also assist in reducing the overall cost to industry due to stock loss, injury and loss of condition.

- Use data from mortality assessments and seal interactions with finfish farms to investigate spatial and temporal variability in seal predation rates at farms. Relate these results to farm seal-mitigation practices, stocking rates, feeding rates, proximity to other farms and to seal haulouts and colonies. Such information would greatly assist in managing seal-finfish farm interactions.

- Monitor the loss of aquaculture equipment and entanglement of marine mammals in connection with aquaculture. This should include any material or equipment used to secure, anchor or mark the position of farm structures and leases.

- Undertake robust, quantitative trials to monitor and assess the efficiency and economic benefit of gear and farm management modifications to reduce the incidence of seal-related mortality and injury of farmed finfish. Such trials should include effective height and construction of seal-fences and more robust mesh design to reduce net maintenance. New technologies for caging kingfish and mulloway should be investigated. Options include the use of heavy-duty net material, steel cages (particularly for the raceways, where fish are held prior to harvesting), and incorporation of stainless steel ‘rub rings’ in the nets through which the feed-cage ropes pass (to prevent the formation of holes caused by abrasion). Introduction of new farm systems such as sea-cages for shellfish should be undertaken on a trial basis, with independent observer monitoring, to assess the risk of such systems to marine mammals. Further research is also required to reduce technology costs in an attempt to encourage industry to adopt new technologies that exclude seals from finfish farms.

- Improve or develop formal strategies for information exchange between research, government and industry agencies and among individual operators for the distribution and exchange of information on technological advances, assessment of mitigation measures and guidelines and progress of research projects. This would promote industry ownership and stewardship and an effective industry-wide active management regime.

- Further satellite tracking of ASL at Dangerous Reef during seasons not covered by the present study (i.e. winter) should be undertaken to improve our understanding of the factors influencing temporal variation in foraging areas and improve spatial and temporal foraging models. This would allow greater temporal accuracy in modeling the overlap of ASL foraging areas with activities within the Tuna Farming Zone (TFZ) and other finfish farm leases. Because the seasons in which the breeding activities of ASL occur vary between years, seasonal comparisons of foraging areas should take into account possible variation due to differences in reproductive activities. Satellite tracking of ASL should also be undertaken from the English Island colony, which is the closest ASL breeding site to the TFZ. This study would determine whether ASL from English Island interact with the aquaculture industry.

- Focus future foraging studies on adult females and juvenile seals, as these are the most critical demographic groups within ASL populations. Some tracking of males would be informative, because their foraging range typically exceeds that of females, and they may interact more with finfish farms than females and juveniles.

- Conduct appropriate spatial analysis of tracking data to provide quantitative spatial data that determines the appropriate duration of individual deployments and the sample size required for each demographic group.

- Conduct appropriate spatial analysis of tracking data in order to provide spatial maps of the distribution of foraging effort of seal populations in South Australia and assess the extent of spatial overlap with current and planned finfish and other aquaculture zones. Models of the spatial distribution of foraging effort are currently being developed for FRDC-DEWHA project 2007/041. Further development of these in a scale appropriate for aquaculture planning and management would greatly assist the assessment of future aquaculture development applications.

- To assist in determining if the presence of aquaculture operations affects the behaviour of seals, data on the habitat use of seals in the vicinity of proposed operations prior to and at various stages after operations have been established would be valuable. This study has collected data on the foraging behaviour of ASL within the proposed aquaculture zone in western Eyre Peninsula, providing baseline data to which future studies can be compared.

- Data presented in this report have largely focused on the behavior of ASL. Although available data suggests that NZFS are not the major species causing tuna stock mortality, they have the potential to create significant problems for the aquaculture of smaller finfish species. Further abundance and at-sea distribution data may be required in future in order to mitigate these interactions. Data on foraging habitat use by NZFS in the vicinity of Port Lincoln and the Eyre Peninsula is currently limited.

- Monitoring ASL population trends at colonies that are adjacent to existing and proposed sea-cage aquaculture sites would provide a key performance measure to assess the potential impact of aquaculture operations.

- Develop a trapping and tracking program of seals that directly interact with finfish aquaculture in the Port Lincoln region. Recent tracking of Australian fur seals and NZFS caught at salmonid finfish farms in Tasmania has demonstrated the extent to which parts of the seal population have adapted to foraging in and around finfish cages, with many seals spending long periods feeding in association with salmonid farms throughout winter months (Robinson et al. 2008). Trapping technology used to capture interacting ASL and NZFS could be adapted and applied to capture and track individuals that interact with finfish farms in South Australia. The new generation of satellite linked GPS tags now available provide much greater precision and increased number of locations at sea, enabling accurate quantification of the time spent at individual finfish cages. Greater information about the behaviour and extent of interaction by the subset of the population that interacts with finfish farms would provide important information to assist managing that part of the seal population into the future. In addition, the deployment of critter-camera technology would provide invaluable footage to demonstrate how seals enter finfish farms and kill farmed fish. Such data would underpin attempts to categorising the nature and extent of injury and probable cause of death of farmed finfish.

12 PLANNED OUTCOMES

Five main Planned Outcomes/Outputs were identified in the research application for this project. How the project has contributed to these and the outcomes contributed to date are detailed below.

1. Advice to PIRSA Aquaculture regarding the placement of finfish aquaculture developments relative to seal foraging areas and breeding and haulout sites. Specifically, how to plan the location of finfish aquaculture sites to minimise seal interactions.

The project has provided the most comprehensive appraisal of the status of ASL populations in southern Spencer Gulf and the Nuyts Archipelago, and identified several new breeding populations and haulout locations. It has also provided the most comprehensive data on the foraging behaviour of ASL based on the satellite tracking of over 100 individuals. These data have provided unparalleled detail of the spatial distribution of foraging effort of ASL in the region.

During the course of the project, PIRSA Aquaculture and the aquaculture industry have made use of results of tracking ASL to assist decisions regarding the appropriate placement of abalone sea-cages in Denial Bay (Goat Island) and Anxious Bay (Waldegrave Island) (west coast Eyre Peninsula). In both of these cases, results from this project were used to assist the Development Assessment Commission (South Australia) reach their decision. Future adoptions of research outputs from this project are detailed in Chapter 11.

Recommendations to PIRSA Aquaculture with respect to management and policy advice for minimising seal interactions in the aquaculture industry, including future research needs, are detailed in this report. With respect to management for the future placement of finfish farms in proximity to seal colonies, we have recommended some changes to those of the Marine Mammal – Marine Protected Areas Aquaculture Working Group (MM-MPA AWG), detailed in Chapter 11.

2. Data and maps indicating the location of seal colonies, haulout sites and foraging zones adjacent to regions zoned for finfish aquaculture.

This project has provided comprehensive data and maps on the location of seal breeding colonies and haulout sites, including many previously unknown sites, as well as estimates of the relative size of breeding colonies based on pup production. The project has also provided unparalleled data and maps on the feeding ecology of ASL in southern Spencer Gulf and the Nuyts Archipelago, including regions adjacent to finfish farming zones (Port Lincoln TFZ).

3. Data on the nature and incidence of seal-finfish farm interactions.

This study has provided the first detailed investigation into the nature and extent of seal finfish farm interactions in the Port Lincoln region, based both on industry surveys as well as quantitative assessments based on independent observer coverage (see chapter 6).

4. Recommendations to finfish farmers on ways to reduce seal interactions.

This study has provided recommendations to industry and managers on ways to reduce seal interactions. These include incorporation of seal-fences on the pontoons of a minimum height of 2 m; regular and frequent net maintenance, including repair of holes; regular and frequent removal of tuna carcasses; and the industry-wide adoption of measures that effectively mitigate adverse interactions. We have also recommended the adoption of three main performance measures to assist ongoing management of seal-aquaculture interactions. These included: 1) standardised and mandatory reporting of the causes of fish mortality in farms, to monitor changes in the level of seal attacks, the effectiveness of mitigation procedures written into management plans, and the costs associated with seal interactions; 2) annual farm assessments to ensure that seal-mitigation practices meet minimum requirements; and 3) population monitoring of selected seal colonies to demonstrate that aquaculture activities are not adversely affecting these populations.

5. Recommendations on the need for further investigation into mitigation options if required.

A number of research and development recommendations have been made as part of the outputs of the project (summarised in chapter 11).

13 CONCLUSIONS

The broad aims of this study were to provide information on the foraging zones of seals and the location of breeding colonies and haulouts in the Eyre Peninsula region of South Australia. This information on the distribution of regions used by seals was needed to assist in the zoning, placement and management of future finfish aquaculture developments. In addition, the study aimed to evaluate the nature and extent of seal-finfish farm interactions through observation and satellite tracking, and to provide baseline data against which future changes can be assessed. The study also aimed to provide information on the foraging behaviour of ASL in the Nuyts Archipelago where finfish aquaculture was proposed, but where none currently exists. This project also aimed to provide recommendations on how finfish farmers may minimise interactions between seals and their farms and recommendations and information were also provided to assist management and policy development with respect to the future placement and zoning of aquaculture in South Australia, including recommendations for further research.

The study has provided the most comprehensive appraisal of the status of ASL populations in southern Spencer Gulf and the Nuyts Archipelago, including the discovery of four new breeding populations. Of the 18 breeding colonies inspected, Dangerous Reef remains the largest in terms of pup production. While the number of pups born on Dangerous Reef appears to have increased, the status of other sites remain uncertain due to a lack of historical data.

Tuna farmers participated in a questionnaire to determine the types of equipment used to deter seals at farms and to assess the nature and extent of seal interactions. The survey results confirmed that operational interactions with seals are a continuing problem, although there were opposing views on whether they were increasing or decreasing. The most significant effect of interactions was death of tuna, followed by stress and damage to the fish and the associated financial costs. Australian sea lions were considered to be responsible for most attacks on tuna and for most of the interactions that caused stress. Available data suggest that ASL attempt to prey on penned fish at night, making assessment of the nature and extent of seal predation based on operator observations and reports difficult to interpret. New Zealand fur seals have previously been thought to be the main species responsible for predation attempts as they are frequently seen around and within cages and resting on the pontoons. However, most NZFS observed were juveniles and were not considered a threat to farmed tuna, being too small to attack them. Fur seals within the TFZ were most likely taking advantage of baitfish fed to the tuna or preying on other fish attracted to the area. New Zealand fur seals are known to prey on farmed salmon in Tasmania and may be targeting farmed kingfish or mulloway within Boston Bay.

Based on satellite tracking studies of ASL in southern Spencer Gulf, there was limited spatial overlap in the major areas used by ASL and the TFZ. Sea lions utilised a large and diverse range of marine habitats including both inshore and offshore habitats, with some evidence of seasonal difference in the distribution of foraging effort. Data from juveniles, adult females and males were collected. Extensive tracking was also undertaken in the Nuyts Archipelago from 6 different colonies all within a 40 km radius. There was a marked inter-colony difference in foraging behaviour, and evidence of two broadly different foraging ecotypes: inshore (shallow) and offshore (deep) foragers. Most seals tracked, including adult females, used at least one additional haulout site. Females tracked from Dangerous Reef used a total of 13 additional haulouts, while males from the same site used up to 21 additional sites. Results suggest that universal parameters of foraging are unlikely to be appropriate in this species, due to the high level of inter-colony variation and specialisation identified in this study.

This study provides a number of management recommendations. Procedures for minimising finfish mortality caused by seals should be included in the management plans of tuna farms and other finfish species. These procedures should include detailed requirements for seal fences on pontoons; regular and frequent net maintenance, including repair of holes and regular and frequent removal of tuna carcasses, which may attract seals.

With respect to the management of finfish farms in proximity to seal colonies, we recommend assessment of the risk of ASL-finfish farm interaction on a site-by-site basis. Such assessments would be based on satellite tracking of a representative number of ASL from colonies adjacent to the proposed aquaculture zone. Given the high vulnerability (risk of extinction) of small ASL colonies, the recommended buffer of 5 km for minor ASL colonies should be reviewed.

To reduce the potential for interactions between NZFS and finfish farms (mulloway, kingfish, Atlantic salmon) distance restrictions to haulouts should also be considered, as should buffer zones for other sea-cage aquaculture (shellfish).

Adoption of three main performance measures is recommended to assist ongoing management of seal-aquaculture interactions in South Australia. These are: 1) standardised and mandatory reporting of the causes of fish mortality in finfish farms, which would facilitate monitoring changes in the rates of seal attacks, the effectiveness of mitigation procedures that are written into management plans and the costs associated with seal interactions; 2) annual farm assessments to ensure that seal-mitigation practices meet minimum requirements; and 3) population monitoring of selected seal colonies to assist in the ecological sustainability assessments.

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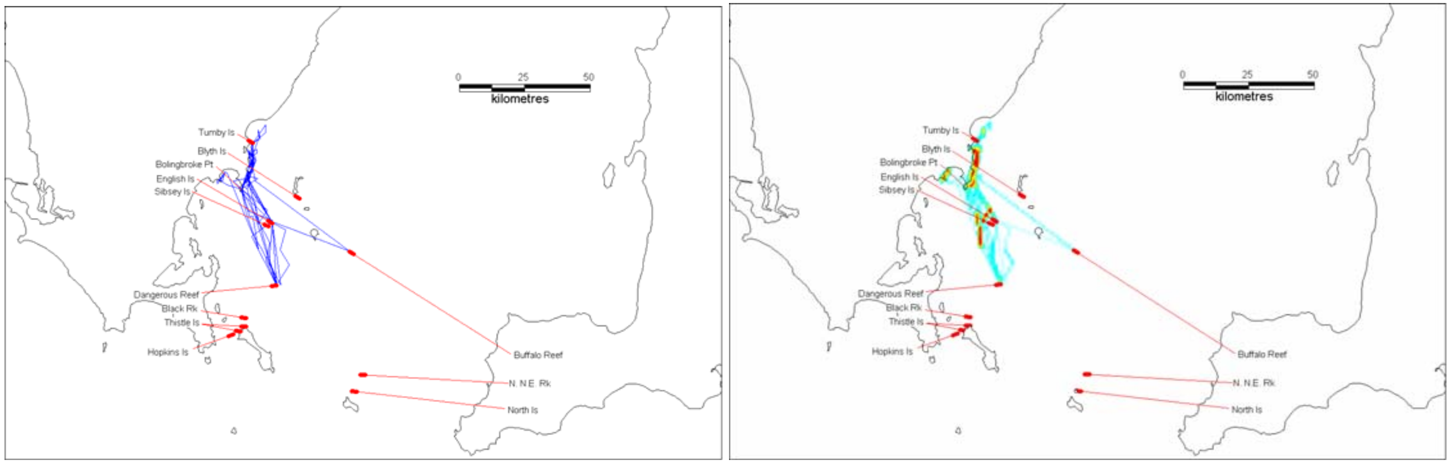
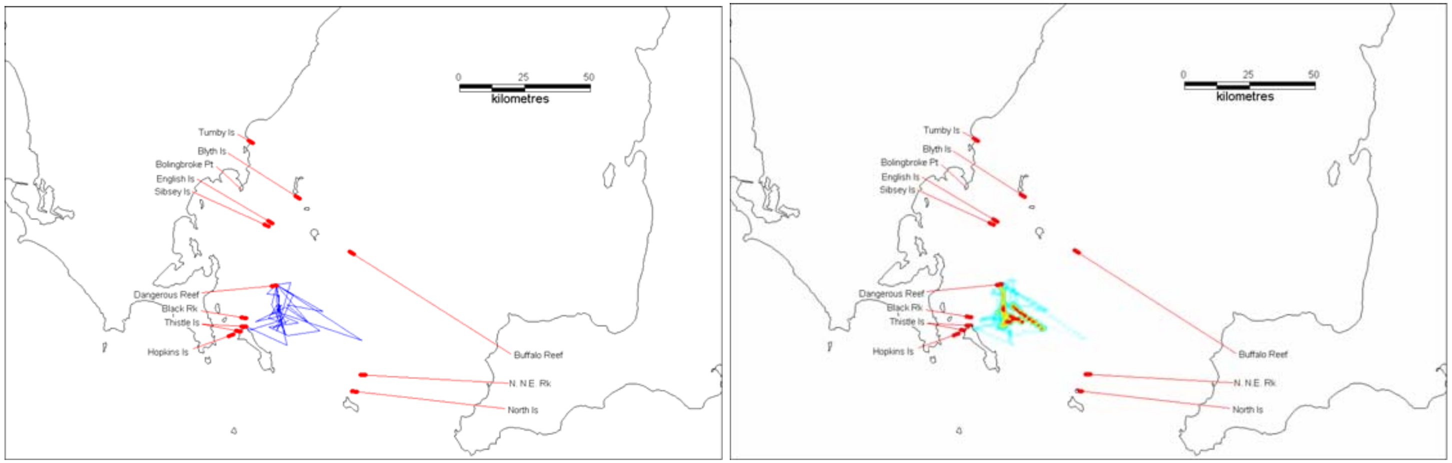
15 APPENDIX

Appendix 1. Distribution of foraging effort for each individual ASL that was satellite tracked



Adult female 10011 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).

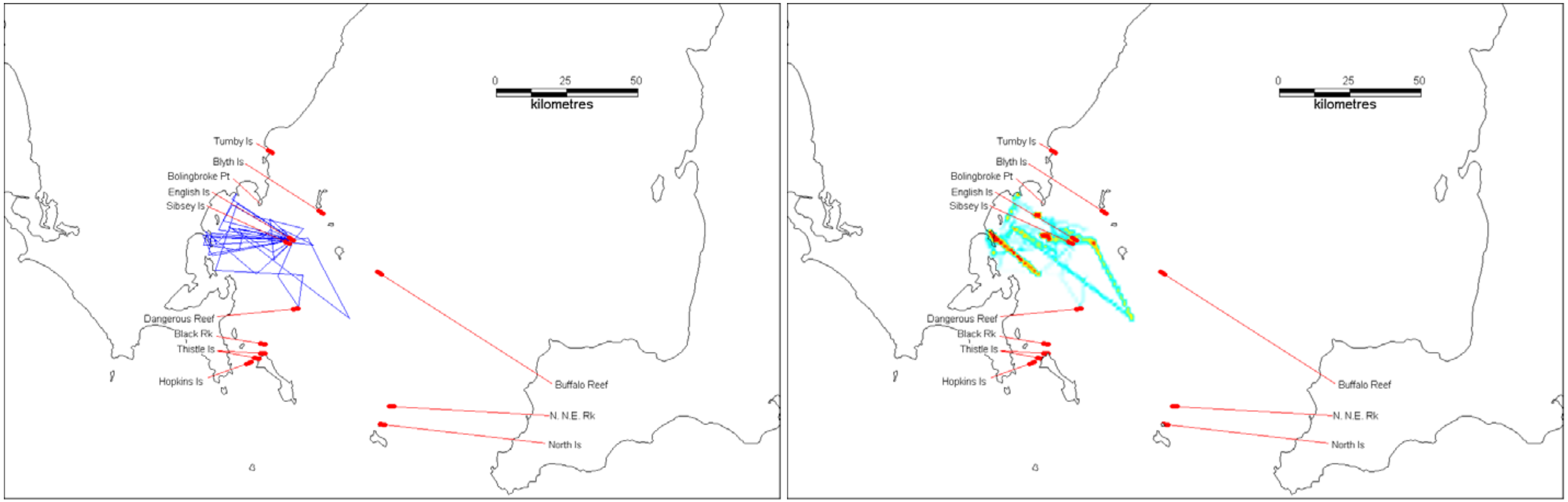


Adult female 10111 from Dangerous Reef. Tracks of 6 foraging trips (left) and time spent in 1 x 1 km areas (right).

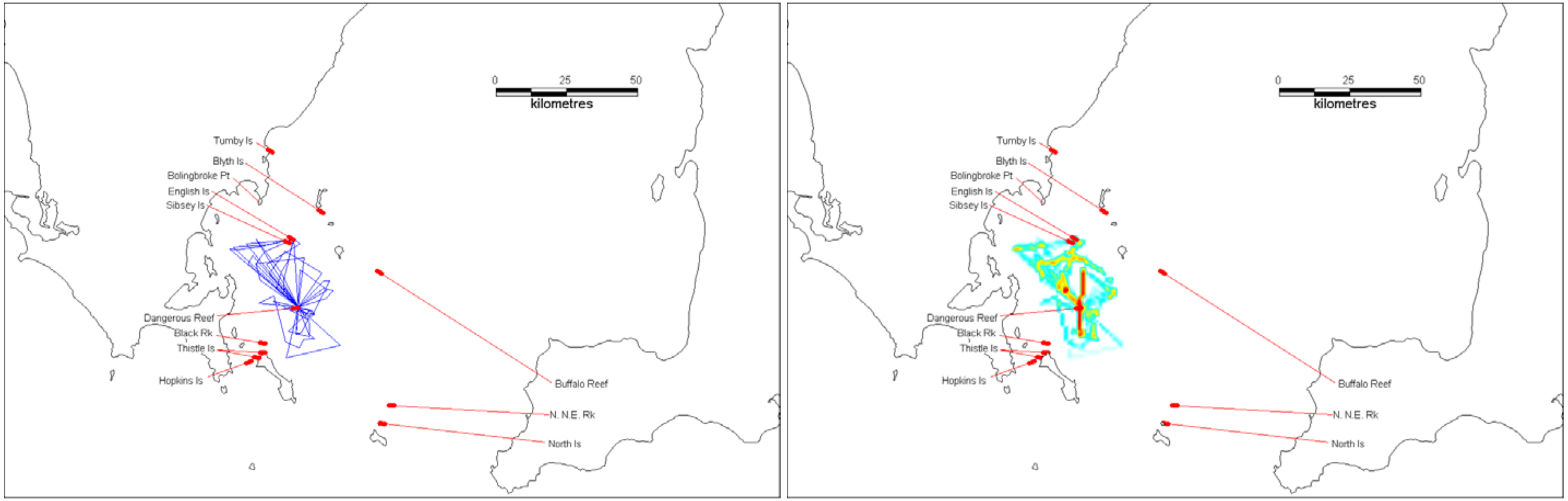
Adult female 10211 from Dangerous Reef. Tracks of 6 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 10411 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).

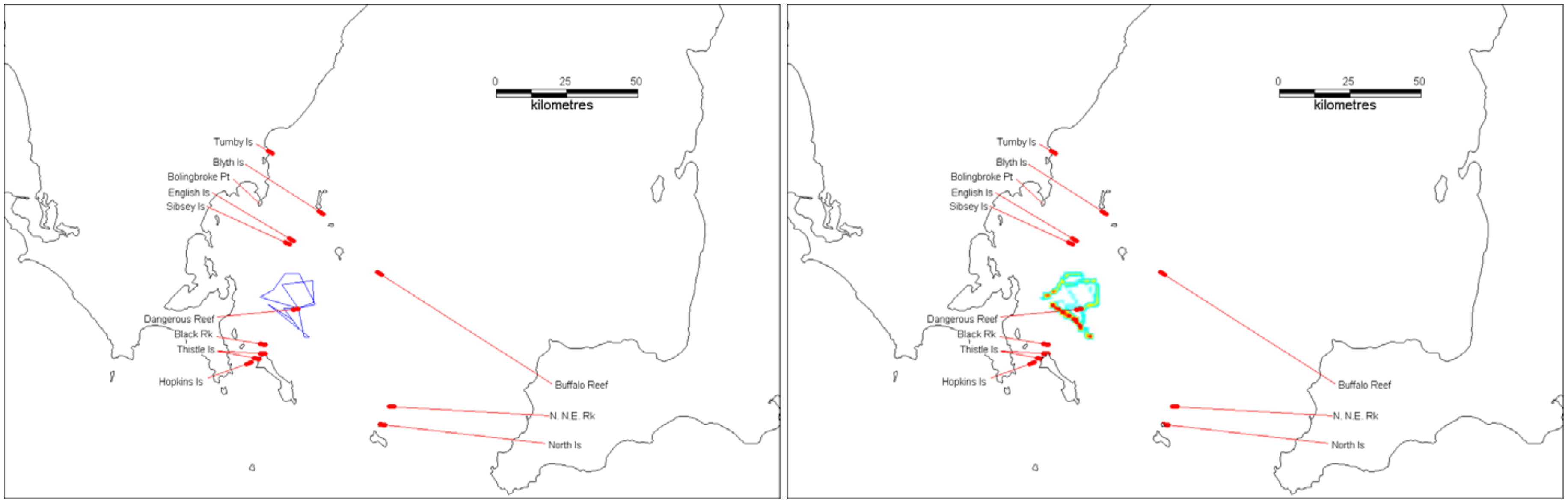
Adult female 10511 from Dangerous Reef. Tracks of 7 foraging trips (left) and time spent in 1 x 1 km areas (right).



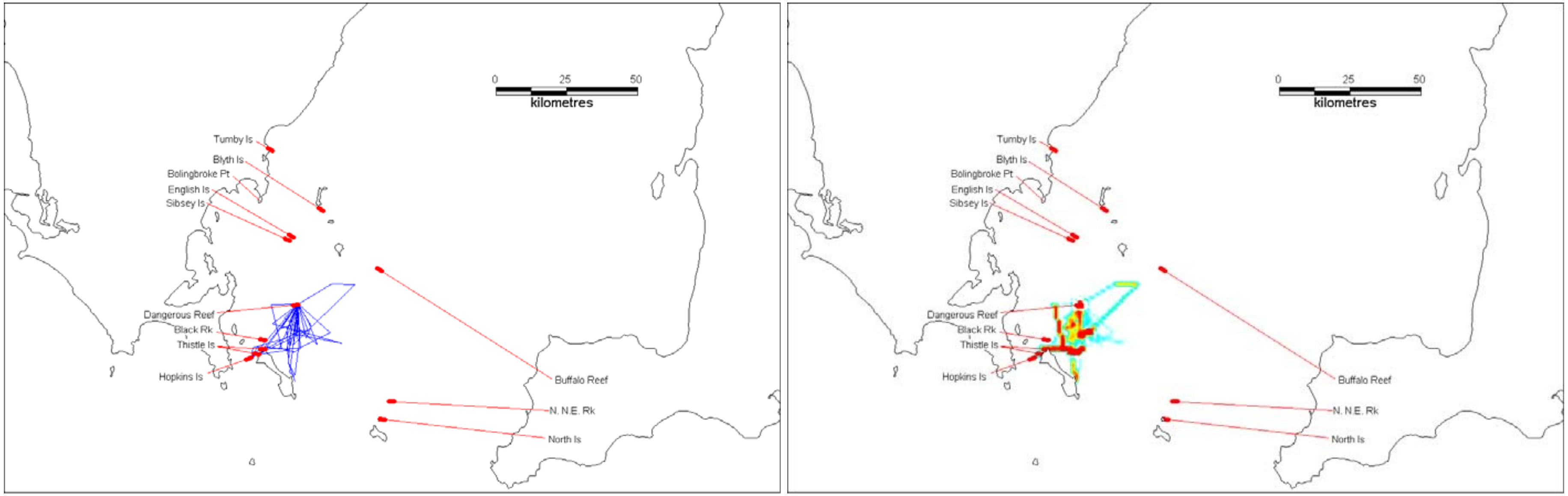
Adult female 10611 from Dangerous Reef. Tracks of 13 foraging trips (left) and time spent in 1 x 1 km areas (right).



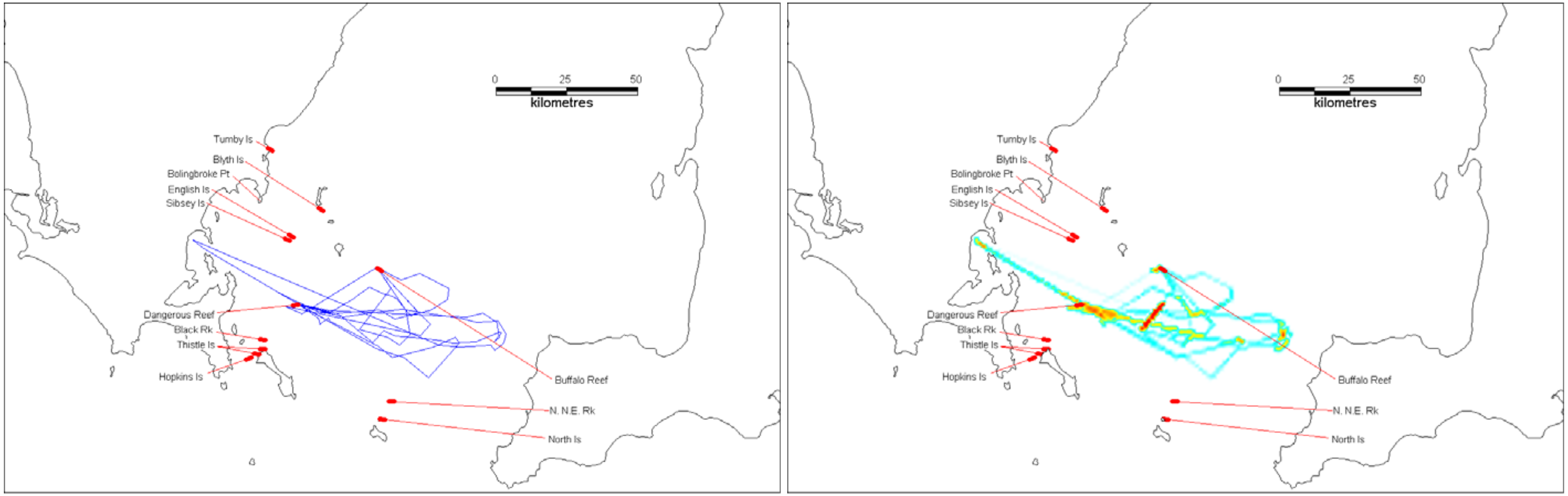
Adult female 10711 from Dangerous Reef. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).



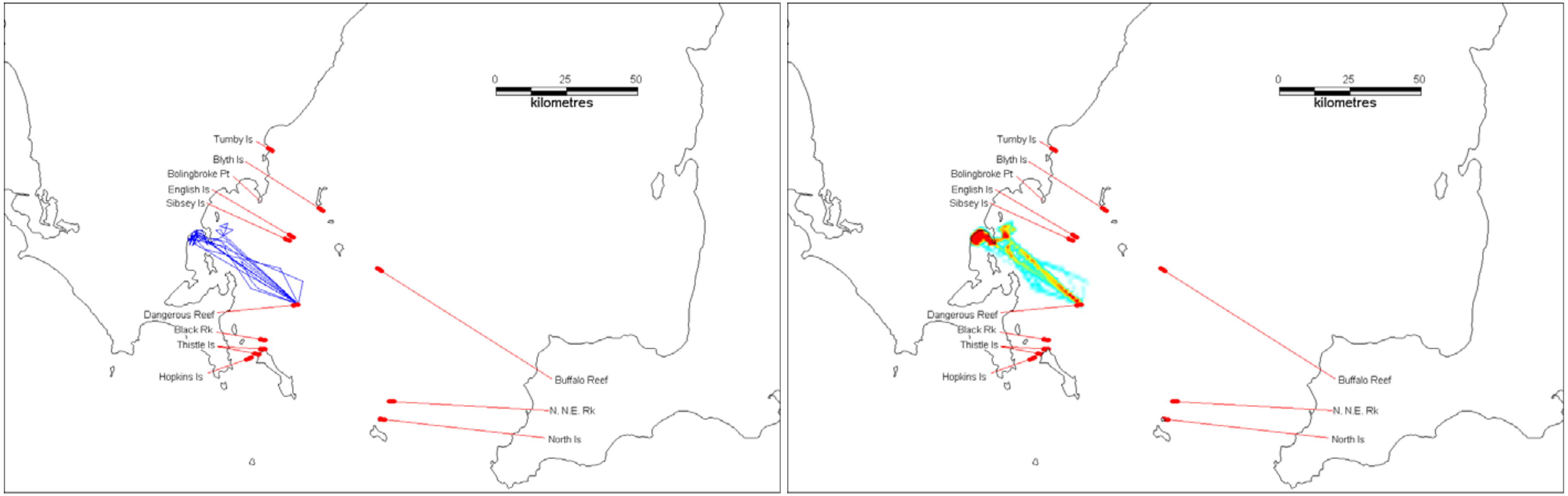
Adult female 10811 from Dangerous Reef. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 10911 from Dangerous Reef. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).

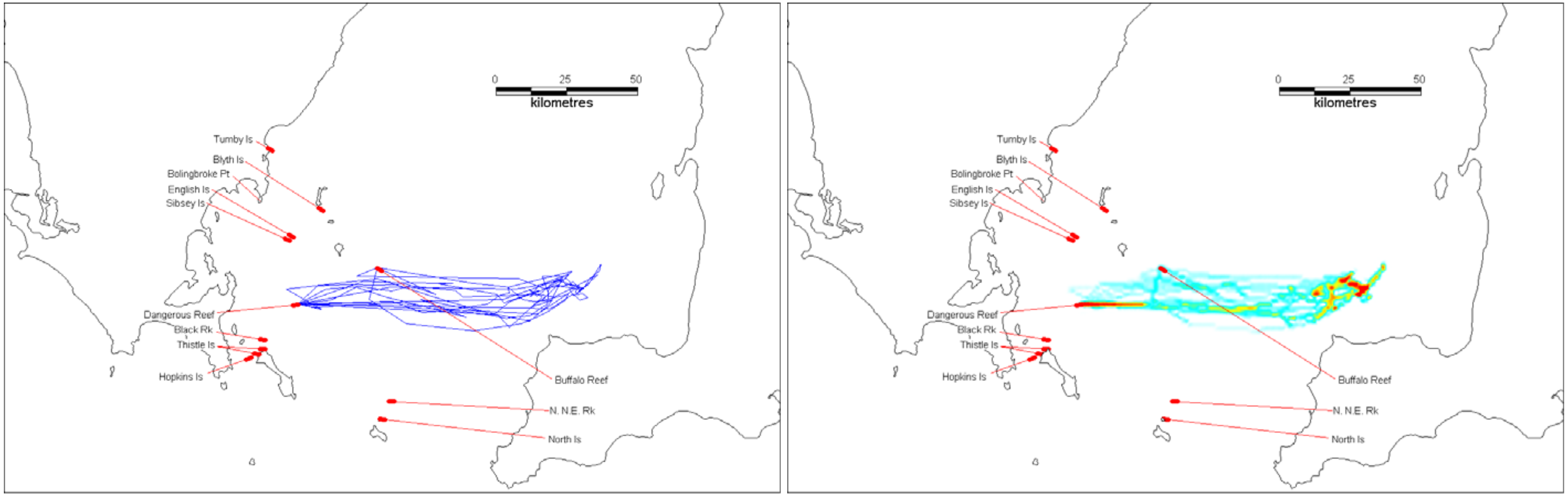


Adult female 11011 from Dangerous Reef. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



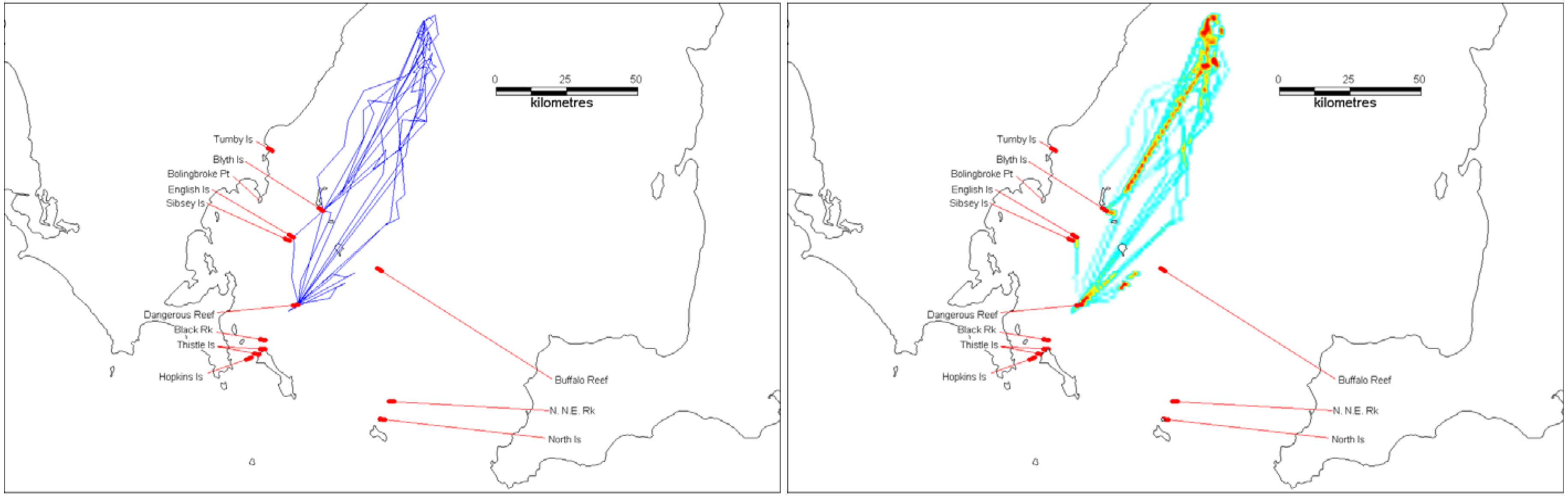
Adult female 11111 from Dangerous Reef. Tracks of 7 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 11211 from Dangerous Reef. Tracks of 35 foraging trips (left) and time spent in 1 x 1 km areas (right).



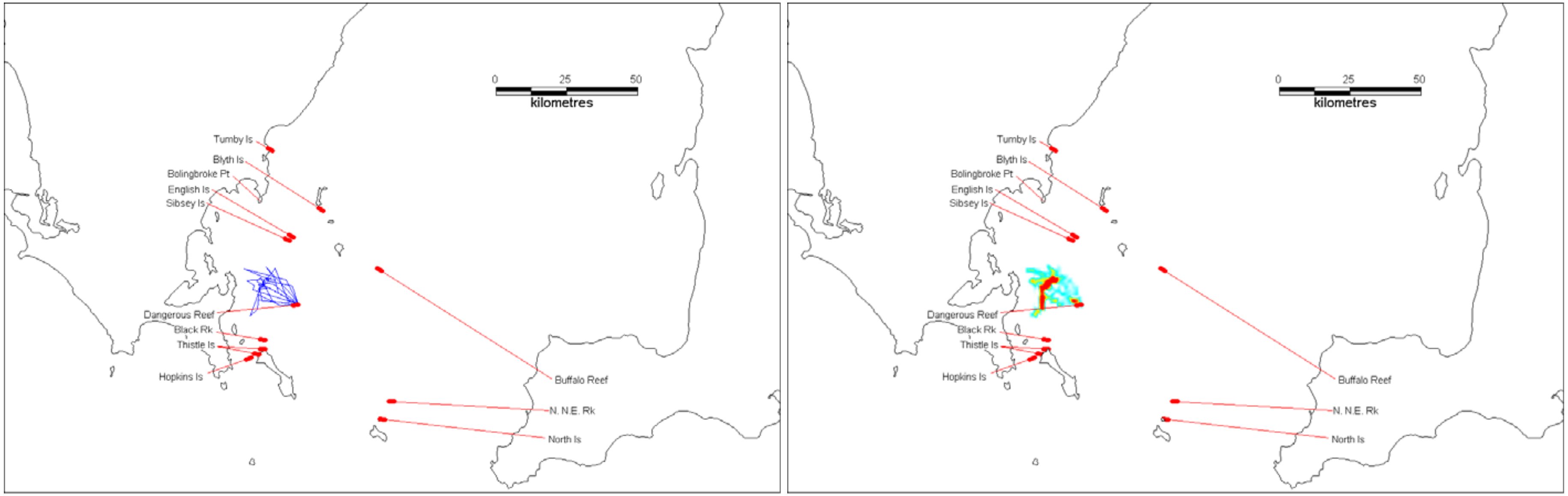
Adult female 11311 from Dangerous Reef. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 11411 from Dangerous Reef. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).

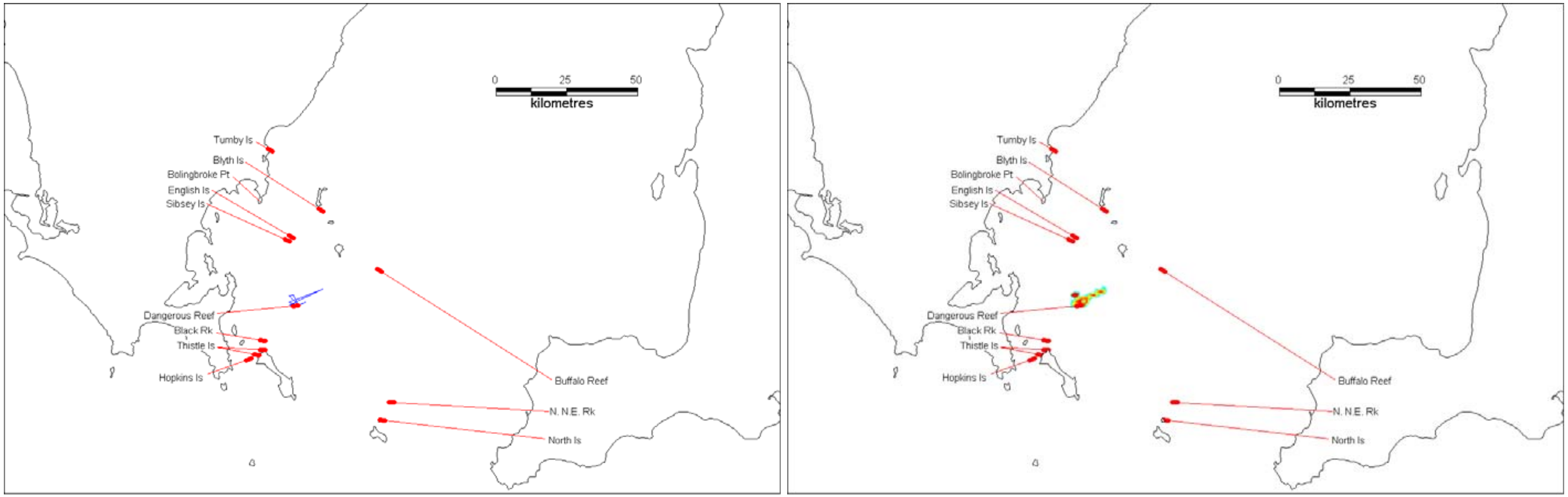


Adult female 11511 from Dangerous Reef. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).

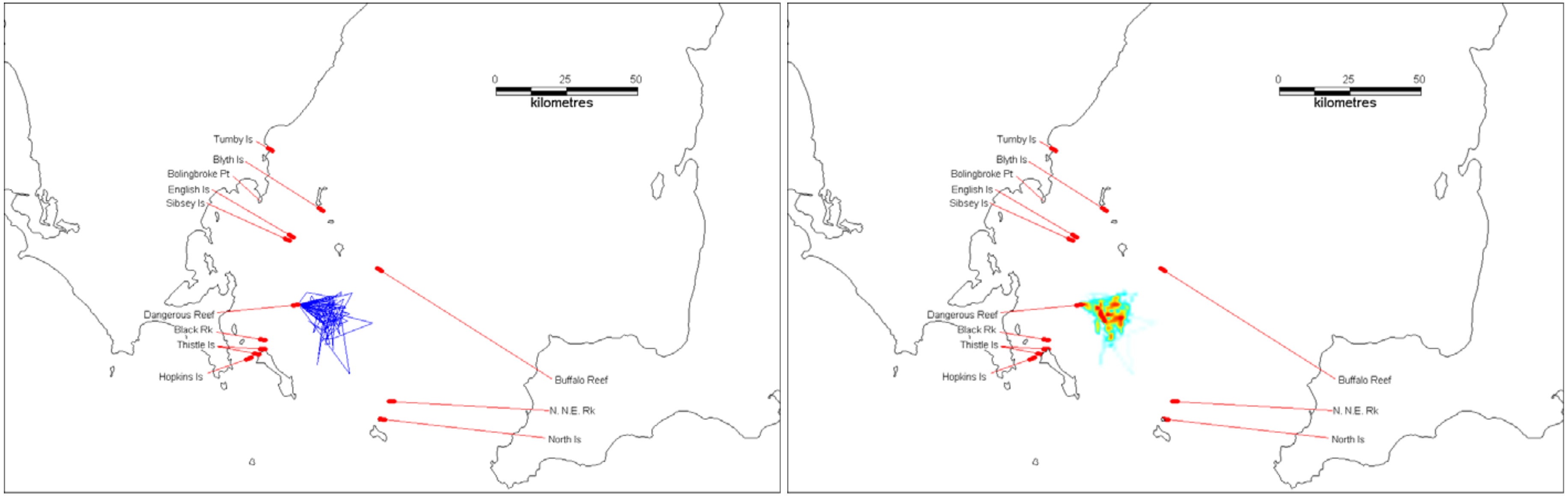
Adult female 11611 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).



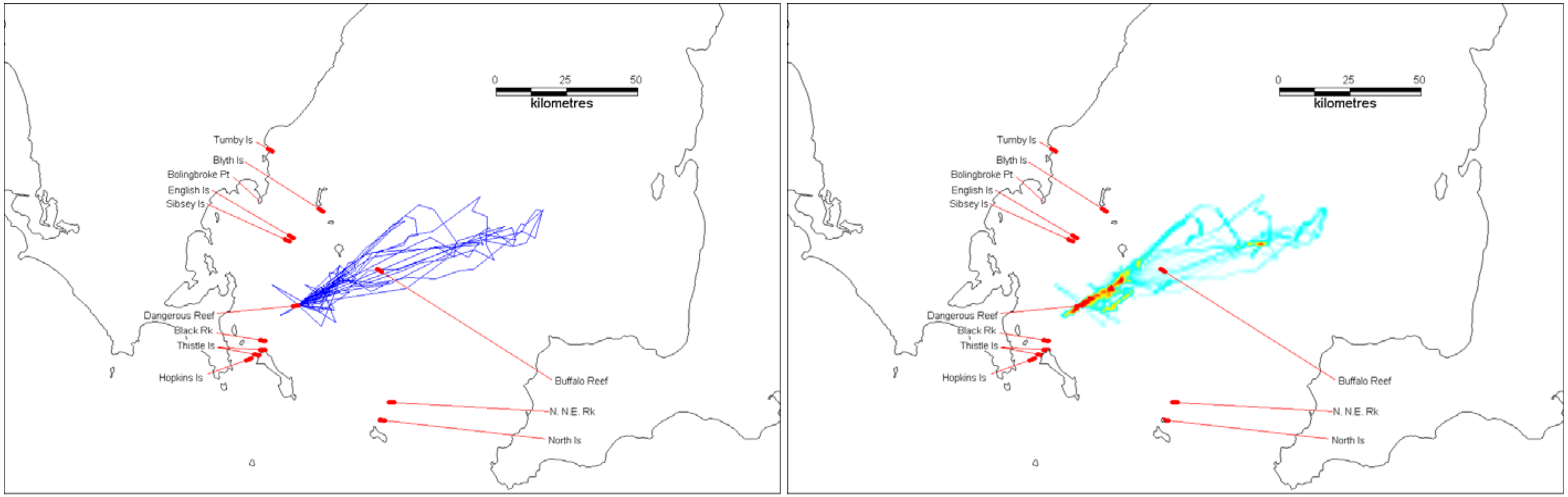
Adult female 11711 from Dangerous Reef. Tracks of 6 foraging trips (left) and time spent in 1 x 1 km areas (right).



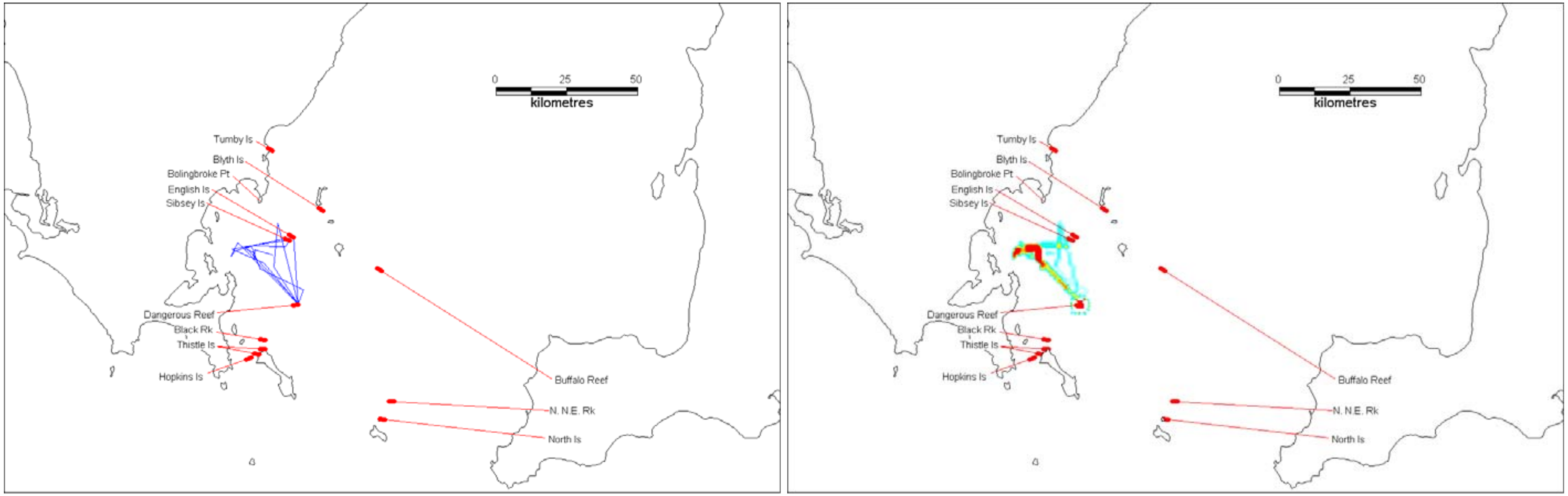
Adult female 11811 from Dangerous Reef. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 11911 from Dangerous Reef. Tracks of 16 foraging trips (left) and time spent in 1 x 1 km areas (right).

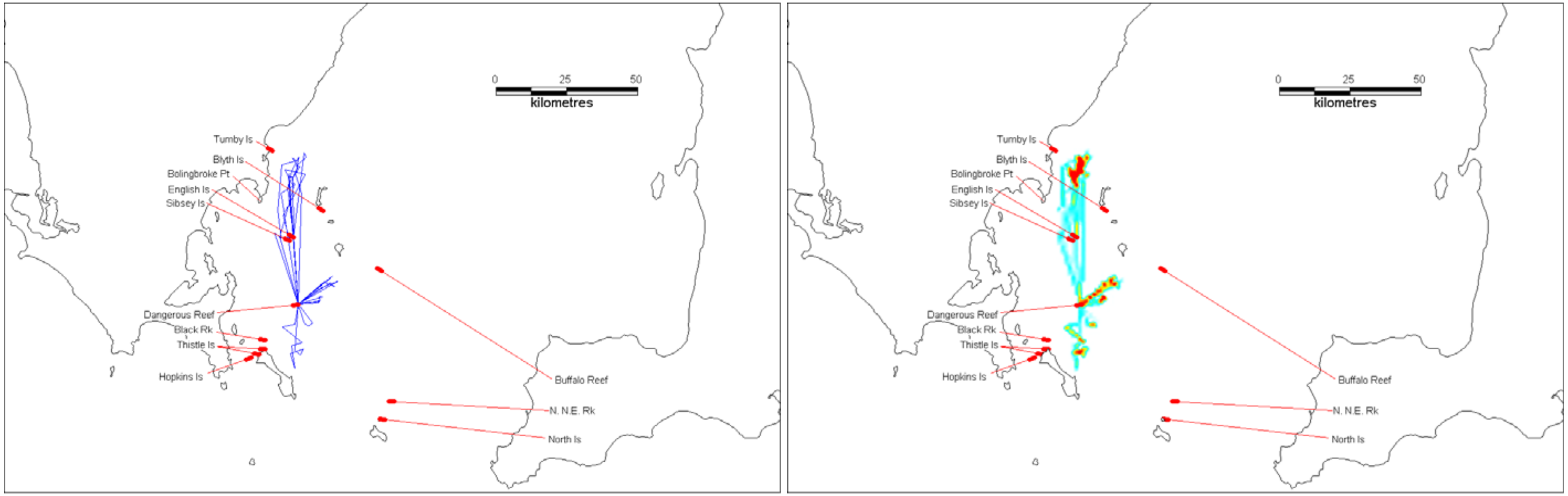


Adult female 12011 from Dangerous Reef. Tracks of 23 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 12111 from Dangerous Reef. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 12211 from Dangerous Reef. Tracks of 13 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 12311 from Dangerous Reef. Tracks of 13 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 12411 from Dangerous Reef. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 111 from Dangerous Reef. Tracks of 68 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 311 from Dangerous Reef. Tracks of 91 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 1111 from Dangerous Reef. Tracks of 23 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 1211 from Dangerous Reef. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 1311 from Dangerous Reef. Tracks of 14 foraging trips (left) and time spent in 1 x 1 km areas (right).

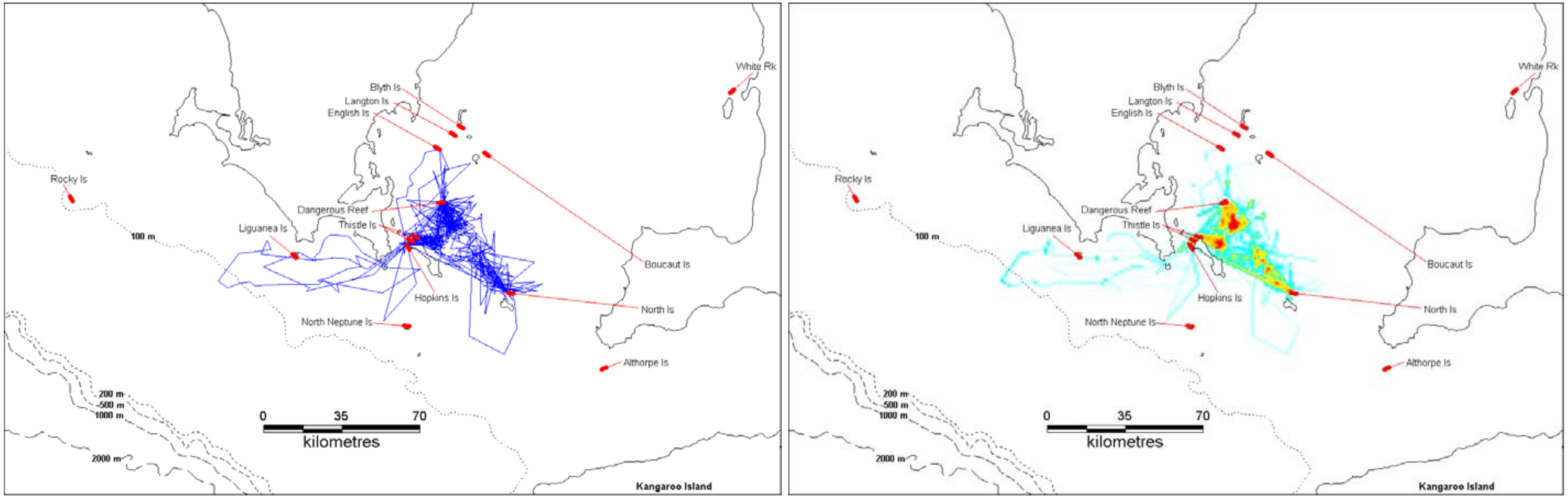
Adult female 1411 from Dangerous Reef. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 1511 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).

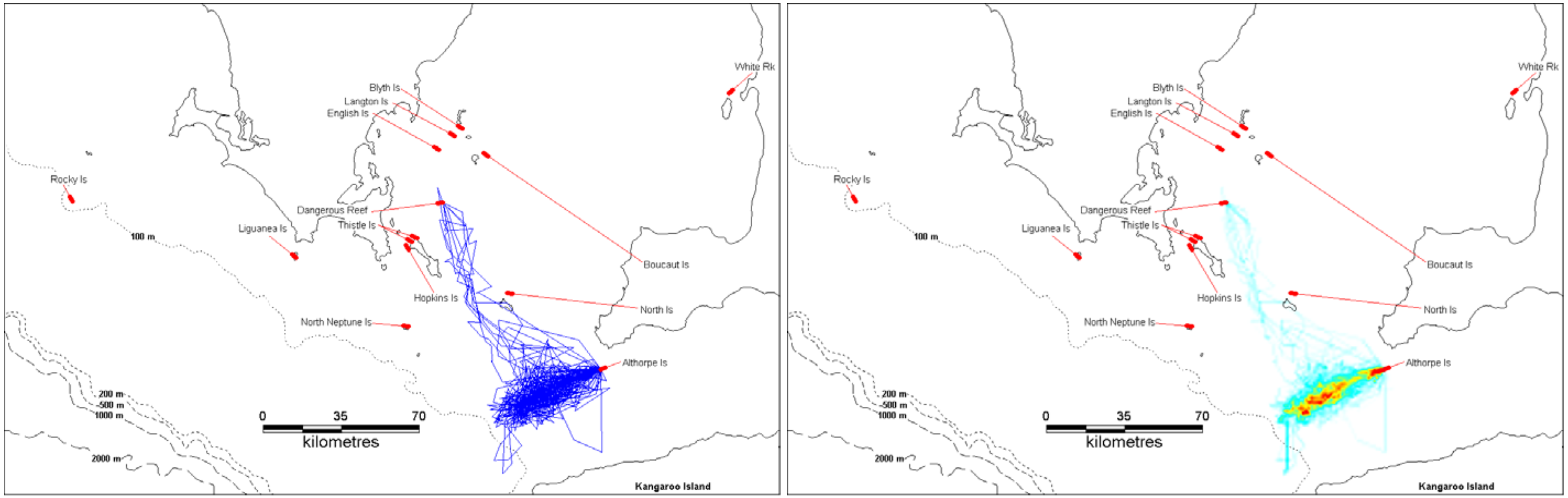
Adult female 1611 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 1711 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).

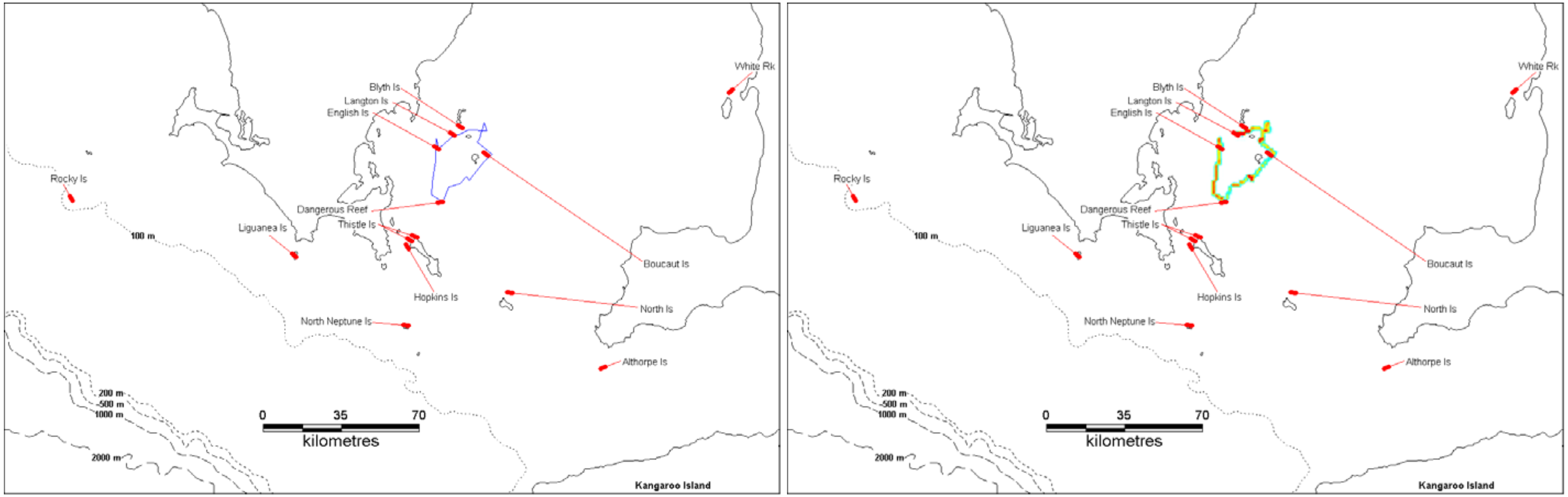
Adult female 1811 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).



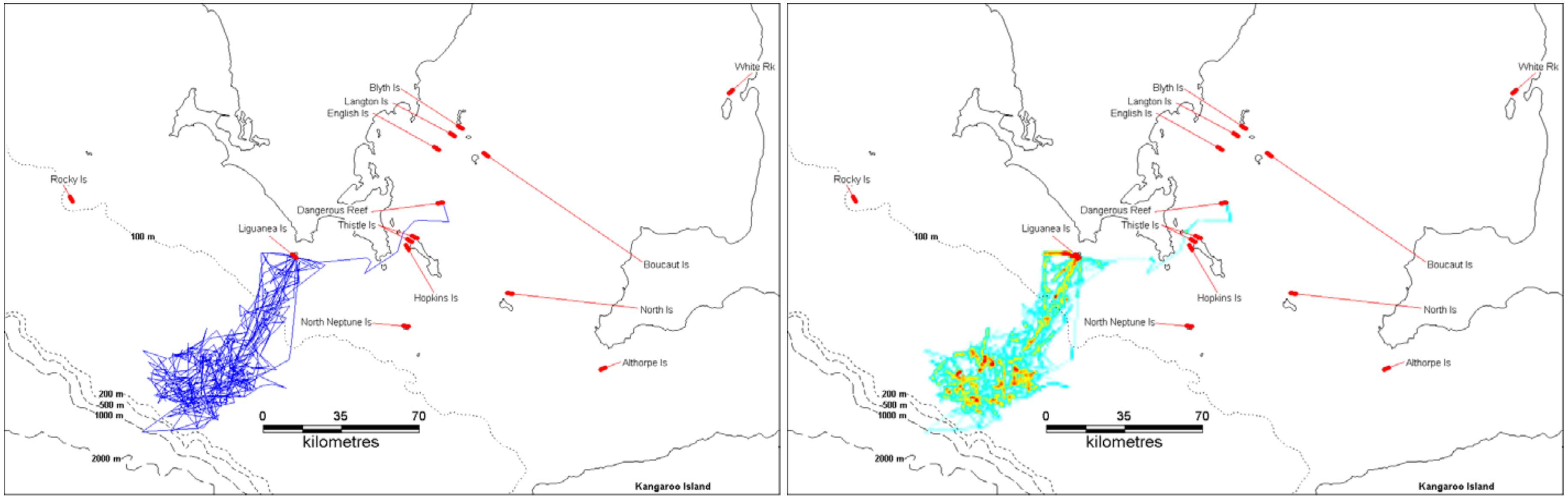
Adult male 212 from Dangerous Reef. Tracks of 46 foraging trips (left) and time spent in 1 x 1 km areas (right).



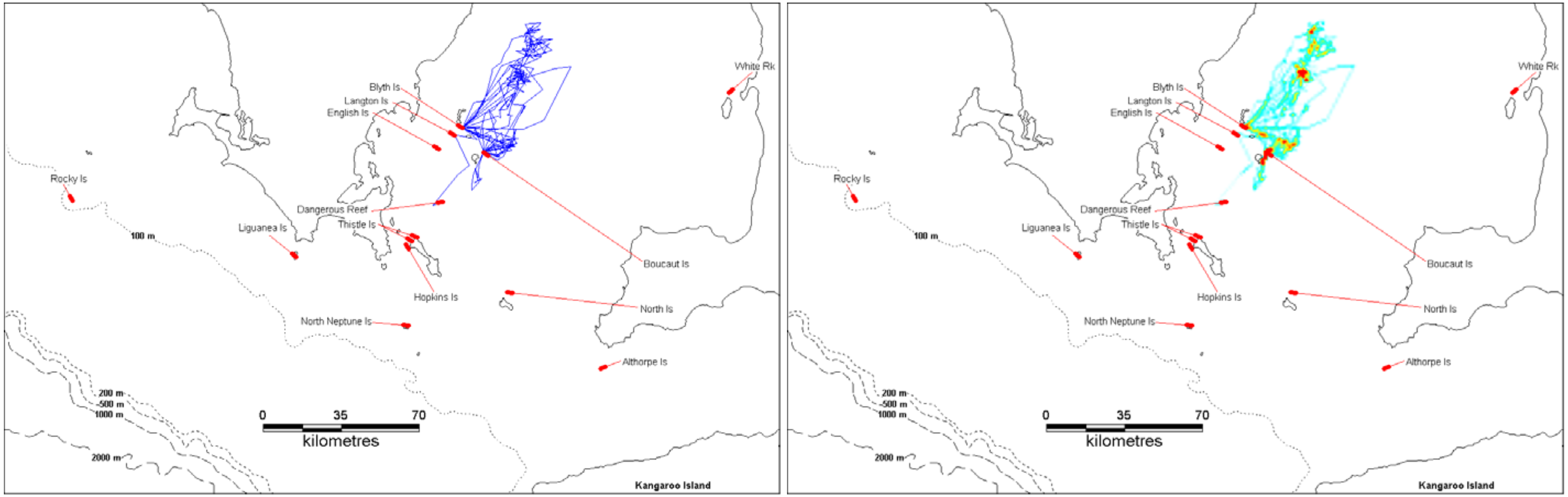
Adult male 412 from Dangerous Reef. Tracks of 44 foraging trips (left) and time spent in 1 x 1 km areas (right).



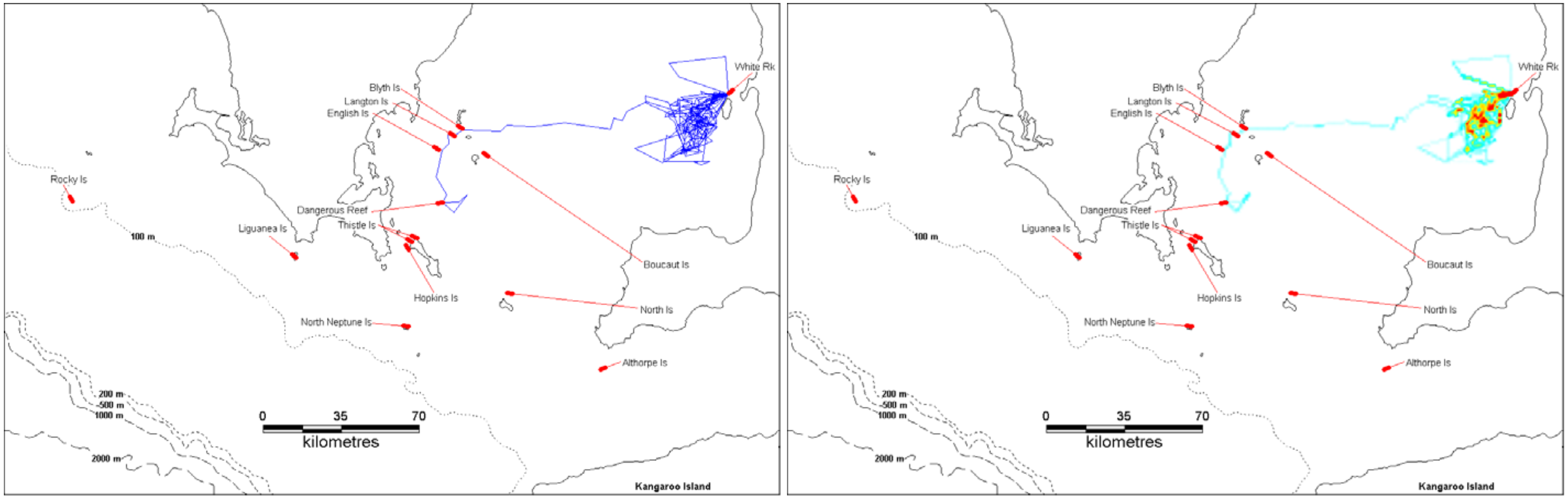
Adult male 512 from Dangerous Reef. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



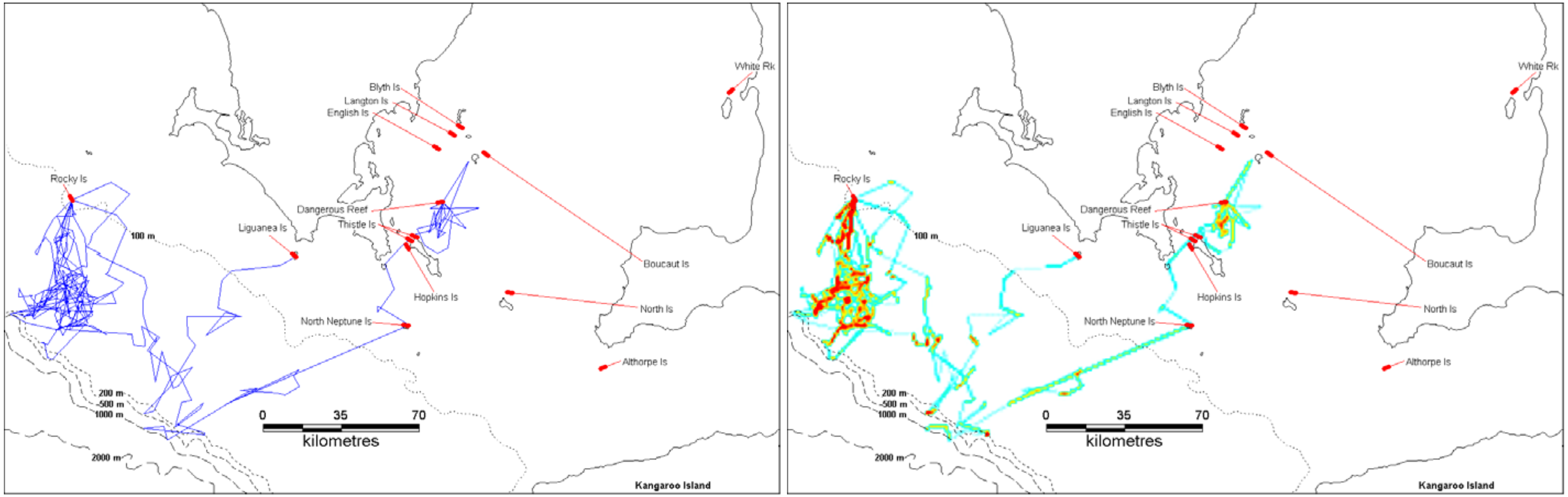
Adult male 3012 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



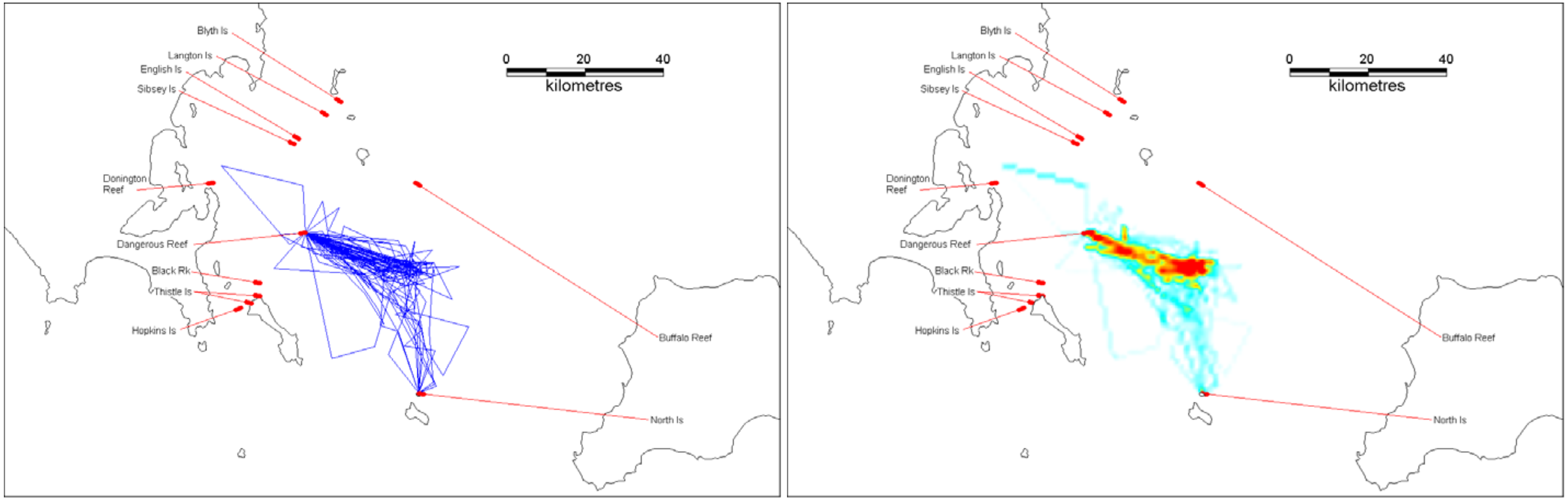
Adult male 3112 from Dangerous Reef. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



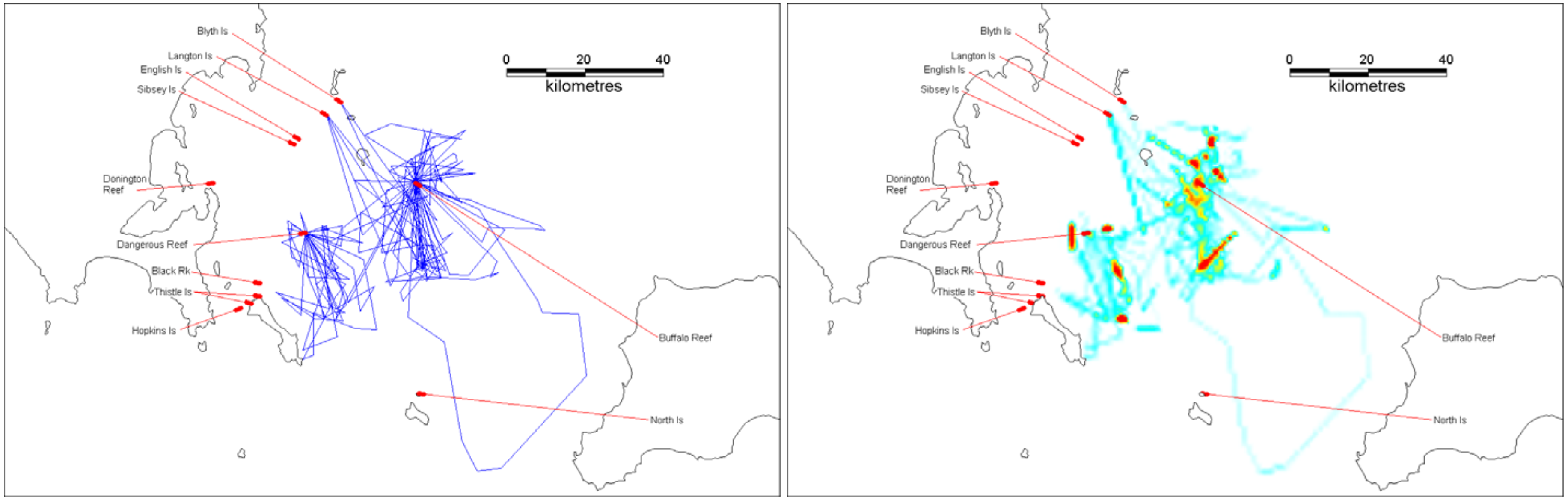
Adult male 3212 from Dangerous Reef. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



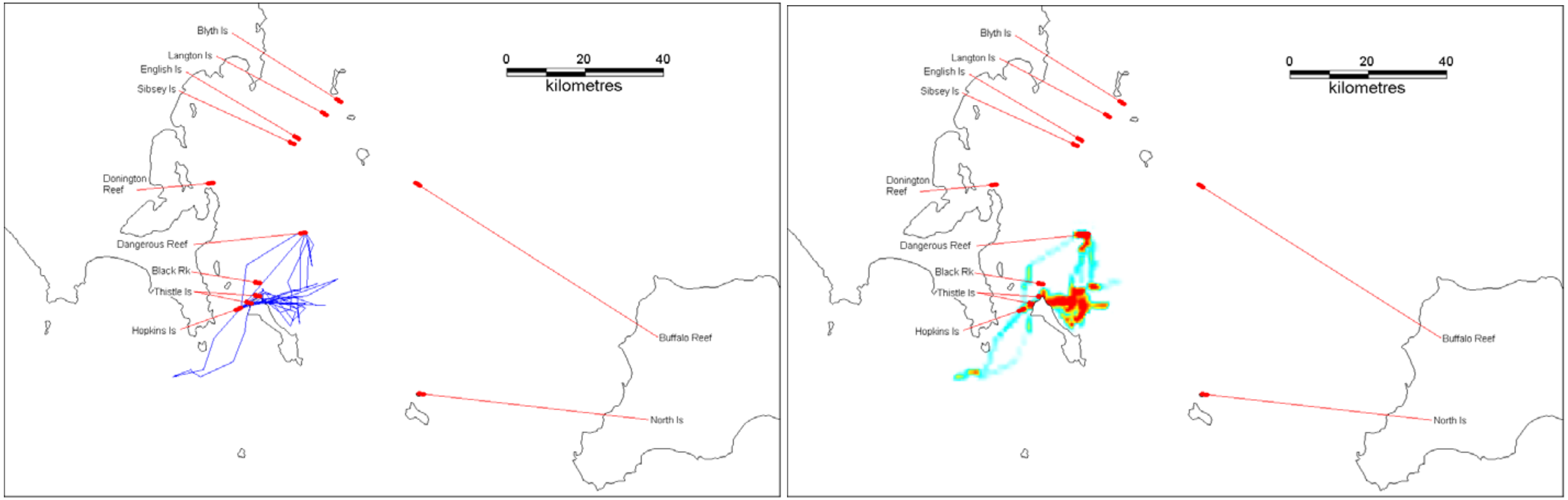
Adult male 3312 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



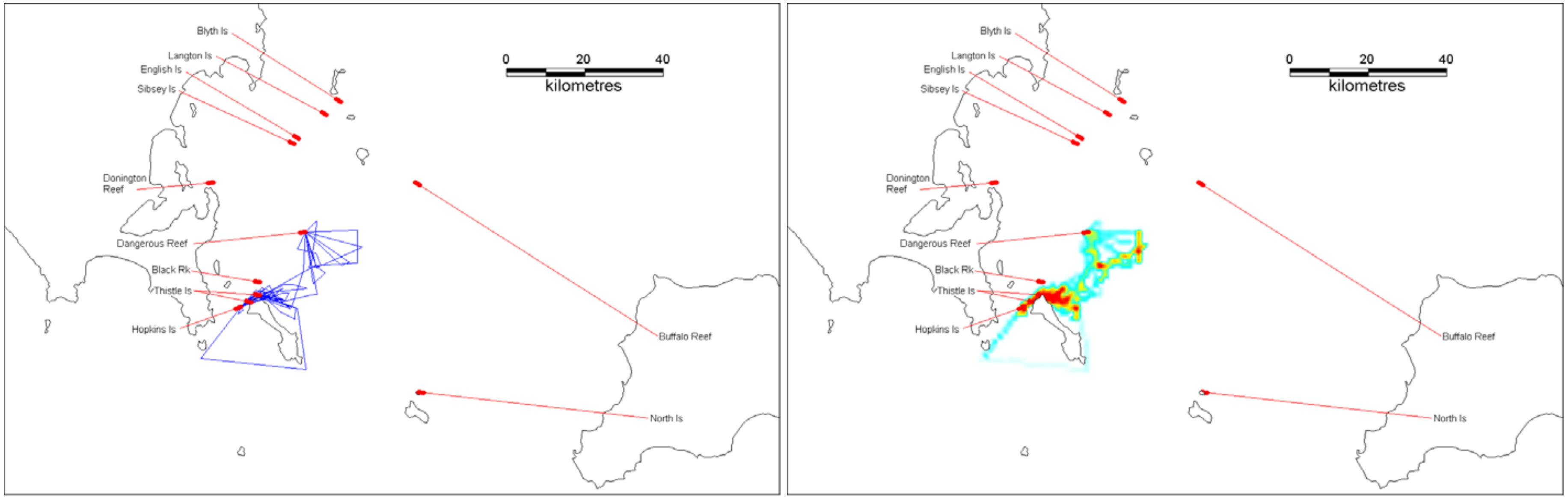
Juvenile male 10314 from Dangerous Reef. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



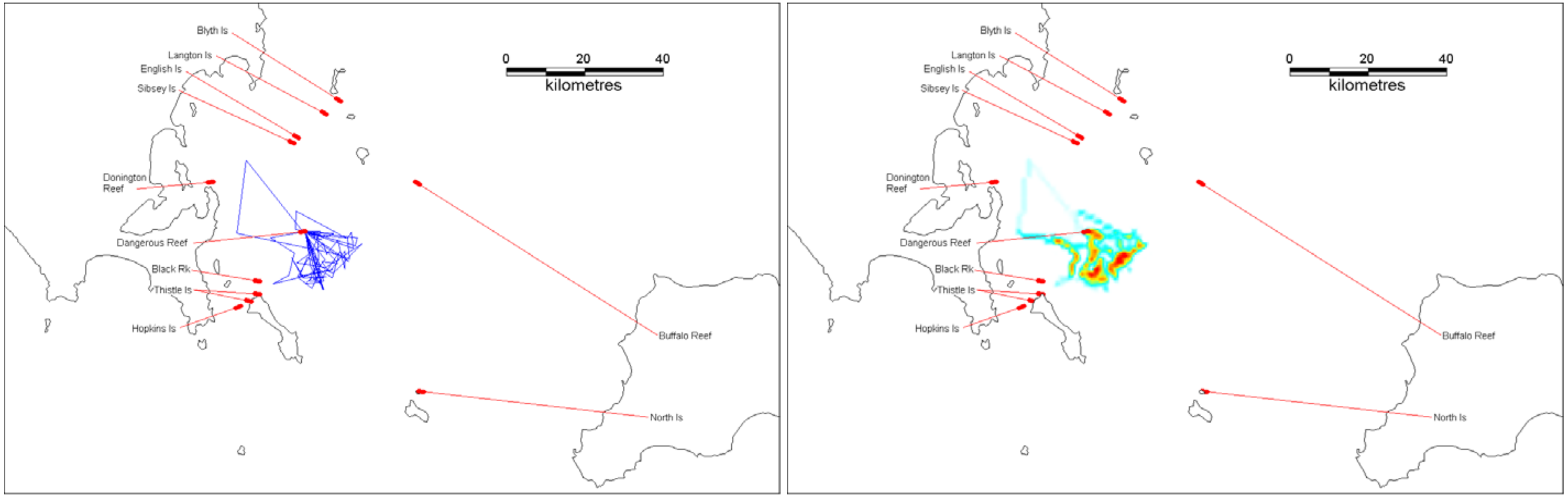
Juvenile male 12514 from Dangerous Reef. Tracks of 40 foraging trips (left) and time spent in 1 x 1 km areas (right).



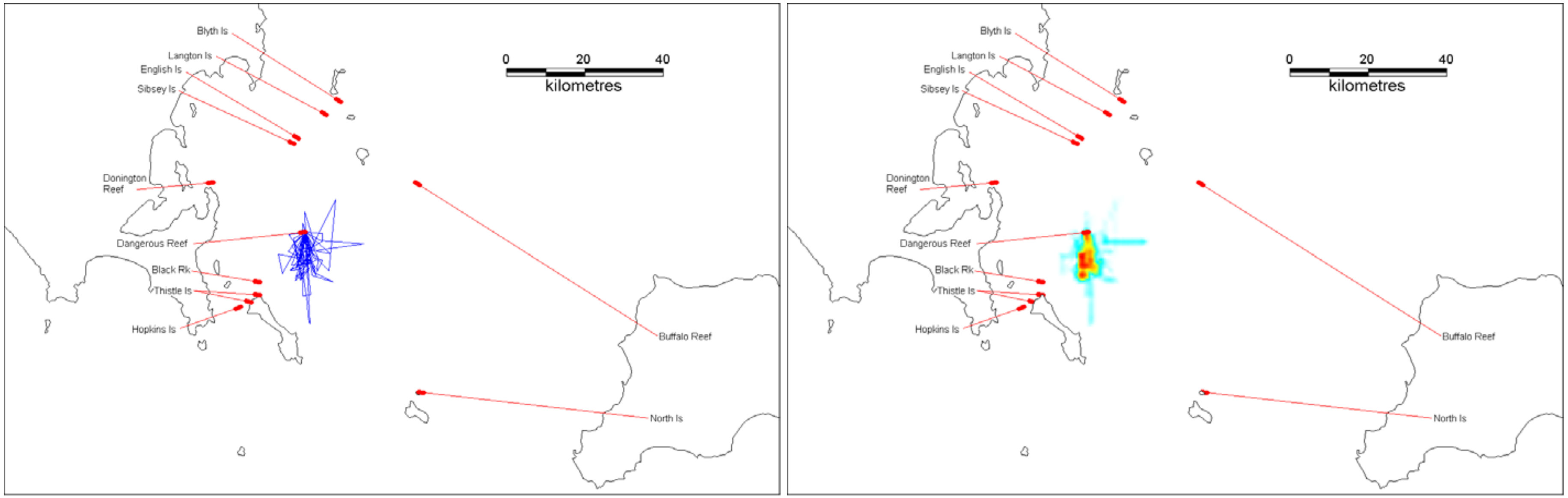
Juvenile male 614 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



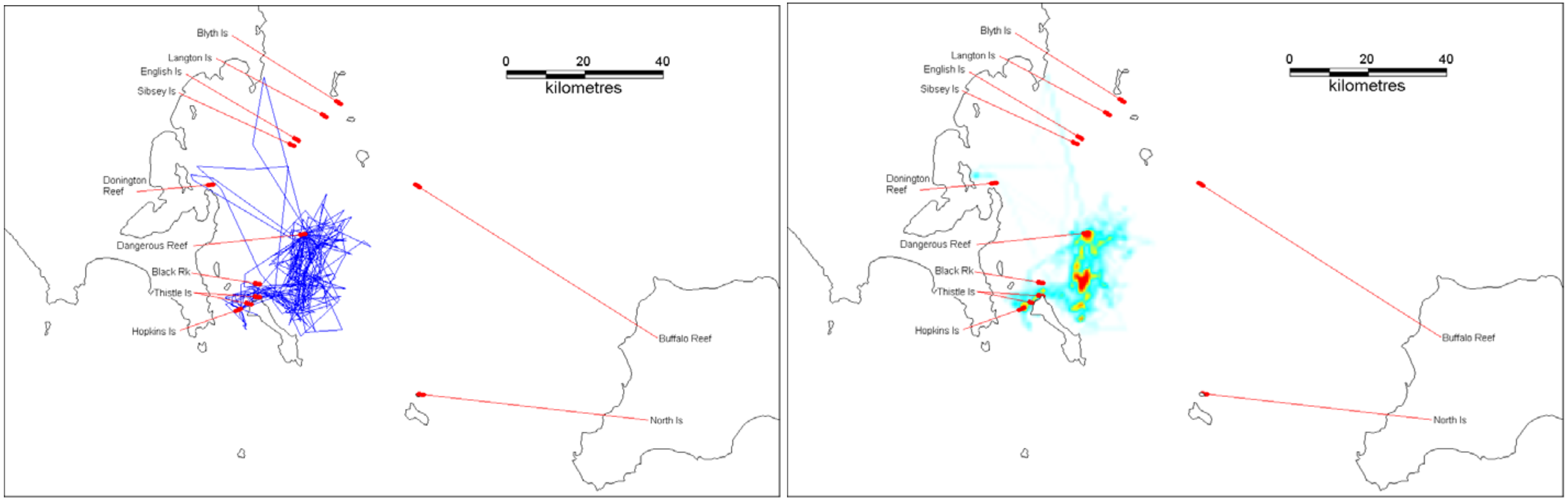
Juvenile male 714 from Dangerous Reef. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



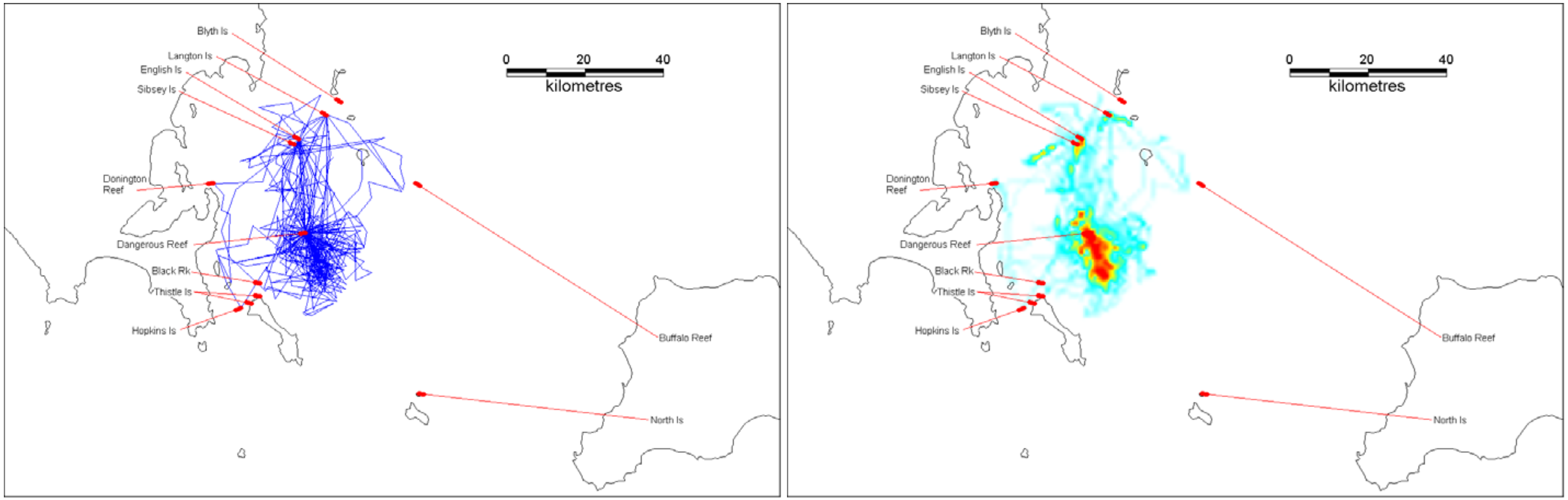
Juvenile male 914 from Dangerous Reef. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



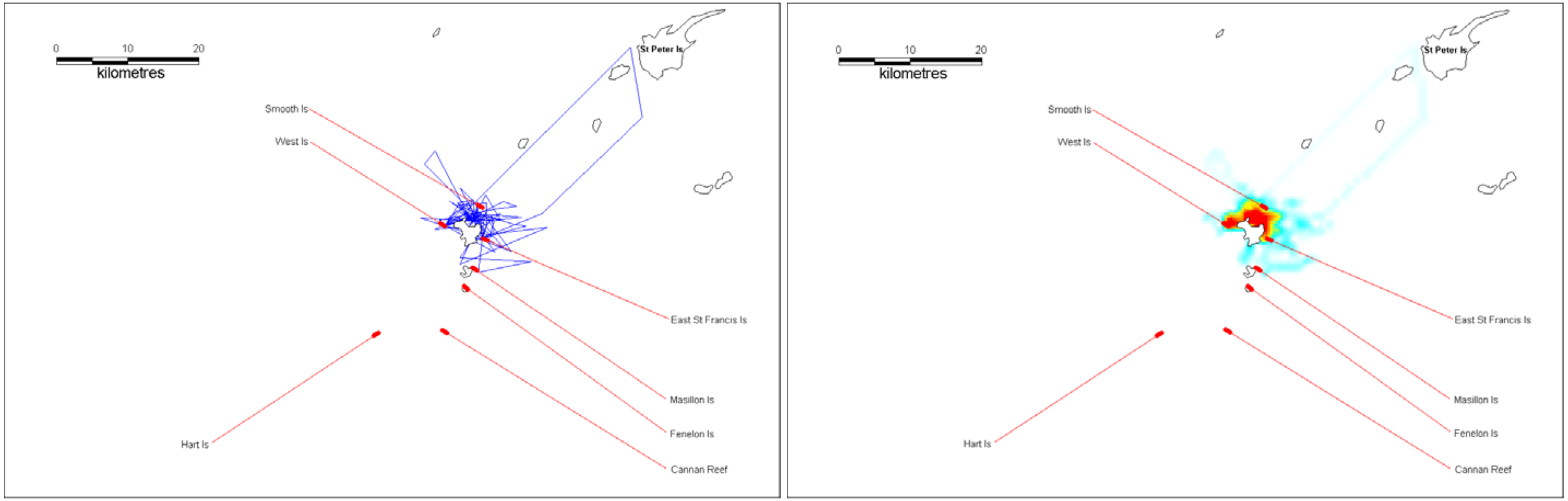
Juvenile male 1914 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).



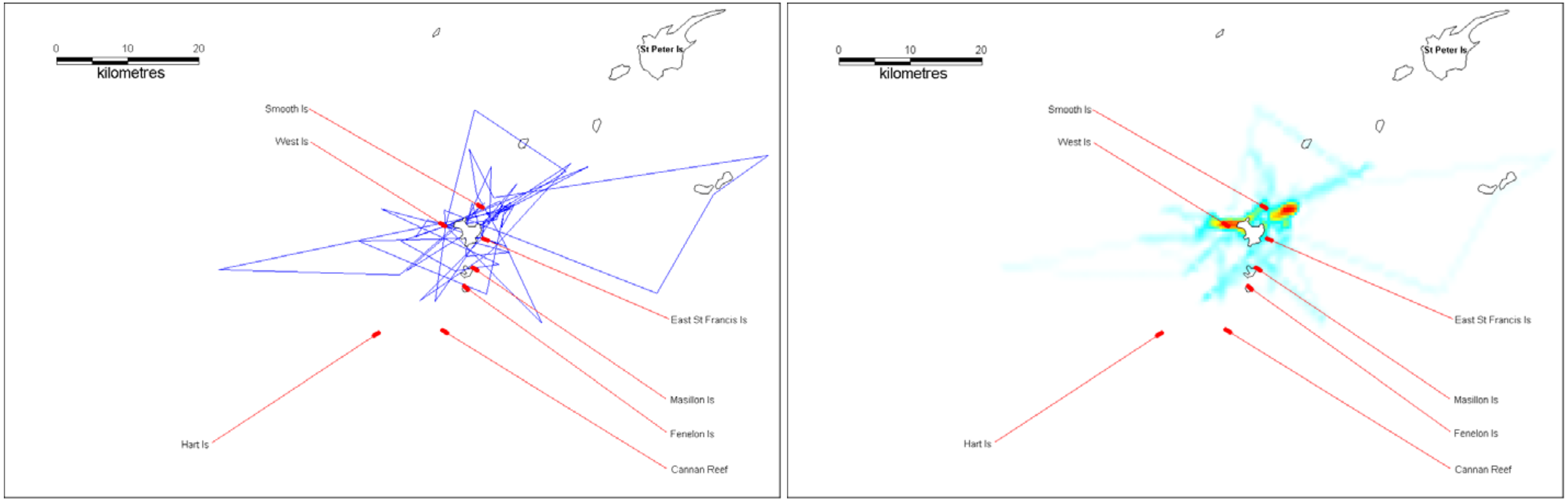
Juvenile male 2014 from Dangerous Reef. Tracks of 34 foraging trips (left) and time spent in 1 x 1 km areas (right).



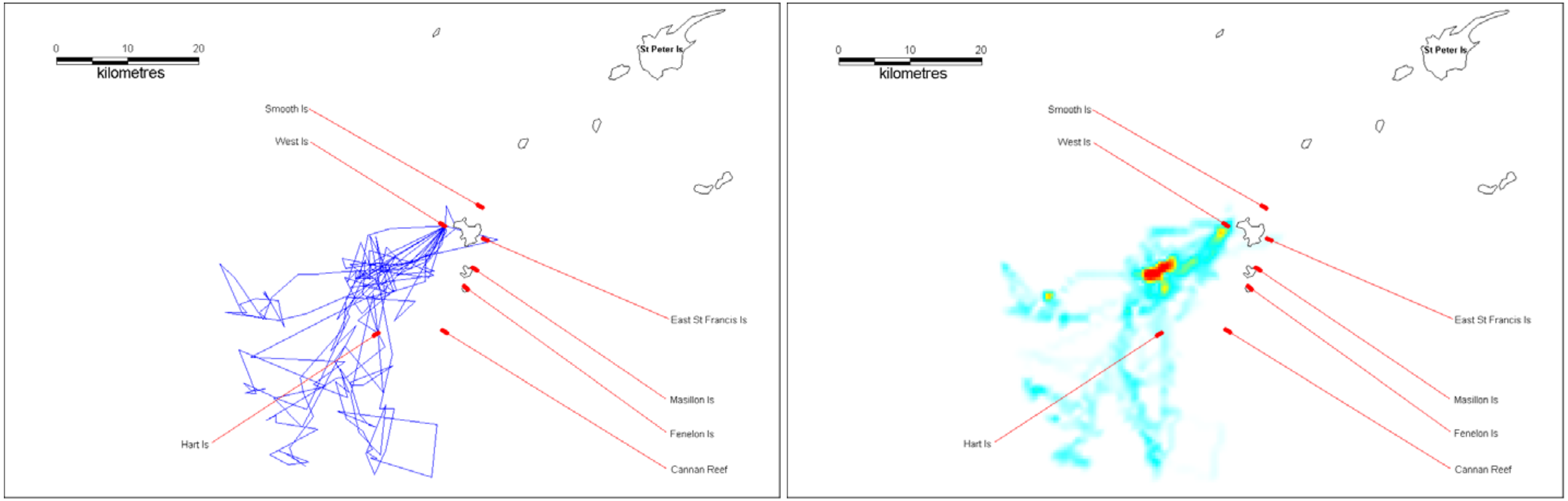
Subadult male 1015 from Dangerous Reef. Tracks of 78 foraging trips (left) and time spent in 1 x 1 km areas (right).



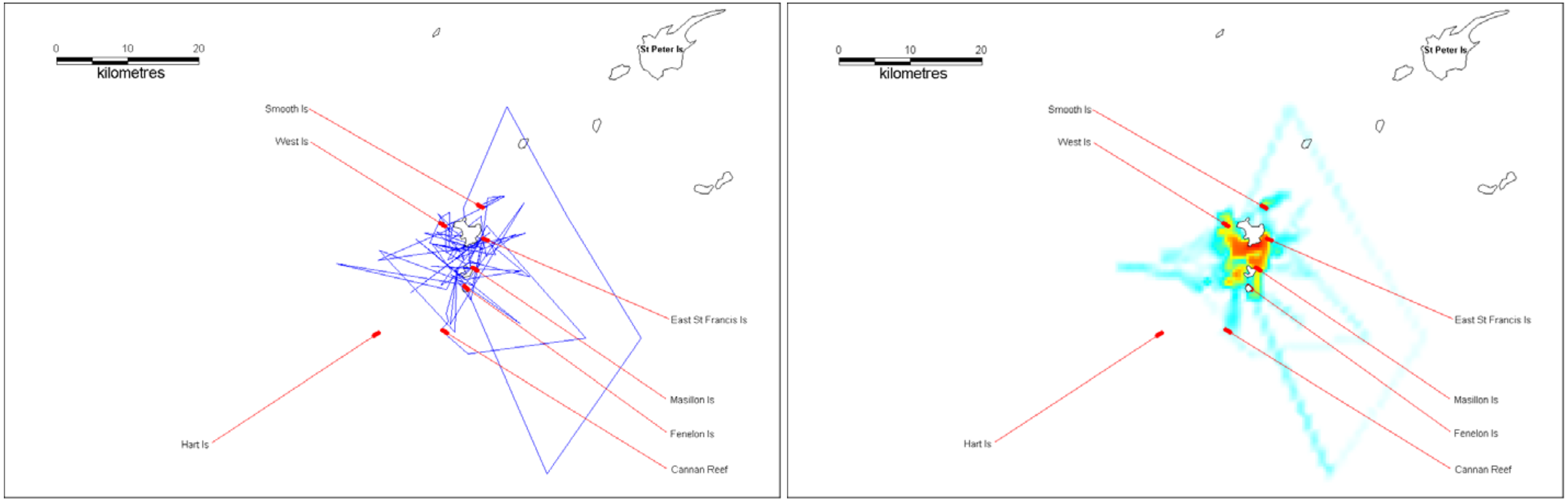
Adult female 121 from West Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).



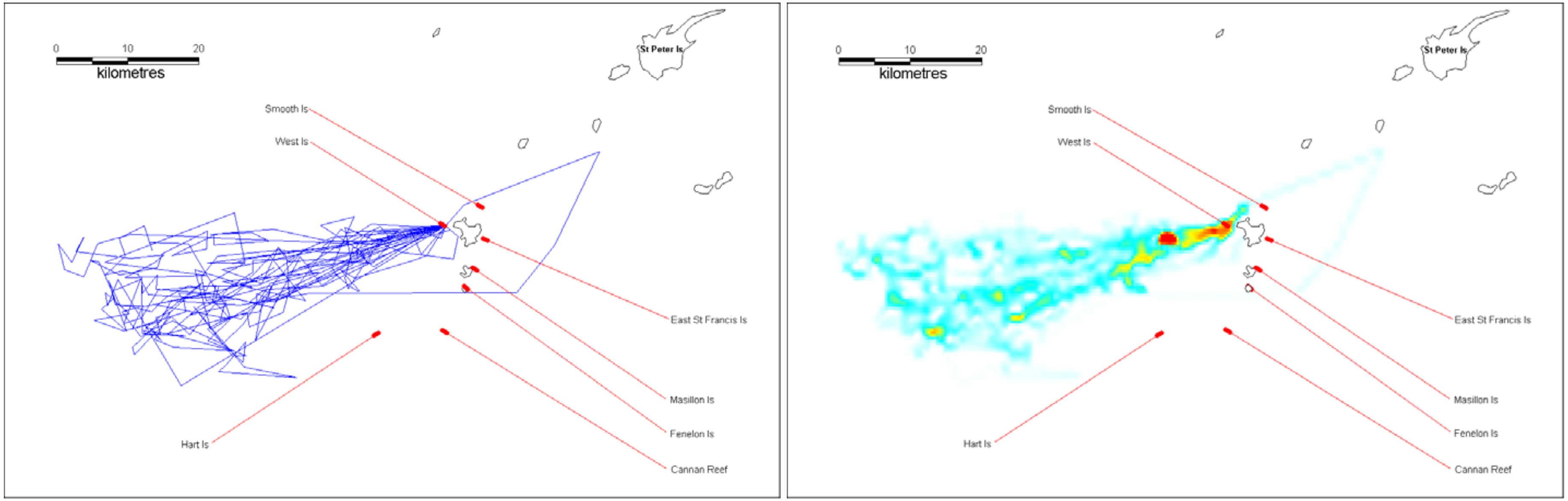
Adult female 321 from West Is. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



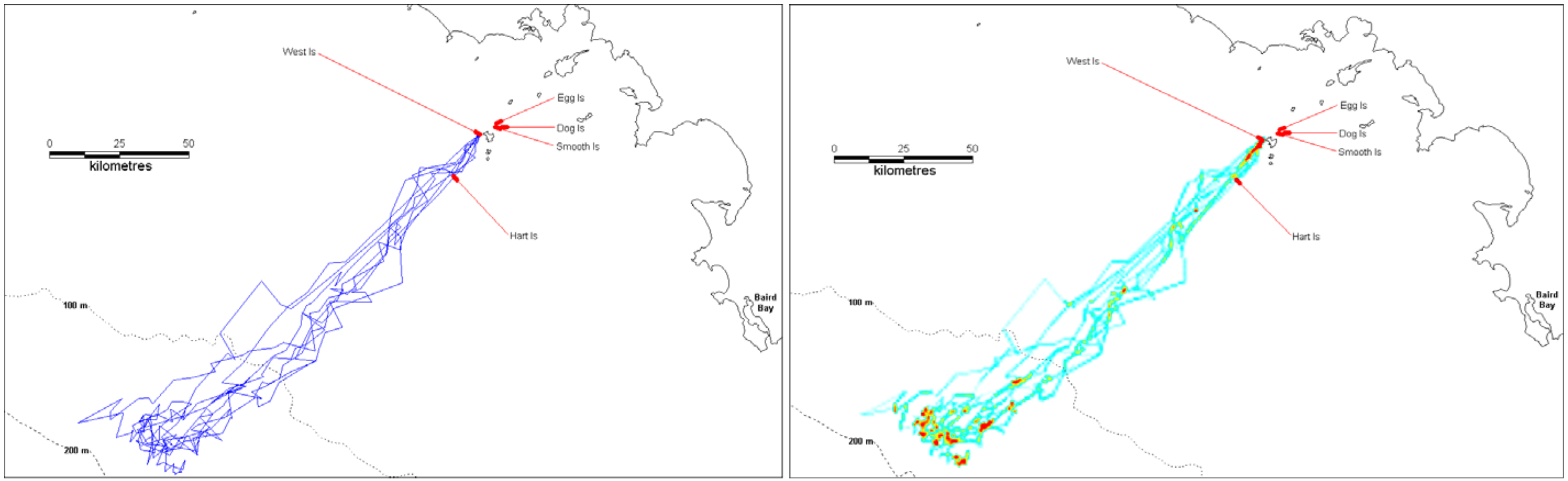
Adult female 421 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



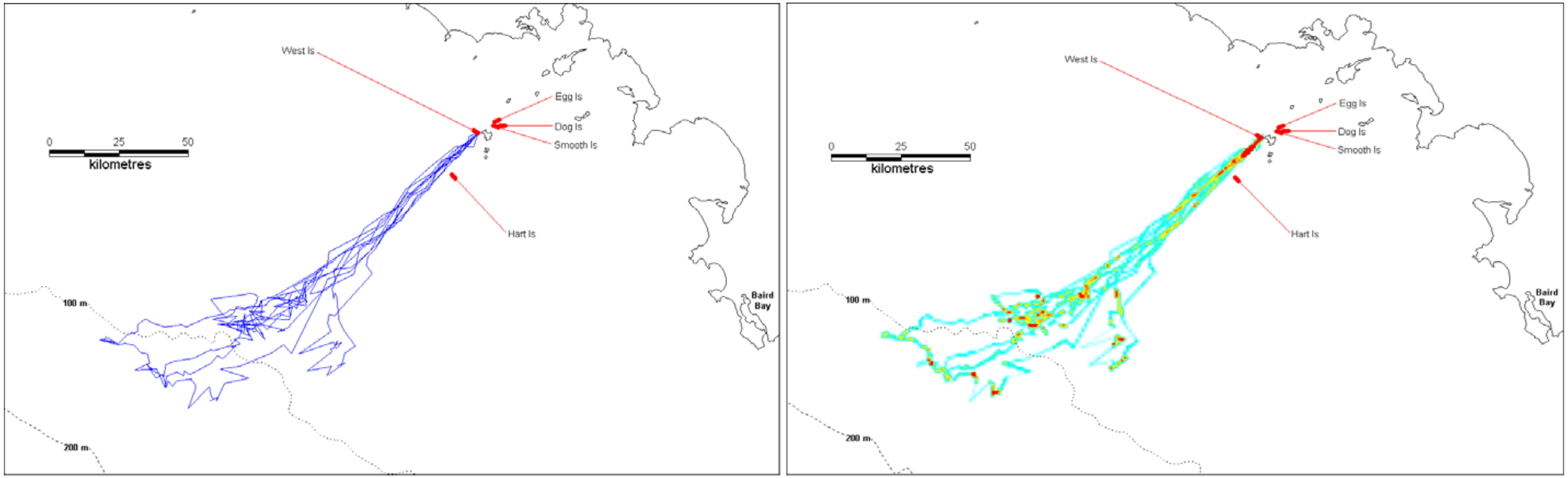
Adult female 521 from West Is. Tracks of 16 foraging trips (left) and time spent in 1 x 1 km areas (right).



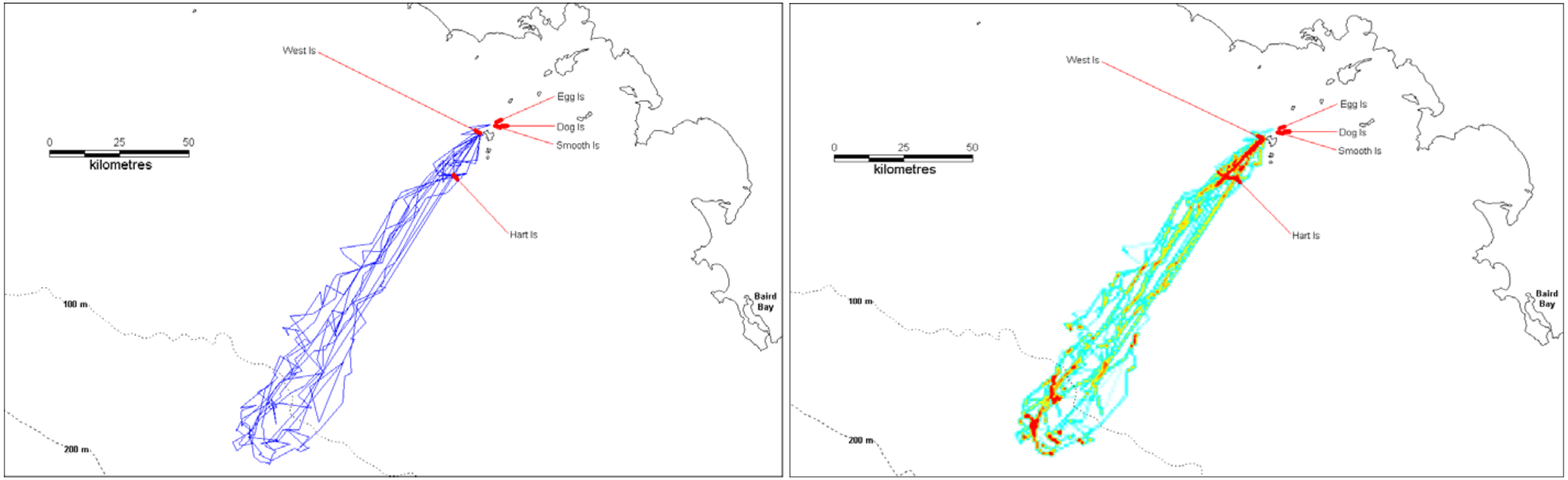
Adult female 621 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



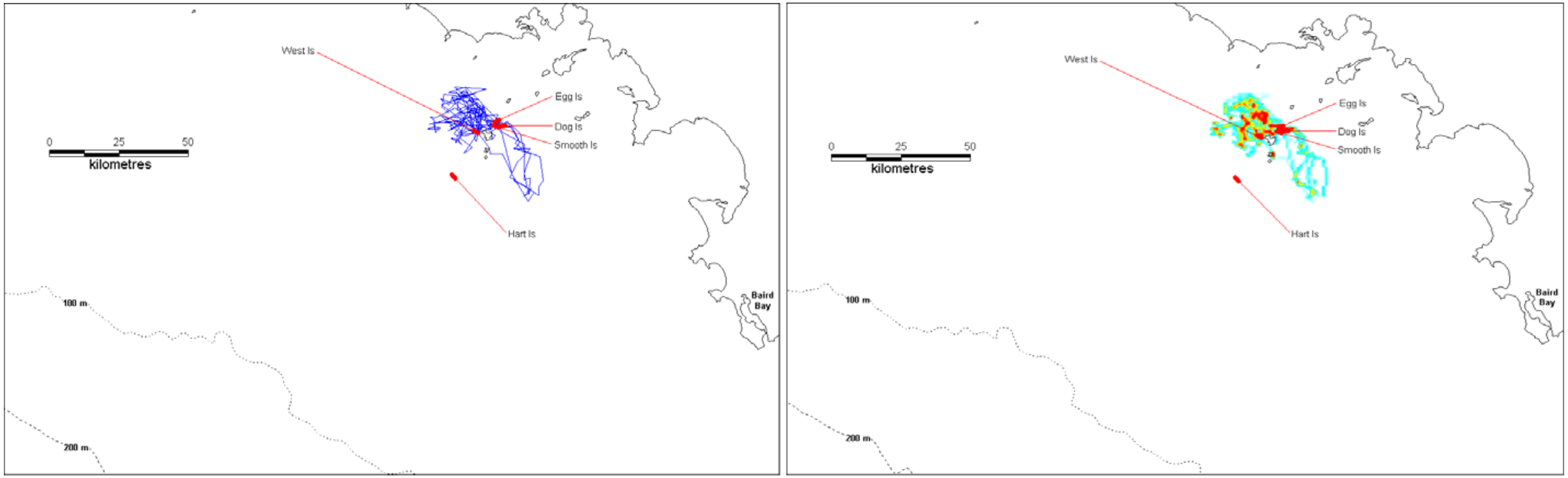
Adult male 1222 from West Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



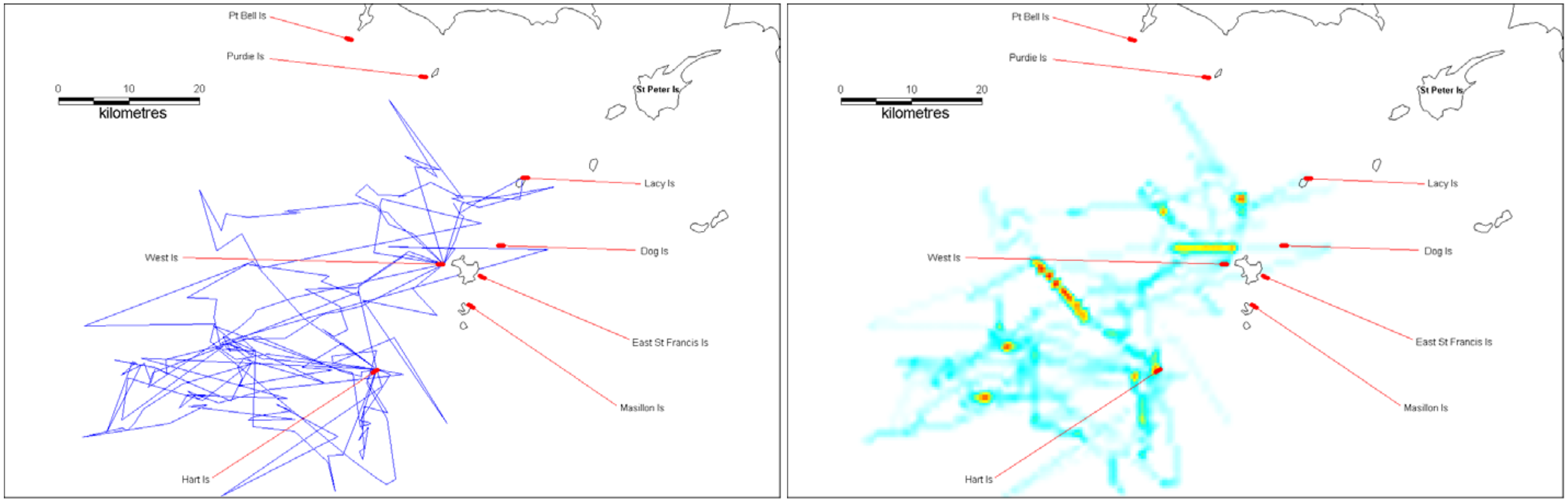
Adult male 1322 from West Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).



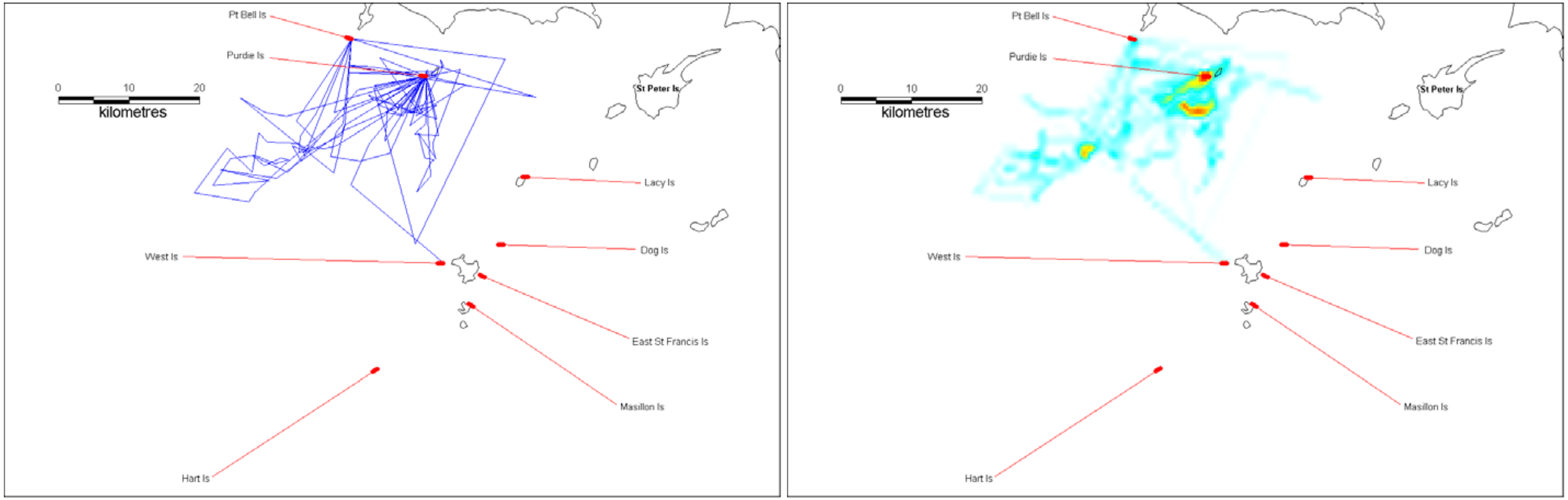
Adult male 1422 from West Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



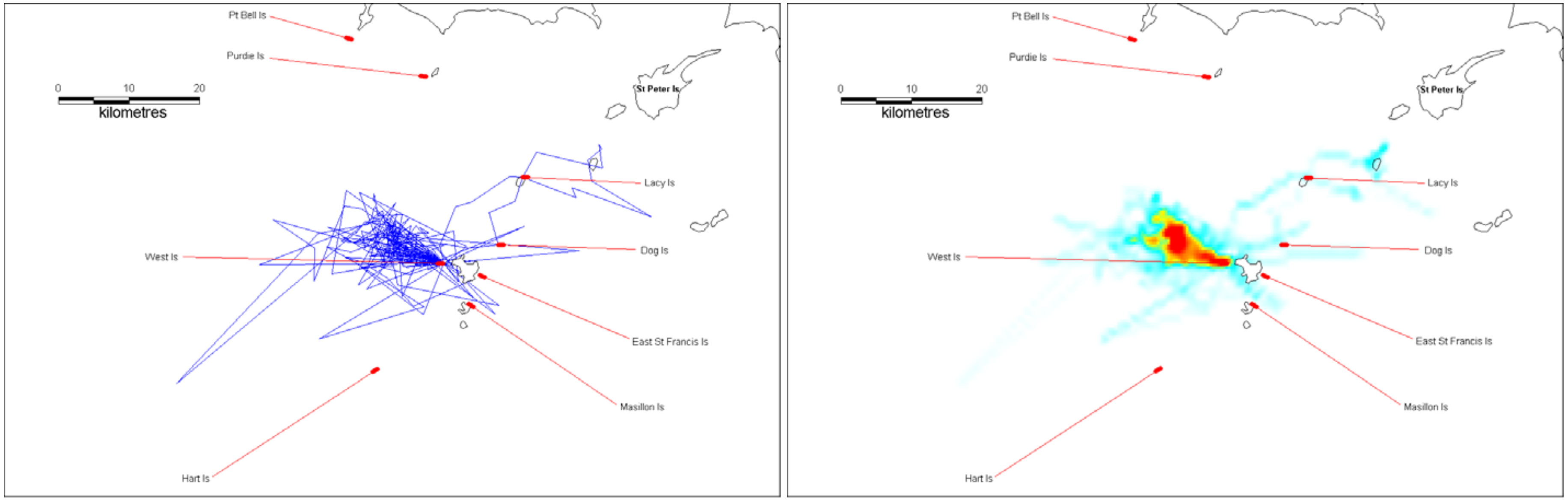
Adult male 1522 from West Is. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).



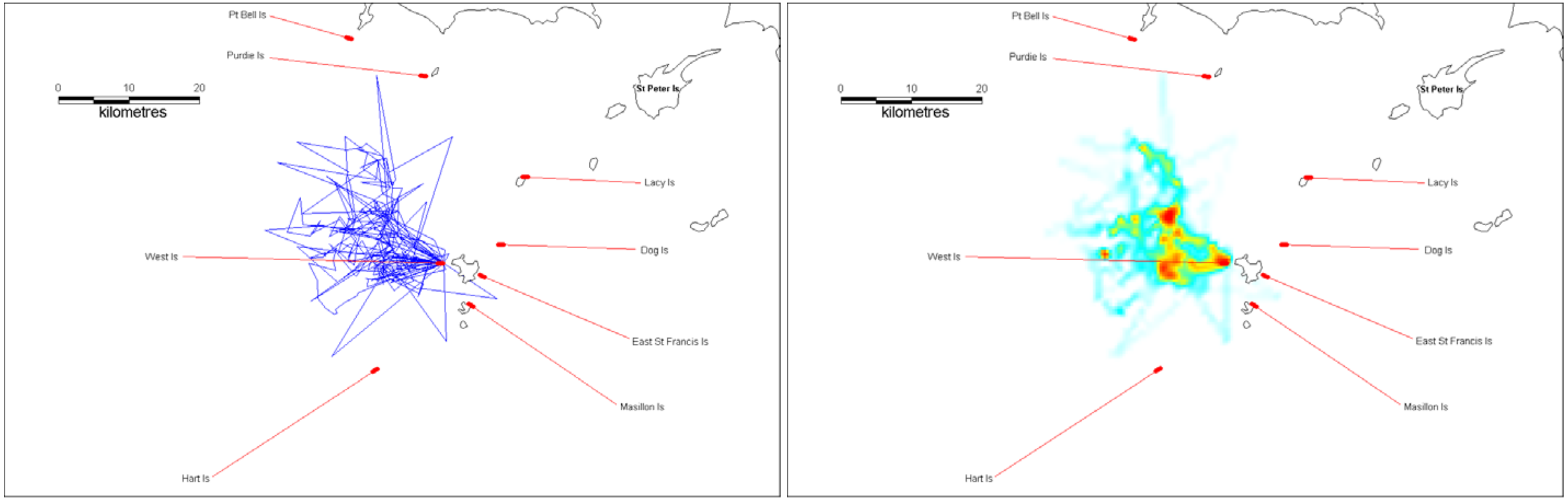
Juvenile female 723 from West Is. Tracks of 14 foraging trips (left) and time spent in 1 x 1 km areas (right).



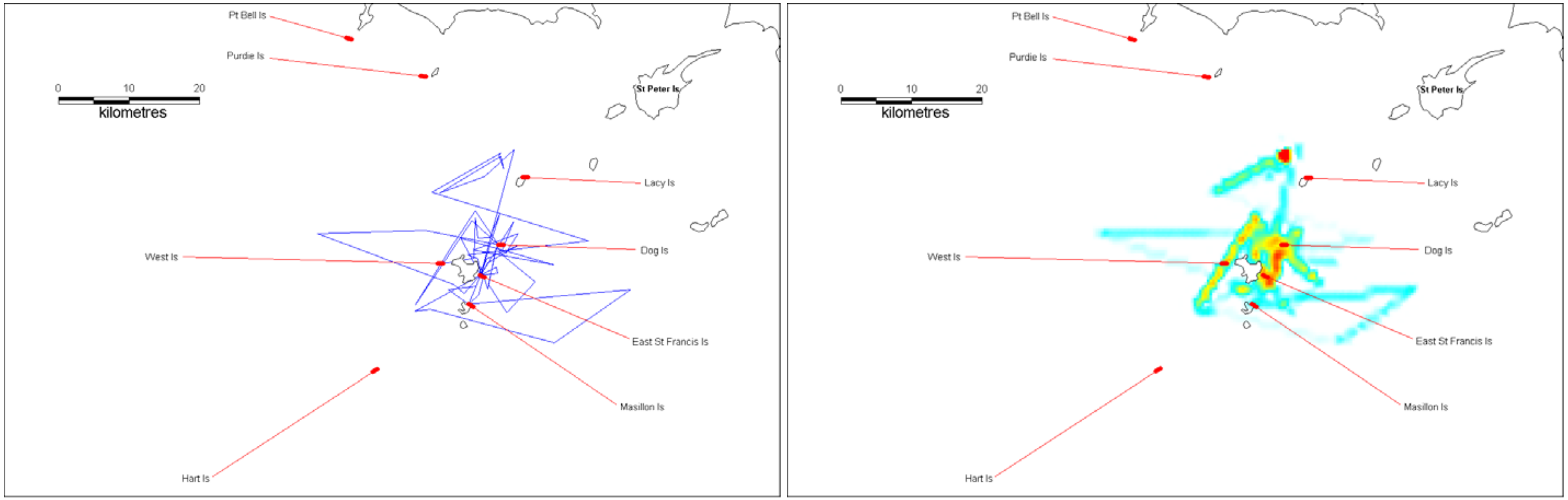
Juvenile female 923 from West Is. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).



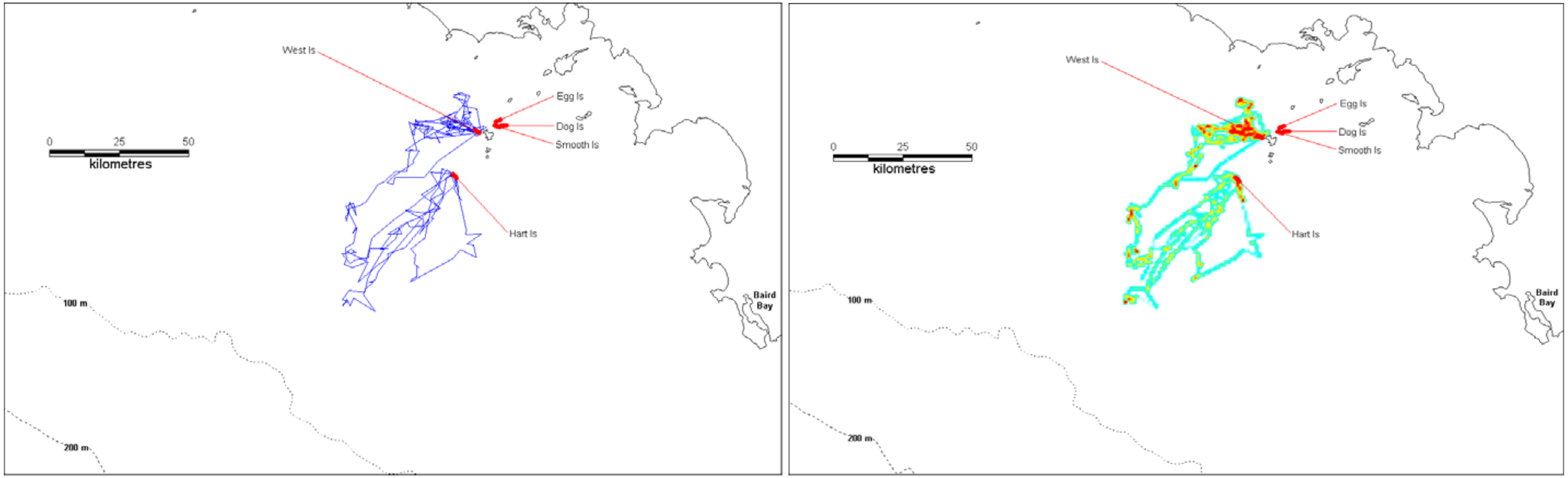
Juvenile male 224 from West Is. Tracks of 29 foraging trips (left) and time spent in 1 x 1 km areas (right).



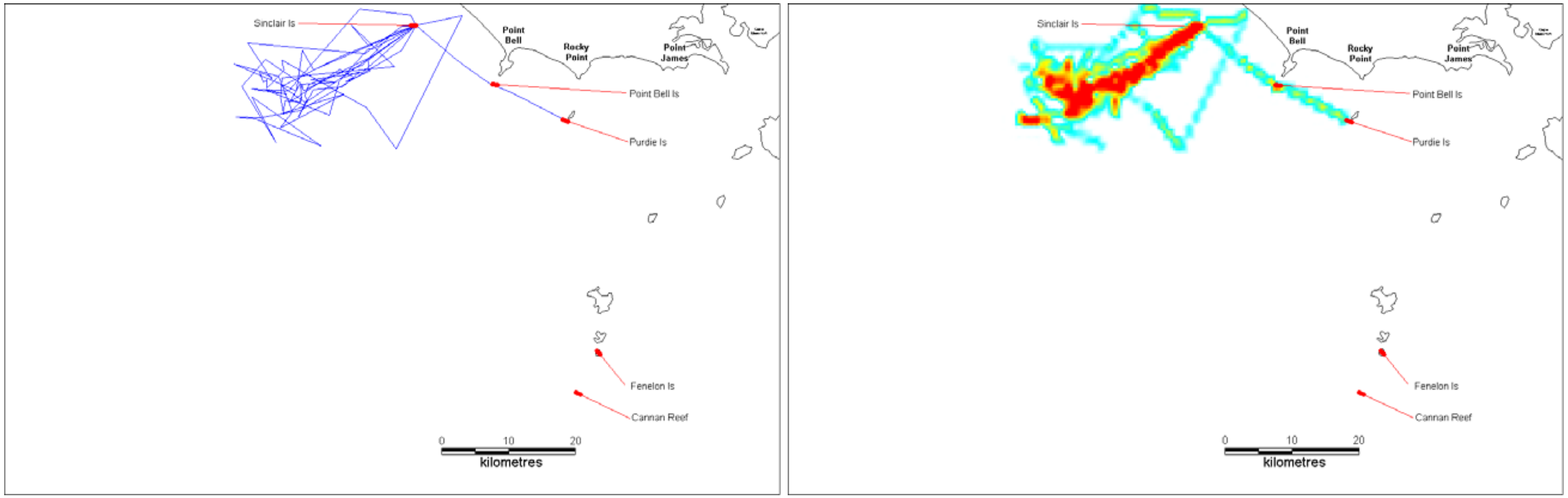
Juvenile male 824 from West Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



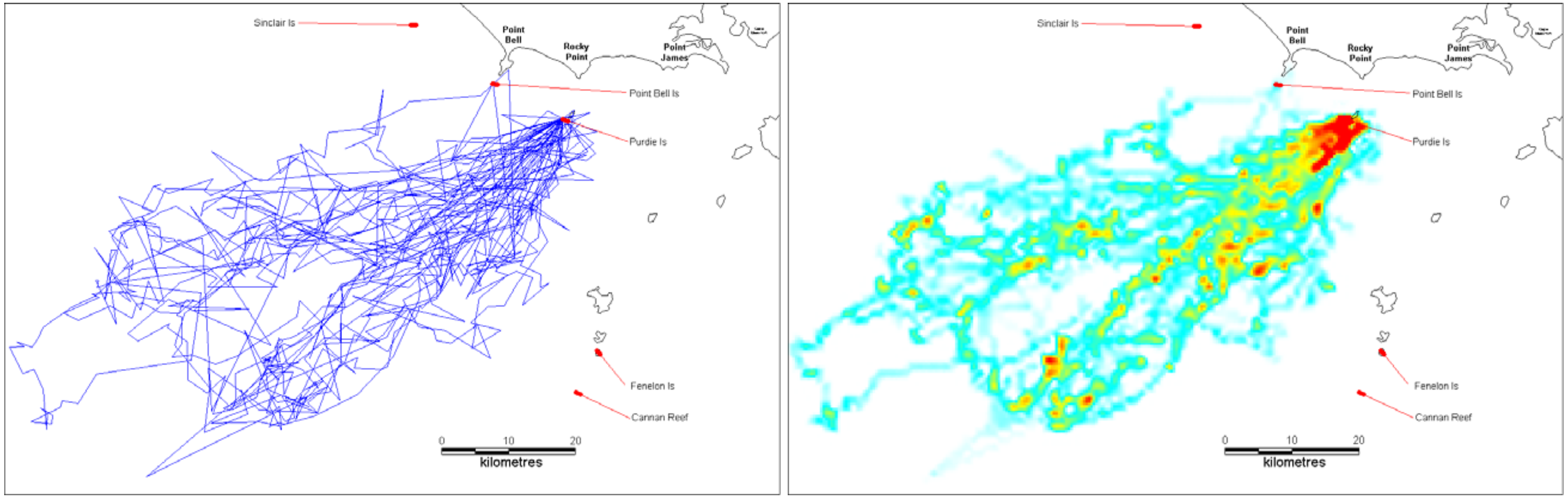
Juvenile male 1124 from West Is. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



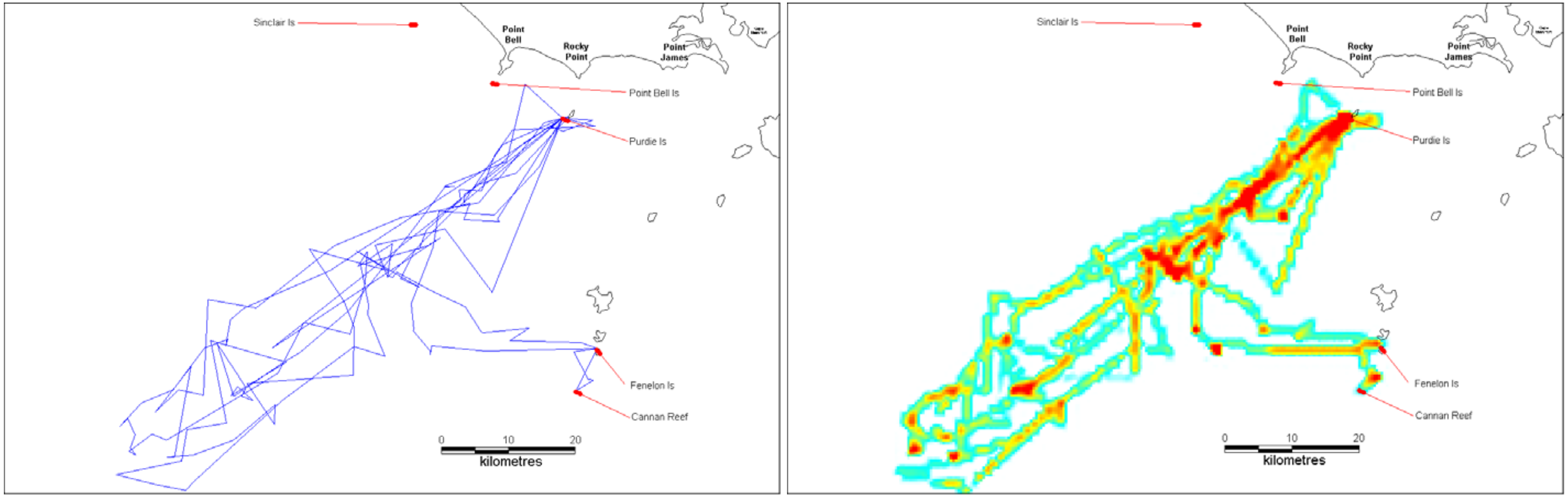
Subadult male 1025 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



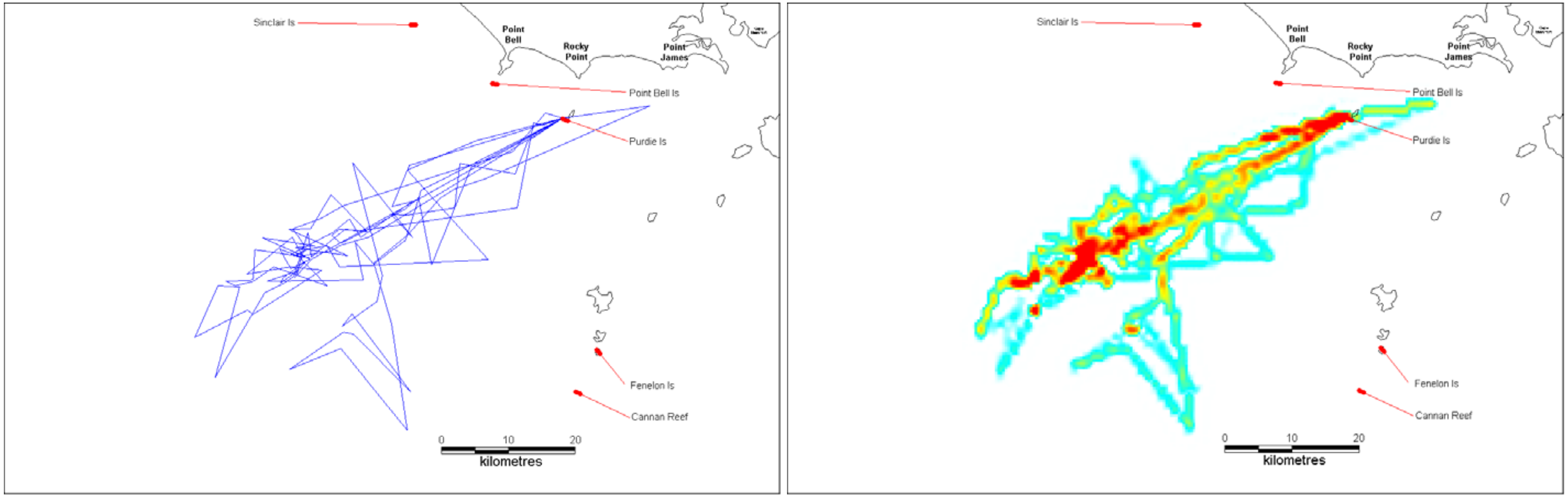
Adult female 131 from Purdie Is. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



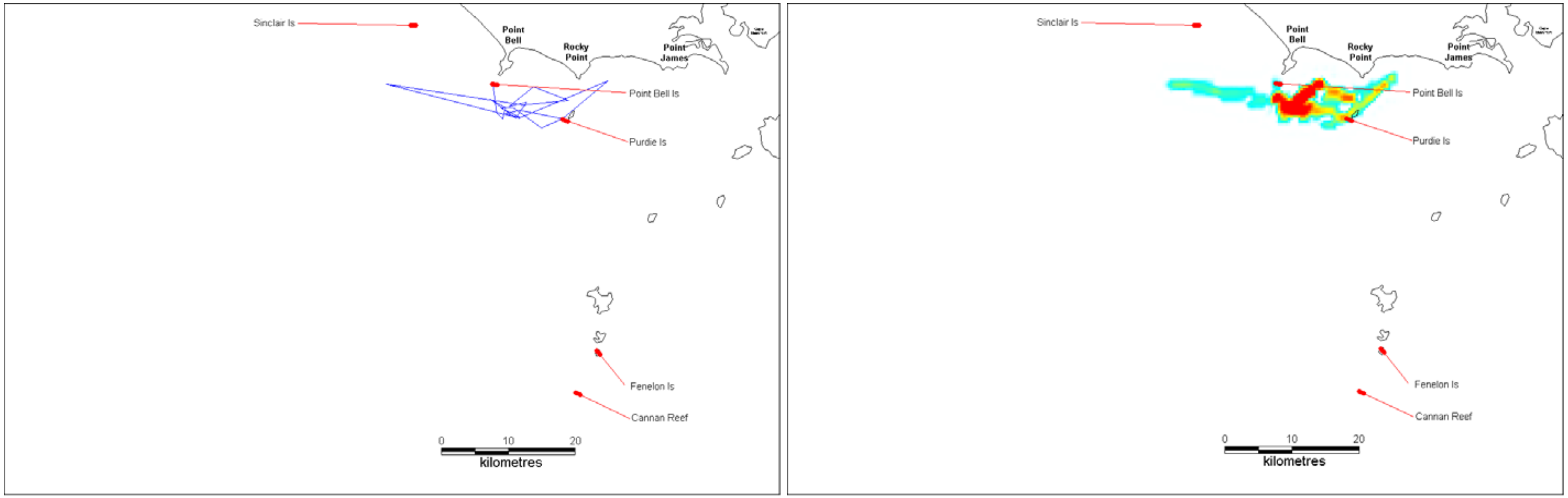
Adult female 331 from Purdie Is. Tracks of 25 foraging trips (left) and time spent in 1 x 1 km areas (right).



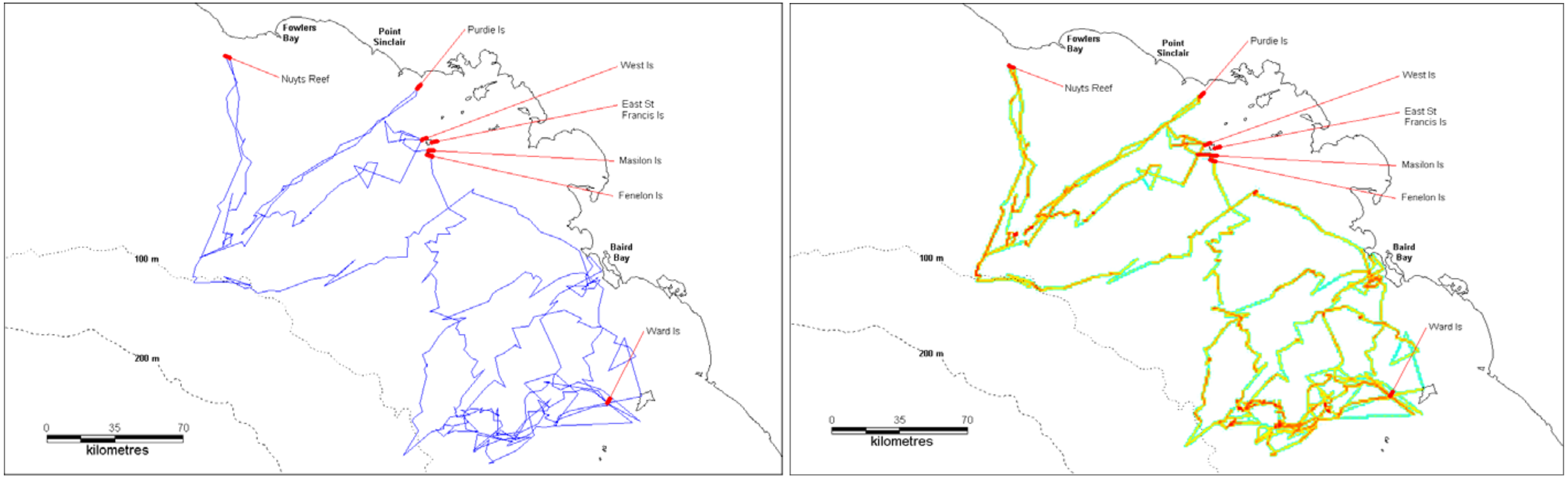
Adult female 431 from Purdie Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



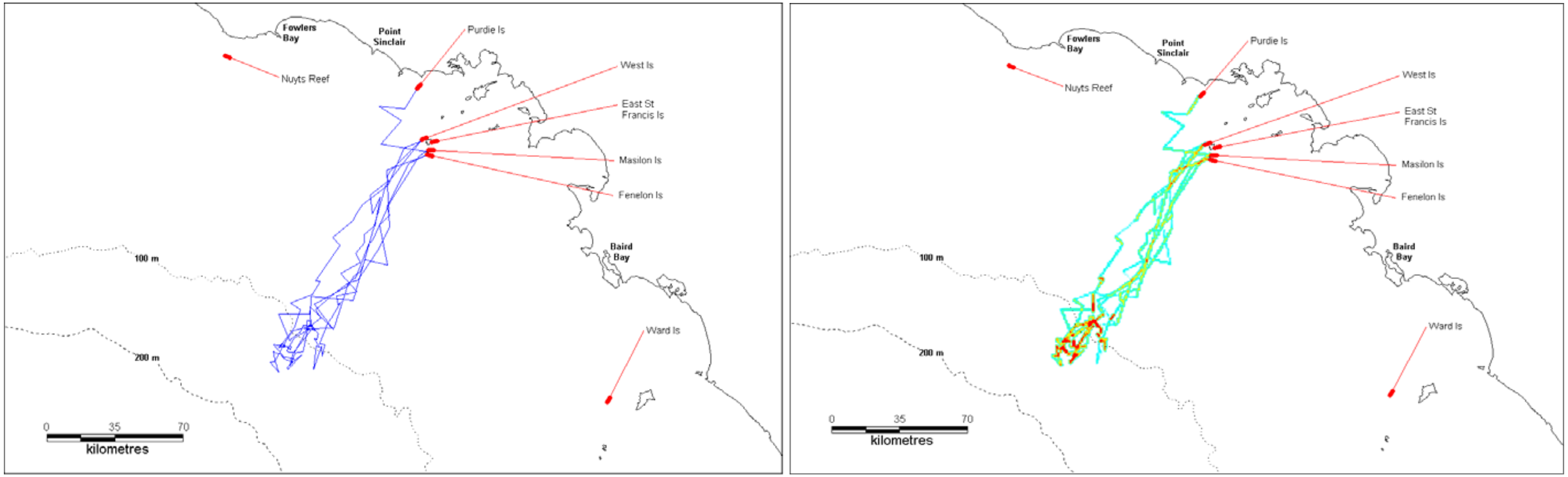
Adult female 531 from Purdie Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).



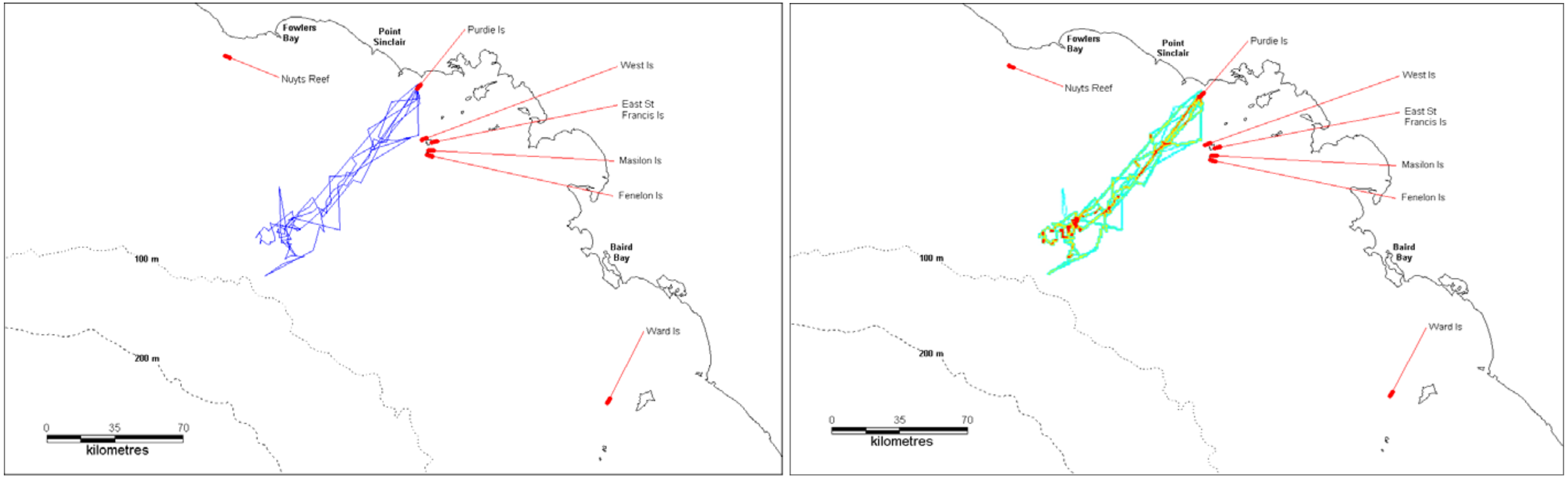
Adult female 731 from Purdie Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



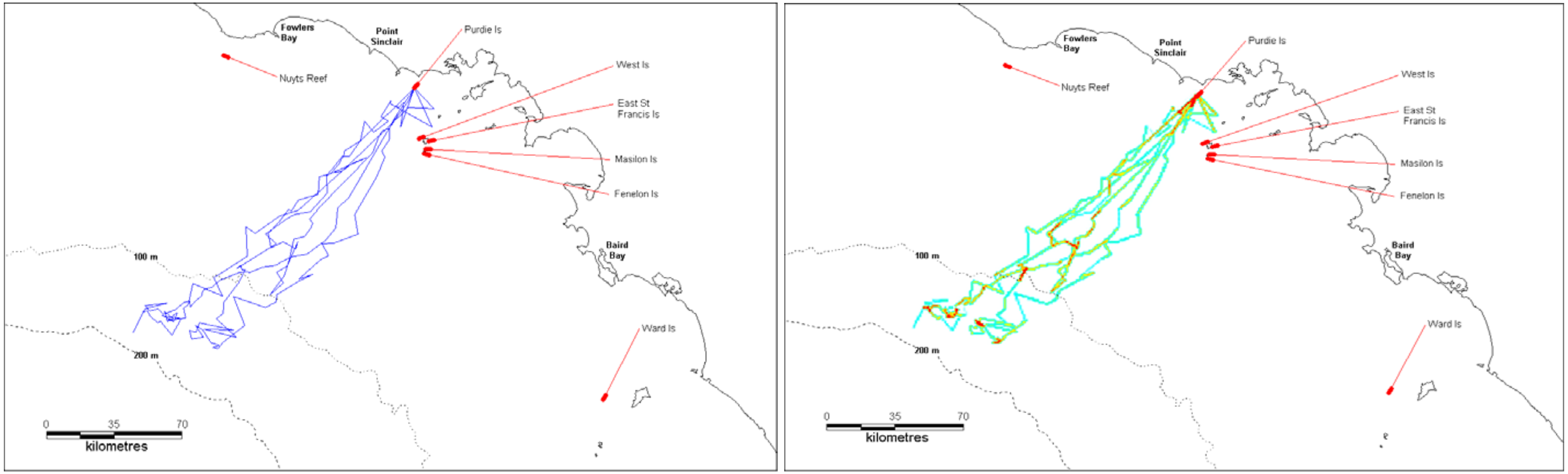
Adult male 1132 from Purdie Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



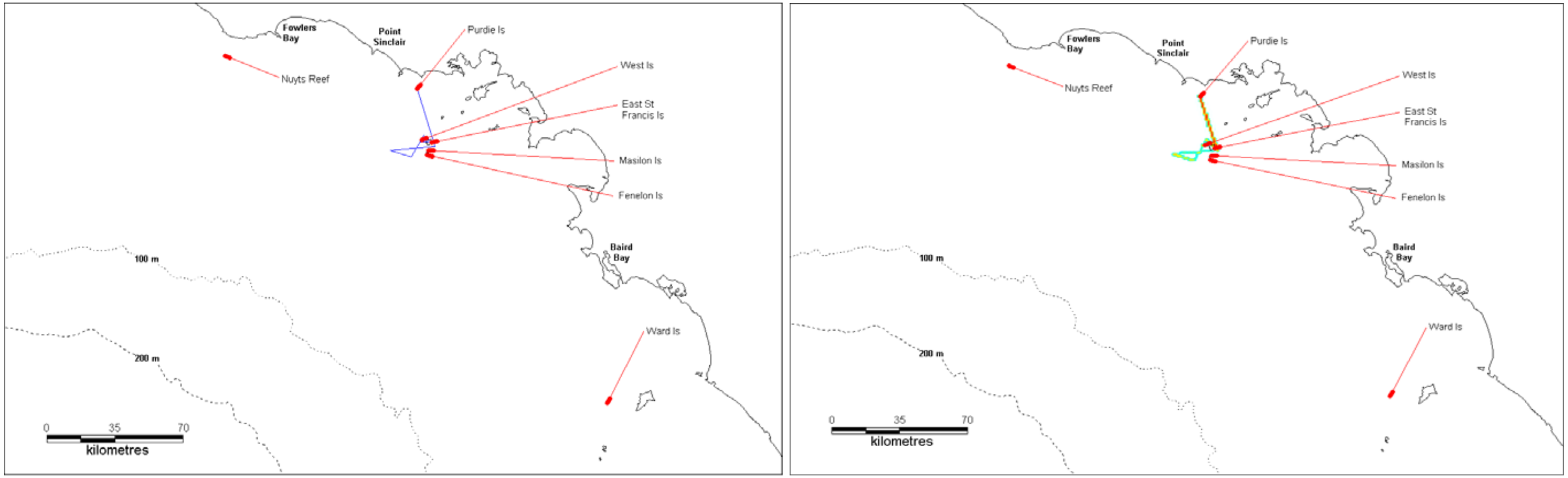
Adult male 1232 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



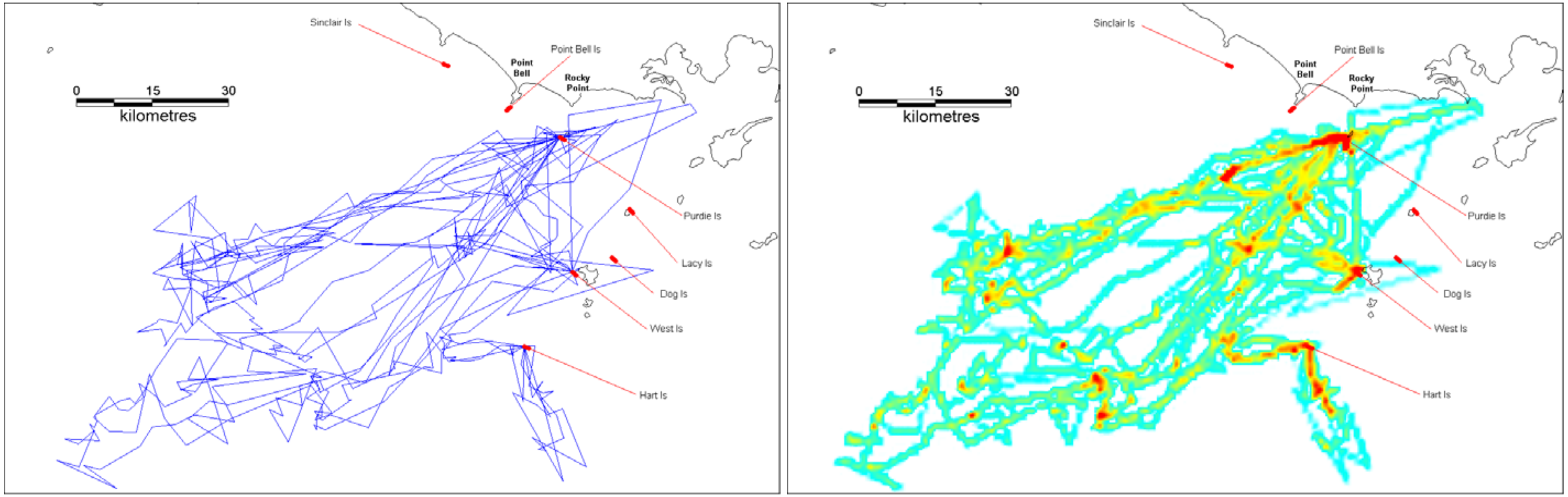
Adult male 1332 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



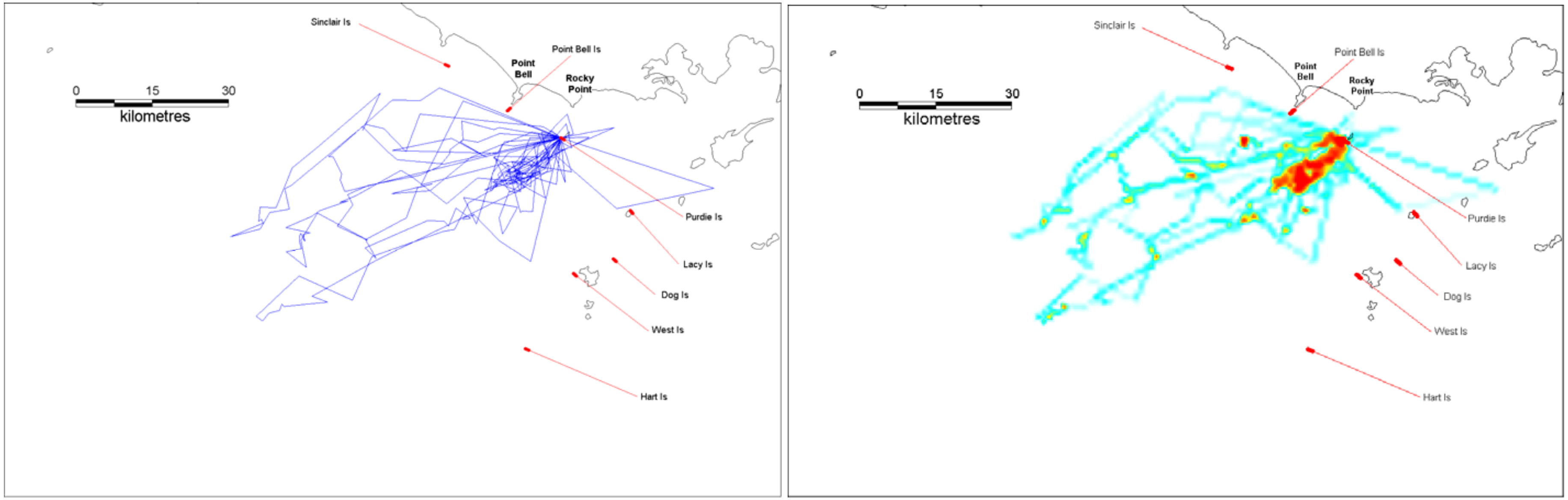
Adult male 1432 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



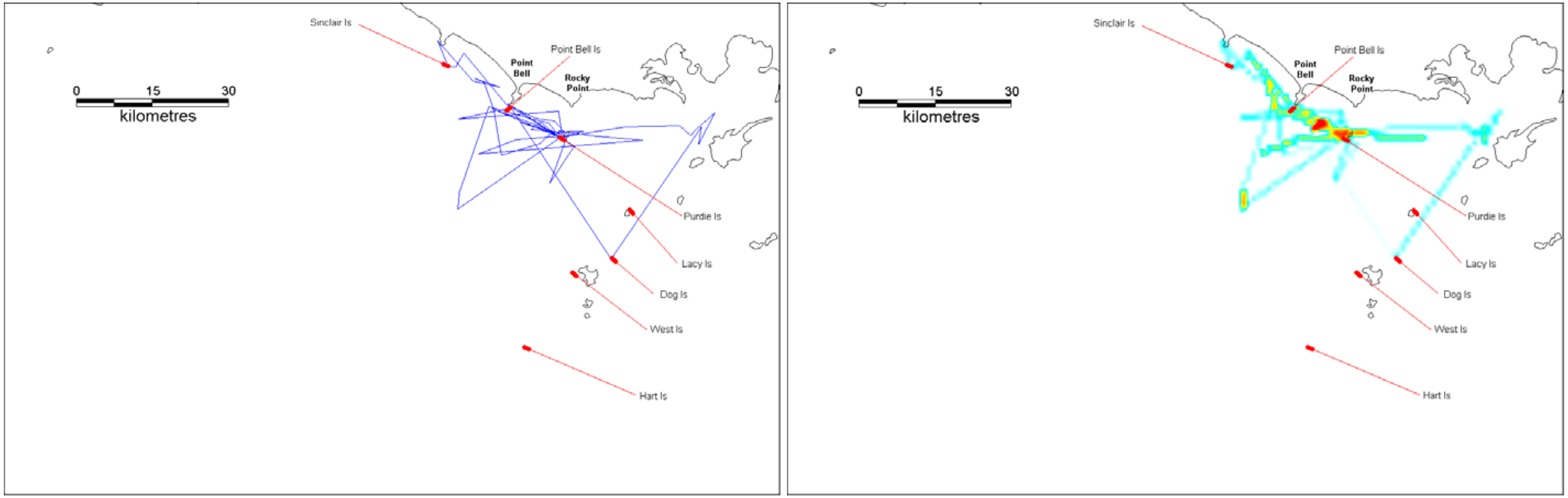
Adult male 1532 from Purdie Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



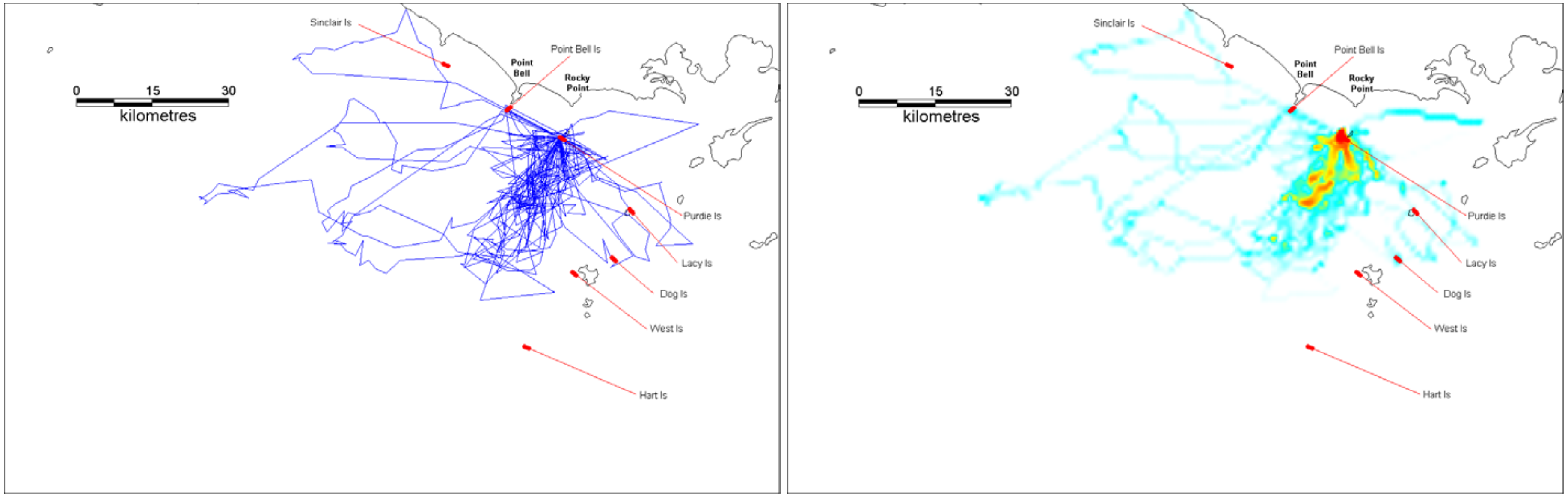
Juvenile male 234 from Purdie Is. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



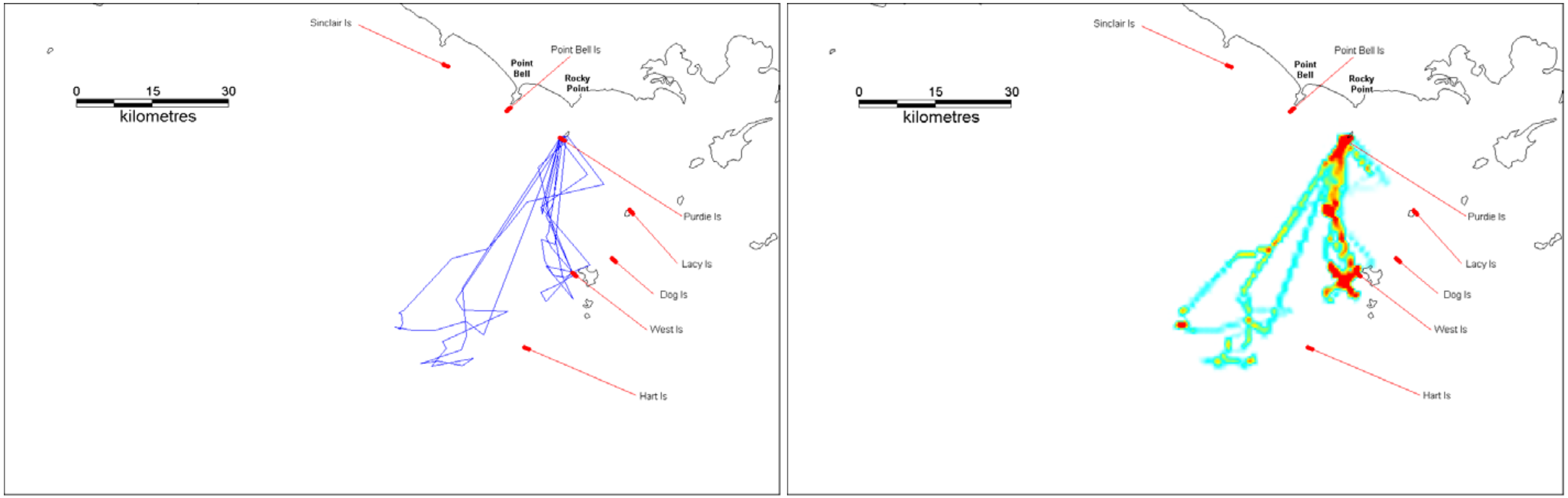
Juvenile male 634 from Purdie Is. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



Juvenile male 834 from Purdie Is. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



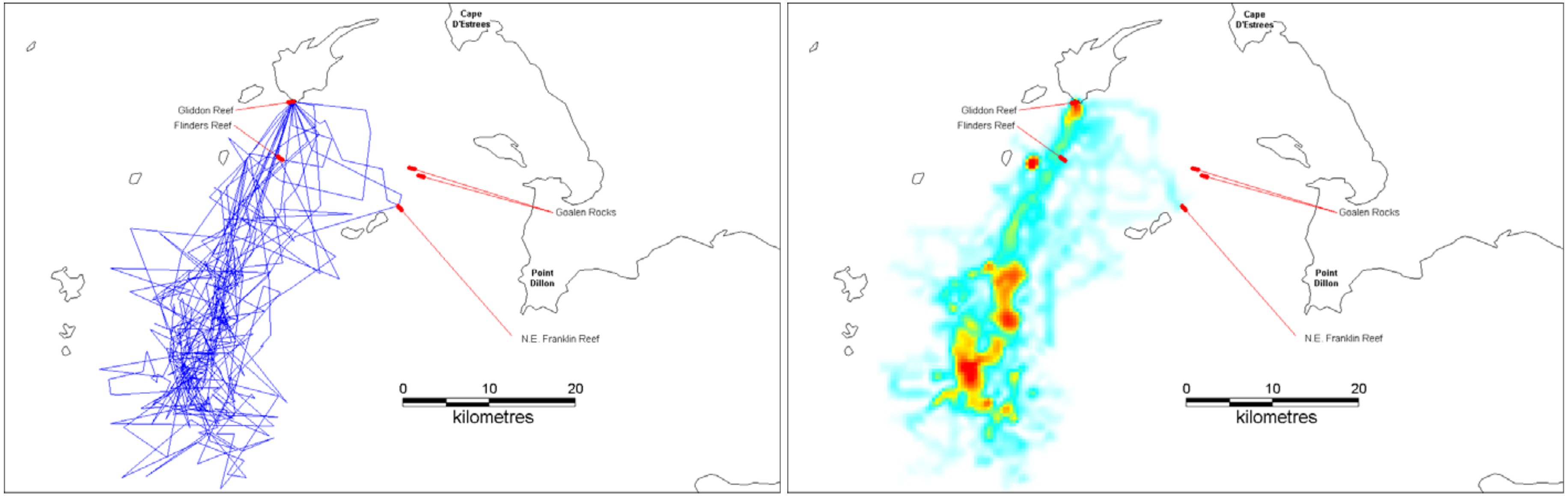
Juvenile male 934 from Purdie Is. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



Juvenile male 1034 from Purdie Is. Tracks of 10 foraging trips (left) and time spent in 1 x 1 km areas (right).

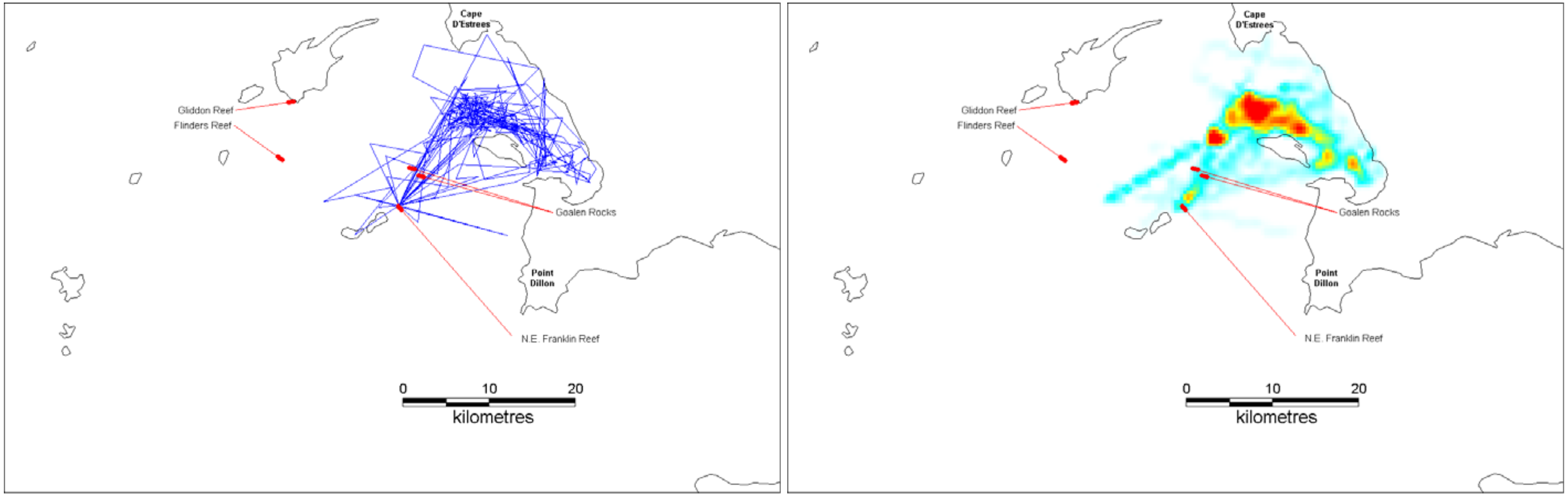
Adult female 241 from NE Franklin Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 341 from NE Franklin Is. Tracks of 33 foraging trips (left) and time spent in 1 x 1 km areas (right).

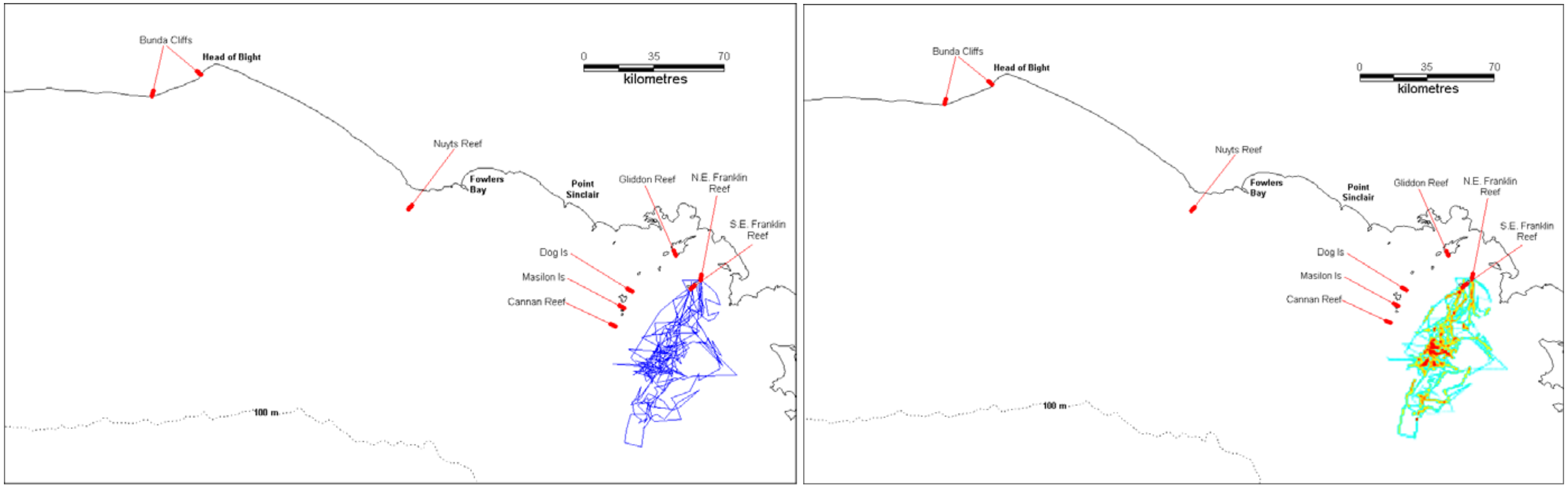


Adult female 441 from NE Franklin Is. Tracks of 16 foraging trips (left) and time spent in 1 x 1 km areas (right).

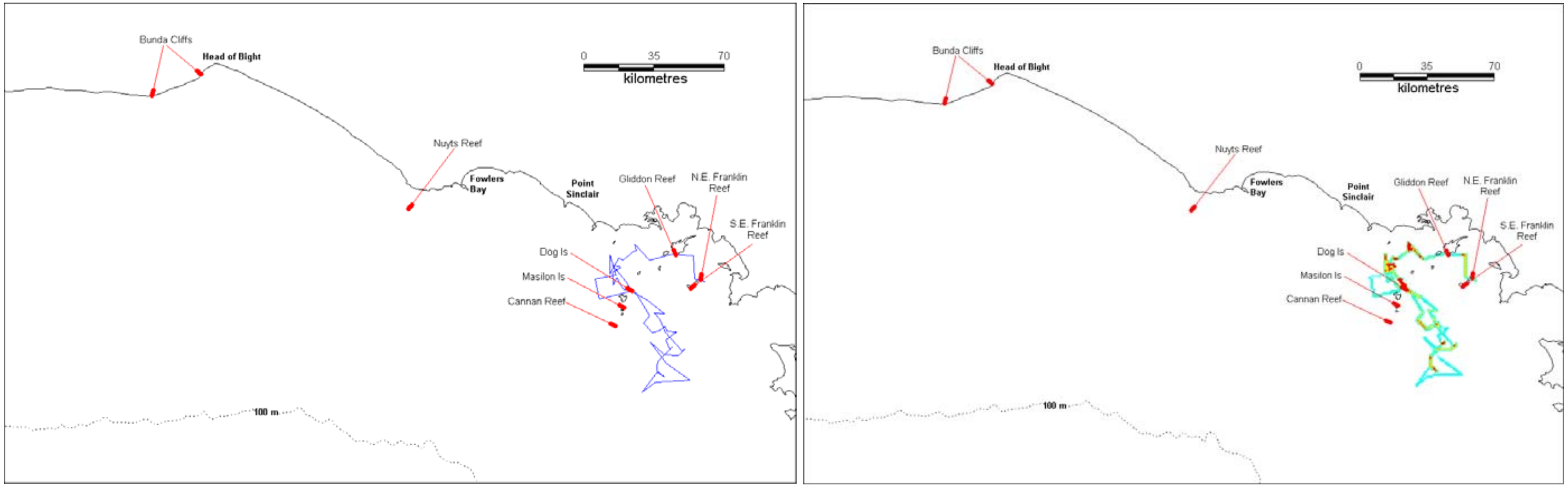
Adult female 641 from NE Franklin Is. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



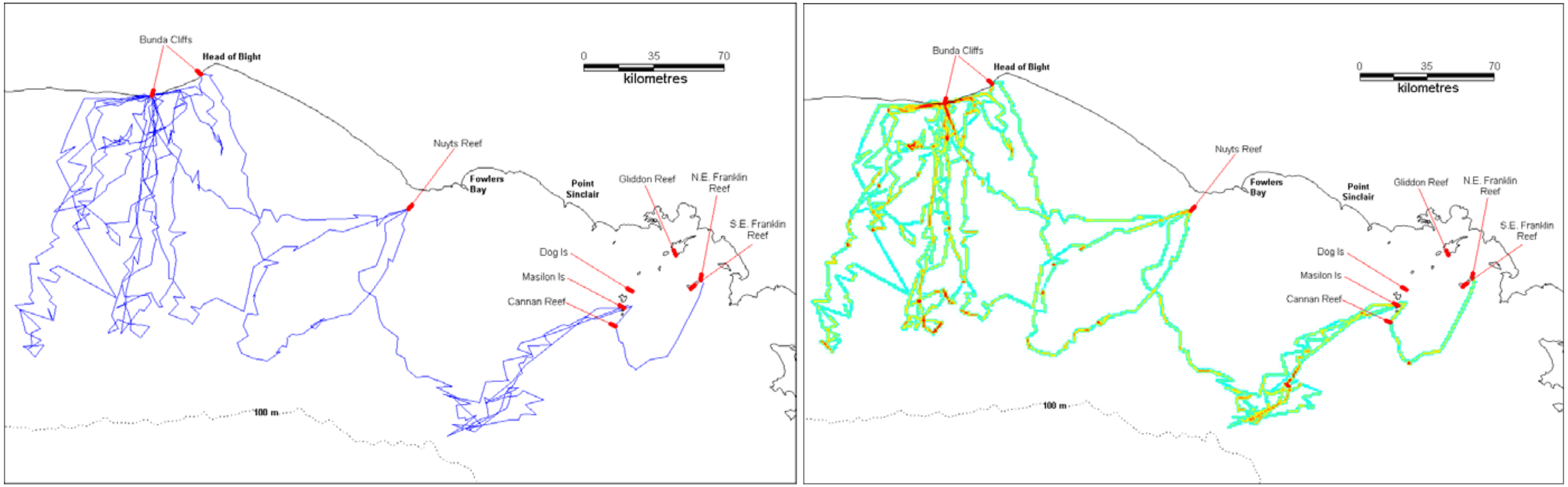
Adult female 941 from NE Franklin Is. Tracks of 14 foraging trips (left) and time spent in 1 x 1 km areas (right).



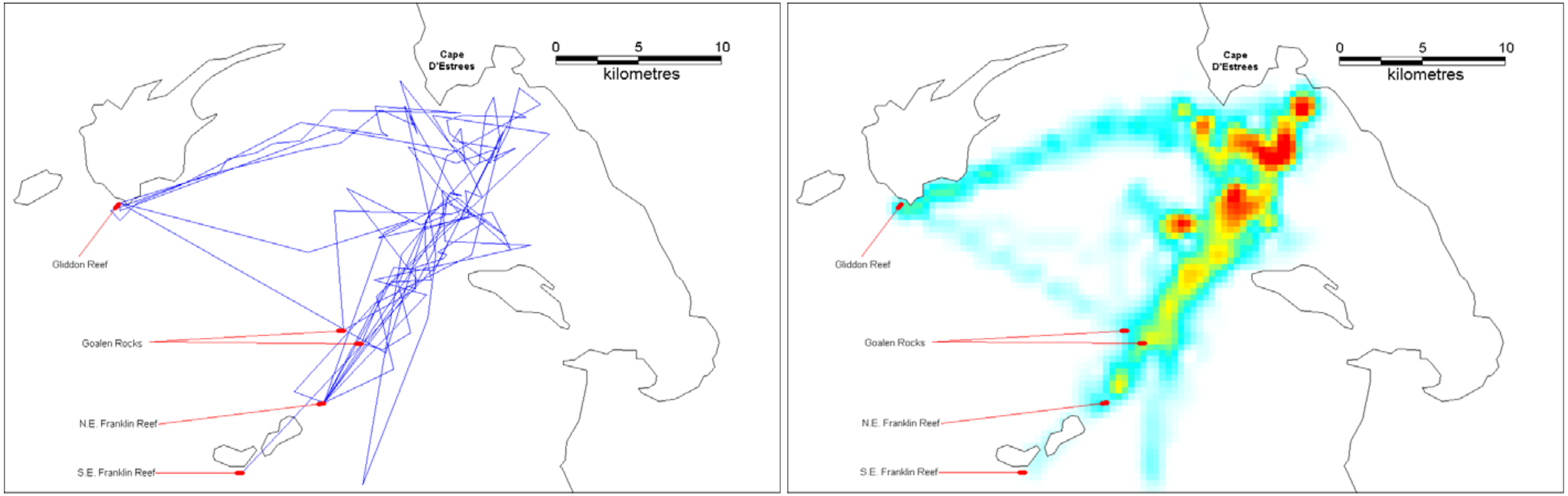
Adult male 142 from NE Franklin Is. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



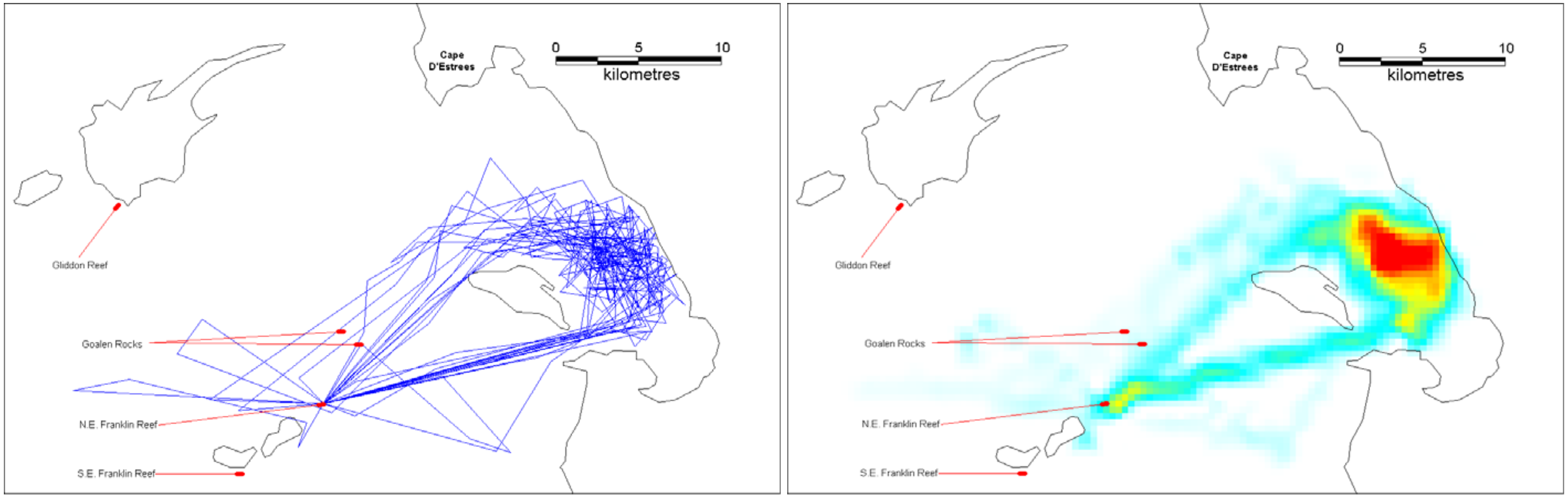
Adult male 742 from NE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



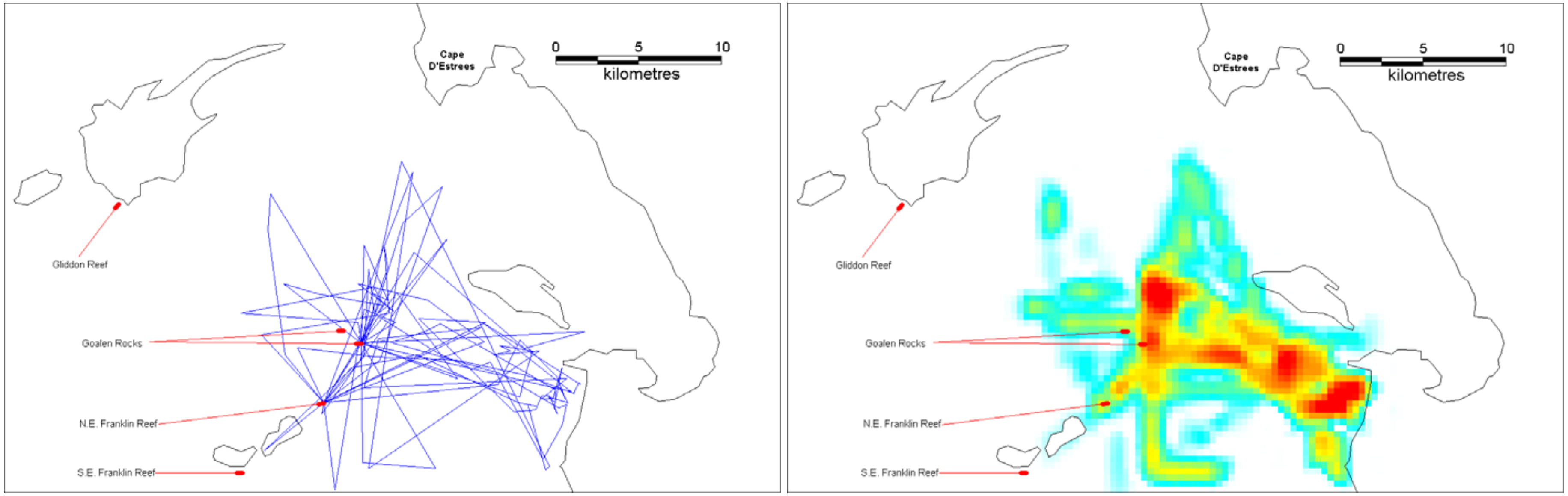
Adult male 842 from NE Franklin Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).



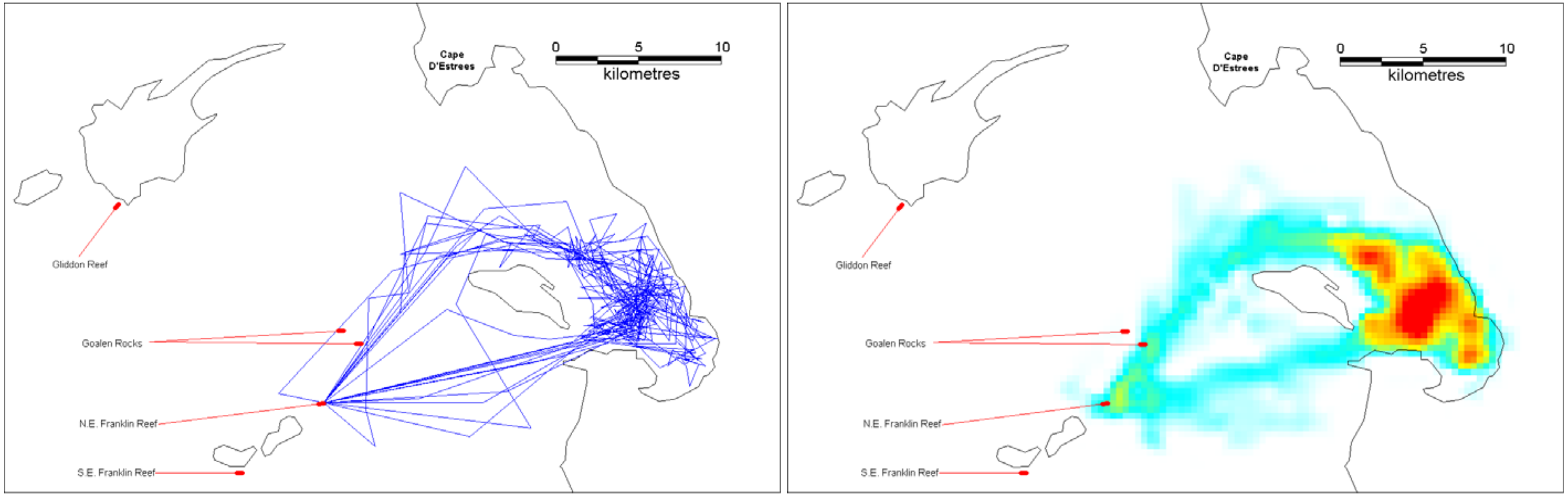
Juvenile female 543 from NE Franklin Is. Tracks of 10 foraging trips (left) and time spent in 1 x 1 km areas (right).



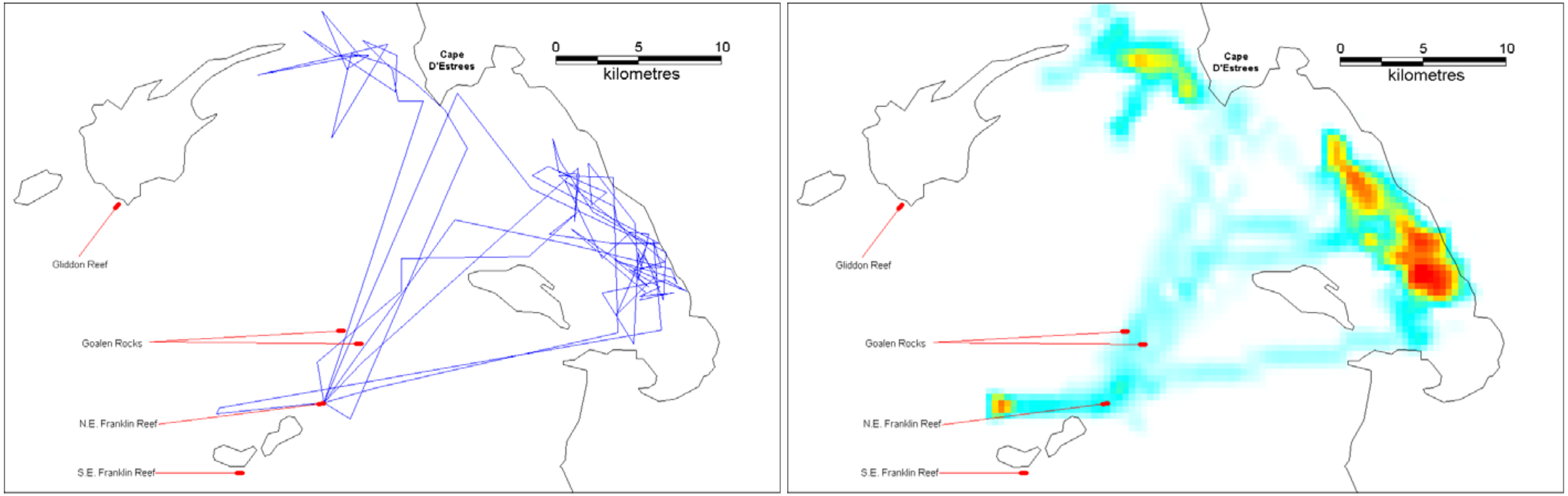
Juvenile female 1043 from NE Franklin Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).



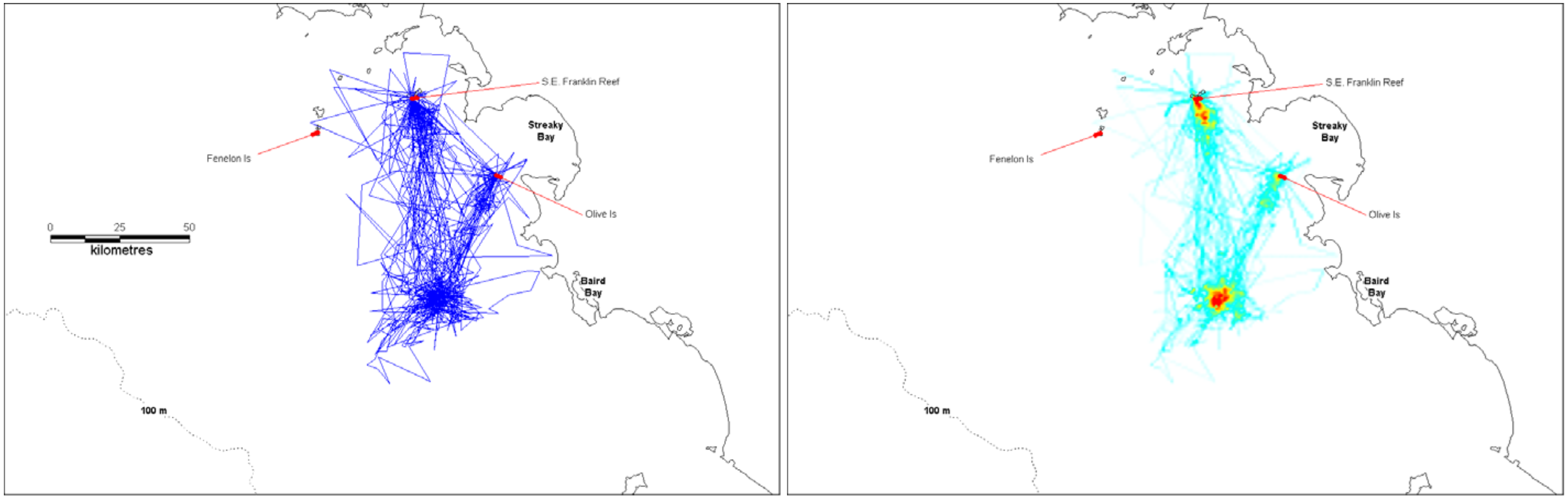
Juvenile female 1243 from NE Franklin Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



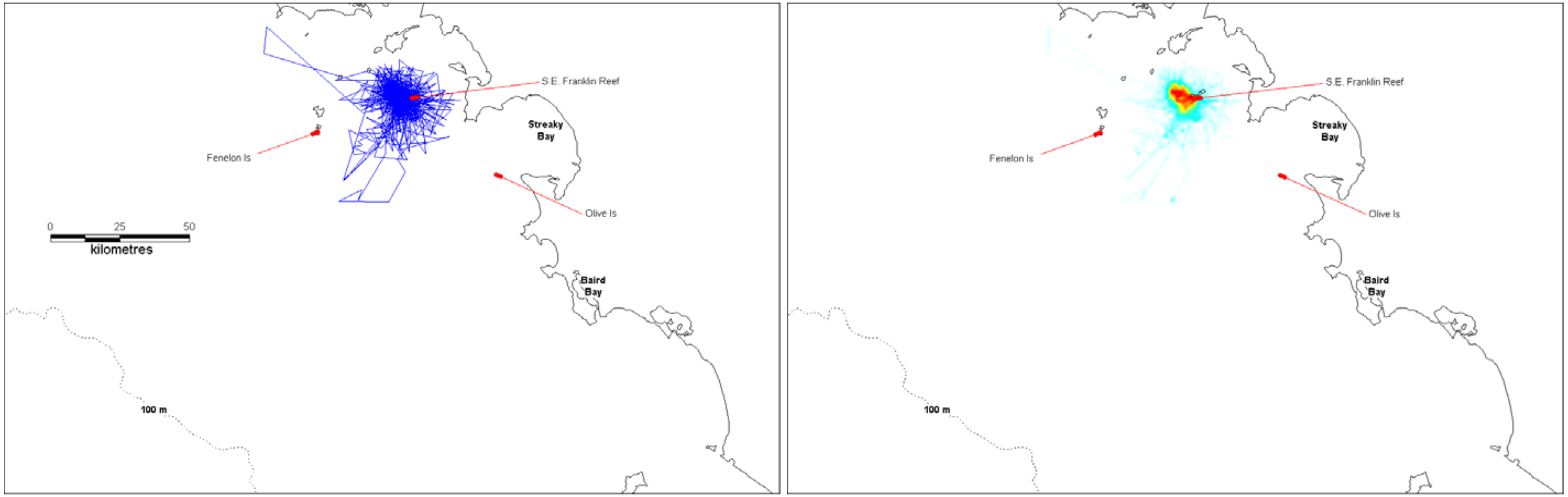
Juvenile female 1343 from NE Franklin Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



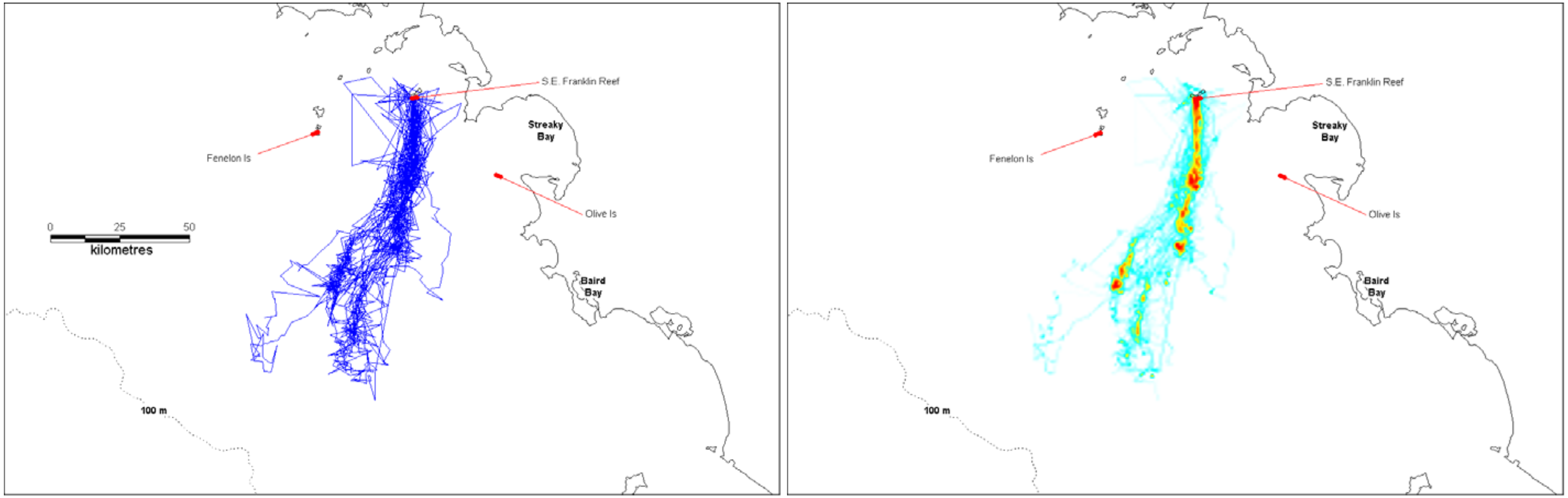
Juvenile male 1144 from NE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



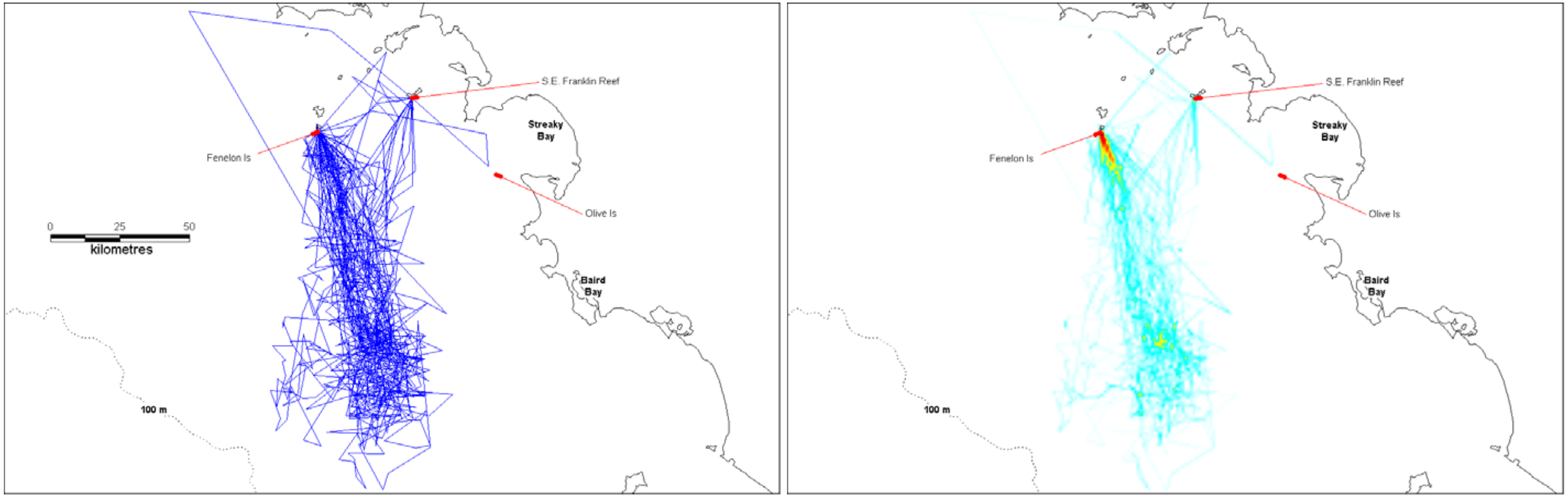
Adult female 251 from SE Franklin Is. Tracks of 67 foraging trips (left) and time spent in 1 x 1 km areas (right).



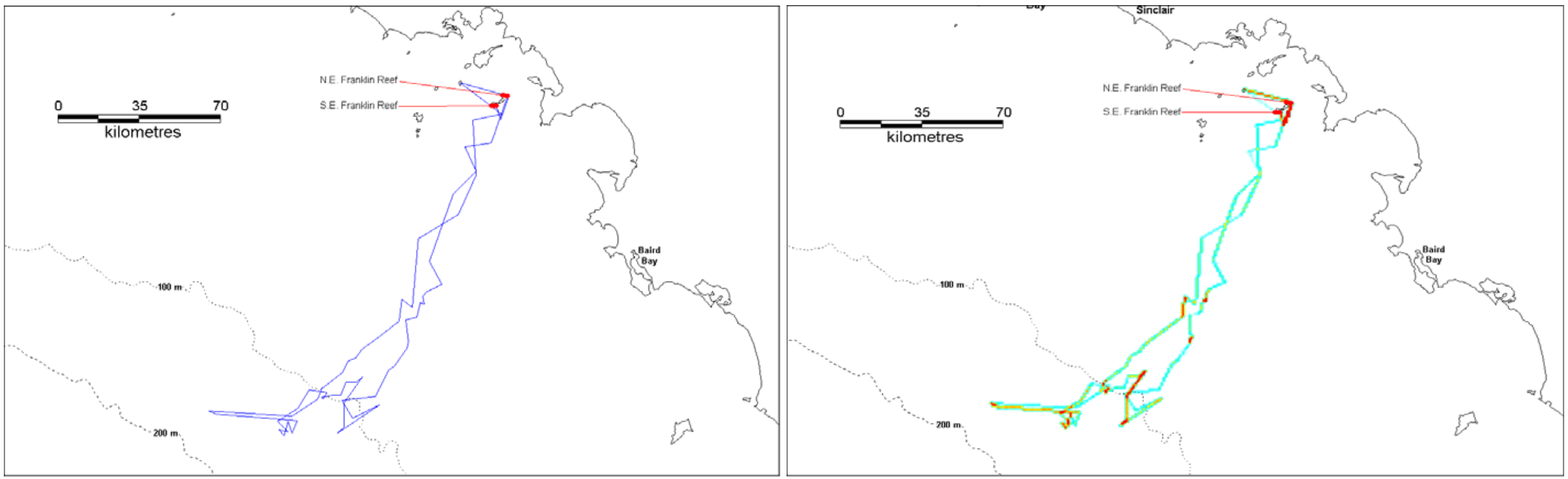
Adult female 351 from SE Franklin Is. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



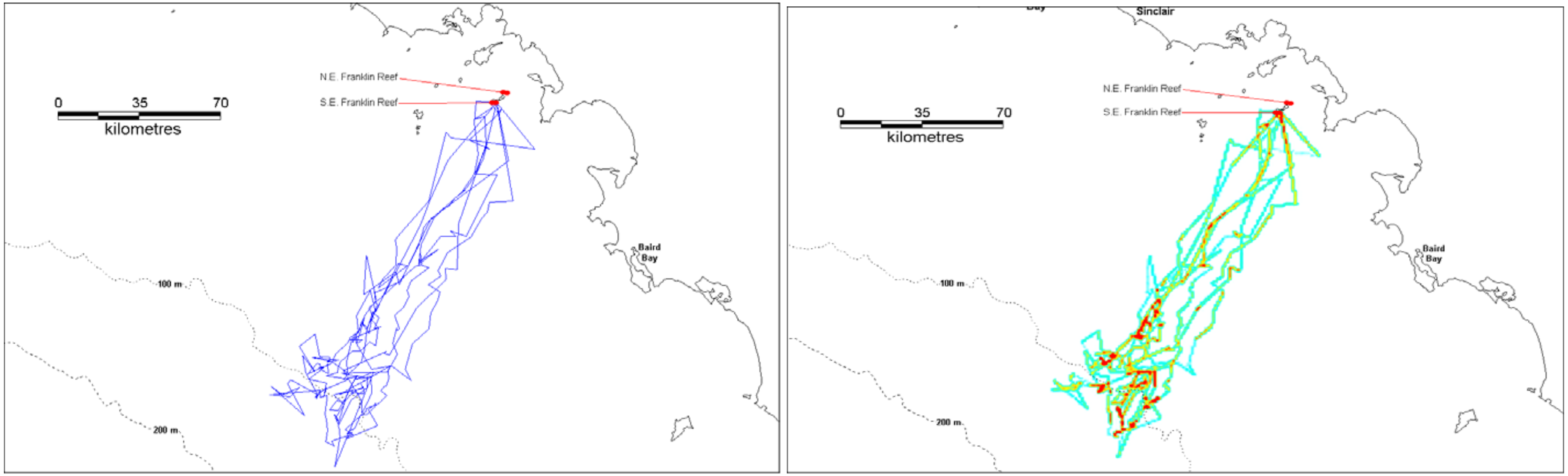
Adult female 451 from SE Franklin Is. Tracks of 37 foraging trips (left) and time spent in 1 x 1 km areas (right).



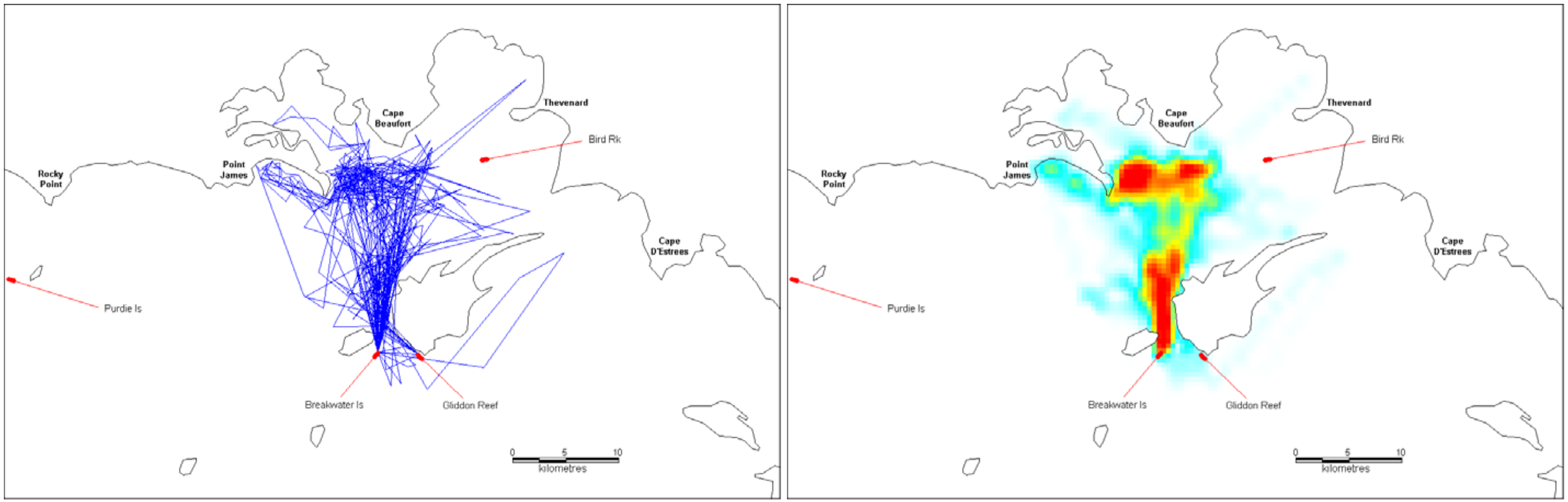
Adult female 651 from SE Franklin Is. Tracks of 132 foraging trips (left) and time spent in 1 x 1 km areas (right).



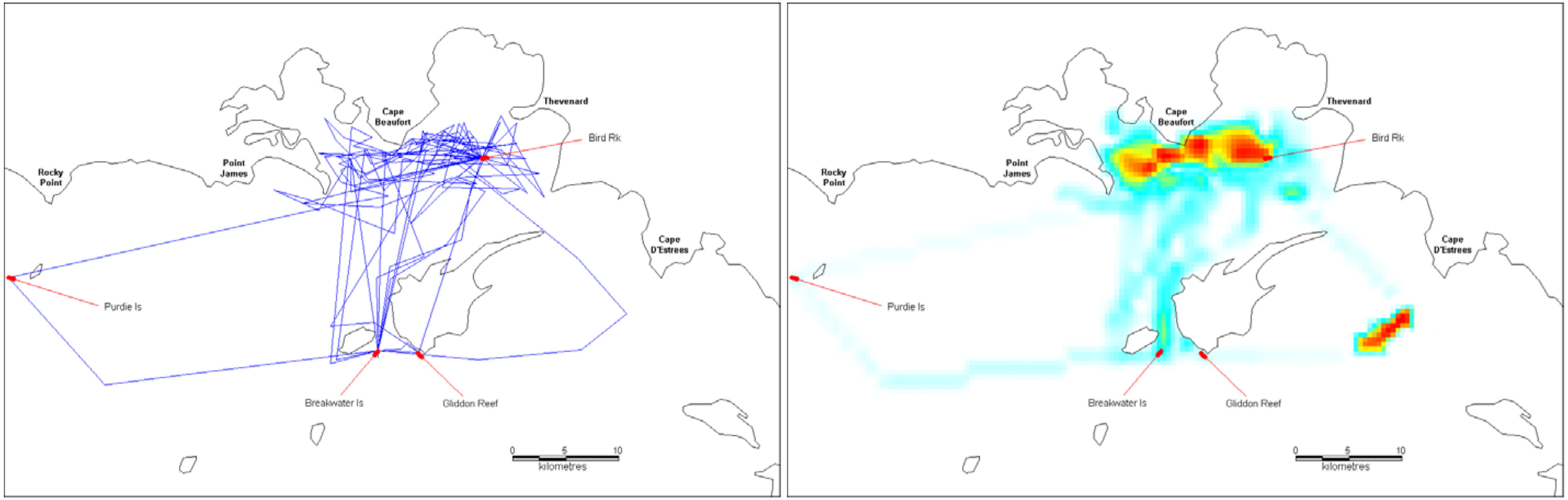
Adult male 152 from SE Franklin Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



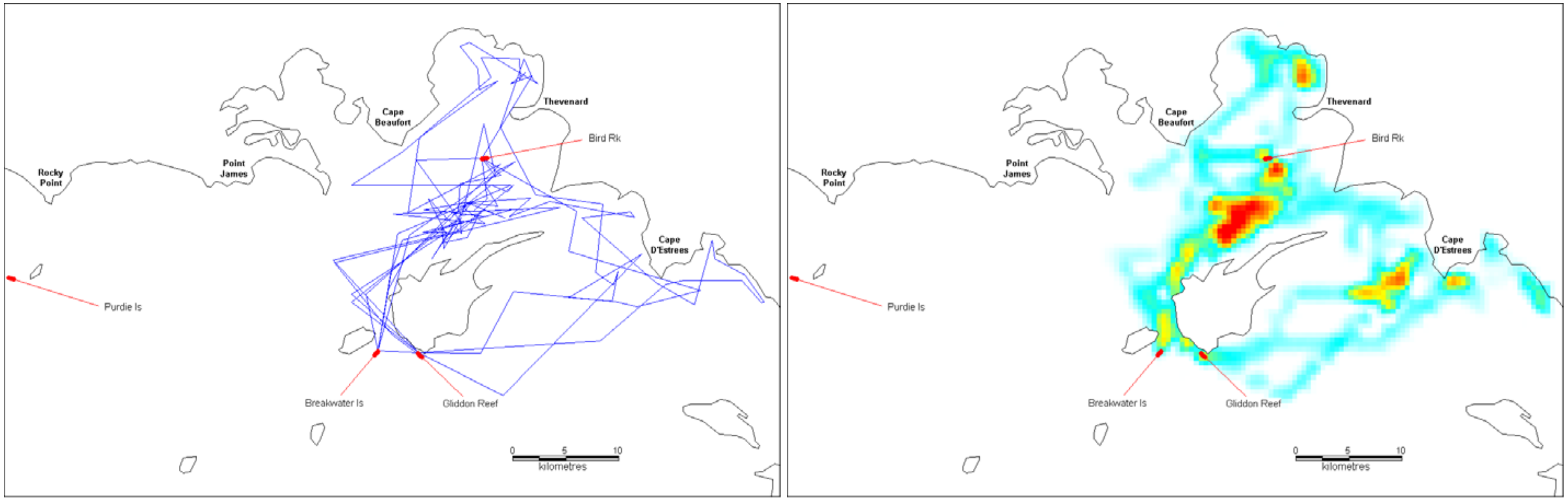
Adult male 252 from SE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



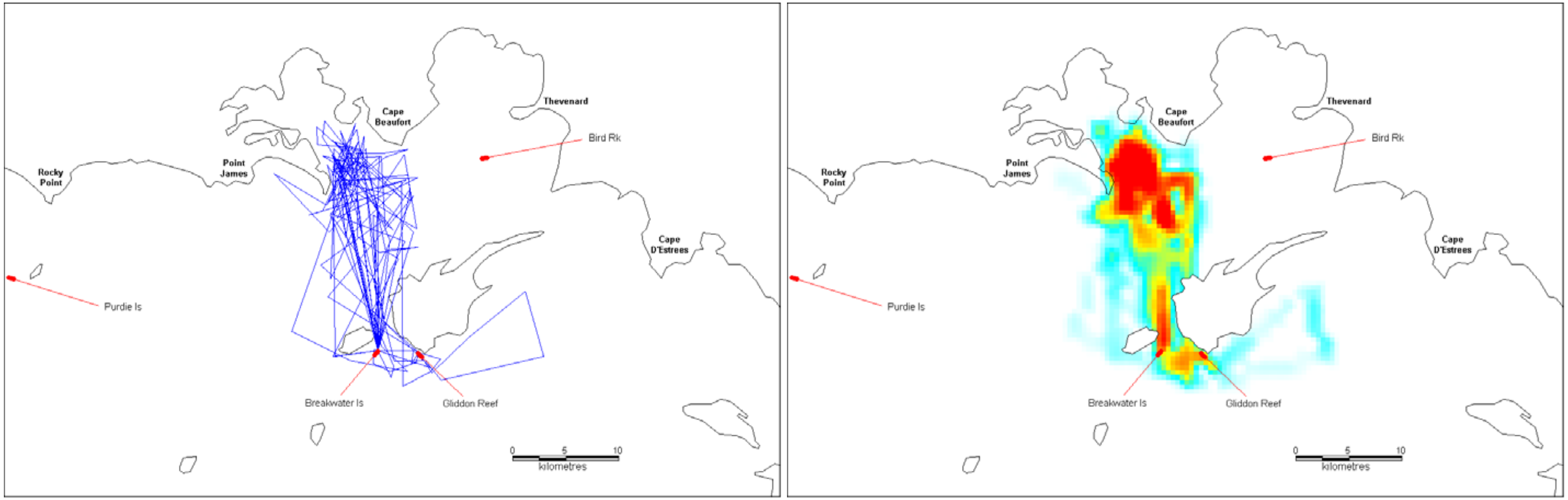
Adult female 181 from Breakwater Is. Tracks of 35 foraging trips (left) and time spent in 1 x 1 km areas (right).



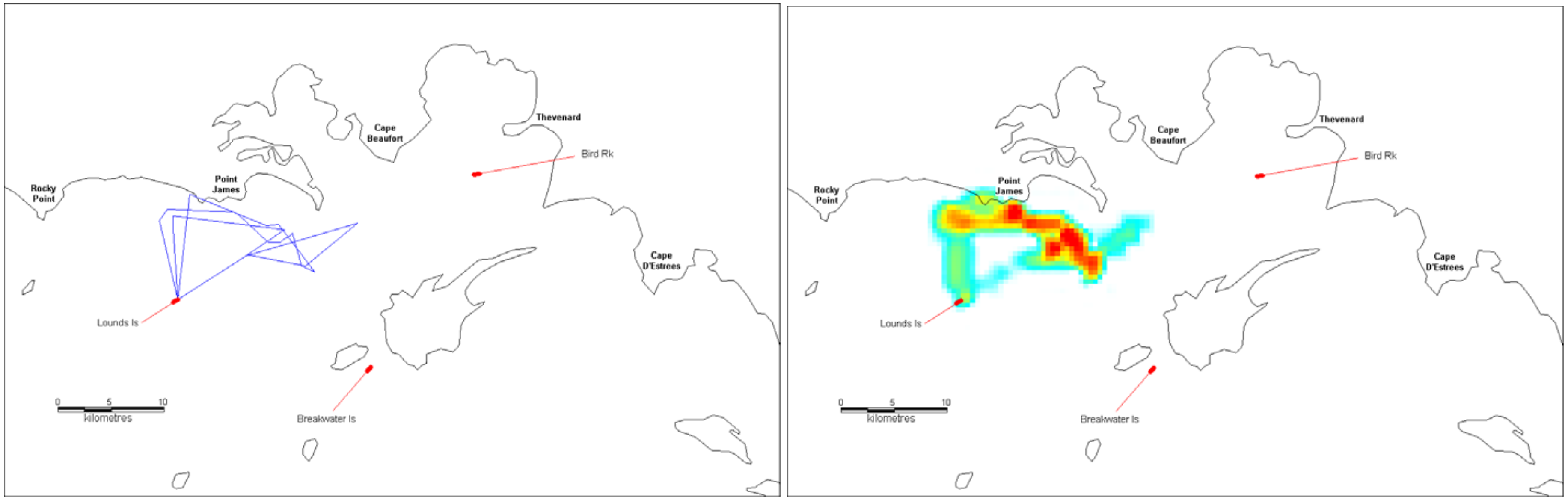
Adult female 281 from Breakwater Is. Tracks of 22 foraging trips (left) and time spent in 1 x 1 km areas (right).



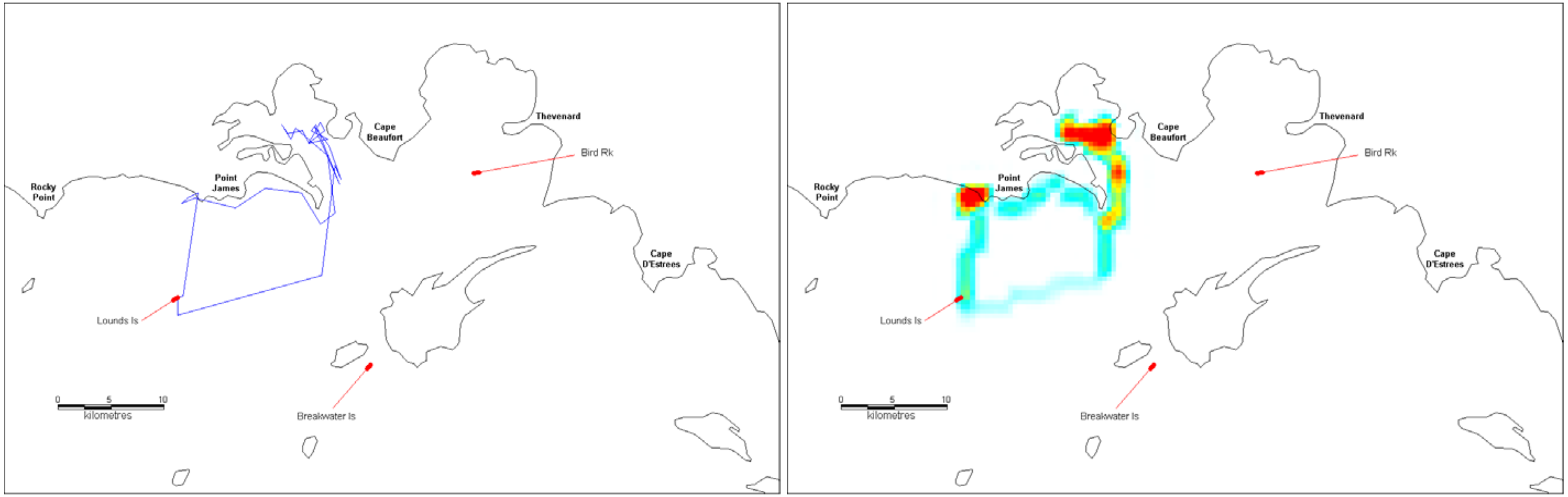
Adult female 381 from Breakwater Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



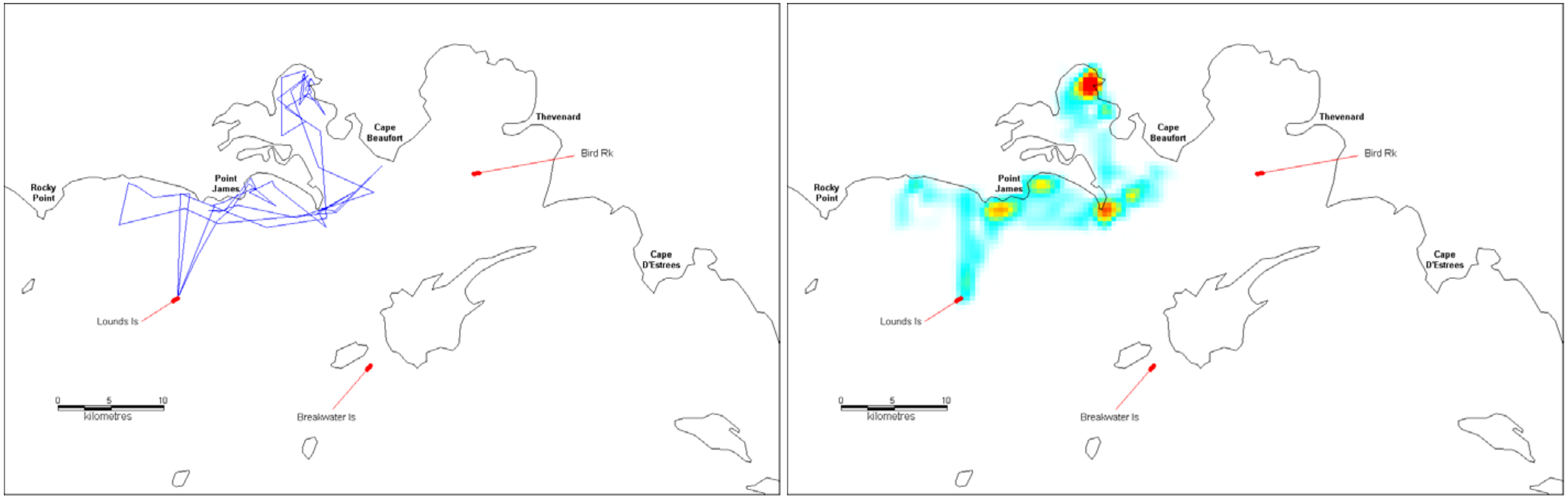
Adult female 481 from Breakwater Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



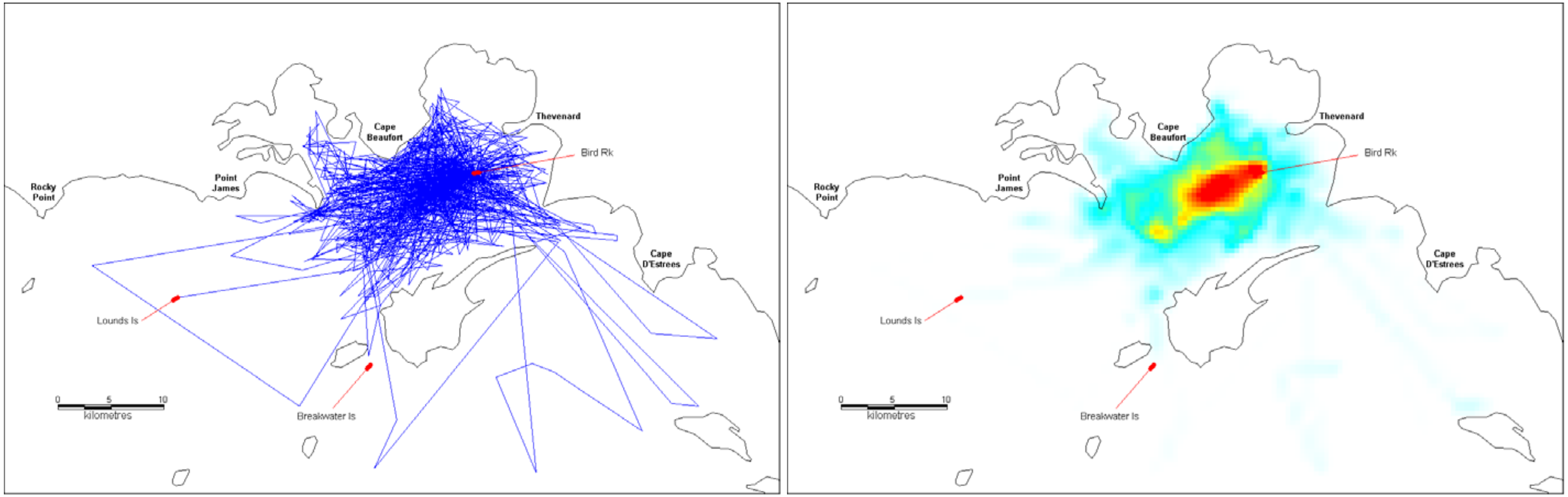
Adult female 161 from Lounds Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



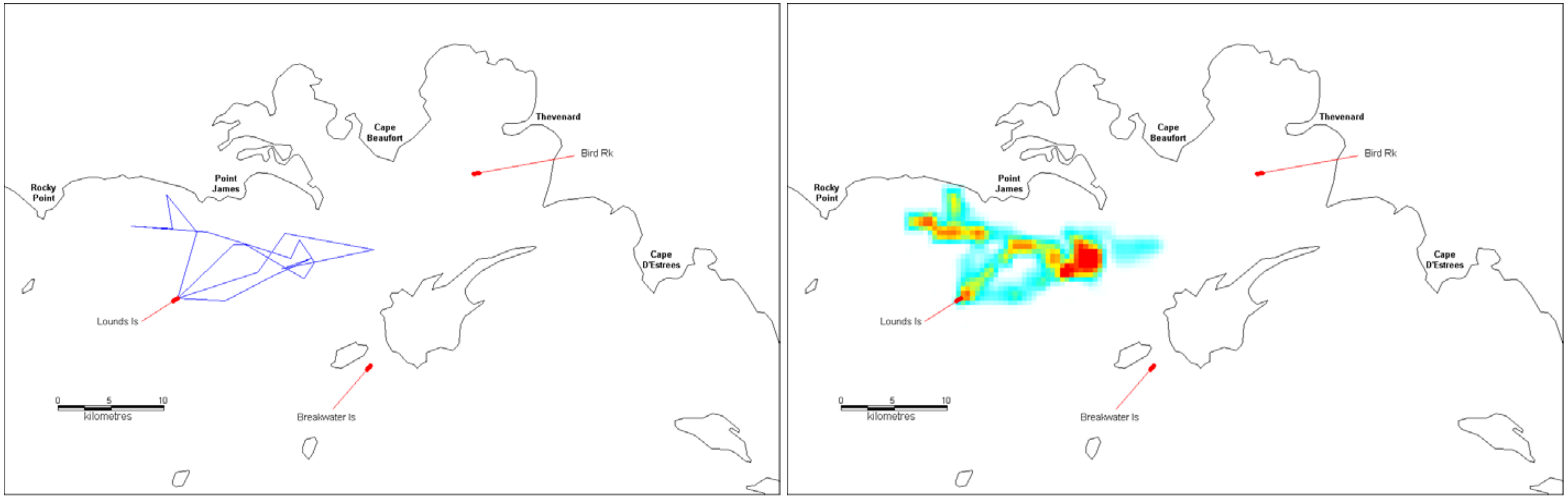
Adult female 261 from Lounds Is. Track of 1 foraging trip (left) and time spent in 1 x 1 km areas (right).



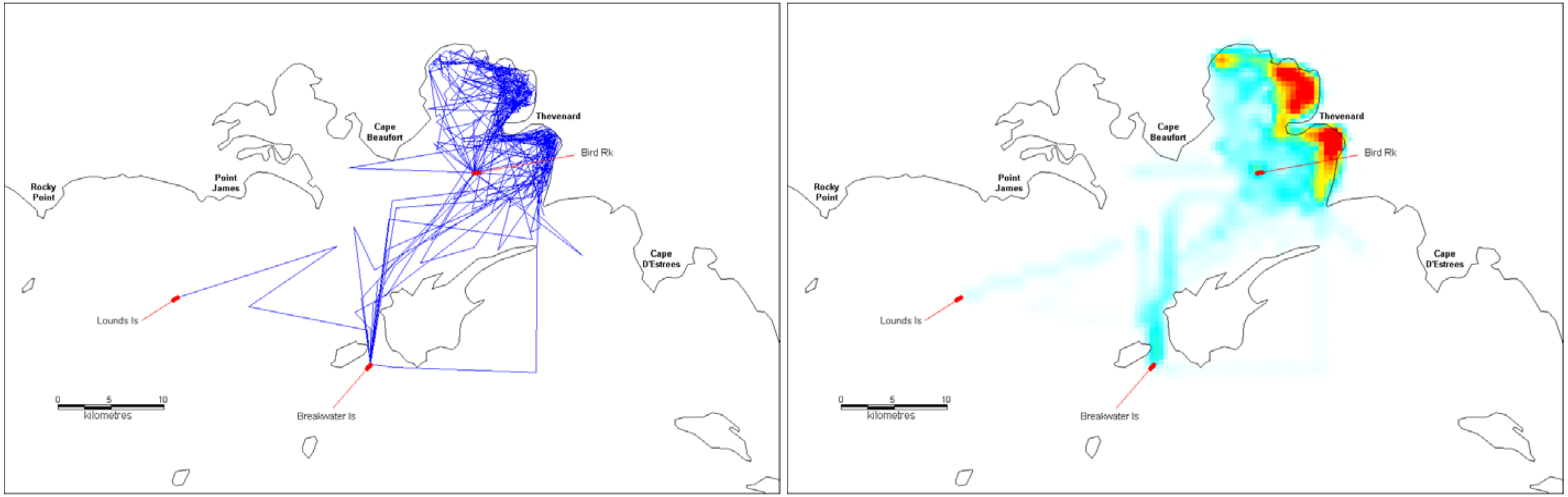
Adult female 361 from Lounds Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



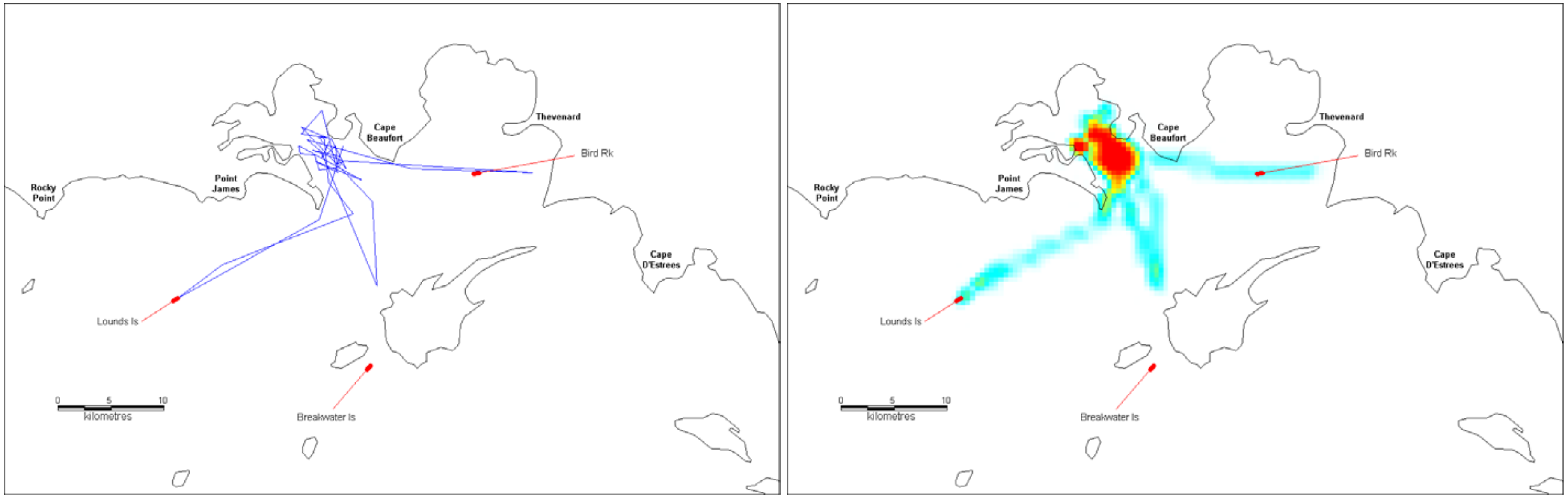
Adult female 461 from Lounds Is. Tracks of 114 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 561 from Lounds Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 661 from Lounds Is. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).



Adult female 761 from Lounds Is. Track of 1 foraging trip (left) and time spent in 1 x 1 km areas (right).

Appendix 2. Cost of seal interactions to finfish aquaculture industry: questionnaire.

1. How would you rate the significance of seal problems?
2. Have problems associated with seal interactions increased, decreased or remained the same?
3. In what year did interactions with seals become a problem?
4. What is the nature of interactions between seals and tuna/finfish farms?
5. Please specify how seals damage farm equipment.
6. Please specify how seals cause stress and reduction in growth/health of fish
7. Please specify how seals enter pens.
8. Please specify how seals might reduce the market value of fish that seals have interacted with, but that have remained alive.
9. Please specify how seals harass workers.
10. What species of seal interacts with tuna/finfish pens?
11. How often were tuna injured or killed when a seal was observed in a pen?
12. Have you taken steps to mitigate interactions between seals and tuna/finfish farms in the past?
13. Are you planning to trial new equipment to reduce interactions between seals and tuna/finfish farms in the future?
14. Are you willing to share your past, current and future ideas with other farms for the purpose of broad area mitigation of seal interactions?
15. Please outline the methods and equipment currently implemented with the aim of mitigating interactions with seals.
16. What other appropriate actions could be taken to mitigate interactions with seals?
17. Do you think the responsibility of mitigating seal interactions should rest with licence holders?
18. Do you think the responsibility of mitigating seal interactions should rest with management and regulatory organisations, such as DEH or PIRSA/SARDI?
19. Would you be willing to participate in an ongoing and standardised recording program of seal interactions with tuna/finfish farms in the future?

Appendix 3. Location and classification of known breeding and haulout sites of the ASL in the study area

Sites highlighted in bold indicate new sites or there was a classification change during this study. The status of sites that were not confirmed by ground or boat surveys, but were visited by satellite-tracked animals are indicated by an asterisk (*). The breeding or haulout status of some of these sites is not known. Projection: Mercator, WGS84.

Site	Lat.	Long.	Status (McKenzie et al. 2005)	Current status
Goose Island	-34.457	137.364	Haulout	Haulout
White Rocks	-34.452	137.362	Haulout	Haulout *
Daly Head Islet	-35.029	136.925	Haulout	Haulout
Seal Island	-35.339	136.921	Haulout/Possible breeding	Not checked
Haystack Island	-35.322	136.908	Haulout	Not checked
Althorpe Island	-35.369	136.861	Haulout	Haulout *
Little Althorpe Islands	-35.373	136.845	Haulout/Possible breeding	Not checked
Point Gibbon	-33.829	136.779	Haulout	
N NE Rocks	**-35.071**	**136.499**		**Haulout ***
Peaked Rocks	-35.187	136.483	Breeding	Breeding
South-west Rock	-35.187	136.483	Haulout	Not checked
North Islet	-35.121	136.476	Haulout	**Breeding**
Buffalo Reef	-34.759	136.421	Haulout /Possible breeding	Haulout *
Boucaut Island	**-34.649**	**136.376**		**Haulout ***
Rosemary Shoal	-34.693	136.366	Haulout	Not checked
Hareby Island	-34.582	136.296	Haulout	Not checked
Blyth Island	-34.568	136.292	Haulout	Haulout
Reevesby Island	-34.523	136.280	Haulout	Not checked
Smith Rock	-34.586	136.265	Haulout /Possible breeding	Not checked
Langton Island	-34.597	136.252	Haulout	**Haulout/Possible breeding site**
Dangerous Reef	-34.817	136.217	Breeding	Breeding
English Island	-34.638	136.196	Breeding	Breeding
Sibsey Island	**-34.647**	**136.185**		**Haulout**
Albatross Island	**-35.069**	**136.181**	Haulout, occasional pupping	**Breeding**
Thistle Is 1	-35.009	136.181	Haulout	Haulout *

Site	Lat.	Long.	Status (McKenzie et al. 2005)	Current status
Thistle Is 2	-34.948	136.086		Haulout *
Tumby Island	**-34.408**	**136.129**		**Haulout ***
South Neptune - Main	-35.330	136.112	Breeding	Haulout
South Nept. - Lighthouse	-35.336	136.111	Haulout	Haulout
Black Rock	**-34.910**	**136.104**		**Haulout ***
Bolingbroke Point	**-34.541**	**136.089**		**Haulout ***
North Neptune (East) Is	-35.230	136.068	Breeding	Breeding
Hopkins Island	-34.968	136.061	Haulout	Haulout
Lewis Island	**-34.957**	**136.032**	Haulout /Possible breeding	**Breeding**
Smith Is	-34.986	136.029	Haulout/Possible breeding	Haulout
Little Islet	**-34.950**	**136.025**	Haulout	**Haulout/Possible breeding site**
Donington Reef	-34.721	135.999	Haulout	Haulout *
Rabbit Is (Louth Bay)	-34.605	135.986	Haulout	Haulout
Williams Island	-35.029	135.971	Haulout	Haulout *
Curta Rocks	-34.948	135.870	Haulout	Haulout *
Liguanea Island	-34.998	135.620	Breeding	Breeding
Cape Rocks	-34.913	135.534	Haulout	Not checked
Golden Island	-34.700	135.332	Haulout	Not checked
Price Island	-34.708	135.290	Breeding	Not checked
Rocky Is (North)	-34.259	135.261	Breeding	Not checked
Perforated Island	-34.727	135.158	Haulout	Not checked
Cap Island	-33.947	135.113	Haulout	Not checked
Four Hummocks (Little north-east) Island	-34.751	135.082	Haulout	Not checked
Four Hummocks (North)	-34.758	135.042	Breeding	Not checked
Four Hummocks (South)	-34.778	135.032	Haulout	Not checked
Four Hummocks (Central)	-34.769	135.031	Haulout	Haulout *
Greenly Island	-34.639	134.791	Haulout/Possible breeding	Haulout
East Waldegrave Island	-33.599	134.774	Haulout	Not checked
West Waldegrave Island	-33.596	134.762	Breeding	Not checked
Rocky Is (South)	-34.810	134.718	Haulout/Possible breeding	Haulout *
Topgallant Island	-33.717	134.612	Haulout	Not checked
Jones Island	-33.185	134.367	Breeding	Not checked

Site	Lat.	Long.	Status (McKenzie et al. 2005)	Current status
SE Ward Island	-33.757	134.306	Haulout	Not checked
Ward Island	-33.741	134.285	Breeding	Haulout *
Veteran Isles (North Islet)	-33.968	134.265	Haulout	Not checked
Veteran Isles (South Islet)	-33.975	134.263	Haulout	Not checked
Pearson Island	-33.949	134.261	Breeding	Breeding
Point Labatt	-33.152	134.261	Haulout, occasional pupping	Not checked
Dorothee Island	-33.997	134.249	Haulout, occasional pupping	Haulout
Slade Point (Pt Searcy)	-33.055	134.168	Haulout	Not checked
Nicolas Baudin Island	-33.016	134.133	Breeding	Not checked
Olive Island	-32.719	133.970	Breeding	Breeding
Goalen Rocks 2	**-32.399**	**133.719**		**Haulout ***
Goalen Rocks 1	**-32.392**	**133.708**		**Haulout ***
NE Franklin Island	-32.449	133.669	Breeding	Breeding
SE Franklin Island	-32.462	133.639	Breeding	Breeding
Bird Rock	-32.183	133.617	Haulout	Haulout *
Gliddon Reef	**-32.323**	**133.564**		**Breeding**
Breakwater Island	-32.322	133.561	Haulout, occasional pupping	**Breeding**
Flinders Reef	-32.387	133.551	Haulout	Haulout
Goat Island	-32.309	133.521	Haulout	Not checked
Evans Island	-32.369	133.482	Haulout	Haulout *
Lacy Island	-32.399	133.371	Haulout	Haulout *
Lounds Island	-32.273	133.366	Breeding	Haulout *
Rocks NW of Lacy Island	-32.367	133.349	Haulout	Not checked
Freeling Island	-32.480	133.344	Haulout	Not checked
Dog Island	-32.489	133.331	Haulout	Haulout *
Egg Island	-32.473	133.315	Haulout	Haulout *
Smooth Island	-32.485	133.309	Haulout	Haulout *
St Francis Island	-32.506	133.287	Haulout	Haulout *
Fenelon Island	-32.581	133.282	Breeding	Breeding
Masillon Island	-32.559	133.281	Breeding	Haulout *
West Island	-32.511	133.251	Breeding	Breeding
Cannan Reef	-32.639	133.246	Haulout	Haulout *
Purdie Island	-32.270	133.228	Breeding	Breeding
Hart Island	-32.642	133.151	Haulout	Haulout *

Site	Lat.	Long.	Status (McKenzie et al. 2005)	Current status
Island near Point Bell	-32.221	133.113	Haulout	Haulout *
Sinclair Island	-32.143	132.991	Haulout	Haulout *
Point Fowler	-32.030	132.473	Haulout, occasional pupping	Not checked
Nuyts Reef (East)	-32.048	132.179	Haulout	Haulout *
Nuyts Reef (middle)	-32.139	132.141	Haulout, occasional pupping	Not checked
Nuyts Reef (South)	-32.139	132.131	Haulout	Not checked
Nuyts Reef (West)	-32.119	132.131	Breeding	Not checked
D'Entrecasteaux Reef	-31.981	131.930	Haulout	Not checked
Bunda Cliffs B1	-31.518	131.061	Breeding	Haulout *
Bunda Cliffs H1	-31.529	131.041	Haulout, occasional pupping	Not checked
Bunda Cliffs H2	-31.604	130.801	Haulout	Haulout *

Appendix 4. Australian sea lion colonies classified by the number of pups born per season, according to the classifications used by the MM-MPA AWG (minor or major) and the NSSG (small, moderate or large). The classifications of new colonies that were identified during this study are highlighted in bold. Colony names are the same as those used by MM-MPA AWG.

Location	MM-MPA AWG classification	NSSG classification in 2004	Max. pup count in 2004	Max. pup count per this report	Classification post-report (MM-MPA)	Classification post-report (NSSG)	Distance to nearest fish farm	Prospect of fish farms in vicinity
The Pages Is (N & S)	Major	Large	609	-	Major	Large	>50	No
Dangerous Reef	Major	Large	526	617	Major	Large	19	Yes
Seal Bay	Major	Large	179	-	Major	Large	>50	No
West Waldegrave Is	Major	Large	157	-	Major	Large	>50	Yes
Olive Is	Major	Large	121	-	Major	Large	>50	Yes
Franklin Is (SE & NE)	Major	Large	121 (2 sites)	151	Major	Large	>50	Yes
Purdie Is	Major	Large	112	132	Major	Large	>50	Yes
Lewis Is	-	-	-	78	**Major**	**Large**	28	Yes
Nicolas Baudin Is	Major	Large	72	-	Major	Large	>50	Yes
Pearson Is	Minor	Moderate	29	-	Minor	Moderate	>50	Yes
North Islet	-	-	-	28	**Minor**	**Moderate**	>50	?
Lounds Is	Minor	Moderate	26	-	Minor	Moderate	>50	Yes
Price Is	Minor	Moderate	25	-	Minor	Moderate	>50	No
Peaked Rocks	Minor	Moderate	24	3	Minor	Moderate	>50	No
Liguanea Is	Minor	Moderate	23	43	Minor	Moderate	>50	No
Langton Is	Minor	Moderate	22	-	Minor	Moderate	15	Yes
Fenelon Is	Minor	Moderate	21	10	Minor	Moderate	>50	No
Seal Slide	Minor	Moderate	20	-	Minor	Moderate	>50	No
Bunda Cliffs B5	Minor	Moderate	19	-	Minor	Moderate	>50	No
Bunda Cliffs B1	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B3	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B4	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B2	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B6	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B7	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B8	Minor	Moderate	18	-	Minor	Moderate	>50	No
Bunda Cliffs B9	Minor	Moderate	18	-	Minor	Moderate	>50	No
West Is	Minor	Moderate	18	56	Minor	Moderate	>50	Yes
English Is	Minor	Moderate	18	27	Minor	Moderate	9.5	Yes
Breakwater Is	-	-	-	17	**Minor**	**Moderate**	>50	Yes
Rocky Is (N)	Minor	Moderate	16	-	Minor	Moderate	>50	No
Neptune Is (N and E)	-	-	-	14	**Minor**	**Moderate**	>50	?
Jones Is	Minor	Moderate	12	-	Minor	Moderate	>50	Yes
Four Hummocks (N)	Minor	Moderate	12	-	Minor	Moderate	>50	No
Albatross Is	Minor	Moderate	12	15	Minor	Moderate	40	No
Masillon Is	Minor	Small	9	-	Minor	Small	>50	No
Ward Is	Minor	Small	8	-	Minor	Small	>50	No
Gliddon Reef	-	-	-	7	**Minor**	**Small**	>50	Yes
Neptune Is (S)	Minor	Small	4-6	-	Minor	Small	>50	No
Point Labatt	Minor	Small	2-9	-	Minor	Small	>50	Yes
North Casurina Is	Minor	Small	-	-	Minor	Small	>50	No
Cape Bouguer	Minor	Small	2-3	-	Minor	Small	>50	No
Nuyts Reef (mid)	Minor	Small	-	-	Minor	Small	>50	No
Nuyts Reef (west)	Minor	Small	-	-	Minor	Small	>50	No
Smith Is	Minor	Small	-	0	Minor	Small	30	No
Point Fowler	Minor	Small	-	-	Minor	Small	>50	No
Dorothee Is	Minor	Small	-	-	Minor	Small	>50	No